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Editorial

Energy Storage Systems and Power Conversion Electronics for E-Transportation and Smart Grid

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Abstract: The special issue "Energy Storage Systems and Power Conversion Electronics for E-Transportation and Smart Grid" on MDPI *Energies* presents 20 accepted papers, with authors from North and South America, Asia, Europe and Africa, related to the emerging trends in energy storage and power conversion electronic circuits and systems, with a specific focus on transportation electrification and on the evolution of the electric grid to a smart grid. An extensive exploitation of renewable energy sources is foreseen for smart grid as well as a close integration with the energy storage and recharging systems of the electrified transportation era. Innovations at both algorithmic and hardware (i.e., power converters, electric drives, electronic control units (ECU), energy storage modules and charging stations) levels are proposed.

Keywords: electric vehicles (EVs); hybrid EV (HEV); plug-in EV (PEV); intelligent transport systems; renewable energy sources; battery; energy storage; electric machines; electric drives; electronic control unit (ECU); fast charging; smart grid; automotive electronics; power converters; Internet of Energy; Internet of Things (IoT)

1. Introduction

The proposed special issue has invited submissions related to energy storage, power converters and e-drive systems for electrified transportation and smart grid [1–20]. The particular topics of interest include:

- New emerging energy storage technologies;
- Ageing mechanisms of power converters and energy storage devices;
- Electronic control units (ECU) for energy storage system monitoring and management;
- Online estimation of state-of-charge and state-of-health;
- Power conversion electronics for renewable energy sources;
- Fast chargers and smart chargers for electric-vehicles;
- Integration of charging infrastructures in the smart grid for E-transportation;
- Predictive diagnostic for renewable energy sources and energy storage systems;
- Methods for design and verification of hardware and software for energy storage and renewable energy systems;
- Integration of Internet of Things (IoT) into E-transportation.

Research and technology transfer activities in energy storage systems, such as batteries and super/ultra-capacitors, are essential for the success of electric transportation and to foster the use of renewable energy sources. The latter are intermittent in nature and are not directly matched with users'

requirements. Energy storage systems are the key technology to solve these issues and to increase the adoption of renewable energy sources in the smart grid. However, major challenges have still to be solved such as the design of high performance and cost-effective energy storage systems, the on-line estimation of state-of-charge/state-of-health of batteries and super/ultra-capacitors, the estimation of aging effects, the design and optimization of fast chargers and the integration within the smart grid of the charging infrastructure for electrified transportation. The strategic interest for this R&D activity is proved by the rise of initiatives such as the Battery 2030+ initiative or the European Battery Alliance [21] where a mixed effort of the European Commission, industries and research organizations aims at developing an innovative, sustainable and competitive battery "ecosystem" in Europe, from raw material to cell and battery manufacturing to electric vehicle (EV) manufacturing to recycling.

Power converters and electric drives need also optimization in terms of increased efficiency and implementation of predictive diagnostic features. Beside the hardware parts, also the role of the software is increasing and new design and verification methods have to be investigated to achieve high functional safety levels. Due to the increasing role of information and communication technology (ICT) in smart grid and electrified transportation, towards an Internet of Energy scenario, cybersecurity is also becoming a key issue.

The main objective of the 20 works published in the Special Issue is, hence, to provide timely solutions for the design and management of energy storage systems, of renewable energy sources and of the relevant power electronics conversion systems. Proposed works addressed these issues from the low component level, up to the Integration of all these sub-systems within the smart grid for e-transportation and smart/green cities.

2. Review of the Contributions

The special issue includes, after a strict review process, 20 published works of which 18 are original research papers [1–18], while papers [19,20] are survey papers.

