Guest Editorial
Special Issue on IoT for Power Grids

RECENT years have witnessed the exciting developments for the power grid. For instance, many traditional mechanical components are being replaced by modern electronics devices that can operate intelligently; new elements, such as renewable energy resources and various large-scale energy storage, are introduced into the grid to bring a new outlook on the system operation and control; smart appliances are produced to facilitate more customized and efficient energy usage; and advanced sensors, such as the phasor measurement units (PMUs) and the advanced metering infrastructure (AMI), are designed and implemented for real-time wide-area monitoring of the system conditions. In general, the power grid is increasingly organized and managed as an interconnected network of many different individual components that operate intelligently in a distributed but connected manner, as opposed to the traditional centralized fashion. In other words, the power grid is evolving into a big Internet of Things (IoT).

On the one hand, this new IoT aspect of the grid engenders many potential benefits to the power systems, such as improved situational awareness (SA) in monitoring, enhanced intelligence and automation in operation and control, boosted efficiency in energy dispatch and management, as well as cheaper and cleaner energy usage, just to name a few. On the other hand, the IoT perspective of the grid also introduces many challenges, such as interoperability of the devices, the Quality of Service (QoS) for the communications among heterogenous components, the cyber and physical security of the infrastructure, the reliability and resiliency of the entire system, massive data processing, etc. In this special issue, we call for the efforts both to explore the benefits and address the challenges in the IoT for power grids. The Calls for Papers was issued in the middle of 2021, with the submission deadline set as 15 December 2021. We have received 74 submissions and ultimately 23 high-quality papers have been selected, which are categorized into the following six groups.

I. IoT for Power System Monitoring

The paper by Liu et al. [A1] presents a machine-learning framework for training robust event classifiers to enhance the SA of power systems using PMU data. The paper by He et al. [A2] presents a novel data-driven SA paradigm, named DT-SA, as a promising alternative based on the Digital Twin of Energy IoT (EIoT-DT).

The paper by Wang et al. [A3] proposes the temporal weighted network that combines topological characteristics and temporal feature of the operation status of power networks. The paper by Sarker et al. [A4] presents developing metrics for monitoring the resiliency of the cyber-power distribution system, while maintaining consumers' privacy. The last paper in this group by Tarahi et al. [A5] proposes an IoT-based solution to a real problem posing top threats to the physical security of power transmission towers.

II. IoT for Power System Optimization

The paper by Edib et al. [A6] presents a cross-domain optimization framework for PMU and communication link placement to achieve multidomain resiliency and global cost effectiveness. The paper by Huang et al. [A7] proposes a deep reinforcement learning-based scheduling method to solve the fleet management problem in the shared on-demand green logistic system in an online manner.

The paper by Han et al. [A8] proposes a demand response (DR) scheduling algorithm for coordinative optimization between multiple data center operators (DCOs) and system operator (SO). The paper by Qiu et al. [A9] proposes a hybrid state system modeling method based on the discrete hybrid automaton (DHA).

The paper by Bhatia et al. [A10] proposes the IoT–Fog–Cloud (IFC)-based smart framework for power utilization analysis and an automated game-theoretic decision-making model to assist power grid house managers in optimizing the spatial–temporal distribution of electricity resources. The paper by Yin et al. [A11] proposes a health-aware energy management strategy in the environment of Internet of Storage (IoS), enabling distributed storage systems to cooperate through information and communication technology.

III. Cyber Security Issues in Energy IoT

The paper by Gong et al. [A12] proposes a novel attack identification mechanism for IoT-based converter composed of dc grids, where each agent collects its own and neighbors' measurement data for output regulation to meet a preceding power-sharing consensus. The paper by Ren and Xu [A13] proposes a universal defense strategy for the ML-based SA models based on the randomized smoothing algorithm to resist the adversarial attacks and an effectiveness index for the proposed universal strategy to quantify the maximum ability of resistance to adversarial examples.

The paper by Ospina et al. [A14] proposes a quantitative cyber–physical security metric for cyber–physical energy system (CPES) and a cyber-constrained ac optimal power flow (ACOPF) formulation to cope with the security challenges of

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modern CPES. The paper by Asadi et al. [A15] proposes a data-driven adaptive control (DDAC) technique for the automatic generation control (AGC) problem of an interconnected power grid subject to deception attack (DA).

The paper by Wang et al. [A16] presents a cryptography-based, programmable control (crypto control) scheme to provably preserve the privacy of distributed energy resources (DERs) while ensuring fast, flexible distributed control in networked microgrids (NMs). The paper by Wu et al. [A17] presents analyzing of the intrusion paths, the invasion mechanisms, and the possible consequences of most potential attacks in power communication networks (PCNs) and also proposed a method for classifying and evaluating defense measures considering security indices.

