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Editorial

Energy Conversion Using Electronic Power Converters: Technologies and Applications

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1. Introduction

Nowadays, energy conversion plays a crucial role in sustainable growth and development. In the past, energy conversion was achieved using electromechanical converters based primarily on rotating machines. In recent years, conversely, the energy conversion process has been performed by several power electronic circuits [1].

Power electronic converters are switching circuital structures used to achieve efficient energy conversion systems for various applications such as renewable energy conversion, smart grid arrangement, energy storage management, and sustainable transport. Power electronic converter systems are composed of several switching topologies, each related to the specific application. Power electronic circuit solutions are continuously under study to improve existing converter topologies or create new ones. Furthermore, the improvement in technologies of power electronic devices and passive components is leading to the unceasing development of the qualities of converters such as high efficiency, high gain, high power density, and fast transient response. To use a corporeal analogy, muscles are represented by the topological structure, whereas the brain function of the power converters is performed by increasingly performing control techniques. Advanced topologies and control methods are necessary to respond to the progressively more challenging demands of modern applications. Thus, the research of advanced design criteria, the use of innovative technologies, and improved regulating techniques are required to reach the target of obtaining more efficient, compact, cost-effective, and sustainable energy conversion systems [2].

In the field of power converter application to energy conversion, several articles have contributed to the growth of knowledge within the portion of the scientific community that is involved in the publications and use *Energies* to exchange and build knowledge and skills in this strategic technological area of development. In this Editorial, a variety of articles have been selected to disseminate the technical-scientific contributions most read and cited by the scientific community, whether belonging to the journal *Energies* or another publication. The time frame considered in the choice of the selection of the significant articles ranges from 2020 to 2022.

The next section provides a classification of the considered paper contributions according to the main topics. Furthermore, the specific focus and the worth of each article are summarized.

2. Overview of the Contributions

The articles included in this editorial on energy conversion using power converters review some of the significant contemporary trends in the strategic power engineering field.

For the sake of clarity and the effectiveness of this Editorial, the paper's contributions have been selected and thus inserted into four, more general categories. For each energy conversion category considered, the contribution of each article to evolving the state of the art in the related topics is indicated.

2.1. Renewable Energy Conversion System

Solar photovoltaic (PV) systems are much more attractive in the current energy conversion scenario due to their continuous technological development. In renewable energy conversion applications from PV sources, DC–DC power converters are used in several non-isolated and isolated topologies [3]. These electronic power converters are necessary to regulate the voltage of the source to bring it to the values required by the DC or AC bus onto which the photovoltaic systems are inserted. The basic boost power converter and its circuit evolution used to adjust the PV output voltage [4] is one of the stimulating subjects of the current research objectives. In PV source systems, the maximum power point tracking (MPPT) methods are implemented to extract maximum power. The boost converter, regulated by the MPPT control technique, is an optimum workbench to investigate the maximum power extraction in a PV system. In [5], C.H. Hussaian Basha and C. Rani investigate several MPPT techniques suitable for boost converter topology. Their paper carried out a comprehensive comparative analysis of the recent MPPT techniques developed. Furthermore, the MPPT methods in static and dynamic irradiation conditions were evaluated to find the optimum duty cycle control.

The limit of the basic boost converter topology is the step-up gain achievable by the actual converter operation compared with the ideal one. Generally, PV systems need step-up voltage management to grid connection. To further increase the boost converter's gain, in [6] Amir Farakhor et al. used three winding-coupled inductors without increasing the number of switches. The topology solution, at the expense of greater passive components circuit complexity, increased the step-up voltage attainable, reducing the voltage stress across the driven single switch [7].

