Guest Editorial
Special Issue on Emerging Applications of Power Electronics in Developing Economies

THREE billion people around the world live in severe energy poverty, including 1.1 billion who live completely off-grid. Providing affordable energy access to them can dramatically impact their living standard, health, education, productivity, and ability to be a part of modern society. In developing economies, the utilization of energy is also limited to some extent. Many programs and initiatives (e.g., the IEEE Empower a Billion Lives and the IEEE Smart Village) have been doing stellar work in tackling energy poverty in developing economies. However, much remains to be done to crowdsource relevant innovation to accelerate the deployment of energy access solutions in the affected areas, including the developing economies. According to the previous programs and initiatives, it has been identified that power electronics is one of the key technologies to address real-life issues in energy access and utilization, water supply, rural transportation, etc., for developing economies. In this context, it calls for innovative and scalable solutions that should be for emerging applications of power electronics with an emphasis on technical innovation and business viability to rapidly and sustainably scale to a wide range of customers in developing economies. Hence, we organized this Special Issue on *Emerging Applications of Power Electronics in Developing Economies*, aiming to bring together researchers, experts, policy makers, and stakeholders to tackle energy poverty issues in developing economies.

The call for papers of the IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS (JESTPE) Special Issue on Emerging Applications of Power Electronics in Developing Economies was published in October 2020. We received 74 submissions to this special issue. Reviews were promptly organized by invited Associated Editors from Australia, China, Greece, India, Norway, The Netherlands, the United States, South Africa, and Singapore. Reviewers are invited from across the globe. After rigorous reviews, 22 papers were accepted, while 19 papers were included in this special issue. Each of these special issue papers addresses the technical challenge with innovative solutions, seen from the power electronics perspective, to tackle energy poverty. The Special Issue papers are broadly categorized into three groups, and they are briefly discussed as follows.

A. Power Semiconductors and Converter Technologies

The Special Issue emphasizes the emerging applications of power electronics, which is the key to efficient and effective use of energy. In this issue, we collected eight papers on this area, ranging from the advances in power semiconductor technologies, converters, and their applications.

In [A1], Ming *et al.* developed the silicon-carbide-silicon (SiC-Si) hybrid module technology, improving the reverse recovery characteristics of SiC Schottky diodes. As such, the developed module effectively mitigates the challenging issue of high current spikes with conventional solutions. The final-fabricated hybrid SiC-Si module has been tested and compared with two counterparts, validating its effectiveness. The module is an essential component for reliable and affordable ac–ac power converters, e.g., matrix converters, which can be adopted in drive systems for industrial pumping, cooling, and refrigeration, as well as others needed in developing economies.

Efficiency is of importance in any energy conversion systems, especially in developing economies with energy poverty. Apart from advances in semiconductor technologies, efficiency can be improved by the design of converters, including magnetics and passives, which is a big challenge. This also applies to the machines used widely in pumping systems. In [A2], Lin *et al.* explored the eddy current loss mechanism of the dual-permanent-magnet-excited machine (DPMM) based on the flux modulation effect. The theoretical eddy current losses were obtained with this modulation according to the harmonic contents. The loss distribution as well as its thermal effect was validated on the fabricated machine.

In developing economies, heating pans for cooking is important. In [A3], considering traditional domestic induction heating for the ferromagnetic (FM) pans and its incompetence in the heating of non-FM pans, Han *et al.* introduced a series–parallel resonance (SPR) network with a relay to the induction heating technology. The concept is inspired by the compensation network in the wireless power transfer (WPT) technology. A dual-resonant topology-reconfigurable inverter was then developed for all-metal induction heating applications. The developed inverter can be flexibly configured into various topologies to heat FM pans and also non-FM pans, with dedicated pulsewidth modulation strategies. With this solution, the overcurrent issue is effectively addressed, resulting in a high overall system efficiency of 94.32% and 91.05%, when the inverter is heating FM and non-FM pans, respectively; as well as it is capable of detecting the loading and matching the impedance automatically. The flexibility and feasibility of the solution were validated by hardware systems.

