Guest Editorial: Energy Storage in Smart Grids

Energy storage systems and smart grids cooperation is now crucial and will encourage collaborative engagement by different players in the energy market, offering sophisticated management and control approaches. Therefore, new advances and innovative solutions for such cooperation are of preeminent importance. Moreover, electric mobility should also be considered in this scenario. Electric vehicles (EVs) can be seen as distributed energy storage systems that generally need to be charged but, in some cases, can be adopted to support the grid thanks to vehicle-to-grid (V2G) and vehicle-for-grid (V4G) modes, offering advantages of controlled operation with active or reactive power. So, energy storage systems can be distinguished into aggregated and distributed structures, and they can be based on different technologies, such as batteries, fuel-cells, and super-capacitors. Furthermore, the integration of new renewable energy solutions with energy storage systems in smart grids should also be promoted. Power and energy management are crucial for the upcoming challenges and novel opportunities in smart grids.

In line with this trend, this Special Issue aims to present further research on and developments in energy storage systems in smart grids, including power electronics converters, novel modulation schemes, energy and power management strategies, advanced battery packs and Battery Management Systems (BMSs). Novel renewable energy solutions are also of interest, as well as their cooperative and strategic integration with storage and EV chargers. Advanced EV services, such as V2G and V4G in the perspective of contributions to improve power quality, can also be considered.

Three main topics can be found in this Special Issue: power electronic converters, converter and machine modelling and lithium-ion battery packs. In the following section, the papers accepted per each topic will be rapidly summarized along with their main achievements.

Topic A: Power electronic converters for energy storage systems (ESS)

L. Sun et al., in their paper “A gridded modular bidirectional high voltage gain soft-switching dc-dc converter and its multiport expansion”, proposed a novel high-gain soft-switching converter achieving a wide range expansion of port voltage and voltage gain by gridded filling of modules. An auxiliary zero-current transaction cell is added to each module to achieve full-load soft-switching operation in both power directions. The new topology is controlled by a distributed control system consisting of a centralized supervisor and local controllers displaced in each module to improve flexibility and dynamic performance. Efficiency analysis is provided to prove the better performance of the novel converter with and without the zero-current transaction cell. Simulations and experimental results on the SiC-based prototype have been provided to confirm the feasibility of the proposed dc-dc converter.

Q. Wang et al., in their paper “A type of piecewise and modular energy storage topology achieved by dual carrier cross phase shift SPWM control”, proposed a new concept and structure for a modular energy storage topology. The main idea is to break down the whole battery pack into the sub-modules of a modular multilevel converter by enabling the micro-unit concept. A dual carrier cross phase shift sinusoidal pulse width modulation is proposed to control the new topology allowing high fault tolerance, easy fault detection and localisation, and lower modules with the same output voltage. Simulations and experimental results validate the proposed structure and its control.

P. R. Kasari et al., in their paper “A hybrid energy storage system with a modified MMCC-TSBC converter comprised of VSPS, BESS and supercapacitor storage”, presented a modified modular multilevel cascaded converter based on a triple star bridge cell. Different types of energy storage are integrated into the structure leading to a hybrid energy storage system. Supercapacitors, batteries, and a variable speed pump storage are considered. Thanks to their characteristics and the modular structure of the converter, different control tasks can be provided resulting in a high-power energy storage system. The grid current and the doubly fed induction machine current can be independently regulated with the proposed converter. Its effectiveness has been proven with both simulations and experimental results.

Topic B: Converter and machine models for ESS

Z. Xiao et al., in their paper “Full-state discrete-time model-based stability analysis and parameter design of dual active bridge converter in energy storage system”, proposed a stability study of a DAB converter in different charging modes. After deriving its discrete-time small-signal model, the stability analysis has been conducted for constant current, constant power and constant voltage charging modes. Afterwards, a design of the system parameters has been carried out based on the previous analysis. Simulations and experimental results have been provided to validate the proposed approach.

Y. Liu et al., in their paper “Mathematical modelling and control of bearingless BLDC machine with motor and generator double modes for flywheel battery”, presented a bearingless brushless DC machine model for flywheel battery. First, the structure and the principle of the suspension force are introduced. Afterwards, the mathematical model for both motor and generator mode has been realised and validated by adopting finite element analysis. The control structure has then been designed based on the achieved model. Simulation results of rotation, power generation and suspension have been provided, which, together with experiments, demonstrate a stable suspension and excellent working performance.