An improvement of the boost converter efficiency may be achieved by the reduction of switching power losses. The soft switching techniques address the improvement of the energy conversion efficiency of the power converter interfacing with the PV system [8]. Following this design approach, Khairy Sayed et al. in [9] present an advanced soft-switched boost-type converter using an additional resonant cell. The circuital topology achieved is denominated edge resonance switched-capacitor (ER-SC) boost converter. The boost circuit is composed of coupled resonant inductors, an auxiliary switch, some auxiliary diodes, and a resonant capacitor. The coupled inductors increase the gain of the DC–DC converter according to the winding turns ratio [10]. The boost operation conditions have been analyzed and discussed in continuous and discontinuous modes and the PWM modulation technique. Furthermore, the effectiveness of the proposed ER-SC boost converter has been experimentally tested. Finally, a comprehensive comparison with the state-of-the-art soft-switching topologies is presented and analyzed, highlighting both advantages and drawbacks.

From the above considerations, meeting high step-up requirements and attaining satisfactory efficiency are significant challenges in these power converter designs. An attractive suggestion is given by M. Karthikeyan et al. in [11] to achieve these design targets. The authors investigate a circuit integration between a Cuk with a boost converter, maintaining a single-switch circuit solution. This way, the high gain requirement is met with substantial efficiency. Furthermore, the converter topology obtained complements the benefits of boost and Cuk converters. The experimental results, obtained on the integrated power converter circuit, feature continuous current mode operation with low voltage stress on the controlled switch and diodes.

Usually, buck-boost DC–DC converters which are used to regulate the output voltage in PV systems, do not provide the isolation between input and output sides [12]. To achieve AC load utilization, the conventional converters produce DC voltages from the PV panels and then invert them into AC through open-loop inverters. A circuital isolation settlement is implemented by Tehzeeb-ul Hassan et al. The authors in [13] propose a push–pull boost converter topology with a computationally fast, rugged, and efficient MPPT algorithm using a fuzzy logic controller.

The MPPT method tracks the maximum power point (MPP) in real-time, while the push–pull boost converter allows for a high gain by adjusting the turn ratio of the high-frequency transformer [14].

2.2. Smart Grid Components and Applications

Nowadays, high-performance power conversion requirements are of increasing interest in microgrid and smart grid applications [15].

Issues like the analysis of power converter topologies and components, protection and monitoring, power quality, and optimization, when applied to smart distribution systems, are continuously under study by academic and industrial researchers. The research effort is oriented to keeping power converter solutions updated, with the latest technological developments and new challenges in energy conversion applied to power systems [16].

DC microgrids are a topic of great attention in the generation–storage and distribution of electrical energy. The DC–DC power converters play a crucial role in regulating the output voltage of various distributed generation (DG) units.

In [17], Javed Ahmad et al. present an improved DC–DC converter with quadratic voltage gain and reduced voltage stress across switching devices. The described converter topology is composed of a merger of a conventional boost converter and a quadratic boost converter (QBC) [18,19]. The high gain step-up converter is implemented to regulate the voltage of DG sources connected to DC microgrids [20]. Furthermore, in the paper, an interesting comparison with several step-up DC–DC converters applied in DG sources to interface the DC grid is made.

In [21], Sara J. Ríos et al. deal with a dual-active bridge (DAB) DC–DC converter applied to a DC microgrid, with a comprehensive point of view on the converter application. The DAB converter interfaces with the renewable energy source (RES) systems and the battery energy storage BES systems in a DC microgrid in a bidirectional way [22]. Thus, the power flow control investigation is carried out. Furthermore, the authors introduce a power management algorithm to select the proper operation of the RES system and BES system, based on load/generation power and state-of-charge of the battery conditions.

In energy conversion systems for AC grids, the quality of the waveform with reduced harmonic distortion and a convenient trade-off between cost and performance are fundamental targets to reach [23]. A three-level neutral-point-clamped (NPC) converter is widely used to achieve these design constraints [24].

In [25], Hao Lin et al. propose an integral sliding-mode control (ISMC)-based direct power control (DPC) strategy for application NPC converters to improve the system disturbance rejection ability. Experimental results show the effectiveness and the advantage of the control strategy developed for the NPC power converter, compared with a conventional PI-based DPC strategy. In AC grids, the integration of the high-power static synchronous compensator (STATCOM) and energy storage in the same system arouses particular interest.

