

Special Issue “AI Facilitated Cyber–Physical Energy Systems—Planning, Operation, and Markets”

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AI technologies are rapidly becoming a foundational enabler for modern cyber–physical energy systems, supporting more efficient planning, safer and more flexible operation, stronger cybersecurity, and more dynamic energy markets. Together, these advances lay the groundwork for next-generation smart grids characterized by high renewable penetration, real-time situational awareness, and closed-loop intelligent decision-making. This Special Issue collects seven original research articles and two comprehensive review articles that together cover the full pipeline of AI-driven innovation in cyber–physical energy systems, from risk mining and wide-area monitoring to distribution network planning, scenario generation, energy forecasting, and quantum-enhanced simulation.

The first paper in this Special Issue is a novel data mining approach for accident factor analysis in intelligent energy systems by Li et al. (Contribution 1). Focused on unstructured power accident text records, the authors propose a Sparse Coefficient Optimized Weighted FP-Growth (SCO-WFP) algorithm that combines Word2Vec semantic embedding, K-means clustering, cosine similarity weighting, and sparse factor enhancement. The method improves the detection of low-frequency but high-impact risk factors and ranks their importance relative to accident severity. The results offer strong support for safety early warning and risk prevention in smart grid operations.

The review paper by Ogbogu et al. (Contribution 2) provides a comprehensive overview of wide-area measurement systems (WAMS) and phasor measurement unit (PMU) technologies for smart grid fault mitigation and cybersecurity. The work compares WAMS with traditional SCADA systems, outlines system architectures, optimal PMU placement, communication frameworks, and AI-enhanced fault detection. It also addresses challenges in developing economies, aging infrastructure, and cyber–physical system (CPS) resilience, offering a clear roadmap for future deployment and research.

Next, a technical contribution on distribution network planning is presented by Ma et al. (Contribution 3). To handle the uncertainty and complexity introduced by distributed photovoltaics and wind generation, the authors develop a deep reinforcement learning (DRL) framework based on the Proximal Policy Optimization (PPO) algorithm. By modeling network planning as a Markov decision process with multi-objective rewards including investment cost, voltage deviation, and renewable accommodation, the method automatically generates optimal network topologies. When compared with heuristic approaches, the proposed solution achieves lower costs, higher renewable integration, and greater computational efficiency.

Another important contribution addressing uncertainty in energy systems is presented by Ma et al. (Contribution 4). The authors propose a multi-time-scale scenario generation method using a Temporal Generative Adversarial Network (TGAN) enhanced with multi-head attention and temporal convolutional networks. The model captures spatiotemporal



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correlations in source–load behaviors and generates realistic daily, weekly, and monthly scenarios. By combining Markov chain state transitions and conditional GAN generation, the approach improves scenario fidelity and supports robust long-term distribution network planning and operation analysis.

A privacy-preserving solution for distributed photovoltaic power prediction is introduced by Luo et al. (Contribution 5). Motivated by the non-IID data characteristics and privacy constraints in distributed PV systems, the authors propose a Personalized Federated Multi-Task Learning (PFL) framework combined with an improved CBAM-iTCN predictor. The approach keeps raw data local while enabling collaborative model training, and the attention-augmented temporal convolution network extracts key meteorological and power features more effectively. Experiments show substantial reductions in MAE, RMSE, and MAPE compared with centralized and conventional federated learning models.

Soltaninia and Zhan (Contribution 6) explore an emerging frontier in power system simulation—quantum computing. This work introduces quantum neural networks (QNNs) to solve the high-dimensional differential-algebraic equations involved in power system transient simulation. By designing sinusoidal-friendly and polynomial-friendly QNN architectures, the authors achieve more efficient approximation of dynamic system responses with fewer parameters than classical physics-informed neural networks. The results demonstrate the promising potential of quantum computing to accelerate computationally demanding tasks in future cyber–physical energy systems.

Turning to wind energy forecasting, Xu et al. (Contribution 7) present a novel wind power forecasting framework based on multi-graph neural networks considering external disturbances. Termed GCN-EIF, the model decouples inherent wind power patterns from external interference factors (EIFs) using a dual graph structure (geographic proximity and power correlation) and attention-enhanced LSTM. By removing disturbances during training and reintroducing predicted external factors at forecasting stage, the method reduces RMSE by 18.99% and MAE by 5.08% over state-of-the-art methods, with strong real-time performance for industrial applications.

The eighth paper provides a systematic review by Saldaña-González et al. (Contribution 8) on active distribution network (ADN) planning and generative AI applications. The work classifies core planning elements including time horizons, objectives, decision variables, uncertainty modeling, and optimal power flow formulations. It further reviews GANs, diffusion models, VAEs, flow-based models, and large language models for scenario generation, uncertainty quantification, and decision support, offering a unified view for future AI-driven distribution planning.

Closing this Special Issue, Ji et al. (Contribution 9) propose an integrated energy management strategy for fuel cell hybrid-powered unmanned aerial vehicles (UAVs) based on optimal path planning. Using CFD-simulated urban wind fields and LSTM power prediction, a hybrid A*-ACO algorithm generates energy-efficient flight trajectories. A Deep Q-Learning (DQN) controller then optimizes power allocation between fuel cell and battery to reduce hydrogen consumption and suppress power fluctuations.

Together, the papers included in this Special Issue advance the state of the art in AI for cyber–physical energy systems across planning, operation, monitoring, forecasting, security, and computation. The collection combines rigorous methodological innovation, extensive experimental validation, and clear practical relevance, making it a valuable reference for researchers and engineers working toward smarter, more resilient, and sustainable power grids.

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List of Contributions

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