Publication List

Journal Articles:

[1] **W. Meng**, D. Song, L. Huang, X. Chen, M. Dong, J. Yang, M. Talaat, M.H. Elkholy. "Distributed Energy Management of Electric Vehicle Charging Stations Based on Hierarchical Pricing Mechanism and Aggregate Feasible Regions," Energy, vol. 291, p. 130332, 2024, doi: 10.1016/j.energy.2024.130332. (JCR **Q1**, IF: **9.0**)

[2] **W. Meng**, D. Song, L. Huang, X. Chen, M. Dong, J. Yang, M. Talaat. "A Bi-Level Optimization Strategy for Electric Vehicle Retailers Based on Robust Pricing and Hybrid Demand Response," Energy, vol. 289, p. 129913, 2023, doi: 10.1016/j.energy.2023.129913. (JCR **Q1**, IF: **9.0**)

[3] **W. Meng**, D. Song, X. Deng, M. Dong, J. Yang, R.M. Rizk-Allah, V. Snášel. "Dynamic Optimal Power Flow of Active Distribution Network Based on LSOCR and Its Application Scenarios," Electronics, vol. 12, no. 7, p. 1530, 2023, doi: 10.3390/electronics12071530. (JCR **Q3**, IF: **2.9**)

[4] D. Song, **W. Meng**, M. Dong, J. Yang, J. Wang, X. Chen, L. Huang. "A Critical Survey of Integrated Energy System: Summaries, Methodologies and Analysis," Energy Conversion and Management, vol. 266, p. 115863, 2022, doi: 10.1016/j.enconman.2022.115863. (JCR **Q1**, IF: **10.4**)

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[2] Zhao R, Yang J, Song D, **Meng W**, Chang Q, Wang L. "Robust Optimal Scheduling of Wind Thermal Energy Storage System Considering Wind Power Uncertainty," *2021 China Automation Congress (CAC)*. 2021:6. doi: 10.26914/c.cnkihy.2021.053552.

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Distributed energy management of electric vehicle charging stations based on hierarchical pricing mechanism and aggregate feasible regions

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ABSTRACT

With the rapid development of electric vehicle charging stations, effective management of them has become challenging due to the high uncertainty of electric vehicles, the pricing mechanisms of charging stations, and their coupling with distribution networks. To address these challenges, this paper proposes a two-stage framework for energy management at charging stations. In the first stage, a resource allocation model considering the profits of distribution systems, charging stations, and electric vehicle users is established based on the aggregate feasible power regions of charging stations. The aggregate feasible region is obtained based on the combination of Minkowski summation and the data-driven method, which can preserve the privacy of electric vehicle data and reduce the computational burden. In the second stage, a novel hierarchical pricing mechanism is developed, which encompasses both the clearing price between charging stations and distribution networks and the retail electricity price between charging stations and electric vehicle users. Notably, charging stations participate in the power clearing of distributed networks based on the aggregate feasible power region, while a two-stage robust pricing strategy is established between electric vehicle users and charging stations. The model is finally optimized through a distributed coordination mechanism with a clear physical interpretation. The simulation results show that the proposed aggregation method enables charging stations to achieve a total economic profit at least 1.76 % higher than three competitive methods. The hierarchical pricing mechanism allows charging stations to achieve total economic profits 18.60 % and 2.94 % higher than those in the centralized dispatch and price-taker modes, respectively, while simultaneously reducing operating costs for the distributed network by 25.96 % and 27.99 %.

1. Introduction

In recent years, the growing emphasis on sustainable energy usage and reducing greenhouse gas emissions has triggered an increased prevalence of electric vehicles (EVs) [1]. The rising adoption of EVs contributes to the surging need for charging stations to support them [2]. As a natural aggregator of EVs [3], the operation of charging stations enables EVs to participate in the management of the power system through equipped energy storage devices and renewable generation [4]. However, an uncoordinated EV charging schedule would further strain the power grid [5]. Haphazard charging of EVs can result in peak load problems that compromise the overall reliability of the distribution network [6]. The authors of [2] have demonstrated that the uncoordinated charging of EVs can have a counterproductive effect on reducing carbon emissions. Therefore, a reasonable and orderly energy management plan for charging and discharging needs to be developed by charging station operators (CSOs) [7], which can enable EV users to become excellent prosumers [8].