Modular multilevel converter (MMC) topologies represent some attractive power converter topologies for energy storage and static synchronous compensator (ES-STATCOM) arrangement, providing a modular and scalable solution with high efficiency that manages high-power and high-voltage ratings in grid applications [26]. In [27], Sanjay K. Chaudhary et al. provide a dissertation on the MMC converter family application in ES-STATCOM applications. The paper describes and compares several MMC-based ES-STATCOM topologies for both centralized and distributed energy storage needs.

In power system applications, passive transformers are generally used to adjust the voltage request. They exhibit some drawbacks such as a possible DC offset and difficulty in controllability [28]. Noticeable volumes and costs are further limits which must be overcome in modern smart grids.

Solid-state transformers (SSTs) can be identified as promising power electronic structures to substitute for industrial transformers. Furthermore, SSTs improve and harmonize

AC and DC electrical grid interconnection. SST is composed of power converter advanced circuits and high-frequency transformers [29].

Currently, SST demands are growing significantly, as well as those of circuital structures. In [30], Mohammed Azharuddin Shamshuddin et al. provide an overview of the concepts, topologies, control strategy, materials, and classification of SSTs. The paper's aim is to recognize and describe the several power electronic transformer structures available in the energy conversion area. Furthermore, the paper proposes a simplified terminology to identify and standardize the wide number of definitions and SST structures introduced in the current literature.

In electrical networks, the brief voltage reduction appearance (the so-called voltage sags) is a serious issue that lowers the power quality [31].

The short-time voltage reduction can be solved by a dynamic voltage recovery (DVR) system [32]. The DVR arrangement is a controlled power converter that can inject 3-phase voltage in series and synchronism with the distribution of supplied voltages to correct short voltage sags. In [33], Ali Moghassemi and Sanjeevikumar Padmanaban propose a comprehensive review of the DVR system. The topologies of the power converters involved and the control methods used are explored.

2.3. Energy Store Management and e-Mobility

Energy storage management (ESM) is a critical issue in environmental sustainability [34]. Battery energy storage systems (BESSs) are currently fundamental fundamental building blocks of ESM. BESSs are standalone system devices that permit energy from renewables (like solar, wind, etc) to be accumulated and then returned when customers need a surplus of power. It is composed of battery systems, bidirectional power converters (BPC), and a control system [35].

The prevalent storage technology is lithium-ion batteries, used in mobile phones, electronic equipment, and electric cars and in large-scale plants to help electricity grids guarantee a safe and reliable supply of energy [36].

In [37], Andrés Peña Asensio et al. furnish an overall analysis of the effect of the converter synchronizing methods on the contribution that BESSs provide for the support of the inertial response of a power system. System solutions, based on phase-locked loop (PLL) synchronization, virtual synchronous machine (VSM) [38] and synchronization without PLL, are described and then compared. For this, time-domain simulations are used for an isolated microgrid (MG) effective example.

The increase in demand, both for energy storage technologies and electric vehicles, requires high-power DC–DC converters. In EVs, the power can come from fuel cell stacks, supercapacitors, and battery systems [39].

The described energy sources need to step up the voltages. The DC–DC converter for high-power conversion applications (i.e., resonant, full-bridge, or dual-active bridge) requires a high-frequency magnetic transformer for separating and coupling with the requested turn ratio of the input and output converter voltage [40]. The high-frequency transformer is a critical design matter. In [41] Muhammad Zeeshan Malik et al. propose a transformer-less high step-up boost converter. The single command switch topology presented features including a specific charge pump capacitor circuit and a capacitor–inductor–diode (CLD) cell, delivering high gain and quite a satisfactory efficiency. The modified boost converter has been investigated by several simulation results. Furthermore, a small-scale laboratory prototype has been developed for experimental validation.

