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Editorial

Applications of Power Electronics

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1. Introduction

Power electronics technology is still an emerging technology, and it has found its way into many applications, from renewable energy generation (i.e., wind power and solar power) to electrical vehicles (EVs), biomedical devices, and small appliances such as laptop chargers. In the near future, electrical energy will be provided and handled by power electronics and consumed through power electronics; this not only will intensify the role of power electronic technology in power conversion processes, but also implies that power systems are undergoing a paradigm shift, from centralized distribution to distributed generation. Today, more than 1000 gigawatts (GW) renewables (photovoltaic (PV) and wind) have been installed, all of which are handled by power electronics technology. However, areas such as energy saving and electrification transportation are booming, creating a huge market not only for power devices but also for packaging technology and power converter design. Some of the driving forces of the technology are their cost, volume, weight, functionality as well as reliability. At the moment, the technology is seeing a change from being purely silicon-based to being built upon wide bandgap (WBG) technology, such as silicon carbide (SiC) and gallium nitride (GaN), which demands a completely new paradigm in power converter design and layout, as those devices can operate at least an order of magnitude faster.

The main aim of this Special Issue was to seek high-quality submissions that highlight and address recent breakthroughs over the whole range of emerging applications of power electronics, the harmonic and electromagnetic interference (EMI) issues of the devices and system levels, as also discussed in [1–4], robust and reliable power electronics technologies, including fault prognosis and diagnosis techniques [5–7], the stability of grid-connected converters [8,9], and the smart control of power electronics for devices, microgrids and at system levels [10–13].

2. The Present Special Issue

This special issue with 49 published articles has gained a great deal of attention from both academia and industry, clearly showing the growth in significance of "Applications of Power Electronics" in the current research and development arena. The accepted articles cover broad topics in the field of power electronics, and they are categorized into seven different focus areas:

T1: Fault Diagnosis, Reliability and Condition Monitoring [14–17];
T2: Modeling, Control and Design of Power Electronic Converters [18–25];
T3: Electrical Machines, Drives and Traction Systems [26–34];
T4: Distributed Power Generation and e-Grid [35–46];
T5: Emerging Power Electronic Technologies (Pulsed Power, Energy Storage, Others) [47–51];
T6: Energy Access and Micro-Grids [52–56];
T7: Wireless Power Transfer Systems [57–62].

2.1. Fault Diagnosis, Reliability and Condition Monitoring (T1)

In order to extend overall system lifetimes, fault diagnosis, fault-tolerant control and health management systems are of significant importance, and these have been one of the major focus areas in the power electronics field in the last decades. Open circuit fault diagnosis and the fault tolerance control of three-phase active rectifiers as an inherent stage of many power electronics applications have been addressed in [14]. For induction motors, an automatic fault diagnosis system under a transient situation is developed in [15] and a fault-tolerant control strategy for five-phase induction motors under four and three-phase operation is addressed in [16]. Lastly, in [17], a review is provided on a health management system for lithium-ion batteries with a specific focus on electric vehicle applications.

2.2. Modeling, Control and Design of Power Electronic Converters (T2)

In [18], a synchronous reference frame control design methodology is provided for shunt power filters, while the sliding mode control and one-cycle controller design and stability performance of a class-D amplifier and boost power factor correction are discussed in [19,20], respectively.

Performance evaluation and the improvement of a dual active bridge converter as one of the suitable topologies for isolated power converters are discussed in [21,22]. Lastly, digital control techniques for voltage source inverters in renewable energy applications are summarized in [23].

Hardware-in-the-loop (HIL) techniques are identified as effective methods for validation of power converter and/or its controller prior to full system implementation. In [24], two different HIL implementation methods suitable for nonlinear control methods are addressed, while the application of FPGA for HIL implementation and its limitations are discussed in [25].

2.3. Electrical Machines, Drives and Traction Systems (T3)

With the continuous cost reduction of power semiconductor devices, and due to be controllability of power electronics-based systems, more and more motor-driven applications are being equipped with power electronics. Thereby, there is a focus on improving the performance and stability of motor drive systems through control, utilizing multi-phase motors and the proper modeling of motors over a wide range of loading conditions. A robust control with auto-tuned closed loop control is discussed in [26]. In [27], a comparative analysis of different control structures in improving the performance of dual three-phase permanent magnet synchronous motors (PMSM) is addressed. Extending the Kalman filter-based sliding mode control of a parallel-connected two five-phase PMSM drive system is explained in [28]. Since a slim DC-link drive provides a compact drive system, improving the motor drive performance and control stability through modulation and active damping is proposed in [29]. Utilizing composite active vector modulation in improving a direct torque control scheme for PMSM is introduced in [30]. Lastly, the suitability of utilizing a line starter PMSM for industrial applications from the efficiency point of view is discussed in [31].

The knowledge of motor behavior through proper modeling plays an important role for motor drive system design and control. The frequency-dependent behavior of an induction motor's equivalent inductance and its importance on the output current ripple and total harmonic distortion (THD) is analyzed in [32]. In [33], 3D finite element analysis (FEA) is used to analyze the profile effect of various magnet shapes in axial flux PM motors to obtain higher efficiency. Finally, a series active filter design based on a hybrid modular multi-level converter (MMC) suitable for traction systems is introduced and analyzed in [34].

