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Editorial: Optimization and data-driven approaches for energy storage-based demand response to achieve power system flexibility

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Editorial on the Research Topic
Editorial: Optimization and data-driven approaches for energy storage-based demand response to achieve power system flexibility

Introduction

In recent years, with the widespread adoption of distributed renewable energy and electric vehicles, the power grid faces new challenges in ensuring stable and sustainable development. Concurrently, insufficient local consumption resulting from distributed generation also impacts the power grid's safe operation. In this context, energy storage, electric vehicles and demand response play an important role by promoting flexible grid operation and low-carbon transition. In comparison to traditional loads, flexible loads can be efficiently managed through demand response to optimize consumption patterns to meet grid needs. Therefore, the collaborative dispatching of multi-modal energy storage integration technologies, such as batteries, pumped hydro storage, hydrogen storage, and distributed generators, alongside diverse demand-side flexible resources like flexible loads and electric vehicles, holds significant importance. The coordinated optimization of these distributed resources can effectively address the intermittency of variable renewable energies (VERs), encourage the adoption of flexible loads, and enhance the overall adaptability and carbon emission reduction efforts of the power system.

This Research Topic cover latest research in the areas of energy storage system optimization and control, demand response and load management, new power system scheduling, power system security defense and restoration, energy market and trading, and application of machine learning. A summary of the contribution of this research is presented as follows.

For energy storage system optimization and control, Yixi et al. Focus on the lack of flexibility of energy-intensive industrial and mining loads in stand-alone microgrids. This study quantifies the regulation potential of lithium mining loads, combines the regulation boundaries of photovoltaics, gas turbines and energy storage, and constructs a capacity optimization model for industrial and mining loads and energy storage (ES), which improves the capacity of new energy consumption while guaranteeing the balance of power and the electricity demand of energy-intensive loads. On this basis, Wang et al. further deepen the energy storage optimization problem, focusing on considering the coupling effect of storage life and charging/discharging strategy, using the rainflow counting method to establish a life loss model for lithium iron phosphate batteries, to realize the accurate configuration of multi-user shared storage. To address the dynamic stability challenges of grid-connected renewable energy, Yang et al. developed a synergistic control strategy for the power density virtual energy storage (PDVES) model and the energy density virtual energy storage (EDVES) model. The strategy equates wind power, photovoltaic (PV) and electric vehicle (EV) as virtual energy storage units, and constructs a microgrid energy regulation framework to improve the energy regulation and dynamic stability control performance of microgrids.

For demand response and load management, a number of studies focus on demand response modelling, scheduling and optimization strategies. Zhou et al. study the load characteristics of urban grids through IoT technology. On this basis, they comprehensively analyze the impact of IoT-based load control technologies and market maturity differences on load control, providing technical support for relevant carbon emission scenarios. Qian et al. build a demand response model for fused magnesium load (FML), combining principal component analysis and clustering algorithms to generate a set of low-conservative scenarios with spatial and temporal correlation uncertainty. Afterwards, they develop a two-stage robust optimization framework to reduce the cost of day-ahead scheduling and enhance the capacity of renewable energy consumption. Feng et al. optimize the energy storage allocation and grid expansion scenarios by decomposing and reconstructing the model, and assess the impact of the demand response credibility on the planning of a low-carbon power system to optimize the economy and carbon emissions. On the user side, Yang et al. consider the demand-side controllable loads as dispatchable resources, propose a tiered pricing mechanism, and reduce the punitive cost by constructing a stackelberg game model, which improves the user's participation in demand response. Wang et al. model the energy interaction problem between distribution system protocols as a Nash bargaining problem and combine it with the augmented ADMM algorithm to protect privacy. This approach reduces regional operating costs and facilitates the integration of renewable energy sources. Xing et al. select an integrated load model using PMU voltage data as input and refine the initialization process based on good point sets to mitigate the effect of local maxima. By using an improved dung beetle optimization algorithm, this method improves the accuracy of load model parameter identification.

