frontiers | Frontiers in Energy Research

TYPE Editorial
PUBLISHED 10 December 2025
DOI 10.3389/fenrg.2025.1731354

Check for updates

OPEN ACCESS

EDITED AND REVIEWED BY
Michael Carbajales-Dale,
Clemson University, United States

*CORRESPONDENCE
Cong Zhang,
zcong@hnu.edu.cn

RECEIVED 24 October 2025
REVISED 07 November 2025
ACCEPTED 07 November 2025
PUBLISHED 10 December 2025

CITATION
Zhang C and Liu Q (2025) Editorial: Advanced data-driven uncertainty optimization for planning, operation, and analysis of renewable power systems.
Front. Energy Res. 13:1731354.
doi: 10.3389/fenrg.2025.1731354

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Editorial: Advanced data-driven uncertainty optimization for planning, operation, and analysis of renewable power systems

Cong Zhang* and Qi Liu

Hunan University, Changsha, China

KEYWORDS

data-driven optimization, renewable energy uncertainty, power system resilience, intelligent algorithms, collaborative optimization

Editorial on the Research Topic
Advanced data-driven uncertainty optimization for planning, operation, and analysis of renewable power systems

The global energy landscape is undergoing a profound transformation driven by the imperative to decarbonize power systems and integrate renewable energy at an unprecedented scale. This transition, while essential for achieving climate goals, introduces significant technical challenges stemming from the inherent uncertainty, variability, and limited inherent stability characteristics of renewable generation. The Research Topic “Advanced Data-Driven Uncertainty Optimization for Planning, Operation, and Analysis of Renewable Power Systems” addresses these critical challenges by presenting a collection of innovative studies that leverage advanced computational intelligence, robust optimization frameworks, and adaptive control paradigms to enhance the reliability, resilience, and economic efficiency of future power systems.

A predominant focus across the contributions is the development of sophisticated methodologies to quantify and manage the uncertainties associated with renewable generation and load demand. Moving beyond traditional robust optimization, several studies propose data-driven frameworks that harness historical data to construct more accurate uncertainty sets. One notable contribution introduces a polyhedral-ellipsoidal hybrid uncertainty set for industrial park microgrids, effectively reducing solution conservatism while maintaining robustness (Ru et al.). Another significant advancement employs a distributionally robust optimization approach grounded in the Wasserstein metric, demonstrating remarkable improvements in out-of-sample performance and substantial cost reductions compared to conventional methods (Li et al.). Furthermore, the integration of transmission and distribution system coordination is addressed through a bi-level planning model for distributed energy storage, which incorporates Gaussian mixture model-based chance constraints to ensure voltage security under extreme weather events (Xue et al.).

In the realm of system operation and control, the collected research presents groundbreaking strategies to mitigate the impacts of renewable intermittency on dynamic performance. The critical issue of frequency stability in low-inertia systems is tackled through a novel data-model fusion architecture that synergistically combines physics-based modeling with neural network error correction for highly accurate frequency nadir prediction (Li et al.,). For real-time frequency regulation, an intelligent cloudbased PI controller embodies a significant leap beyond conventional control schemes, enabling adaptive parameter tuning to maintain stability under stochastic wind power fluctuations and load disturbances (Li et al.). In voltage control applications, a reinforcement learning paradigm utilizing Q-learning and voltage sensitivity analysis demonstrates superior capability in coordinating doubly-fed induction generator-based wind farms for effective voltage support during grid faults (Song et al.). Complementing these approaches, a non-linear control strategy based on logic bang-bang funnel control provides a robust solution for fault current limitation in full-scale converter-interfaced wind generators, exhibiting insensitivity to system non-linearities and external disturbances (Li et al.).

The proliferation of distributed energy resources necessitates innovative frameworks for their coordinated management and market integration. Research in this Research Topic introduces advanced game-theoretic and optimization models that balance economic objectives with technical constraints. A hierarchical bi-level optimization model, formulated within a Stackelberg game framework and incorporating soft open point technology, successfully enhances both economic efficiency and voltage security in multi-prosumer distribution systems (Lou et al.). The untapped potential of telecommunications infrastructure is harnessed through an optimal scheduling model that aggregates base station energy storage to provide voltage support services to the distribution network, based on accurate load forecasting via long short-term memory networks (Sun et al.). Additionally, the strategic integration of electric vehicles via vehicle-to-grid technology is formalized through a two-stage stochastic programming model that effectively resolves load imbalance problems in low-voltage distribution networks (Lu et al.).

Economic viability and investment efficiency are paramount for the sustainable development of renewable energy systems. Contributions in this area include a multiobjective investment portfolio optimization model based on data envelopment analysis, which identifies Pareto-optimal solutions for grid infrastructure planning under high renewable penetration (Wu et al.). For energy storage systems, a comprehensive life-cycle revenue model provides crucial insights into optimal operational strategies and economic end-of-life determination in electricity spot markets (Li et al.). The emerging concept of shared energy storage is advanced through a planning model based on the adaptive alternating direction method of multipliers, which simultaneously enhances computational efficiency, protects prosumer privacy, and improves renewable energy self-consumption (Zhao et al.).

The integration of diverse power electronic interfaces presents new stability challenges that are addressed through several pioneering studies. The dynamic interaction between grid-following and grid-forming converters during fault conditions is thoroughly analyzed, leading to the development of a hybrid fault ride-through control strategy that ensures stability through coordinated phase angle adjustment and current limitation. For power system analysis under uncertainty, a support vector regression-based interval power flow prediction method offers a computationally efficient solution for real-time assessment in distribution networks with high distributed generation penetration (Liang et al.). Addressing the fundamental need for accurate frequency response modeling, a generalized system frequency response model incorporating virtual synchronous machine technology enables comprehensive analysis of frequency dynamics in renewable-rich power systems (Song et al.). Finally, system security is further enhanced through a two-stage transient stability assessment model that integrates ensemble learning with cost-sensitive classification, significantly improving assessment accuracy for critical samples under renewable energy and load fluctuations (Lei et al.).

In synthesizing these contributions, this Research Topic demonstrates the transformative potential of data-driven optimization and intelligent control methodologies in addressing the multifaceted challenges of modern power systems. The collected research not only provides immediate solutions to pressing operational problems but also establishes foundational frameworks for the future development of resilient, efficient, and sustainable energy infrastructures. As the global energy transition accelerates, we anticipate that these advancements will inspire continued innovation and collaboration across disciplines, ultimately paving the way for a secure and decarbonized energy future.

Author contributions

CZ: Writing – review and editing. QL: Investigation, Writing – original draft.

Funding

The authors declare that no financial support was received for the research and/or publication of this article.

Conflict of interest

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

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