frontiers | Frontiers in Energy Research

TYPE Editorial
PUBLISHED 13 June 2025
DOI 10.3389/fenrg.2025.1626556

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OPEN ACCESS

EDITED AND REVIEWED BY
ZhaoYang Dong,
City University of Hong Kong, Hong Kong SAR, China

*CORRESPONDENCE
Muhammad Khalid,
mkhalid@kfupm.edu.sa

RECEIVED 11 May 2025
ACCEPTED 12 May 2025
PUBLISHED 13 June 2025

CITATION
Khalid M and Jasińska E (2025) Editorial: AI-based energy storage systems. *Front. Energy Res.* 13:1626556. doi: 10.3389/fenrg.2025.1626556

Editorial: AI-based energy storage systems

Muhammad Khalid[1,2]* and Elżbieta Jasińska[3]

[1]Electrical Engineering Department, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia, [2]Interdisciplinary Research Center for Sustainable Energy Systems (IRC-SES), King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia, [3]Wrocław University of Science and Technology, Wrocław, Poland

KEYWORDS

energy storage and conversion, artificial intelligence - AI, optimization, renewable energy, electric vehicles

Editorial on the Research Topic
AI-based energy storage systems

The global shift toward low-carbon energy infrastructure has accelerated innovations in energy storage systems (ESS), where Artificial Intelligence (AI) plays a critical role. The integration of AI into ESS enables real-time optimization, predictive maintenance, and smart grid coordination, which are indispensable for achieving sustainability goals and resilience in the face of increasing renewable penetration and distributed generation. This editorial integrates insights from ten high-impact studies to present a comprehensive outlook on how AI-driven methods are significantly transforming the future of energy storage within smart energy systems.

One key highlight of this progress relates to active power balancing across complex hybrid energy systems. Xiao et al. propose a Transfer Learning Double Deep Q-Network (TLDDQN) to handle active power in wind–photovoltaic–storage systems. This method decreases the requirement for thermal generation and effectively adapts to complex environments. Furthermore, it also implements adaptive entropy mechanisms, which can improve agent training, reduce convergence time, and enhance policy learning under inconsistent environments. Compared to particle swarm optimization, this AI-based approach not only accelerates training but also achieves higher accuracy in handling ESS dispatch. Complementing this, Awaji et al. develop a real-time energy management technique for DC microgrids integrating batteries and supercapacitors. Their energy management system (EMS) uses the Incremental Conductance algorithm for maximum power point tracking (MPPT). Furthermore, it effectively maintains grid stability during fault occurrences, which is also validated through OPAL-RT simulations. The study demonstrates the effectiveness of battery balancing, especially for systems that include PV generation and DC motor loads. Overall, the results show that robust control architectures powered by AI can significantly enhance grid flexibility and operational reliability.

In the broader context of intelligent MPPT systems, Alsulami et al. conduct a comparative analysis of traditional and AI-driven MPPT algorithms. Their work shows that Adaptive Neuro-Fuzzy Inference Systems (ANFIS) and Artificial Neural Networks (ANN) outperform conventional perturb-and-observe methods under fluctuating irradiance. However, they also point out that insufficient training data can impair performance in changing temperature conditions. Fuzzy Logic Control is noted for delivering the most balanced and reliable performance across solar and thermal variations, making it particularly effective for embedded ESS in robotics and autonomous systems. These findings suggest that while deep learning holds promise, hybrid AI methods such as neuro-fuzzy systems may offer more consistent results under real-world uncertainties.

As electrification expands, especially with the growth of electric vehicles (EVs), demand-side management becomes essential. Almutairi et al. present a linear programming-based framework that optimizes EV charging in shared residential parking lots, accounting for transformer limits, charger availability, and user schedules. Their user satisfaction index demonstrates that even at 3%–6% EV penetration, satisfaction exceeds 75%–80% when infrastructure is optimized. Such modeling offers a user-centric approach to managing residential energy demand and reducing grid overload during peak hours. Further advancing this domain, Srihari et al. introduce an Improved Honey Badger Algorithm (IHBA) to manage Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) interactions. Their AI-based EMS integrates PV generation forecasts and user preferences, achieving high efficiency (over 98%), low power loss (0.197 kW), and low harmonic distortion (3.12%). This synergy between AI and EV-ESS coordination reflects a major shift in energy management paradigms, offering a scalable pathway toward intelligent transportation-energy convergence.