IV. IoT for Integrated Energy Systems

The paper by Zang et al. [A18] proposes an asynchronous distributed dynamic state estimation method for integrated electricity–gas energy systems and an adaptive state estimation execution cycle adjustment method to track the state of the natural gas subsystem in real time under conditions of large disturbances in that subsystem. The paper by Xie et al. [A19] proposes a novel deep reinforcement learning algorithm, namely, collaborative learning actor–critic strategy, to solve the problem of strong random disturbances suffered by power grid in integrated energy system (IES) based upon ubiquitous power IoT. The last paper in this group by Si et al. [A20] presents secure multiparty computation (SMPC) to the distributed optimization of the IESs.

V. IoT for Systems With Electric Vehicles

The paper by Wei et al. [A21] proposes an integrated charging and computing (IC^2) architecture for EV-included smart grid which integrated vehicular fog computing (VFC) and smart EV charging for joint optimization. The paper by Rojas and Rodríguez [A22] presents an electric vehicle (EV) charge cycle management system (CCMS) for ComEd real-time pricing (RTP) scheme.

VI. Channel Characterization for Energy IoT

The paper by Zhou et al. [A23] presents a novel channel sounder for achieving omnidirectional measurements and phased array antennas-based directional measurements, and a directional multipath components extraction algorithm is proposed.

In conclusion, the papers presented in this special issue demonstrate the latest advances about the applications of IoT to power grids. We would like to deliver our appreciations to both the authors and the reviewers for their hard work in helping us manage this special issue. Also, we would like to express our sincere gratitude to the former Editor-in-Chief, Dr. H. Wang, for offering this opportunity and lots of guidance throughout the process.

Appendix: Related Articles

[A1] Y. Liu et al., "Robust event classification using imperfect real-world PMU data," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7429–7438, May 1, 2023.

[A2] X. He et al., "Situation awareness of energy Internet of Thing in smart city based on digital twin: From digitization to informatization," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7439–7458, May 1, 2023.

[A3] X. Wang, F. Xue, Q. Wu, S. Lu, L. Jiang, and Y. Hu, "Evaluation for risk of cascading failures in power grids by inverse-community structure," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7459–7468, May 1, 2023.

[A4] P. S. Sarker, S. K. Sadanandan, and A. K. Srivastava, "Resiliency metrics for monitoring and analysis of cyber-power distribution system with IoT," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7469–7479, May 1, 2023.

[A5] H. Tarahi, H. Haghighat, N. Ghandhari, and F. Adinehpour, "Smart online protection system for power transmission towers: An IoT-aided design and implementation," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7480–7489, May 1, 2023.

[A6] S. N. Edib, Y. Lin, V. M. Vokkarane, and X. Fan, "A cross-domain optimization framework of PMU and communication placement for multi-domain resiliency and cost reduction," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7490–7504, May 1, 2023.

[A7] Y. Huang, Z. Ding, and W.-J. Lee, "Charging cost aware fleet management for shared on-demand green logistic system," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7505–7516, May 1, 2023.

[A8] O. Han, T. Ding, C. Mu, W. Jia, and Z. Ma, "Coordinative optimization between multiple data center operators and a system operator based on two-level distributed scheduling algorithm," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7517–7527, May 1, 2023.

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[A11] C. Yin, J. Wang, W. Tang, G. Li, and M. Zhou, "Health-aware energy management strategy toward Internet of Storage," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7545–7553, May 1, 2023.

[A12] S. Gong, T. Dragičević, N. Mijatovic, and Z. Zhang, "A novel attack identification mechanism in IoT-based converter-composed DC grids," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7554–7567, May 1, 2023.

[A13] C. Ren and Y. Xu, "A universal defense strategy for data-driven power system stability assessment models under adversarial examples," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7568–7576, May 1, 2023.

[A14] J. Ospina, V. Venkataramanan, and C. Konstantinou, "CPES-QSM: A quantitative method towards the secure operation of cyber-physical energy systems," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7577–7590, May 1, 2023.

[A15] Y. Asadi, M. M. Farsangi, A. M. Amani, E. Bijami, and H. H. Alhelou, "Data-driven automatic generation control of interconnected power grids subject to deception attacks," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7591–7600, May 1, 2023.

[A16] L. Wang, P. Zhang, Z. Tang, and Y. Qin, "Programmable crypto-control for IoT networks: An application in networked microgrids," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7601–7612, May 1, 2023.

[A17] Y. Wu et al., "Research on cyber-attacks and defensive measures of power communication network," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7613–7635, May 1, 2023.

[A18] H. Zang, M. Geng, M. Huang, Z. Wei, S. Chen, and G. Sun, "Asynchronous and adaptive state estimation of integrated electricity-gas energy systems," *IEEE Internet Things J.*, vol. 10, no. 9, pp. 7636–7644, May 1, 2023.

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