Guest Editorial: Special Section on Advances in Coordination of Large-Scale EV Charging Networks

DUE to the energy demand growth and environmental concerns, electric vehicles (EVs) have received a prominent interest by academia, industry, and government. This has attracted in recent years the study on the integration of EVs in the market. To make this integration widespread, several challenges need to be addressed and various shortcomings require solutions. One of these challenges is controlling the charging/discharging of EVs, which benefits different parties, e.g., EV customers, charging stations, and power grid. EV customers are reasonably the main decision makers, who decide how, when, and where to charge their EVs based on their demands and behaviors. These decisions are affected by the statuses and policies of the charging stations that have different objectives, locations, and types of charging infrastructure. These stations are generally connected to the power grid, which is mostly the main source/sink to charge/discharge EVs. Although the charging loads of EVs can impact the performance of the grid, the EV energy batteries could support the operation of the grid, such as peak load shaving and stability of voltage and frequency. Moreover, controlling a large scale of geographically distributed EVs in terms of spatial-temporal coordination, travel navigation, communication, and cybersecurity can further increase the challenges of their adoptions. For effective coordination of these networked charging systems, new approaches and innovations are needed to improve the overall performance, such as efficiency, flexibility, stability, resiliency, security, and reliability.

This Special Section on "Advances in Coordination of Large-Scale EV Charging Networks" was focused on the development of modeling the charging loads and behaviors of EVs and on the novel control methods for navigating and charging/discharging EVs. Topics that were announced to be addressed in this section included, but were not limited to, the following research areas and technologies:

1) planning of EV charging stations;
2) selection of charging stations by EVs;
3) modeling and extracting of EV loads (e.g., residential and industrial);
4) utilization of smart meters and communication devices;
5) description of user charging behaviors;
6) load-flow initialization methods of EVs;
7) optimal and intelligent charging control;
8) spatial-temporal charging coordination; and
9) privacy protection and cybersecurity.

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We received several papers that were submitted from different research groups and perspectives. After a thorough evaluation by the reviewers, the editorial board chose four well-written papers that represent the latest and most advanced information and coordination technologies in the field. The details of the chosen papers will be explained further in the following section.

In [A1], Xing et al. proposed a platform that uses reinforcement learning for real-time charging navigation of EVs in urban areas. The platform aims to minimize the charging cost and travel time of EV owners by considering the interaction of EVs with charging stations and traffic networks in the tuple "vehicle-station-network.' To achieve this, the authors characterize the EV charging and traveling behavior as a dynamic interaction process using graph-structured networks. They use a graph convolutional network to extract environment information required for the EV charging navigation and feed it into the deep reinforcement learning network to help the agent better understand massive graph-structured data. The platform formulates the real-time navigation problem as a finite Markov decision process and solves it using a rainbow-based deep reinforcement learning algorithm. The platform can sequentially recommend charging stations and plan traveling routes for multiple EVs, and case studies conducted in Nanjing, China, confirm the effectiveness of the developed platform and solving method.

In [A2], Song et al. proposed an ensemble classification model for identifying EVs from smart meter recordings. The motivation for this model is that uncoordinated charging of many EVs can lead to grid overload, which adversely affects other customers. To better manage the operation planning of their distribution grid, electricity distributors require full visibility on the EV distribution in their network, but they often lack this knowledge. Identifying EV customers charging at home using smart meter data is challenging because of the difficulties in recognizing charging patterns, balancing the number of EV and non-EV customers, and building an efficient classification model. To address these difficulties, the authors propose a periodic pattern recognition method to extract useful EV charging patterns and improve K-medoids evaluated by dynamic time warping to obtain representative non-EV training samples, which balances the samples over EV and non-EV customers. The proposed ensemble classification model uses multiple classifiers and optimizes the optimal subset of periodic patterns, optimal parameters in each classifier, and optimal weights for combining classifiers. The proposal is compared to several baseline models.