In optimizing the energy management of CSOs, treating EVs as conventional plug-and-charge loads would waste their potential storage capacity [9]. To meet both the economic and technical requirements of CSOs, peer-to-peer (P2P) energy trading has emerged as a promising technology, allowing participants to exchange energy with each other

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A Bi-level optimization strategy for electric vehicle retailers based on robust pricing and hybrid demand response

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ABSTRACT

The high penetration of electric vehicles (EVs) poses both opportunities and challenges for power systems. EV retailers, playing a critical role in the demand response mechanism, face market risks caused by uncertainties in electricity consumption and prices. To address the operational issues of large-scale EVs and tap the potential of EV retailers, a temporal and spatial domain-based optimization strategy is proposed, which is implemented on bi-level (referring to transmission and distribution grid networks). First, a physical scheduling model of the grid is established, consisting of a novel hybrid demand response mechanism considering the incentives of EV retailers and the retail electricity price of EV users, and a new robust retail electricity pricing strategy handling the uncertainties of EV behavior and the electric market. Then, a bi-level optimization strategy is presented: at the upper level, in the transmission network, based on the robust pricing strategy, a unit commitment model that coordinates the hybrid demand response with other distributed energy resources is designed to optimize load periods of EVs in the time domain; at the lower level, in the distribution network, an optimal power flow model is proposed to spatially dispatch the location of EV loads. The impacts of retail price profile, EV penetration, hybrid demand response mechanism, and EV load location are analyzed in ten tests using the IEEE 33 distribution network. Simulation results indicate that the robust pricing strategy can effectively handle uncertainties, the integration of the hybrid demand response mechanism into scheduling can ensure the benefits of all participants, and the bi-level optimization strategy can accommodate distributed energy resources temporally and spatially.

1. Introduction

In recent years, the utilization of distributed energy resources (DERs) has increased, and many efforts have been made to integrate them into power systems [1]. As a typical form of DERs, electric vehicles (EVs) are seen as gaining importance due to their environmental benefits [2]. The large-scale integration of EVs into the power grid can impose substantial strain on both transmission and distribution networks (TDNs), leading to concerns about potential voltage fluctuations and peak load management [3]. To mitigate these impacts, encouraging the active participation of EVs in energy management is recommended [4].

The increasing uncertainty in electricity market pricing, coupled with the rising prevalence of flexible loads like EVs and renewable energy, has significantly complicated both transmission and distribution network dynamics [5]. On the one hand, the stringent power quality standards and the need for robust power system operation are posing fresh challenges for both transmission and distribution system operators, especially in the context of high EV penetration [6]. On the other hand, consumers are becoming more conscious of grid tariffs and exploring diverse energy procurement methods [7], such as the adoption of demand response mechanisms [8]. The integrated optimization of TDNs necessitates the seamless coordination of both power systems and EVs to enhance the efficiency, reliability, and stability of power grids. As EVs become more widespread and demand response (DR) technologies advance, the coordination of TDNs with large-scale EVs faces new challenges, which can be summarized into three key aspects: the precise scheduling model, economic strategies, and the co-optimization of TDNs

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Article

Dynamic Optimal Power Flow of Active Distribution Network Based on LSOCR and Its Application Scenarios

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Abstract: Optimal power flow (OPF) is a crucial aspect of distribution network planning and operation. Conventional heuristic algorithms fail to meet the system requirements for speed and accuracy, while linearized OPF approaches are inadequate for distribution networks with high R/X ratios. To address these issues and cater to multi-period scenarios, this study proposes a dynamic linearized second-order cone programming-based (SOCP) OPF model. The model is built by first establishing a dynamic OPF model based on linearized second-order conic relaxation (LSOCR-DOPF). The components of the active distribution network, such as renewable energy power generation units, energy storage units, on-load-tap-changers, static var compensators, and capacitor banks, are then separately modeled. The model is implemented in MATLAB and solved by YALMIP and GUROBI. Finally, three representative scenarios are used to evaluate the model accuracy and effectiveness. The results show that the proposed LSOCR-DOPF model can ensure calculation time within 3 min, voltage stability, and error control within 10^{-6} for all three applications. This method has strong practical value in the fields of active distribution network day-ahead dispatch, accurate modeling of ZIP load, and real-time operation.