Battery health forecasting is another important area where AI adds notable value. Rammohan et al. simulate lithium-ion battery degradation in EVs using an Arrhenius-based mathematical framework. Their model indicates that raising the operating temperature from 25°C to 60°C decreases battery life from 6,000 to 3,000 h. These results quantitatively support the importance of thermal management and precise degradation forecasting. Including such models in AI-aided ESS systems could enable real-time lifecycle tracking and preventive adjustments to charging techniques, particularly in climate-sensitive or high-demand conditions.

Securing AI-powered grids is equally essential. Gupta et al. propose an AdaBoost ensemble model for detecting false data injection attacks in smart grids. Trained on real-world advanced metering infrastructure (AMI) data, the model achieves 85.2%–92.3% accuracy across five attack types, surpassing standard classifiers such as SVM and KNN. It dynamically adapts to misclassifications, making it resilient even with imbalanced datasets—a key factor in safeguarding AI-integrated ESS systems. As digitalization of the grid accelerates, such AI-based cybersecurity layers will become indispensable for ensuring uninterrupted and trustworthy energy services.

Long-term planning also benefits from AI integration. Altamimi presents a techno-economic sustainable planning (TESP) model for meshed microgrids, using voltage stability indices and load margin constraints to guide 10-year expansion strategies. These insights, when combined with AI forecasting tools, enable optimized asset allocation and ESS deployment under dynamic generation and load conditions. By simulating future scenarios and investment trade-offs, such frameworks help grid planners to anticipate challenges and improve resilience to volatility in renewable generation.

In the context of solar-ESS applications, Habib et al. analyze rooftop PV for commercial buildings using HelioScope simulation and field validation. Their system achieved inverter efficiencies of 98.83% and projected CO_2 savings of over 5 million metric tons across 25 years. Results show a levelized cost of energy (LCOE) of $0.0229/kWh and a payback period of 4.22 years. These findings show that a PV-ESS system is economically feasible if it is well-designed. Overall, the study emphasizes that accurate modeling and AI-informed configuration can drive both environmental and financial performance in building-scale deployments.

Lastly, for off-grid and remote applications, hybrid microgrids offer novel solutions. Raza et al. estimate the potential of integrating very small modular reactors (vSMRs) with PV, wind, and battery storage. Their simulations using MATLAB indicate that such systems effectively meet demand. They also generate internal rates of return of around 31%, with payback periods below 4 years. The inclusion of vSMRs ensures base-load support, while AI-managed renewable integration maximizes efficiency and availability. This showcases the potential of modular, AI-supervised energy systems in underserved areas, particularly where transmission infrastructure is weak or absent.

These studies emphasize a substantial transformation in energy systems toward intelligent, adaptive, and secure networks—moving beyond traditional passive infrastructure. AI-based energy storage systems are now central to achieving energy reliability, carbon mitigation, and user satisfaction. AI enables ESS to manage the growing complexities of decentralized energy generation and consumption. It does so through real-time energy dispatch, predictive maintenance, intelligent MPPT, cyber-secure grid interaction, and scalable microgrid design.

Altogether, the ten articles presented provide a forward-looking perspective on how AI can unlock new capabilities in energy storage and system optimization. They offer practical methodologies, validated frameworks, and scalable solutions that will inform the next-generation of sustainable energy design. As editor, I am confident that this body of work will serve as a catalyst for interdisciplinary innovation and play a meaningful role in advancing resilient, intelligent energy storage systems for the future.

Author contributions

MK: Writing – review and editing, Writing – original draft. EJ: Writing – review and editing.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

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.

Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. We acknowledge the use of Grammarly to enhance the language and grammar quality of this editorial.

10.3389/fenrg.2025.1626556

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