In [A3], Kumar and Panda designed a novel power quality improved cold ironing (PQICI) system to address air and noise pollution issues at seaports. The system focuses on the infrastructure of electric vessel charging stations, which are being implemented at the busiest commercial ports. These charging stations use modern electronic devices to provide high-quality output power. However, this creates a serious harmonic issue on the input side when supplying megawatt ranges of power to the ships during cold ironing. The proposed PQICI system can supply different types of power, including ac power, dc power, 50 Hz frequency, 60 Hz frequency, single phase, three phases, three-wire network, four-wire network, five-wire network, and different ac and dc voltages. It is also capable of serving four vessels simultaneously and maintaining power quality on the input side, regardless of the loading conditions and power demand of the vessels. The system's capability is tested through simulation and real-time HIL experimentation, and satisfactory results on both platforms show the efficiency of the developed system and its control mechanism. The proposed PQICI system provides a promising solution to the challenges of electric vessel charging stations and could improve the power quality while reducing air and noise pollution at seaports.

Finally, in [A4], Li et al. proposed a method for sizing retired batteries in conjunction with photovoltaic solar energy to meet charging demand for electric vehicle charging stations (EVCS). The optimization approach aims to minimize renewable energy waste, external grid energy purchase, and cost over a 20-year period by employing NSGA-II. To predict the remaining life of retired batteries, a calendar-life degradation model is used in combination with a battery cycle-life counting method. Charging demand uncertainty is modeled with different charging patterns for various EVCS scenarios with different combinations of fast and slow charging demands. The method is validated with real-world data and compared to the use of new batteries. The results indicate that the proposed sizing method can reduce the cost of EVCS operation by 29.4% over the long term when using retired batteries.

To sum it up, there is a great need to investigate more in the coordination of EV charging networks due to the increase in their numbers in the market. Preparing a suitable infrastructure is important, which includes the existence of smart meters to measure critical information. This information will be analyzed at lower and higher levels of management, including distributed and centralized tasks. This is a complex task, particularly when taking the several objectives of the different parties, i.e., EVs, charging stations, and utilities. The problem will be more complicated with a large-scale system. Realization of communication and telemetric systems tailored to the EV requirements is an important step to prepare the infrastructure to implement advanced control and management algorithms. Advanced energy coordination including battery management and energy/power management is demanded to assure reliable, safe, and efficient performance of EVs. The development on the charging stations is with the same importance to deliver reliable green electricity for EVs. A tremendous effort and research still need to guarantee good reliability, security, and efficiency. Guest Editors believe that these papers would stimulate further studies and serve as references for the researchers working in coordinating EV charging networks.

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The Guest Editors would like to express their deep gratitude to all the authors who have submitted their valuable contributions and to the numerous and highly qualified anonymous reviewers. They think that the selected contributions, which represent the current state of the art in the field, will be of great interest to the industrial electronics community. They would also like to thank Prof. Ren C. Luo and Prof. Gerhard P. Hancke, the previous and current Editor-in-Chiefs of the IEEE TRANSACTIONS IN INDUSTRIAL INFORMATICS, for giving us the opportunity to organize this Special Section and for all the encouragement, help, and support given throughout the process and Ms. Lisa Jess for her professional support and assistance during the whole preparation of this Special Section.

APPENDIX: RELATED ARTICLES

[A1] Q. Xing, Y. Xu, Z. Chen, Z. Zhang, and Z. Shi, "A graph reinforcement learning-based decision-making platform for real-time charging navigation of urban electric vehicles," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2022.3210264.

[A2] H. Song, C. Liu, M. Jalili, X. Yu, and P. Mctaggart, "Ensemble classification model for EV identification from smart meter recordings," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2022.3175750.

[A3] N. Kumar and S. K. Panda, "A multipurpose and power quality improved electric vessels charging station for the seaports," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2022.3170424.

[A4] J. Li, S. He, Q. Yang, T. Ma, and Z. Wei, "Optimal design of the EV charging station with retired battery systems against charging demand uncertainty," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2022.3175718.

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