Keywords: optimal power flow (OPF); active distribution network; linearized second-order conic relaxation (LSOCR); network reconfiguration; ZIP load

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1. Introduction

Recently, researchers have shown an increased interest in the active distribution network. The integration of various distributed generations, energy storage units, and active management devices has presented new challenges to the planning and operation of distribution networks [1], especially in the field of active management (AM) of distribution networks [2]. It is particularly urgent to develop optimization algorithms and high-performance computing tools applicable to various fields of active distribution networks. Ref. [3] analyzed three kinds of optimization problems of the smart grid: optimal power flow (OPF), unit commitment, and operation planning. Their essence is distribution network optimization, while having different optimization scales. The OPF is of great significance in the development process of the distribution network, and is the most common and fundamental optimization problem in power systems [4]. Research on distribution network OPF has mainly focused on the alternating current power flow (AC-OPF). Exploring a solution method to enhance the solution speed of distribution network AC-OPF while ensuring its optimal operation and fulfilling the requirements of active distribution network planning and operation has been a major concern in the field of power system

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Review

A critical survey of integrated energy system: Summaries, methodologies and analysis

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ABSTRACT

With a rapid growth of Integrated Energy System (IES) in various scenarios, researches on IES have attracted extensive attention in the last few decades. Inspired by the ever-increasing studies about the IES, which focus on various energy scenarios but lack a systematic summarization, this paper aims to undertake a comprehensive review of the IES models, operation optimization methods, and model tools. Firstly, CiteSpace is used to visually analyze the cooperation and co-occurrence network of related articles in recent two decades, among which 1998 papers from WOS are selected for analyzing. Note that 243 papers highly related to IES are further investigated to systematically analyze and integrate the relevant work. On this basis, different definitions of IES around the world and 12 related research hotspots are summarized. Then, the IES modeling methods are creatively classified from eight aspects. Furthermore, from the perspective of operation optimization methods, three mainly optimal problems, including Economic Dispatch, Unit Commitment and Optimal Power Flow, are comprehensively analyzed. Besides, 22 energy model tools are discussed from the levels of National, Regional, and Users. Finally, seven advantages and three challenges are summarized, four key points are concluded, and six perspectives/recommendations are proposed for future research. In general, this paper is intended to offer an insightful guidance to prompt related researchers/engineers to broaden the horizons of their researches.

1. Introduction

Energy has a bearing on the national economy, national security, as well as the survival and development of mankind, which is vital to promoting social development. Energy plays a fundamental role in the economic system and has played a key role in the previous three technological revolutions. Under the "carbon peak" and "carbon neutral" goals, the new energy industry will usher in a high-quality and leap-forward development. And the proportion of clean power installed capacity will significantly increase, such as PV and Wind power [1,2]. Under the background of Covid-19 pandemic, renewable energy has a record of new power generation capacity in 2020 and is the only source with a net increase in total power generation capacity [3,4]. It is widely known that renewable energy owns various advantages, such as lower