2.4. Distributed Power Generation and e-Grid (T4)

Photovoltaic (PV) applications, as they utilize renewable energy resources to reduce the carbon footprint, are being employed more and more for distributed power generation. Applying the power electronics technique for PV application is the main focus in [35–37], covering different design aspects. While [35] addresses the practical implementation of a three-level boost converter using FPGA, in [36], the importance of using wide band-gap devices such as silicon carbide (SiC) to achieve better performance and power density is addressed. Lastly, the application of a modular multi-level converter (MMC) based on a cascaded connection is described in [37] for PV applications. The application and optimal design of MMC is further extended in [38] for high voltage direct current (HVDC) systems. Another design aspect which has attracted attention is efficiency. In [39], the possibility of improving voltage source converter efficiency through optimal switching frequency selection is discussed. In [40], a new technique to improve power converter efficiency by reducing the switching count for a distribution static compensator (DSTATCOM) and induction motor drive applications is addressed.

With the high penetration of power electronic systems, another aspect that again is attracting increased attention is the mitigation and control of the harmonics and EMI noise emissions of power converters. In [41], the utilization of an online selective harmonic elimination (SHE) method and particle swarm optimization to reduce harmonics is addressed, while in [42], a comprehensive review on control strategies for mitigating the dead-time effect on power converters to improve the total harmonic distortion of output waveforms is presented. With respect to EMI, modeling and proper EMI filter design in order to comply with international standards, which is of high importance, is addressed in [43,44]. Furthermore, applying active spectral shaping can maintain the generated EMI noise while reducing the size of an EMI filter in an effective method presented in [45]. Finally, applying optimization techniques for EMI filter design that not only increase the converter power density but also can make the design process automatic (reducing the time-to-market, to name one benefit) is addressed in [46].

2.5. Emerging Power Electronic Technologies (Pulsed Power, Energy Storage, Others) (T5)

In this sub-topic, the first article addresses the 10 kV high-frequency switching power supply known as a pulsed power supply for plasma generation [47]. In this article, a pulsed power supply is developed for water purification.

As the second focus of this sub-topic in the energy storage area, four articles were accepted and published. The first one provides a review of the electrical circuit modeling of double layer capacitors for energy storage [48]. The reduction of battery cell inconsistency using a composite equalizer to improve overall system performance is addressed in [49]. Improvements of state-of-charge (SoC) estimation using optimization and proper filtering methods are introduced in [50]. Lastly, a review and future challenges of SoC estimation for lithium–ion batteries are provided in [51].

2.6. Energy Access and Micro-Grids (T6)

Five articles have been accepted in the area of microgrids. In all of these articles, innovative control strategies have been proposed for AC, DC and hybrid AC–DC microgrids. In [52], a harmonic linearization technique has been deployed to analyze the stability of the AC microgrid in the sequence domain. Focusing more on the higher-level control, an innovative switching control strategy has been developed for EV charging stations to minimize their effect on the performance of a hybrid microgrid system in [53]. In [54], a power electronic converter interface has been used to allow for the variable-speed operation of hydro-pumped energy storage. On the grid side, this achieved better frequency and voltage regulation compared to scenarios without power electronic interfaces. An islanding mechanism has been proposed for renewable-based microgrids in [55], while an accurate load-sharing even in the presence of faulty communication links was developed for DC microgrids in [56].

2.7. Wireless Power Transfer Systems (T7)

Wireless power transfer (WPT) has emerged as an innovative technology to simplify the charging process, and this is the focus of the last four articles. The importance of synchronization in mitigating power oscillations and ensuring system stability is introduced in [57]. In [58], WPT system efficiency improvement and size reduction is considered by adding a single-switch boost stage at the secondary side, while in [59], the possibility of efficiency improvement using a current-fed inverter is discussed. The simulation modeling of an induction power transfer (IPT) as a replica of a 2-kW IPT charger for an electric vehicle battery charger is addressed in [60,61]. Lastly, in [62], a comprehensive review of WPT system topologies, structures and EMI diagnostics is presented.

3. Concluding Remarks

Although the 21st century can be identified as the golden age of power electronics applications, more in-depth research and development still need to be carried out in this area in order to accelerate the deployment of power electronics applications. This requires further improvements in the areas of power converter reliability, control stability and efficiency, and also the proper modeling of the system itself as well as the system around the application. Furthermore, providing electromagnetic compatibility at both the device level and system level is necessary to ensure interoperability and compatibility, which can be a challenging issue with WBG-based power electronic systems, as mentioned in the Introduction. In addition, the interactions among multitude power converters and the presence of non-ideal conditions, which may lead to instability issues, especially in distributed generation systems, call for further investigation. Combined multi-disciplinary efforts from both academia and industry are essential to provide a brighter future for power electronics applications and enable smarter and carbon-free future power grids.

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