Guest Editorial: Special Issue on Sustainable Energy Through Power-Electronic Innovations in Cyber-Physical Systems

ENERGY sustainability and sustainable energy systems play a major role in the long-term sustenance of human existence and the environment, and improve the coexistence between technology and nature. Cyber-physical systems are one of the means for achieving energy sustainability. The physical layer comprising of power/energy and the cyber layer comprising of control, communication, and computation needs to be designed to achieve the overall goals of energy sustenance such as integration of renewable energy to the grid, reliable control power converters, microgrid control and protection, energy harvesting from nonconventional sources and efficient power circuit topologies. The confluence of the cyber and physical layers is seen in a multitude of applications such as smart connected and self-sustainable electronic grids; smart cities, centers, buildings, and villages; electronically controlled mobility, transportability, and energy transformation (e.g., electric vehicles and locomotives, electronically controlled semiconductor-based transformers); healthcare and biomedicine; cognitics, robotics, and wearables; lighting; telecommunications; aerospace, avionics, and space applications; off-grid and rural-electrification applications; and network-on chips, edge computing, and the Internet of Things (IoT).

This Special Issue on Sustainable Energy Through Power-Electronic Innovations in Cyber-Physical Systems was proposed to present the latest developments in inventions and applications of sustainable energy through power-electronic innovations in physical and cyber systems. In response to the call for papers, we received 32 manuscripts and 15 were finally accepted. The 15 articles in this Special Issue cover a variety of aspects related to the selected special topic. The articles are broadly divided into four categories as follows: review papers, control strategies, converter topologies, and cybersecurity.

We discuss briefly each single article in the following sections.

A. Review Papers

S. Mazumder, A. Kulkarni, S. Sahoo, F. Blaabjerg, H. A. Mantooth, J. C. Balda, Y. Zhao, J. A. Ramos-Ruiz, P. N. Enjeti, P. R. Kumar, L. Xie, J. H. Enslin, B. Ozpineci, A. Annaswamy, H. L. Ginn III, F. Qiu, J. Liu, B. Smida, C. Oglivie, J. Ospina, C. Konstantinou, M. Stanovich, K. Schoder, M. Steuer, T. Vu, L. He, and E. P. de la Fuente, "A Review of Current Research Trends in Power-Electronic Innovations in Cyber-Physical Systems" in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2021.3051876].

This article provides a broad overview of power electronics innovations in cyber-physical systems for application profiles such as smart/microgrid, energy at network edge, wireless EV charger, the IoT, electric trains, and shipboard systems.

A. K. Sahoo, K. Mahmud, M. Crittenden, J. Ravishankar, S. Padmanaban, and F. Blaabjerg, "Communication-Less Primary and Secondary Control in Inverter-Interfaced AC Microgrid: An Overview," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2974046].

This article presents a review of communication-less control techniques and algorithms in microgrids to achieve accurate power sharing along with restoration of microgrid voltage and frequency.

B. Control Strategies

Y. Khayat, R. Heydari, M. Naderi, T. Dragicevic, Q. Shafiee, M. Fathi, H. Bevrani, and F. Blaabjerg, "Decentralized Frequency Control of AC Microgrids: An Estimation-Based Consensus Approach," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2980675].

This article proposes a decentralized secondary control of ac microgrids using a consensus-based protocol, which uses estimation and does not require any communication infrastructure.

Y. Du, X. Lu, J. Wang, B. Chen, H. Tu, and S. Lukic, "Dynamic Microgrids in Resilient Distribution Systems With Reconfigurable Cyber-Physical Networks," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2981921].

This article proposes dynamic microgrid operation with reconfigurable cyber and physical networks to enhance system operation resiliency and flexibility. An evaluation framework is proposed to assess the operational feasibility of distribution feeders with multiple inverter-based dynamic microgrids and come up with possible restoration solutions in the context of cross-layer cyber/physical network reconfiguration.

M. Naderi, Y. Khayat, Q. Shafiee, T. Dragicevic, F. Blaabjerg, and H. Bevrani, "An Emergency Active and Reactive Power Exchange Solution for Interconnected Microgrids," in

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IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2019.2954113].

This article presents an emergency active and reactive power exchange solution using an interlinking back-to-back converter (BTBC) for interconnected microgrids (IMGs). The proposed control is aimed at increasing the reliability and communication challenges in IMGs.

J. Ramos-Ruiz, B. Wang, H.-M. Chou, P. Enjeti, and L. Xie, "Power Electronics Intelligence at the Network Edge (PINE)–An Approach to Interface PV and Battery Energy Storage Systems at the Grid Edge," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2991019].