Abbreviations: CCHP, Combination of Cooling, Heating and Power; CloudPSS, Cloud Based Integrated Energy Planning Studio; COMPOSE, Compare Options for Sustainable Energy; DE, Differential Evolution; DER-CAM, Distributed Energy Resources Customer Adoption Model; DRO, Distributed Robust Optimization; EC, Evolutionary Computation; ED, Economic Dispatch; EH, Energy Hub; EI, Energy Internet; ESME, Energy System Modeling Environment; GA, Genetic Algorithm; GEM-E3, General Equilibrium Model for Economy-Energy-Environment; HOMER, Hybrid Optimization of Multiple Energy Resources; iHOGA, Hybrid Optimization by Genetic Algorithm; IES, Integrated Eenergy System; LEAP, Long-range Energy Alternatives Planning System; MARKAL, Market Alocation model; MIP, Mixed Integer Programming; MILP, Mixed Integer Linear Programming; MINLP, Mixed Integer Nonlinear Programming; NEMS, National Energy Modeling System; OPF, Optimum Power Flow; P2G, Power-to-Gas; POLES, Prospective Outlook on Long-term Energy Systems; PRIMES, Price Induced Market Equity System; PV, Photovoltaics; RE, Renewable Energy; Renpass, Renewable Energy Pathways Simulation System; RES, Renewable Energy Source; RO, Robust Optimization; SI, Swarm Intelligence; SWITCH, Solar, Wind, Transmission, Conventional generation and Hydroelectricity; Temoa, Tools for Energy Model Optimization and Analysis; TIMES, The Integrated MARKAL-EFOM System; TRNSYS, Transient System Simulation; UC, Unit Commitment; WOS, Web of Science.

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Robust Pricing Strategy with EV Retailers Considering the Uncertainty of EVs and Electricity Market

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Abstract: In the context of high penetration of electric vehicles (EVs) in the distribution network, the electricity consumption behaviour of EVs and the real-time electricity market exhibit high uncertainty. EV retailers need to establish reasonable retail pricing to reduce market risks, while ensuring their own profitability and the benefits of EV users. This paper proposes a two-stage robust pricing strategy for EV retailers based on the Stackelberg game, which considers various uncertain factors in the distribution network and satisfies the benefits of both EV users and EV retailers. First, a robust optimization model is established for EV retailers' day-ahead planning and real-time dispatch, considering the uncertainty of EVs and the real-time electricity market. Then, the robust optimization model is divided into a master problem and a sub-problem for two-stage optimization, which is solved iteratively using the Stackelberg game model and the column and constraint generation (CC&G) algorithm. Finally, simulations and verifications based on the IEEE33 benchmark model are conducted to demonstrate the effectiveness of the proposed strategy in the electricity market.
Keywords: Electric Vehicle (EV), retail price, robust optimization, electric market, distribution network

1. Introduction

At present, the uncertainty of the electricity market and the large-scale EVs access lead to fluctuations in retail electricity prices, which will in turn affect the co-economic objectives of EV users and EV retailers. The operational profits of retailers and the benefits for EV users are crucial indicators reflecting the vibrancy of the electricity market. Therefore, an available retail electricity pricing strategy that considers the interests of different stakeholders within the coverage of distribution network under high EV penetration is necessary.

In the retail pricing strategy of EV retailers, EV retailers are characterized as "representing all EVs participating in day-ahead and real-time electricity market transactions, trading with EV users at retail prices, earning profit from price differences, and avoiding market risks [1, 2] ". However, the retail price of EV retailers is influenced by uncertain factors such as the high penetration of EVs distribution and day-ahead and real-time electricity markets [3, 4]. Ref. [5] considers the uncertainty of distribution locational marginal price (DLMP) [6] and obtains the best power purchase plan for retailers based on a two-stage robust optimization model. Ref. [7] investigates the impact of demand-side uncertainty on the bidding decisions of load retailers and develops optimal bidding strategies for retailers. Ref. [8] proposes a detailed robust pricing strategy for power retailers. Meanwhile, since the relationship between retailers and customers constitutes a non-cooperative game, existing research typically employs a Stackelberg game model to describe their interaction [9]. Ref. [10] proposes an intelligent community agent pricing strategy based on the Stackelberg game. Ref. [11] represents an optimal dispatch and bidding strategy of a virtual power plant based on a Stackelberg game. However, existing literature overlooks the uncertainty of EV retail users and the real-time electricity market, which cannot fully coordinate the profits of EV retailers with EV users in the context of high EV penetration.