Reference [1] entitled "Hybrid PV-Wind, Micro-Grid Development Using Quasi-Z-Source Inverter Modeling and Control—Experimental Investigation", by a group of authors, Priyadarshi et al. from India, Denmark, USA and Norway, dealt with the modeling and control of a hybrid photovoltaic-wind micro-grid system using a quasi Z-source inverter (QZsi). A single ended primary inductance converter (SEPIC) module used as DC-DC switched mode converter was employed for maximum power point tracking (MPPT) functions, while a modified power ratio variable step (MPRVS) based perturb and observe (P&O) method had been proposed, as part of the MPPT action for the photovoltaic system. The dSPACE real-time hardware platform had been employed to test the proposed micro grid system under varying wind speed, solar irradiation, load cutting and removing conditions. The results confirmed the performance of the proposed system for a standalone micro grid, which is used specifically in rural places.

Reference [2], entitled "An Overview of Energy Scenarios, Storage Systems and the Infrastructure for Vehicle-to-Grid Technology", by a group of authors, Harighi et al. from Turkey, Denmark, Norway and USA, presented important issues about energy scenarios, storage systems and the infrastructure of the grid related to vehicle-to-grid (V2G) technology. The scenarios, policies and targets of the governments and agencies of the world for lower greenhouse gases (GHG) emissions and high-energy efficiency had also been suggested. One of the conclusions was that the batteries needed to be further developed to comply better with the charge/life cycle and to provide more safety. All mentioned problems forced the infrastructure of the grid to work with poor quality. Today, after the development of the lithium type of batteries and the power electronics systems, including battery management unit, the battery-to-grid technologies will provide fast charging operations. With those benefits, the grid could work properly, so the lack of energy and temporary storage are solved. The power system infrastructure should be designed according to some parameters such as accessibility, reliability and being able to be developed. The result of this action was that the grid can be updated with some

technologies such as V2G and the subset technologies. The grid should support the energy traffic, which was achieved by newer technologies such as V2G or energy storage systems.

Reference [3], entitled "Maximum Power Point Tracking for Brushless DC Motor-Driven Photovoltaic Pumping Systems Using a Hybrid ANFIS-FLOWER Pollination Optimization Algorithm", by a group of authors, Priyadarshi et al. from India, Denmark, and Norway, deals with a hybrid artificial neural network (ANN)-fuzzy logic control (FLC) tuned flower pollination algorithm (FPA) as a maximum power point tracker (MPPT), which was employed to amend root mean square error (RMSE) of photovoltaic (PV) modeling. Moreover, Gaussian membership functions had been considered for fuzzy controller design. Experimental results certify the effectiveness of the suggested motor-pump system supporting diverse operating states. Performed experimental responses revealed that, compared to different bio-inspired, swarm-intelligence and classical MPPT techniques reviewed in the literature, the ANFIS-FPA had superior power tracking ability, fast convergence velocity and accurate system response.

Reference [4] entitled "Boundary Detection and Enhancement Strategy for Power System Bus Bar Stabilization—Investigation under Fault Conditions for Islanding Operation", by a group of authors, Pouryekta et al., from Malaysia and Denmark, proposed a novel scheme for the detection of island boundaries and stabilizing the system during autonomous operation. In the first stage, a boundary detection method was proposed to detect the configuration of the island. In the second stage, a dynamic voltage sensitivity factor (DVSF) was proposed to assess the dynamic performance of the system. In the third stage, a wide area load shedding program was adopted based on DVSF to shed the load in weak bus-bars and stabilize the system. The proposed scheme was validated and tested on a generic 18-bus system using a combination of EMTDC/PSCAD and MATLAB software.

Reference [5], entitled "An Original Transformer and Switched-Capacitor (T & SC)-Based Extension for DC-DC Boost Converter for High-Voltage/Low-Current Renewable Energy Applications: Hardware Implementation of a New T & SC Boost Converter", by a group of authors, Padmanaban et al., from Denmark, Qatar, India and Slovakia, proposed a new transformer and switched capacitor-based boost converter (T & SC-BC) for high-voltage/low-current renewable energy applications. The proposed T & SC-BC was an original extension of the DC-DC boost converter, which is designed by utilizing a transformer and switched capacitor (T & SC). PV energy was a fast emergent segment among the renewable energy systems. The proposed T & SC-BC combines the features of the conventional boost converter and T & SC to achieve a high voltage conversion ratio. The proposed T & SC-BC topology was compared with the recently addressed DC-DC converters in terms of number of components, cost, voltage conversion ratio, ripples, efficiency and power range. Simulation and experimental results were provided, which validated the functionality, design and concept of the proposed approach.