Topic C: Lithium-ion battery packs in ESS

N. Ghaeminezhad et al., in their paper “Charging control strategies for lithium-ion battery packs: review and recent developments”, presented a review of the most modern charging techniques for lithium-ion battery packs, in order to enhance the speed and reliability of the charging process. First, battery charging circuit topologies and classification of possible charging control schemes have been introduced. The latter are classified into three main methods: non-feedback-based charging methods, feedback-based charging methods, and intelligent charging methods. Once all the different techniques have been presented, a comparison has been made among them, highlighting their advantages and disadvantages.

Z. Wang et al., in their paper “A Monte Carlo simulator to investigate cell-to-cell deviation in a grid-tied battery pack”, presented a study of phenomena leading to voltage deviation observed during grid-tied operation of the battery energy storage system. Electrochemical impedance spectroscopy and equivalent circuit modelling have been performed to obtain the distributions of the cell-equivalent circuit parameters. Monte Carlo simulations have been then conducted to study the cell voltage deviation. Simulations and experimental results lead to the same result: the highest cell voltage deviation is obtained at low and high state-of-charge because of the high value and large deviation of the cell internal resistance in that operating area.

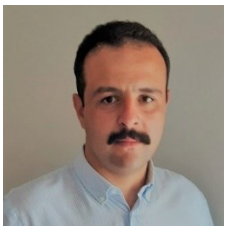
Summary/Conclusion

All of the papers selected for this Special Issue have shown a really important interest in energy storage technologies in smart grids. The main topics cover new power electronics converters for ESS, their models along with the ones of the storage, stability and sensitivity analysis and the design and control of the entire system. Future research works will be oriented to the usage of ESS in smart grids and can promote their integration with renewable energy sources and electric vehicles.

Guest Editor Biographies

Professor Mattia Ricco, Department of Electrical, Electronic, and Information Engineering "Guglielmo Marconi", University of Bologna (Lead Guest Editor). He received his master's degree (cum laude) in electronic engineering from the University of Salerno, Fisciano, Italy, in 2011, and the PhD double degree in electrical and electronic engineering from the University of Cergy-Pontoise, Cergy-Pontoise, France, and in information engineering from the University of Salerno in 2015. From 2015 to 2018, he was a Postdoctoral Research Fellow with the Department of Energy Technology, Aalborg University, Denmark. From 2018 to 2021, he was a Senior Assistant Professor (Tenure Track) and since 2021 he is an Associate Professor with the Department of Electrical, Electronic, and Information Engineering, University of Bologna, Bologna, Italy. His research interests include modular multilevel converters, battery management systems, electric vehicle chargers, field-programmable gate array-based controllers, identification algorithms for power electronics, and photovoltaic systems.

Assistant Professor Jelena Loncarski, Department of Electrical, Electronic, and Information Engineering "Guglielmo Marconi", University of Bologna (Guest Editor). She received her master's degree in electrical engineering from the Faculty of Electrical Engineering, University of Belgrade, Serbia. In 2011 she enrolled in the PhD program in Power Electronics at Department of Electrical, Electronic, and Information Engineering "Guglielmo Marconi" – DEI, University of Bologna and defended her PhD thesis in 2014. In April 2014 she joined the Department of Engineering Sciences, Division of Electricity, Uppsala University, Sweden, for a Post-Doc position. In 2019 she started a researcher position in the Department of Electrical and Information Engineering Polytechnic University of Bari. Currently she is a Researcher in the Department of Electrical, Electronic, and Information Engineering "Guglielmo Marconi" – DEI, University of Bologna, campus Cesena. She is also part of the Junior Core Faculty and Center for sustainability and Climate Change at Bologna Business School. Her research interests include power electronic circuits and power electronic converters for electric drives and renewable energy sources.



Assistant Professor Vitor Monteiro, Department of Industrial Electronics, University of Minho, Portugal (Guest Editor). In 2016, he received his PhD degree in Electronics Engineering and Computers with a specialization in Power Electronics and Energy from University of Minho. He is the Principal Investigator of the FCT project “newERA4GRIDs - New Generation of Unified Power Conditioner with Advanced Control, Integrating Electric Mobility, Renewables, and Active Filtering Capabilities for the Power Grid Improvement”. His research activities are being developed in the ALGORITMI Research Centre, University of Minho, where he is an Integrated PhD Researcher in the Industrial Electronics R&D Line and member of the Group of Power Electronics and Energy. His main research interests are related to power electronics applied to electric mobility, renewables, solid-state transformers (smart transformers), active power filters, energy storage systems, hybrid AC/DC grids, smart grids, wireless power transfer, and industrial applications.