Based on the analysis above, an EV retailer pricing strategy that considers the uncertainty of EVs and real-time electricity markets, based on Stackelberg game and robust optimization is proposed. Firstly, the uncertainty of EVs and real-time electricity markets are described based on the ideas of distributed robust optimization and stochastic optimization respectively. Then, the objective function of the EV retailer is divided into two stages: day-ahead and real-time electricity market optimization, and a two-stage robust optimization model for the EV retailer is established. Considering the game relationship between EV users and EV retailers, a Stackelberg game pricing model for both parties' objective functions is established. Finally, the CC&G algorithm [12] and the Stackelberg model are used for solution, and the effectiveness of the proposed strategy is verified through IEEE33-node distribution network.

2. Operation Mode of Retailers

The EV retailers link the electricity market with the retail market through the operation mode depicted in Fig. 1.

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考虑风电不确定性的风火储能源系统鲁棒优化调度研究

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摘要 风电的不确定性使得其大规模并网存在弃风等诸多问题。为此，针对风电不确定性，本文考虑其预测误差的同时结合先进绝热压缩空气储能(AA-CAES)技术，建立了风火储能源系统鲁棒优化调度模型。模型不仅考虑了AA-CAES电站的运行约束，也针对其运行特性考虑了其在备用容量上的约束。同时，基于极限场景法，结合风险、运行、综合三种成本，建立了最优风电不确定集，实现了系统在鲁棒性与经济性上的最优。最后基于IEEE39节点系统进行算例仿真，仿真结果验证了模型的有效性。

关键词 不确定性，鲁棒优化调度，AA-CAES 电站，备用容量，极限场景

Robust Optimal Scheduling of Wind Thermal Energy Storage System Considering Wind Power Uncertainty

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Abstract *The uncertainty of wind power makes its large-scale grid connection have many problems, such as wind abandonment. In view of its uncertainty, considering its prediction error and combined with advanced adiabatic compressed air energy storage (AA-CAES) technology, a robust optimal scheduling model of air-fire energy storage system is established. The model not only considers the operation constraints of AA-CAES power plant, but also considers the reserve capacity constraints according to its operation characteristics. At the same time, combined with the risk, operation and comprehensive cost, the optimal uncertainty set of wind power is obtained, and the robustness and economy of the system are optimized. Finally, an IEEE 39 bus system is simulated, and the simulation results verify the effectiveness of the model.*

Key Words *Uncertainty, Robust optimal scheduling, AA-CAES, Reserve capacity, Extreme scenario*

引言

近年来，为应对全球气候变暖以及能源危机等挑战，风力发电迅速发展[1]。在中国，风电累计装机容量于 2019 年便达到了 2.1 亿千瓦，占全球的陆地总装机容量的37%[2]。风电飞速发展的同时，种种问题也随之而来。由于风电的间歇性和不确定性，其大规模并网给电力系统的可靠性带来了巨大挑战。以中国为例，2016 年全国平均弃风率达 17%，2019 年虽降低至 4%[3]，但装机容量的增大，意味着弃风问题依旧急需解决。

储能是解决风电大规模利用，减少弃风的关键技术。在各种解决弃风的方案中，先进绝热压缩空气储能(AA-CAES)由于其寿命长、成本低、响应快、选址灵活等优点，近期得到了广泛的关注[4]。AA-CAES 是常规压缩空气储能(C-CAES)的改善。与 C-CAES 不同的是，AA-CAES 能够将压缩热存储起来，减少了化石燃料的使用，同时也比 C-CAES 具有更高的效率。

当前，国内外对于 AA-CAES 参与风电调度消纳的研究还不是很多，而传统的 C-CAES 电站参与的调度已有不少研究。文献[5]提出了一种联合能量和储备的调度模型，系统中考虑风电和 C-CAES。在文献[6]中，通过研究 AA-CAES 调度模型，估计了其在垄断电力市场、能源市场和备用市场中的价值。文献[7]提出了与 AA-CAES 集成的零碳排放微电网的优化调度模型，AA-CAES 既提供电力又提供热量。同样考虑其供热供电的文献[8]建立了一种包含AA-CAES的热电联储/供的 MIES 整体调度模型。文献[9]则从备用容量角度出发，建立了含 AA-CAES 电站的实时调度模型。上述研究大部分还仅仅只是停留在将 AA-CAES 与传统能源相结合利用，忽略了备用容量或可再生能源的不确定性等问题。

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