Reference [6] by a group of authors, Hossain et al., from South Africa, Malaysia, Denmark, Norway and USA, "Sliding Mode Controller and Lyapunov Redesign Controller to Improve Microgrid Stability: A Comparative Analysis with CPL Power Variation", dealt with a storage-based load side compensation technique, which is used to enhance the stability of microgrids. Besides adopting this technique, sliding mode controller (SMC) and Lyapunov redesign controller (LRC), two of the most prominent nonlinear control techniques, were individually implemented to control microgrid system stability with desired robustness. Constant power load (CPL) is then varied to compare robustness of these two control techniques. This investigation revealed the better performance of the LRC system compared to SMC to retain stability in the microgrid with a dense CPL load. The simulation results have been validated on the MATLAB/Simulink software package for authentic verification. Reasons behind inferior SMC performance and ways to mitigate that were also discussed. Finally, the effectiveness of SMC and LRC systems to attain stability in real microgrids was verified by numerical analysis.

Reference [7], entitled "Minimization of Load Variance in Power Grids—Investigation on Optimal Vehicle-to-Grid Scheduling", by a group of authors, Tan et al. from Malaysia, South Africa, Denmark and Norway, dealt with an optimal scheduling of V2G using the genetic algorithm to minimize the

power grid load variance. This was achieved by allowing EV charging (grid-to-vehicle) whenever the actual power grid loading is lower than the target loading, while conducting EV discharging (V2G) whenever the actual power grid loading is higher than the target loading. The performance of the proposed algorithm under various target load and EVs' state of charge selections were analyzed. The effectiveness of the V2G scheduling to implement the appropriate peak load shaving and load levelling services for the grid load variance minimization was verified under various simulation investigations. A performance index was also introduced in this paper to provide an excellent indication on the overall performance of the proposed V2G optimization algorithm.

Reference [8], co-authored by Bhaskar et al. from South Africa, India, Norway, Denmark and Malaysia, entitled "Hardware Implementation and a New Adaptation in the Winding Scheme of Standard Three Phase Induction Machine to Utilize for Multifunctional Operation: A New Multifunctional Induction Machine", presented a new distinct winding scheme that is used to utilize three phase induction machines for multifunctional operation. It can be used as a three-phase induction motor (IM), welding transformer and phase converter. The proposed machine design also worked as a single-phase IM at the same time it worked as a three-phase to single-phase converter. The proposed motor provided an operative solution for agricultural as well as industrial purposes because of rugged construction and less maintenance needs. The proposed concept was verified by designing a motor by modifying the windings of an old IM and the proposed motor was well tested to find its efficiencies and the experimental results are provided in the article to validate the design and construction.

Reference [9], entitled "Development of Sliding Mode Controller for a Modified Boost Ćuk Converter Configuration" from a group of authors, Padmanaban et al. from South Africa, Slovakia and Denmark, introduced an SMC-based equivalent control method to a novel high output gain Ćuk converter. An additional inductor and capacitor improves the efficiency and output gain of the classical Ćuk converter. An SMC-based equivalent control method, which achieved a robust operation in a wide operation range was also proposed. Switching frequency is kept constant in appropriate intervals at different loading and disturbance conditions by implementing a dynamic hysteresis control method. Numerical simulations conducted in MATLAB/Simulink confirm the accuracy of analysis of high output gain modified Ćuk converter. In addition, the proposed equivalent control method was validated in different perturbations to demonstrate robust operation in a wide operation range.