Battery charging in electrical vehicles (EVs) is a meaningful topic to consider in the e-mobility field. Several converter solutions are presented in the literature [42]. In [43], a multi-leg interleaved DC–DC buck converter with digital control is introduced. Stefania Cuoghi et al. describe the design/tuning procedure for the control of an interleaved buck converter in the EV charger system. In the paper, the power converter's continuous and discrete-time model is carried out. Furthermore, reduced power converter operations, are explored using an experimental set-up of a three-switching legs interleaved buck converter.

From the experimental results arise an acceptable level of robustness under load variations of the control approach defined.

In [44] (by Khairy Sayed et al.), a full bridge phase-shift PWM DC–DC converter with a high-frequency transformer and current doubler rectifier in the second stage, designed for an onboard charger, is investigated.

The converter circuit operation is analyzed in detail and the design guidelines are provided. The effectiveness of the proposed converter is validated by several experimental results. In the paper, the current doubler rectifier solution presented achieves an improvement in the converter efficiency.

The battery source EVs are in full development. Battery-powered EVs have a high weight factor for available energy [45]. Currently, the range at full charge is limited to around 500 km. Fuel cells are an energy source substitute for battery-powered systems.

Fuel cells are particularly interesting for long-distance driving [46]. Furthermore, in EV applications, fuel cell stacks with hybrid energy storage systems, composed of batteries and supercapacitors, can be merged to fit the dynamic power demand required by the electric motor and auxiliary systems [47]. In [48], Ioan-Sorin Sorlei et al. explored fuel cell-based EV topologies and energy management strategies. In the paper, the main DC–DC converters' topologies interfacing with the fuel cells were investigated and discussed. Furthermore, the advantages and disadvantages of three types of strategies (rule-based strategies, optimization-based strategies, and learning-based strategies) are described and evaluated.

Considering the power switches used in converter topologies, it is important to evaluate the impact of the new wide bandgap (WBG) semiconductor technologies. WBG power electronic devices such as silicon carbide (SiC) MOSFET and gallium nitride (GaN) FET represents the technological evolution of pure silicon devices [49]. SiC MOSFET and GaN-based devices display superior thermal performances compared to silicon MOSFETs [50,51].

WBG devices can be used to obtain high power density and efficient power converters. GaN technology devices are currently undergoing a significant evolution. In recent years, the need to increase the voltage limits of the GaN FET devices has represented a challenge to semiconductor manufacturers, who require these devices for their use in high-voltage power converters applications. Currently, technology with a maximum voltage of up to 650 V is available on the market, and a higher voltage can be obtained with cascode solution [52,53]. At low voltage (up to 200 V) the GaN FETs are much attractive not only in DC–DC converters for their high switching frequency that can be reached (up to tens of MHz) but also in DC–AC converters for AC motor control as described by the authors in [54]. In the paper, the efficiency and size of the electric motor control system are improved compared with Silicon (Si) MOSFET devices for small battery-powered electric vehicle systems (so-called micro-mobility or light mobility) such as e-kick scooters, e-bikes, electronic skateboards, hover boards, etc. This strengthening of qualities stems from the use of GaN FET switches.

Wireless Power Transfer Applications

A wireless power transfer (WPT) system transmits electrical power based on technologies using time-varying electric, magnetic, or electromagnetic fields. There are different applications where WPT technology are applied such as electronic equipment (mobile phone, home appliances), Unmanned Aerial Vehicles (UAV), and charging system [55]. Nowadays, EV using WPT technologies to charge the battery is quite widespread. Generally, WPT systems are composed of a primary power converter that transmits the power, a coupling system, and a secondary power converter that releases the power to a load. In some specific applications, the power flow can be unidirectional or bidirectional [56]. The main WPT solutions on the market are achieved by the use of the inductive coupling method, the so-called inductive power transfer (IPT). However, capacitive power transfer (CPT) at the present time is growing in use, especially for lower power [57]. Furthermore, the WPT methods in EV battery chargers are classified into the static charging technique and dynamic charging technique. The static charging technique is achieved by IPT and CPT solutions, while the dynamic wireless power transfer (DWPT) technique is obtained by the IPT system.