For new power system scheduling, Gong et al. propose an active optimization scheduling model for the distribution network by considering the regulation capacity, and a fast solution method is designed herein to formulate the priority control order of the adjustable units. In view of the dual uncertainty of renewable energy output and demand response, Zhang et al. design a multi-source uncertainty quantification framework based on cloud modelling theory, taking into account both the uncertainty of renewable energy and demand response, and its effectiveness and superiority is verified in a typical case of IEEE 33 nodes. To extend the multi-energy synergy scenario, Zhou et al. proposed a distributed optimization method for electro-thermal-hydrogen systems based on the alternating direction multiplier method (ADMM). The method accurately models the power-to-hydrogen (P2H) conversion process in an electrolyzer, and comprehensively investigates the impact of microgrid connection topology on the total operating cost. Finally, Tan et al. focus on the key challenges in the field of large-scale scheduling of heterogeneous elastic resources, and propose a two-layer asynchronous optimization model, which reduces the computational complexity through the decomposition-coordination mechanism, and provides theoretical support for real-time co-optimization of multiple types of energy storage and loads.

For power system security defense and restoration, the following three studies propose innovative solutions from different perspectives. Wang et al. focus on building a hardware-in-the-loop co-simulation platform based on RT-LAB and OPNET. This research verifies the effectiveness of the platform in analyzing the impact of network attacks on the power system in real time through DDOS attack and intermediate node attack scenarios in the communication network, which provides an experimental basis for the formulation of smart grid security strategies. Wang et al. propose a defense strategy that combines Petri net modelling with mobile energy storage pre-layout. This method first assesses system vulnerability by integrating historical attack data, and then simulates and verifies the effectiveness of the proposed planning strategy in a 33-node system using the Columns and Constraints Generation (C&CG) algorithm. Zhang et al., on the other hand, address the uncertainties introduced by renewable energy sources and controllable loads by designing a Deep Reinforcement Learning (DRL)-based Soft Actor-Critic algorithm (Soft Actor-Critic, SAC). Based on this, combined with an improved Markov decision process model, it achieves fast recovery of system frequency and minimization of dispatch cost of controllable loads, and effectively solves the source load uncertainty problem exacerbated by faulty power shortage.

For energy market and trading, Li et al. propose an integrated energy system model to address the existing deficiencies in the coupled electricity-carbon market. Combined with the baseline carbon emission quota allocation method and the actual emission data of gas equipment, an improved carbon trading mechanism is designed to achieve the low-carbon operation of the system, and the numerical case verifies its effectiveness in reducing carbon emissions and improving energy efficiency. Yan et al. on the other hand, put forward a two-tier gaming framework, by integrating the carbon emission flow theory to construct a comprehensive energy carbon pricing mechanism, which encourages virtual power plants (VPPs) to dynamically adjust their trading strategies in a multi-energy system. Case studies show that this strategy can effectively promote multi-initiative co-optimization for emission reductions and the economics of energy trading. Moreover, in response to the irregular relationship between the dynamic service scope of charging stations (CSs) and the real-time charging price, Yang et al. propose a dynamic service field strength (SFS) model to optimize charging station service range delineation and real-time pricing, and validate its effectiveness in reducing the regional power bias and improving the operator's revenue.

For application of machine learning, Xiong et al. embed Kalman filtering and sparse self-encoder into the Transformer framework, which is capable of realizing dynamic noise suppression and multidimensional feature extraction, providing a new solution for battery state prediction in high volatility scenarios. Wang et al. correct the numerical weather prediction (NWP) wind speed error through ResNet-GRU network and optimize the parameters of CNN-LSTM model by combining with Keplerian Optimization Algorithm (KOA), which effectively improves the accuracy of short-term wind power prediction. Aiming at the PV uncertainty modelling, Deng et al. propose a StyleGAN framework incorporating meteorological physical constraints to generate diversified year-round weather scenarios with spatio-temporal correlation. This study provides a high-fidelity experimental data base for PV planning and risk assessment under extreme weather. Moreover, Wang et al. and Zhang et al. also introduce machine learning methods into power system security defense and restoration, and Zhao et al. focus on the financial management and leverage the advantages of deep learning to capture complex patterns and dependencies in financial time series data.

In addition to the above topics, Chen et al. propose a control strategy with a current hysteresis loop to address the issues of high inductance current ripple in photovoltaic systems and achieve real-time duty cycle regulation, which provides reference for the follow-up studies on the control of renewable energy and energy storage.

In summary, due to the limit of time, there could be many related works that could not be collected in this Research Topic. We look forward to keep following Frontiers in Energy Research, especially with a focus on the Research Topic of energy storage-based demand response.

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ZW: Writing – original draft. Yue Xiang: Writing – review and editing. Yingjun Wu: Writing – review and editing. LW: Writing – review and editing. CG: Writing – review and editing.

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