Reference [10], by Tiwari et al., a group of authors from India and South Africa, entitled "Coordinated Control Strategies for a Permanent Magnet Synchronous Generator Based Wind Energy Conversion System", proposed a novel coordinated hybrid MPPT-pitch angle based on a radial basis function network (RBFN) for a variable speed, variable pitch wind turbine. The proposed controller was used to maximize output power when the wind speed is low and optimize the power when the wind speed is high. The proposed controller provides robustness to the nonlinear characteristic of wind speed. It used wind speed, generator speed, and generator power as input variables and utilizes the duty cycle and the reference pitch angle as the output control variables. The duty cycle was used to control the converter so as to maximize the power output and the reference pitch angle was used to control the generator speed in order to control the generator output power in the above rated wind speed region. The effectiveness of the proposed controller was verified using MATLAB/Simulink software.

Reference [11], by Ganesan et al., a group of authors from India, South Africa and Norway, entitled "Study and Analysis of an Intelligent Microgrid Energy Management Solution with Distributed Energy Sources", proposed a robust energy management solution which will facilitate the optimum and economic control of energy flows throughout a microgrid network. This study enabled precise management of power flows by forecasting renewable energy generation, estimating the availability of energy at storage batteries, and invoking the appropriate mode of operation, based on the load demand to achieve efficient and economic operation. The predefined mode of operation was derived out of an expert rule set and schedules the load and distributed energy sources along with the utility grid. A robust control methodology had been developed and demonstrated in a deterministic way to operate the microgrid network in a sustainable mode. Faster communication topologies were deployed

to achieve a better response time for the control commands at local as well as centralized controllers. This work can be enhanced by interlinking multiple microgrid networks with a more complex source and load system. The load management and control could be further improved by using artificial intelligence and optimization techniques as future work.

Reference [12], entitled "A Modular AC-DC Power Converter with Zero Voltage Transition for Electric Vehicles", by Ramirez-Hernandez et al., from Mexico and Chile, presented a study of the fundamental of operation of a three-phase AC-DC power converter that uses zero-voltage transition (ZVT) together with space vector pulse width modulation (SVPWM). The proposed converter was basically an active rectifier divided into two converters: a matrix converter and an H bridge, which transfer energy through a high-frequency transformer, resulting in a modular AC-DC wireless converter appropriate for plug-in EVs (PEVs). The principle of operation of this converter considered high power quality, output regulation and low semiconductor power loss. The circuit operation, idealized waveforms and modulation strategy were explained together with simulation results of a 5 kW design. The target application was suitable for light EVs (e-scooters, small city cars) or for hybrid vehicles where the internal combustion engine was supported at low speed by an electric motor.

Reference [13], entitled "Interconnecting Microgrids via the Energy Router with Smart Energy Management" by Liu et al. from China, presented a novel and flexible interconnecting framework for microgrids and corresponding energy management strategies. The proposed solution was presented in response to the situation of increasing renewable-energy penetration and the need to alleviate dependency on energy storage equipment. The key idea was to establish complementary energy exchange between adjacent microgrids through a multiport electrical energy router, according to the consideration that adjacent microgrids may differ substantially in terms of their patterns of energy production and consumption, which can be utilized to compensate for each other's instant energy deficit. Based on multiport bidirectional voltage source converters (VSCs) and a shared direct current (DC) power line, the energy router served as an energy hub, and enabled flexible energy flow among the adjacent microgrids and the main grid. The analytical model was established for the whole system, including the energy router, the interconnected microgrids and the main grid. Various operational modes of the interconnected microgrids, facilitated by the energy router, were analyzed, and the corresponding control strategies are developed.