In terms of energy harvesting and conditioning, Chen *et al.* presented a generalized method in [A4] to derive quasi-Z-source dc–dc converters (QZSCs) that are of potential

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use in remote solar PV applications. More importantly, compared to the conventional solution, the generalized QZSC converters have achieved a higher efficiency, further ensuring the energy harvesting from solar PV panels in developing regions. In addition, the harvesting of vibration energy is emerging, where the design and control of the corresponding power converters are challenging. Accordingly, Jung *et al.* proposed a digitally controlled power management circuit (PMC) in [A5] to enhance the vibration energy collection in vehicle suspension systems. This PMC scheme enables the electromagnetic energy harvester to convert energy from bi-directional vibration to unidirectional rotation with higher efficiency. The digital controller consumes much lower power than the harvested vibration energy, being a feasible solution.

Solar PV panels can be a promising energy source in developing economies. For roof-top and small-scale applications, transformerless inverters are widely adopted. In [A6], Gao *et al.* proposed a MOSFET-switch-based common-ground transformerless inverter. The common-ground configuration ensures that the transformerless inverter produces zero leakage currents. Basic operational principles and control strategies for the inverter were discussed, and the efficacy is validated through experimental tests. Considering the power quality issue in solar PV systems, an 11-level packed U cell (PUC) converter was presented in [A7] for solar PV applications. Using eight active switches, two capacitors, and a PV array, the converter can attain an 11-level output voltage. Issues related to active and reactive power regulation, capacitor voltage balancing, and maximum power point tracking for this topology were detailed in this work, the steady-state and dynamic performances of which were also validated on a real-time testbench.

Considering the loads in residential applications, i.e., a mix of ac and dc loads, in [A8], Goud and Gupta proposed a hybrid converter that can simultaneously supply both dc and ac loads with less conversion stages for developing economies. The proposed converter—modular multioutput hybrid converter (MOHC) is assembled with multiple basic unit cells called boost-derived hybrid converter (BDHC) that can generate a three-level ac output and a single dc output. The effectiveness of the hybrid converter was validated and demonstrated on a two-unit/cell laboratory model.

B. Control of Hybrid Energy Systems

Control underpins the implementation of power conversion units in energy systems, e.g., from basic control to optimize the energy capture to advanced control to achieve specific demands. Through this special issue, six papers on this topic were collected, which addressed the control of wind and solar PV (and integrated into pumping) systems.

Wind energy is an essential type of energy source to tackle the energy poverty issue. In [A9], Das *et al.* explored the power quality issue brought by doubly-fed induction generator (DFIG)-based wind energy conversion systems that are usually integrated with local nonlinear and unbalanced loads. In addition, it has been discussed that the sudden wind speed changes and load variations could challenge the stability of the grid. Thus, Das *et al.* [A9] adopted a normalized least mean squares adaptive filtering scheme based on an arctangent cost function (Arc-NLMS) scheme to address the power quality issue and developed a power management scheme to alleviate the stability issue. The effectiveness has been verified through experimental tests. In [A10], the large-scale wind power plants (WPPs) were considered by Guo *et al.*, who analyzed the stability impact on the grid in remote areas when such WPPs are connected to. With this analysis, the active power transfer capability of DFIG-based WPP systems was enhanced under the condition of weak grids, which was verified experimentally.

In developing economies, drinkable water is usually attained through pumping underground water, and also irrigation is largely dependent on efficient pumping. As such, in [A11], Jain *et al.* proposed an efficient control scheme for the two-stage water pumping system, which is supplied by solar PV panels. Hence, the maximum power tracking was discussed, and a model-based sliding mode controller (SMC) was developed to regulate the dc-link voltage. The advantage of this system lies in the removal of a dc-link voltage sensor and a speed encoder, being cost-effective. Similarly, in [A12], Yalavarthi and Singh adopted an SMC for switched reluctance motor (SRM)-based PV-battery standalone submersible pumps. Furthermore, in [A13], Kashif and Singh adopted a reverse saliency (RS) spoke-type permanent magnet synchronous motor (PMSM) to drive a solar PV-fed water pumping system. In this work, the RS-PMSM is operated with a flux-intensifying current and a hybrid adaptive notch filter is adopted to estimate the rotor angle, eventually ensuring the high performance of the RS-PMSM water pumping system, as validated by experimental tests.

For large-scale PV systems, the configuration strongly affects the maximum power point tracking. Thus, in [A14], Changmai *et al.* proposed a total cross-tied (TCT) connection scheme for PV modules, achieving better performance under partial shading conditions compared to the bypass diode solution. Moreover, an analytical algorithm was presented in this work to assist the PV system operator to evaluate the output power of large-scale TCT-based PV systems for better planning. This is validated by laboratory-scale systems under partial shading conditions.