This article proposes a self-organizing power electronic converter with control intelligence at the edge of the distribution network. The proposed converter is called power electronics intelligence at the network edge (PINE); it has the potential to add intelligence at the network edge to the electricity delivery system of the present and in the future.

A. Sadu, G. K. Roy, F. Ponci, and A. Monti, "Methodology for Reliability Analysis of Cyber-Physical MTdc Grids," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2976748].

This article proposes a reliability evaluation method based on continuous time Markov Chain (CTMC) for cyber-physical multi-terminal dc (MTdc) grids. Detailed failure models of the cyber-physical components of the MTdc grids are presented. A method is proposed to derive the multi-domain reliability of MTdc grids.

X. Li, Q. Xu, and F. Blaabjerg, "Adaptive Resilient Secondary Control for Islanded AC Microgrids With Sensor Faults," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2988509].

In this article, adaptive resilient secondary voltage and frequency control problem is investigated for islanded ac microgrids (MG) in the presence of sensor faults. Sensor faults or data attacks have a great impact on the stability and quality of MG and are typically not considered in the existing solutions.

C. Converter Topologies

R. Das, G.-S. Seo, and H.-P. Le, "Analysis of Dual-Inductor Hybrid Converters for Extreme Conversion Ratios," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: DOI 10.1109/JESTPE.2020.2985116].

This article presents a dual-inductor hybrid converter that is capable of efficient non-isolated dc–dc conversions with extremely large voltage conversion ratios. The converter topology combines a switched-capacitor network and two interleaved inductors, which supports simple duty-cycle control for output regulation.

G. Saini, L. Somappa, and M. S. Baghini, "A 500 nW to 1 mW Input Power Inductive Boost Converter With MPPT for RF Energy Harvesting System," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2979005].

This article discusses a novel RF energy harvesting system for available power as low as 500 nW. The system includes a main RF rectenna, which is an antenna followed by a rectifier, for energy harvesting, an auxiliary RF rectenna for power detection, and a boost converter along with its control circuit. The proposed system includes maximum power point tracking (MPPT) of the RF energy.

Y. Wang, T. Zhao, M. Rashidi, J. Schaar, and A. Trujillo, "An Arcless Step Voltage Regulator Based on Series-Connected Converter for Branch Current Suppression," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2989164].

This article proposed a new topology of arcless step voltage regulator (SVR) based on a series-connected converter for current suppression. The proposed arcless SVR can eliminate arcing during the tap change and reduce the contact erosion rate by over 10 000 times the conventional arcing SVR.

D. Cybersecurity

M. Babakmehr, F. Harirchi, P. Dehghanian, and J. Enslin, "Artificial Intelligence-Based Cyber-Physical Events Classification for Islanding Detection in Power Inverters," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2980045].

In this article, the principles of informative sparse representation-based classification (TISC) are used to develop a comprehensive artificial intelligence framework for fast and reliable classification of DGU islanding and nonislanding events with the focus on practical limitations and requirements of a smart power electronics inviter as the desirable observational site.

M. R. Habibi, H. R. Baghaee, T. Dragičević, and F. Blaabjerg, "Detection of False Data Injection Cyber-Attacks in DC Microgrids Based on Recurrent Neural Networks," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2968243].

In this article, a new artificial intelligence (AI)-based method is proposed for the detection of cyber-attacks in dc microgrids and also identification of the attacked distributed energy resource (DER) unit.

J. Liu, Y. Du, S. Yim, X. Lu, B. Chen, and F. Qiu, "Steady-State Analysis of Microgrid Distributed Control Under Denial-of-Service Attacks," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2020.2990879].

In this article, a novel cyber-induced microgrid model is developed. With this model, the cyber-physical system is transformed into a pure physical model, where the disruption effects of denial-of-service (DoS) attacks in the cyber layer are shown to be equivalent to the variations of the physical model parameters. With the transformed system, a sufficient condition to ascertain the system power balance under unknown DoS attacks is developed.

S. Sahoo, T. Dragičević, and F. Blaabjerg, "Cyber Security in Control of Grid-Tied Power Electronic Converters—Challenges and Vulnerabilities," in IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS [doi: 10.1109/JESTPE.2019.2953480].

This article discusses portions of the power converter control systems that are vulnerable to cyber-attacks. Typical cyber-attacks are overviewed by considering different applications of

grid-tied converters. Furthermore, the impact of different types of cyber-attacks on grid support functions is studied. Overall, the editorial team hopes that this Special Issue will provide readers with new inspirations for research and will encourage them to make further progress in sustainable energy through the confluence of power electronics and cyber-physical systems. We would like to thank the authors for their valuable contributions and reviewers, who have voluntarily provided constructive and timely feedback. Moreover, we want to thank the following Guest Associate Editors for their support of the publication of this Special Issue:

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