

# Guest Editorial: Special Section on Toward Low Carbon Industrial and Social Economy of Energy-Transportation Nexus

**T**HE transportation sector accounts for almost one-third of the global energy demand and contributes more than 20% carbon footprint. Facing the carbon-neutral target for global temperature control, transportation electrification has become an irreversible trend in all the attached sectors, including electric vehicles, railways, ships, and airplanes, which has drawn more and more attention in both industrial and academic ways. The trend of electrification will undoubtedly drive the emergence of energy and transportation systems as “energy-transportation nexus.” To facilitate the development of this “energy-transportation nexus” toward a low-carbon future, it becomes more and more critical to coordinate the operation and planning of energy and transportation systems to fully explore their respective flexible potentials to enhance the industrial and social economy and reduce the carbon emission as an integrated system, which provides a vast platform for the utilization of different advanced methodologies and equipment.

This special issue aims to identify, address, and disseminate state-of-the-art research works that optimize the operation and planning of “energy-transportation nexus” and improve social welfare toward a low-carbon future. A large number of papers have been received from different research groups around the world, with diverse perspectives. After a detailed and rigorous examination of these papers by expert reviewers in the relevant fields, the editorial board finally selected 11 original articles to be included in this special section. We divide these articles into the following four categories:

- 1) system operation;
- 2) resilience control;
- 3) electric vehicle battery management;
- 4) energy consumption estimation.

## I. SYSTEM OPERATION

Transportation electrification has become a trend in all transportation sectors, including electric vehicles, railways, ships, and aircraft. The charging behavior of all means of electric transportation links the transportation system and energy system, increasing the total charging load into the power grid. Due to different operational and technical characteristics of charging demands, they can be operated flexibly, which would aid in

enhancing the operational performance of both the transportation and energy system.

In the article “Aviation-to-Grid Flexibility through Electric Aircraft Charging” by Guo *et al.* [A1], a new concept of aviation-to-grid that utilizes electric aircraft charging is proposed to provide flexibility to the power grid. Hourly energy dispatch strategy is produced based on the mixed-integer linear programming method to meet electrified aviation charging demand and provide aviation-to-grid frequency response to the power grid. Results of case studies conducted in eight major U.K. airports show that the annual aviation-to-grid frequency response revenue is estimated to be £46.58 million, which can cover 19.8% to 30% of electric aircraft charging costs.

Photovoltaic generation plays a significant role in realizing the target of carbon neutralization. In the article “Maximum Hosting Capacity of Photovoltaic Generation in SOP-based Power Distribution Network Integrated with Electric Vehicles” by Zhang *et al.* [A2], a two-stage robust optimization model is proposed to assess the maximum hosting capacity of photovoltaic generation in power distribution networks considering the integration of soft open point and electric vehicles. Case studies are carried out on the modified IEEE 33-bus power distribution network integrated with soft open point and electric vehicles. The results show the advantages of the proposed model and solving strategy.

The autonomous mobility-on-demand system is a promising shared mobility method for a sustainable transportation system. In addition, battery swapping could become efficient energy-refueling means for electric vehicles. In the article “Quality-of-Service Aware Battery Swapping Navigation and Pricing for Autonomous Mobility on Demand System” by Ding *et al.* [A3], the quality-of-service aware battery swapping price-based charging management strategy determined by the battery swapping stations considers the interaction between autonomous mobility-on-demand fleet and BSSs, formulated as a bilevel optimization problem. An iteration-based algorithm is applied to attain the results, and the algorithm’s effectiveness is validated by the real-world data from New York.

In the article “A Multilateral Transactive Energy Framework of Hybrid Charging Stations for Low-Carbon Energy-Transport Nexus” by Zhang *et al.* [A4], a multilateral multienergy trading framework for synergetic hydrogen and electricity transactions among renewable-dominated hybrid charging stations is proposed. In this framework, each autonomous hybrid charging

station with various renewable energy resource endowments can harvest local renewables for internal green hydrogen and electricity generation to meet the demands of electric and hydrogen-powered vehicles from the transportation network. A distributed multilateral pricing algorithm is developed to iteratively derive the optimal prices and quantities for transactive electricity and hydrogen. Comparative studies corroborate the superiority of the proposed methodology on economic merits and renewable energy resource accommodation.

Co-phase traction power supply system is a promising solution in the smart electrified railways to effectively eliminate the neutral section, improve regeneration braking energy utilization, and mitigate voltage unbalance. It works by coordinating the power flow distribution among the energy storage, power flow controller, and traction transformer. In the article “Dynamic Voltage Unbalance Constrained Economic Dispatch for Electrified Railways Integrated Energy Storage” by Chen *et al.* [A5], driven by the day-ahead forecasted information, a dynamic voltage unbalance regulation strategy is proposed to draw up the voltage unbalance compensation schedule, which can satisfy the probabilistic limitations of power quality standards. Case study tests verify the efficiency of the proposed approach. The results show that the scheme can improve energy storage cycle life and decrease cost under the probabilistic limitations of voltage unbalance.