C. System Coordination and Operation for Resilience

Wide-scale adoption of renewable energy, like wind and solar photovoltaic, is necessary to fully address energy poverty in developing economies. The integration of multienergy vectors is achieved by power converters that operate statically to form microgrids or even nanogrids. This greatly challenges the stability of the entire grid. Advanced control and service schemes should be developed. In this Special Issue, five relevant papers were collected, discussing the inverter control scheme, inertia support, frequency regulation, black start for resilience enhancement, and voltage control.

In [A15], Li *et al.* presented a voltage and current dual-loop control structure for the emerging decentralized control scheme—virtual oscillator control (VOC) for grid-forming inverter applications. This control structure augments the

VOC grid-forming scheme to compensate for power device nonideality impacts and output filter voltage drops. With the establishment of a full small-signal model for multiple-inverter system-based microgrids, the system stability was assessed in this work by analyzing the eigenvalue and participation factor. Experimental tests have validated the analysis and the control scheme's effectiveness. As the conventional rotational synchronous generators are being replaced by power electronics inverters that are operating in the grid-forming mode, the inverters may face a big challenge under grid faults. With this respect, Erdocia *et al.* [A16] proposed a dual-voltage-current control scheme for grid-forming inverters in microgrids. This scheme enables the grid-forming inverters to quickly limit the current under various loading conditions, e.g., overloading or short-circuit conditions, and thus, protecting the power electronics inverters, as well as the entire system, which was validated through experimental tests on a standalone system.

One distinct difference between power electronics systems and synchronous generators is the lack of rotating mass, and thus, system inertia is continuously declining in renewable energy systems, challenging the frequency stability. With this background, Liu *et al.* [A17] proposed a wind turbine system (WTS) ancillary transient frequency regulation strategy (TFRS). This scheme is based on the frequency trajectory planning for direct-drive permanent magnet synchronous generator (D-PMSG) WTSs. According to this scheme, the frequency trajectory can be actively planned with a sufficient margin, providing flexible controllability of the WTS ancillary power output. The presented TFRS ensures a safe and stable operation of the grid, while the wind power generation is economically maintained. Simulations have been conducted and the strategy has been demonstrated on an RT-LAB hardware-in-loop (HiL) platform in terms of effectiveness and economy.

In developing economies, the strength of the grid may be not strong enough and the resilience is challenged. It means that under natural disasters, power outages will occur in such regions. Hence, in [A18], Du *et al.* discussed novel solutions (black start) to system restoration in the case of power outages. The novelty in this work lies in that the distribution system is partitioned into microgrids that have dynamic and adjustable boundaries nested in the distribution system. Subsequently, a two-stage restoration procedure was proposed in this work to black start with self-organizing inverters. A sequence of actions during restoration was detailed in this work, where the control design considering practical implementation was also presented. The restoration procedure was validated on a 34-bus system implemented on a real-time HiL simulation platform.

Beyond the above solutions for a more resilient and stabler grid with more renewable energy systems, the electric power tariff schemes should also be advanced and continuously updated. In [A19], Saxena *et al.* developed a customer persuaded tariff scheme based on the composition of additionally required services from renewable energy systems. As one of the typical ancillary services, reactive power compensation for voltage control has been exemplified and explored in this work considering the system operator criteria (financial aspect). Then, it provides ways to the optimization of reactive power compensation supplied by static devices and dynamic units to maintain the voltage profile.

The editorial team hopes that this Special Issue can be inspiring and exciting for the audience to drive extensive research on the emerging applications of power electronics in developing economies. This is just the start of tackling energy poverty. Much more effort, and innovative, affordable, scalable, and practical solutions are desired. We hope that through advanced power electronics technologies, the living in energy poverty regions can be greatly improved. Enjoy reading this Special Issue.

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APPENDIX: RELATED ARTICLES

[A1] L. Ming *et al.*, “A SiC-Si hybrid module for direct matrix converter with mitigated current spikes,” *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 10, no. 4, pp. 3804–3816, Aug. 2022.
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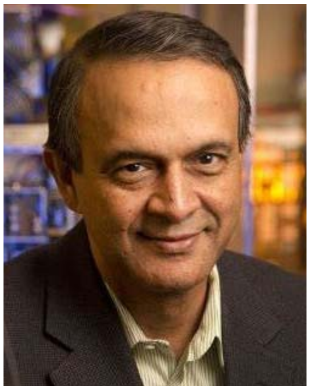

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