Guest Editorial: Special Section on Distributed Integrated Multi-energy System (DIMS)

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THE increasing pressure from energy supply sustainability and environmental protection has made the research for advanced energy infrastructures urgent. Distributed integrated multi-energy system (DIMS), focusing on the deep integration of advanced multi-energy and information technologies, is regarded as the most likely form of resilient energy utilization for the future human society. Many challenges exist and require further research and development on the modeling, planning, operation, and control of the distributed information and energy systems, including interdependent infrastructures such as electricity, transportation, communication, heat, and natural gas networks. This special section aims at addressing and disseminating state-of-the-art research and opportunities regarding applications of innovative solutions to achieve the deep integration of multi-energy systems and advanced communication and information technology. The call for papers invited original submissions from various countries, with the emphasis placed preferably on the issues of modeling, planning and energy management structure, cooperative operation and dispatching, control and stability analysis, sensitivity and techno-economic analysis.

A. Modeling Issue

Modeling is the most fundamental research in the development of DIMS. The following three papers are devoted to novel model development from different views as well as the corresponding solutions.

Existing system modeling methods lack generality and are very case-specific for system planning and operation. To address this issue, the paper entitled "System Modeling and Optimal Dispatching of Multi-energy Microgrid with Energy Storage" presents a generalized modeling approach including static and dynamic characteristics and sheds light on the feasibility of the energy transfer process of a multi-energy microgrid. A mixed-integer linear programming framework is proposed for the optimization of integrated electricity, heat, and gas dispatching. It is verified that the proposed model and approach are reasonable for a meaningful DIMS, and provide an effective way for the analysis of energy consumption.

DIMS can be regarded as virtual power plants to provide additional flexibility to the power system. In the paper entitled "Active Dynamic Aggregation Model for Distributed Integrated Energy System as Virtual Power Plant," a robust active dynamic aggregation model for the distributed integrated multi-energy systems is presented to describe the maximum feasible region. The multi-energy systems are regarded as virtual power plants to provide additional flexibility. Moreover, a two-stage robust optimization model is proposed to acquire the optimal parameters of the proposed aggregation model. The simulation results show that the aggregation of a real DIMS in Beijing, China could adjust its power consumption between about 2-5 MW, which provides flexibility to the power system.

Currently, there is a lack of universal unified modeling and optimization methods considering the constraints of the industrial production process (IPP) in the industrial park. In the paper entitled "Optimization of Distributed Integrated Multi-energy System Considering Industrial Process Based on Energy Hub," a model of the industrial production process is proposed by dividing the process into different adjustable steps. Based on the concept of energy hub (EH), a universal extension EH model is proposed considering the coupling among electricity, heat, cooling, and material. An extension energy hub considering IPP is established to analyze generalized energy flow for industrial park distributed integrated multi-energy system. In addition, the corresponding optimal scheduling strategy is also discussed. The simulation results show that coordinative optimization of DIMS and IPP can achieve economic system operation for industrial park

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DIMS.

With regard to modeling issues, future work may consider more complex and standard models with consideration of the underlying control model, social factors, and the information infrastructure.

B. Planning and Energy Management Structure

The planning and structure design are vital issues for DIMS considering multi-energy systems. The next two papers are focusing on developing a novel structure and planning method for DIMS. Power grids include players such as home microgrids (H-MGs), consumers, and retailers. Each player has a unique and sometimes contradictory objective compared to other players while exchanging electricity and heat with other H-MGs. As a result, a smart structure to handle the new situation is necessary.

The paper entitled "Coalition Formation of Microgrids with Distributed Energy Resources and Energy Storage in Energy Market" presents a bi-level hierarchical structure for designing and planning distributed energy resources and energy storage in H-MGs by considering demand response. Furthermore, a multiple-leader-common-follower game is modeled, which states the effectiveness of the market competition in multiple H-MGs. The simulation results show that the proposed structure can effectively encourage consumers to participate in the electricity market.

Due to different energies with diverse characteristics and coupled to each other, it is difficult for an energy hub to implement the optimal scheduling of multiple energy sources. The paper entitled "Multi-party Energy Management of Energy Hub: a Hybrid Approach with Stackelberg Game and Blockchain" proposes an energy optimization management model based on the Stackelberg game. This model considers the exergy conversion of multi-party energy sources in different operation modes. Furthermore, a credit-based blockchain framework and concurrent block building consensus process are explored to reduce the calculation cost and promote the exergy trading efficiency. The simulation results verify that the credit-based blockchain framework and the concurrent block building consensus process can help reduce the calculation cost and time delay and to promote the exergy trading efficiency.

For this planning and energy management structure issues, future work should consider some safety and reliability factors; e.g., when the DIMS is faced with large system disturbances or natural disasters, how to reasonably design the system structure to enhance the resilience of the whole system.

C. Cooperative Operation and Dispatching

It is crucial to design a centralized or distributed cooperative operation strategy or algorithm to ensure the economy and effectiveness of the DIMS. The following three papers are devoted to novel algorithms with the consideration of different goals and constraints.

The traditional fixed time-interval dispatch scheme is unable to adapt to the need for transient network dynamic properties, various demand response characteristics, different dispatch cycles in energy subsystems, and renewable uncertainties. To address this issue, the paper entitled "A Dispatching Method for Integrated Energy System Based on Dynamic Time-interval of Model Predictive Control" proposes a dynamic time-interval dispatching model based on model predictive control (MPC) of integrated energy systems. With trajectory deviation-control energy-control cost as the performance index, a dynamic time-interval decision index is established to ensure the timely and accurate dispatching of the system. By using this method, the dispatch cost of the DIMS is reduced by 6.55% and 6.63%, respectively, compared with the fixed energy system with fixed time intervals of 5 minutes and 1 minute.