## II. RESILIENCE CONTROL

As extreme weather events may exacerbate system vulnerability, there are difficulties in the stability and reliability of energy system operations. Resilience control has been studied to handle these potential severe contingencies. Resilience refers to the ability of the energy system to anticipate, respond and withstand external shocks, quickly bounce back to its preshock state, maintain the survivability of essential loads, and adapt to be better prepared for future catastrophic events. Due to their significant advantages in mobility and flexibility, electric vehicles can be called up in a short time and deployed in appropriate locations for resilience enhancement.

In the article “A Coordinated Restoration Method of Hybrid AC/DC Distribution Network with Electric Buses Considering Transportation System Influence” by Zhang *et al.* [A6], a coordinated restoration method of a distribution network with electric buses is proposed, with flexible power transfer capability. The control modes of voltage source converters during the postdisaster period and the electric bus restoration capability considering transportation system constraints are analyzed in detail. Then, a bilevel programming model is developed to optimize the network reconfiguration, voltage source converters outputs, and the proposed electric bus dispatching scheme simultaneously to achieve a better power transfer capability for load restoration considering their coordination. Simulation studies are performed to verify the proposed method.

The intermittency of renewable energy resources raises the power system vulnerability and even causes severe damage under extreme events. In the article “Hybrid Multi-Agent Reinforcement Learning for Electric Vehicle Resilience Control Towards a Low-Carbon Transition” by Qiu *et al.* [A7], the

distributed control of electric vehicles under extreme circumstances in a power-transportation network is proposed with enormous dynamics and uncertainties. To this end, a multiagent reinforcement learning method is proposed to compute discrete and continuous actions simultaneously, aligning with the nature of electric vehicle routing and scheduling problems. Simulation results based on the IEEE-6 and 33 bus power networks integrated with transportation systems validate its effectiveness in providing system resilience and carbon intensity service.

## III. ELECTRIC VEHICLE BATTERY MANAGEMENT

The battery management system monitors the status of electric vehicle battery usage in real time, alleviates inconsistencies in the battery pack through necessary balancing strategies, and ensures the safe operation of the energy storage system.

Grid-connected electric vehicles and energy-transportation nexus bring a bright prospect to improve the penetration of renewable energy and the economy of microgrids. However, it is challenging to determine optimal vehicle-to-grid strategies due to the complex battery aging mechanism and volatile microgrid states. In the article “Online Battery Protective Energy Management for Energy-Transportation Nexus” by Li *et al.* [A8], a novel online battery antiaging energy management method is developed for energy-transportation nexus by using a novel deep reinforcement learning framework. The developed energy-transportation nexus energy management method is verified to be effective in optimal power balancing and battery antiaging control on a microgrid in the U.K. This research provides an efficient and economical tool for microgrid power balancing by optimally coordinating electric vehicle charging and renewable energy, thus helping promote a low-cost decarbonization transition.

A battery-based energy storage system is a crucial component to achieving low-carbon industrial and social economy, where battery health status plays a vital role in determining the safety and reliability of the energy-transportation nexus. In the article “A Transferred Recurrent Neural Network for Battery Calendar Health Prognostics of Energy-Transportation Systems” by Liu *et al.* [A9], the base framework for a transferred recurrent neural network is proposed to achieve efficient calendar capacity prognostics under both witnessed and unwitnessed storage conditions. The proposed framework could assist engineers in significantly reducing battery aging experiment burden and is also promising to capture future capacity information for battery health and life-cycle cost analysis of energy-transportation applications.

## IV. ENERGY CONSUMPTION ESTIMATION

Estimating energy consumption is mainly used for electric vehicle navigation functions similar to gas vehicle eco-routing, which is a navigation strategy for finding the route that consumes the least fuel or produces the least emissions or for finding ways to reduce energy consumption.

Considering the limited battery capacity of electric vehicles, accurate battery energy consumption prediction is crucial for charging navigation because it determines the maximum traveling distance. In the article “En-Route Electric Vehicles

Charging Navigation Considering the Traffic-Flow-Dependent Energy Consumption” by Lu *et al.* [A10], a comprehensive electric vehicle energy consumption prediction model is developed. Moreover, a stochastic traffic flow model is proposed to improve the energy consumption prediction precision, in which the related uncertainties, such as travel time and vehicle speed, are captured. The simulation verification is carried out in the real road network of a typical city and the IEEE 33-node coupling system. Results demonstrate the feasibility and effectiveness of the proposed model and solution algorithm.

The widespread adoption of electric vehicles has been hampered by two factors: the lack of charging infrastructure and the limited cruising range. Energy consumption estimation is crucial to address these challenges as it provides the foundations to enhance charging-station deployment, improve eco-driving behavior, and extend the electric vehicle cruising range. In the article “Fine-grained RNN with Transfer Learning for Energy Consumption Estimation on EVs” by Hua *et al.* [A11], an electric vehicle energy consumption estimation method capable of achieving accurate estimation despite insufficient electric vehicle data and ragged driving trajectories is proposed. Experimental evaluation shows our method outperforms other machine learning benchmark methods in estimating energy consumption on a real-world vehicle energy dataset.

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#### APPENDIX RELATED WORK

- [A1] Z. Guo, J. Zhang, R. Zhang, and X. Zhang, “Aviation-to-Grid Flexibility through Electric Aircraft Charging,” *IEEE Trans. Ind. Informat.*, doi: [10.1109/tii.2021.3128252](https://doi.org/10.1109/tii.2021.3128252).

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