Reference [14] by Brenna et al. from Italy and Canada, entitled "Modelling and Simulation of Electric Vehicle Fast Charging Stations Driven by High Speed Railway Systems" aimed at the analysis of the opportunity introduced by the use of railway infrastructures for the power supply of fast charging stations located in highways. Actually, long highways were often located far from urban areas and electrical infrastructure, therefore the installations of high power charging areas could be difficult. Specifically, the aim of the investigation in this paper was the analysis of the opportunity introduced by the use of railway infrastructures for the power supply of fast charging stations located in highways. This paper was focused on fast-charging electric cars in motorway service areas by using high-speed lines for supplying the required power. Economic, security, safety and environmental pressures were motivating and pushing countries around the globe to electrify transportation, which currently accounted for a significant amount, above 70% of total oil demand. Electric cars required fast-charging station networks to allowing owners to rapidly charge their batteries when they drive relatively long routes. In other words, this meant the infrastructure towards building charging stations in motorway service areas and addressing the problem of finding solutions for suitable electric power sources. A possible and promising solution was proposed in the study that involves using the high-speed railway line, because it allowed not only powering a high load but also it can be located relatively near the motorway itself. This paper presented a detailed investigation on the modelling and simulation of a 2 $\times$ 25 kV system to feed the railway. A model had been developed and implemented using the SimPowerSystems (Simscape/Specialized Power System) tool in MATLAB/Simulink to simulate the railway itself. Then, the model had been applied to simulate the battery charger and the system as a whole in two successive steps. The results showed that the concept could work in a real situation.

Nonetheless if more than twenty 100 kW charging bays were required in each direction or if the line topology is changed for whatever reason, it cannot be guaranteed that the railway system will be able to deliver the additional power that is necessary.

Reference [15], entitled "Real-Time Analysis of a Modified State Observer for Sensorless Induction Motor Drive Used in Electric Vehicle Applications" by Krishna et al., from India, South Africa and Norway, proposed an adaptive sliding mode Luenberger state observer with improved disturbance rejection capability and better tracking performance under dynamic conditions. The sliding hyperplane was altered by incorporating the estimated disturbance torque with the stator currents. In addition, the effects of parameter detuning on the speed convergence are observed and compared with the conventional disturbance rejection mechanism. The entire drive system was first built in the MATLAB-Simulink environment. Then, the Simulink model was integrated with real-time (RT)-Lab blocksets and implemented in a relatively new real-time environment using OP4500 real-time simulator. Real-time simulation and testing platforms had succeeded offline simulation and testing tools due to their reduced development time. The real-time results validated the improvement in the proposed state observer and also correspond to the performance of the actual physical model. The real-time results also validated the improvement in the disturbance rejection capability for the different test cases presented and also provided more credibility as compared to other offline simulated results.

Reference [16], entitled "Control Strategy for a Grid-Connected Inverter under Unbalanced Network Conditions—A Disturbance Observer-Based Decoupled Current Approach", by Ozsoy et al., a group of authors from Turkey, Norway, Slovakia, and South Africa, presented a new approach on the novel current control strategy for grid-tied voltage-source inverters (VSIs) with circumstances of asymmetrical voltage conditions. A standard grid-connected inverter (GCI) allowed the degree of freedom to integrate the renewable energy system to enhance the penetration of total utility power. This paper proposed a proportional current controller with a first-order low-pass filter disturbance observer (DOb). The proposed controller established independent control on positive, as well as negative, sequence current components under asymmetrical grid voltage conditions. A numerical simulation model of the overall power system was implemented in a commercial software tool and the results showed that double-frequency active power oscillations were suppressed by injecting appropriate negative-sequence currents. The simulation results matched the developed theoretical background for its feasibility. The proposed current controller seemed to be a valid alternative solution for GCIs under unbalanced conditions.

Reference [17] by Vavilapalli et al., a group of authors from India, South Africa, Norway, entitled "Power Balancing Control for Grid Energy Storage System in Photovoltaic Applications—Real Time Digital Simulation Implementation" presented a Power Balancing Control (PBC) method for a grid energy storage system for PV applications containing three different power sources, PV array, battery storage system and the grid, was proposed to operate the system in three different modes of operation. Control of a dual active bridge (DAB)-based battery charger which provides a galvanic isolation between batteries and other sources is explained briefly. Various modes of operation of a grid energy storage system are also presented. Hardware-in-the-loop (HIL) simulation is carried out to check the performance of the system and the PBC algorithm. A power circuit (comprised of the inverter, DAB based battery charger, grid, PV cell, batteries, contactors, and switches) is simulated and the controller hardware and user interface panel are connected as HIL with the simulated power circuit through real time digital simulator (RTDS). The PBC technique is implemented on a TMS320F2812 processor-based controller card and tested. Dynamic responses of the inverter and battery charger system are verified by applying a step change in the reference values and satisfactory results are obtained.