Currently, the research mainly focuses on deterministic optimization technology. The uncertainties during operation are not considered well. In the paper entitled "Coordinated Chance-constrained Optimization of Multi-energy Microgrid System for Balancing Operation Efficiency and Quality-of-service," a two-stage optimization scheme is proposed for a multi-energy microgrid (MEMG) system. The optimization scheme enhances flexible interactions among multiple energy carriers. By adopting this method, the operation cost can be minimized in day-ahead dispatching, while the uncertainty of forecasting can be smoothed out in real-time dispatching. The simulation results show that the operation efficiency and feasibility of MEMG can be increased by implementing the proposed method.

Existing studies on distributed optimization algorithms for DIMS seldom address communication packet loss during the process of information exchange. The paper entitled "Relaxed Alternating Direction Method of Multipliers for Hedging Communication Packet Loss in Integrated Electrical and Heating System" proposes a distributed control paradigm for coordinating the operation of an integrated electrical and heating systems considering communication packet loss. A simple alternating direction method of multipliers (ADMM) with better robustness is proposed over a lossy communication network, which can still converge and shows faster con-

vergence rates than the classical methods. The simulations in two test systems validate that the proposed algorithm possesses better robustness against the probabilistic communication loss.

For the cooperative operation and dispatching issues, future works may focus on the improvement of convergence speed. Meanwhile, the impacts of multiple types of network attacks should be studied.

D. Control and Stability Analysis

The underlying control and stability analysis are necessary to guarantee the safe and stable operation for DIMS. The following two papers try to design the coordinated control scheme and analyze the stability region within the context of DIMS.

For a multi-energy power network, it is a more complex task to analyze the frequency feature and design the corresponding control strategy than the traditional power system. To this aim, the paper entitled "Electro-mechanical Modeling of Wind Turbine and Energy Storage Systems with Enhanced Inertial Response" proposes a coordinated control scheme for wind turbine generator and supercapacitor energy storage system for temporary frequency supports. Based on the result of small-signal stability analysis, it is proven that the proposed controller can effectively improve the stability of the whole multi-energy power network. The simulations also show that the proposed method can improve the frequency nadir and mitigate secondary frequency dip. The magnitude of oscillations in the mechanical subsystem is decreased as well.

The interaction among subsystems may often cause an instability problem. Meanwhile, the conventional generalized Nyquist criterion is complex, and it is not suitable for the design of the AC system. In the paper entitled "Steady-state Stability Assessment of AC busbar Plug-in Electric Vehicle Charging Station with Photovoltaic," a modified infinity-one-norm stability criterion based on the impedance method is proposed to assess the stability of the charging station. Through theoretical analysis, simulation, and experimental results, it is verified that the proposed stability criterion can assess the researched system stability.

The control and stability analysis for multi-energy systems (i.e., electricity, heat, and gas, etc.), should be simultaneously taken into account in future work. Also, the large-signal stability analysis method may be more suitable for the DIMS.

E. Sensitivity and Techno-economic Analysis

There are many kinds of distributed renewable energy resources in DIMS. The sensitivity and techno-economic analysis are helpful for reasonably integrating those renewable energy resources. The next two papers focus on this topic, and some better results have been obtained.

The inevitable uncertainty may cause DIMS to deviate significantly from the deterministically obtained expectations, in both aspects of optimal design and economical operation. It thus necessitates performing sensitivity analysis to quantify the impacts of the massive parametric uncertainties. The paper entitled "Multi-stage Sensitivity Analysis of Distributed Energy Systems: a Variance-based Sobol Method" focuses on quantitatively evaluating the sensitivity of various parameters in distributed energy systems (DES) from a comprehensive perspective. A mathematical model of a DES is proposed, and a multi-stage sensitivity analysis of the DES is carried out in terms of the evaluation criteria, optimal design, and operation strategy. The simulation results show that the energy parameters have a significant impact on the annual energy consumption, while the annual total cost mainly depends on the device investment costs.

Standalone microgrids with hybrid energy sources being environmentally friendly is a cost-effective solution that ensures system reliability and energy security. The paper entitled "Optimal Energy Management and Techno-economic Analysis in Microgrid with Hybrid Renewable Energy Sources" evaluates the techno-economic benefits of standalone microgrid with hybrid energy sources and battery energy storage (BES) device. Different feasible configurations of hybrid power systems with photovoltaic/wind turbine/diesel generator/BES sources are studied in this paper, and a detailed comparative analysis has been presented. This paper concludes that, among the various feasible configurations at the project location, the photovoltaic and BES system is the most economical with lower net present cost and cost of energy.

For sensitivity and techno-economic analysis issues, we hope to see more comparison analysis reports. In addition, the multiple timescale feature among multi-energy resources should be considered in future work.

We want to thank all the authors for submitting their high-quality papers to this special section. We would also like to thank the six guest editors for their assistance and effort in completing a quick turnaround of this special section. Special thanks are given to the editorial staff of the Journal of Modern Power Systems and Clean Energy, whose diligent

work has further enhanced the readability of the papers. Last but not least, we sincerely hope that the readers learn more about DIMS via reading those papers.

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