Nowadays, DWPT systems are becoming increasingly pivotal for moving electric vehicle (EV) charging solutions. This attractive charging technique features an issue with the misalignment tolerance between the coupling inductors. In [58], Eiman ElGhanam et al. propose a DWPT charging system for EVs with improved misalignment tolerance based on inductor–capacitor–capacitor (LCC) compensation. A class D inverter is used on the primary side of the coupling inductors, while a boost rectifier circuit is selected on the secondary side to obtain the AC–DC conversion stage. The detailed DWPT charging system design is discussed. The design constraints and solutions include EV specifications, inductive links, compensation network constraints, and power electronic converter circuits. CPT is a valid charging technique in several wireless power transfer applications. In perspective, CPT can result in lower cost and higher reliability than IPT because it does not need coupling coils and related shields. Furthermore, CPT features the capability to transfer power through metal barriers thanks to the coupling capacitive effect. In low-power transfer solutions, a single-device converter structure may be used. In [59], F. Corti et al. present a complete, detailed design of an E-Inverter for CPT charging systems which is suitable for electronic equipment or small drones. The design procedure guarantees both zero voltage switching (ZVS) and zero derivative switching (ZDS) conditions for the switching device (a silicon MOSFET) at an optimum coupling coefficient, thus enabling high transmission and conversion efficiency. An experimental prototype at 24 V of input voltage with 100 kHz of switching frequency is used for the design validation. The tested prototype can transfer 83.5 Wat at optimal capacitive coupling with a maximum efficiency of 92.5%.

2.4. Power Converters Prototyping Methodology

In power converters for energy conversion, the design methodology will need a noticeable effort to achieve the targets of satisfactory static and dynamic performances, high efficiency, thermal management, and reduced volumes involved. The hardware in the loop (HIL) is a cost-effective technique that allows for the simulation of the system under design, avoiding setting up expensive and cumbersome actual converter structures to validate the effectiveness and accuracy of the control methods [60]. HIL utilizes a hardware platform to build, e.g., a microprocessor or FPGA, and the required number of channels and I/O types to test the implemented system. The hardware platform and the real-time model of the power converter topology are interfaced to simulate the whole system under investigation with a quite satisfactory approximation with respect to the real one system. In [61] Leonel Estrada et al. use a well-known and flexible platform such as LabVIEW application software for HIL simulation. The topology of the considered power converter is obtained by means of differential equations that define each state of the converter circuit. The developed method takes place in 5 steps:

- Converter under test design
- Numerical modeling
- off-line simulation of the numerical model using fixed-point representation
- implementation in a Field-Programmable Gate Array (FPGA).

In the paper, two examples of the HIL application technique are detailed: a buck converter and a three-phase Voltage Source Inverter (VSI) system. The results obtained are compared with the simulation of commercial software and actual power converter tests, showing the effectiveness of the HIL technique proposed. The methodology presented is suitable for people with not quite enough experience in the use of software languages and tools such as very high-speed integrated circuit hardware description language (VHDL), real-time simulation (RTS), and HIL simulation tools.

3. Conclusions

The collection of articles in this Editorial provides some indications of the directions of the current research development for the power converters topologies, control methods and technologies applied to the energy conversion field. For homogeneity of investigations presented, three of the most significant sectors have been identified in the area of energy conversion, and the Special Issue is arranged along these lines.

1. Renewable Energy Conversion System
2. Smart Grid Components and Applications
3. Energy Store Management and e-Mobility

The last section is dedicated to the power converter's prototyping methodology. It will be helpful for giving useful suggestions to the designers of power converters in this strategic research field.

The articles considered in the different sections show the vitality of the research on this trending topic and will contribute noticeable development opportunities, ideas, and valuable skills to the international research community.

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