Reference [18] by Chandramohan et al., a group of authors from India, South Africa and Norway, entitled "Grid Synchronization of a Seven-Phase Wind Electric Generator Using d-q PLL", presented the development of a comprehensive model of the wind turbine driven seven-phase induction generator (7PIG) along with the necessary power electronic converters and the controller for grid interface.

The dynamic model of the system was developed in MATLAB/Simulink and the system response is observed for various wind velocities. The effectiveness of the seven phase induction generator was demonstrated with the fault tolerant capability and high output power with reduced phase current when compared to the conventional three-phase wind generation scheme phase model. The performance of the synchronous reference frame phase-locked loop (SRF-PLL) incorporated in the grid connected seven-phase wind electric generator was analyzed for various operating grid conditions. The use of multiphase machines along with the PLL synchronization of the grid increased the reliability of the wind electric generator.

After the first 18 research papers the special issue also includes two excellent and comprehensive survey papers.

The group of authors in reference [19], from Bangladesh, South Africa, USA and Norway, proposed "A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development", which presented a comprehensive study about EVs, including battery EV (BEV), hybrid EV (HEV), plug-in HEV (PHEV) and fuel cell EV (FCEV). This paper was focused on reviewing all the useful data available on EV configurations, battery energy sources, electrical machines, charging techniques, optimization techniques, impacts, trends, and possible directions of future developments. Its objective was to provide an overall picture of the current EV technology and ways of future development to assist in future research in this sector. The authors concluded that the EVs have great potential of becoming the future of transport while saving this planet from imminent calamities caused by global warming. They were a viable alternative to conventional vehicles that depend directly on the diminishing fossil fuel reserves. The impacts EVs cause in different sectors had been discussed as well, along with the huge possibilities they hold to promote a better and greener energy system by collaborating with smart grid and facilitating the integration of renewable sources. Limitations of current EVs had been listed along with probable solutions to overcome these shortcomings. The current optimization techniques and control algorithms had also been included. A brief overview of the current EV market had been presented. Finally, trends and ways of future developments had been assessed followed by the outcomes of this paper to summarize the whole text, providing a clear picture of this sector and the areas in need of further research.

The last contribution, reference [20], was a survey by the editors Mihet-Popa and Saponara, entitled, "Toward Green Vehicles Digitalization for the Next Generation of Connected and Electrified Transport Systems". This survey paper reviewed recent trends in green vehicle electrification and digitalization. First, the energy demand and emissions of EVs were reviewed, including the analysis of the trends of battery technology and of the recharging issues considering the characteristics of the power grid. Solutions to integrate EV electricity demand in power grids were also proposed. Integrated electric/electronic architectures for HEVs and full EVs were discussed, detailing innovations emerging for all components (power converters, electric machines, batteries, and battery-management-systems). 48 V HEVs were emerging as the most promising solution for the short-term electrification of current vehicles based on internal combustion engines. The increased digitalization and connectivity of electrified cars was posing cyber-security issues that were discussed in detail, together with some countermeasures to mitigate them, thus tracing the path for future on-board computing and control.

3. Conclusions

The special issue entitled "Energy Storage Systems and Power Conversion Electronics for E-Transportation and Smart Grid" presented 18 original research works and 2 comprehensive survey papers, with a worldwide group of authors, related to the emerging trends in energy storage, power converters and e-drives. The works, addressing both algorithmic-level and hardware-level aspects, were focused on applications such as transportation electrification (Full EV and HEV, mainly for automotive and railway scenarios) and the evolution of the electric grid to a smart grid, with massive use of renewable energy sources. Moreover, a close integration is foreseen between the smart electric grid and the electrified vehicles due to the need of an efficient and fast recharging infrastructure.

Therefore, the proposed special issue provides an overview, for the energy and power electronic aspects, of the evolution and trend towards electrified, automated and connected vehicles.

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