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Editorial: Process and energy systems engineering: advances in modeling, and technology

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Editorial on the Research Topic
Process and energy systems engineering: advances in modeling, and technology

Introduction

The global energy sector faces unprecedented challenges, with greenhouse gas emissions and resource scarcity demanding urgent attention. The International Energy Agency's 2022 flagship report revealed record-high global CO_2 emissions, with the electricity and heat production sector contributing 46% of the increase. This situation, coupled with water scarcity affecting over one billion people globally, necessitates innovative solutions in energy systems engineering.

The Research Topic of presented papers demonstrates significant progress in addressing these challenges through advanced modeling, control strategies, and technological integration. This editorial synthesizes key findings from recent scholarly contributions showcasing innovative approaches to enhancing energy systems' efficiency, stability, and sustainability.

Sun et al. present a significant advancement in power system stability analysis through their work on Load Frequency Control (LFC) with interval time-varying delays. This work falls into the observed trend in model research applications frequently used, especially in describing complex systems (Machowski et al., 2020; Milano et al., 2022; Krzywanski et al., 2024; Win et al., 1995). Their innovative approach employs augmented Lyapunov-Krasovskii Functionals (LKF) and introduces delay-dependent matrices, effectively reducing conservatism in stability analysis. By implementing their methodology through the MATLAB LMI toolbox, they achieve enhanced stability margins for power systems operating over open communication networks. This work contributes crucial insights for maintaining grid frequency stability under varying communication delay conditions.

Model research can also often be applied when describing sophisticated systems' dynamic behavior. The dynamic behavior of district heating systems is thoroughly examined by Chen et al. in their study of the Chengde heating system in Hebei province. Their research quantifies temperature decline patterns, demonstrating that indoor temperatures take 150–245 min to drop to 16°C following primary network disconnection. The study incorporates detailed technical parameters, including pipe network configurations, heat transfer coefficients, and system operating conditions. Their findings regarding the 5°C threshold for intermittent heating temperatures provide practical guidance for system operators. Despite various assumptions, e.g., heat transfer processes, usually indispensable in the existence of several uncertainties in such considerations (Grabowska et al. (2018), these insights are vital for optimizing heating strategies to minimize energy wastes while maintaining occupant comfort, making the findings particularly relevant for cities pursuing sustainable heating solutions.

Strunge et al. makes a significant methodological contribution by presenting a comprehensive framework for uncertainty quantification in the Techno-Economic Analysis (TEA) of carbon capture technologies.

Using CO_2 mineralization in cement production as a detailed case study, they demonstrate the limitations of traditional local sensitivity analyses and provide structured guidance for selecting appropriate analytical methods. Their work is particularly relevant for decision-makers evaluating carbon capture technologies to achieve net-zero emissions by 2050 (Bergero et al., 2023; Davis et al., 2018; Muskała et al., 2008).

The paper by Mujahid et al. falls into a similar research area. Moreover, the rapid development of intelligent methods and solutions can also be observed in energy and environmental engineering systems (Shi et al., 2020; Ashraf et al., 2020; Krzywanski et al., 2019).

The paper introduces an innovative multi-agent, multi-layer framework for managing interconnected microgrids across different sectors. Their implementation of Modified Multi-objective Gray Wolf Optimization (MMGWO) and Modified Multi-objective-Prioritized Plug-and-Play (MMPPnP) algorithms demonstrates advanced capabilities in real-time energy management and market optimization. The framework successfully integrates renewable resources while maintaining system efficiency and economic viability.

In resource extraction, Cao et al. present findings from their study of Block X in the Chunfeng Oilfield, investigating thermochemical composite flooding mechanisms in extra-heavy oil reservoirs. Detailed 1D and 2D sand-pack model experiments demonstrate that composite flooding can increase recovery rates by up to 30.46% compared to conventional steam flooding. While erosion processes in oil reservoirs differ from those studied in other energy systems, such as Circulating Fluidized Bed (CFB) boilers where particle velocity and material hardness are vital factors (Tarodiya and Levy, 2021; Muskała et al., 2010; Zhang and Liu, 2023), the research establishes critical parameters for managing erosion channels in oil recovery.

Finally, the research establishes optimal parameters for viscosity reducer concentrations and characterizes emulsion behavior under various operating conditions.

In a related development focusing on renewable energy integration, Xu et al. address the optimization of hydrogen energy storage in Integrated Energy Systems (IESs) centered on water electrolysis technology. The study evaluates optimal hydrogen storage capacity using a data-driven DOuble-layer Mixed Integer Nonlinear Optimization (DOMINO) algorithm by developing a two-layer optimization model. The research explicitly targets the problem of wind and solar curtailment in new energy development, proposing hydrogen storage as an effective solution within comprehensive energy architectures. The study validates algorithm convergence through simulation analysis and determines optimal hydrogen capacity configuration, contributing to enhanced renewable integration.

The discussed studies employ sophisticated computational tools and simulation methods, including MATLAB-based implementations, computational fluid dynamics, and artificial intelligence algorithms. These tools enable complex system modeling and optimization under various operational conditions. Future developments in this field will likely focus on enhanced integration of renewable energy sources, improved grid stability mechanisms, and more sophisticated uncertainty quantification methods.

Integrating these technological advances points toward a future where energy systems are increasingly efficient, resilient, and environmentally sustainable. Emerging trends suggest continued development in areas such as:

- Advanced control algorithms for complex grid systems;
- Enhanced integration of renewable energy sources;
- Improved methods for uncertainty quantification in system design;
- More sophisticated approaches to resource extraction and utilization.

Conclusion

The collected works demonstrate significant progress in addressing contemporary energy challenges through innovative engineering solutions. Integrating advanced modeling techniques, control strategies, and optimization methods provides a robust foundation for future developments in energy systems engineering. These contributions are precious as the global energy sector transitions toward more sustainable and efficient operations.

This editorial offers a comprehensive overview of current research while highlighting the interconnected nature of various energy engineering disciplines. The findings and methodologies presented provide valuable insights for researchers, practitioners, and policymakers working toward more sustainable and efficient energy systems.

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Publisher's note

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