Advanced Control Methods for Power Converters in Distributed Generation Systems and Microgrids

FLEXIBLE control of power converters, which serve as interfaces between the distributed generation (DG) units and the legacy alternating-current (ac) grid or the ac or direct current (dc) microgrid (MG), are the key to realization of high penetration of renewable energy in a safe and stable fashion. When connected to the ac legacy grid, these power converters need to provide ancillary services such as frequency and voltage support, harmonic compensation, as well as synthetic inertia emulation. Another emerging solution is to interface the DG units with the ac legacy grid through an intermediate entity called a MG. MG can be based either on ac and dc architecture and can work in both stand-alone and grid-connected modes. Since it is responsible for multiple power converters, a MG has higher operational flexibility than individual units. However, due to a lack of stiff voltage reference source and natural inertia, control of MGs is generally more challenging than control of individual grid-connected power converters.

In both grid-connected and standalone applications, most power converters used in modern DG technologies rely on cascaded linear control, mostly because it allows analytical design and guaranteed performance. However, such control also inevitably leads to severe performance limitations, most notably high sensitivity, inflexibility and limited bandwidth. Therefore, the design of advanced control strategies has been and continues to be one of the main drivers of the research community in the power electronics control area. In particular several types of linear, nonlinear and adaptive control techniques have shown promise to significantly improve the robustness, flexibility and dynamic performance of state-of-the-art cascaded linear control methods. The motivation for this special section has been precisely in this area, i.e. to collect the latest achievements on advanced control strategies for power electronic converters.

This special section has received a total of 67 papers, 22 out of which were accepted. Accepted papers can be divided into three basic categories, as follows.

First category [item 1]–[7) of the Appendix] focuses on developing new and improving known advanced control techniques for grid-tied power converters aiming to achieve better transient performance compared to conventional controllers. In [item 1) of the Appendix], a new method based on artificial neural networks is proposed to design the weighting factors for the cost function of finite-set model predictive controller (FS-MPC), thereby proposing a solution to a long-standing research challenge. In [item 2) of the Appendix], an adaptive cascaded delayed signal cancellation technique for accurate phase estimation of distorted three-phase grid voltages including unbalanced amplitudes and/or phase angles is proposed. Method also includes an algorithm for removing the phase angle deviations from the three-phase voltages including unbalanced phase angles. In [item 3) of the Appendix] an adaptive quasi-proportional-resonant (AQ-PR) controller for the grid current is adopted in combination with equivalent inductance identification algorithm, which assures that the parameters of the AQ-PR controller can be online calibrated to attain accurate current regulation under ac side inductance uncertainties. On the other hand, a super-twisting algorithm sliding mode (STA-SM) controller for the dc-link voltage is proposed to enhance system behavior under both internal and external disturbances. In [item 4) of the Appendix] a new algorithm for estimation of the magnitude of voltage sag (MoVS) is proposed. Interesting novel feature is that the existence of correlation between magnitudes of a set of low-order harmonics during transient of voltage PQ events with MoVS is for the first time determined and statistically proved. In [item 5) of the Appendix], an extended Kalman filter based control strategy for fault ride-through operation in two-stage grid-connected photovoltaic system in proposed. The proposed strategy does not compromise with power quality improvement features in the system while enabling ride-through operation. In [item 6) of the Appendix], an innovative design and experimental validation of disturbance observer-based control for grid-tied photovoltaic inverters fed by a dc-dc boost converter considering unbalanced grid voltages is developed. A disturbance observer is designed to estimate the unknown perturbation, which is then canceled by a feedback-linearizing control. Finally, [item 7) of the Appendix] capitalizes on the fact that islanding or non-islanding events in grid-connected distributed generation brings along a typical distinguishable transient signature in its frequency profile and proposes a new islanding protection approach, which is based on the estimation of frequency waveform parameter (transient's frequency) by Matrix Pencil (MP) method.

Second category [item 8]–[17) of the Appendix] focuses on developing new and improving known advanced control techniques for grid-tied power converters aiming to achieve better steady-state performance compared to conventional controllers. In [item 8) of the Appendix] a two-degrees-of-freedom control algorithm based on uncertainty and disturbance estimator (UDE) is proposed, aimed to minimize the total harmonic distortion of inverter output voltage. A multiple-time-delay action is combined with a commonly utilized low-pass UDE filter to increase the range of output impedance magnitude minimization around odd multiples of base frequency for enhanced rejection of typical single-phase nonlinear loads

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harmonics. In [item 9) of the Appendix], a new active damping method based on a robust disturbances observer is proposed. The proposed method is designed to mitigate resonance issues encountered in islanded MGs with multiple electronically interfaced DGs and loads. The main merit of the proposed approach is to calculate the appropriate resonances compensating signal without prior knowledge of the system parameters and without affecting the control bandwidth. In [item 10) of the Appendix], earlier findings about the need to have passive input admittance of grid tied converters is extended in the sense that passivity indices are used to quantify the required degree of input admittance. In [item 11) of the Appendix], a new method to compensate multiple harmonics based on a down-sampled multirate resonant controllers (MRRSCs) scheme is proposed. The proposed control scheme is composed of an inner control loop with a fast sampling rate, which is identical to the switching frequency, and an array of paralleled MRRSCs based external control loop with a reduced sampling rate. [item 12) of the Appendix] capitalizes on the fact that submodule (SM) capacitors in modular multilevel converters can be used as energy storage to provide a degree of synthetic inertia for system frequency support. To exploit it, an MMC synthetic inertia concept is proposed, where corresponding analysis shows that a substantial portion of system inertia can be provided by MMCs. In [item 13) of the Appendix], new Leaky Least Logarithmic Absolute Difference (LLLAD) algorithm MPPT algorithm, for grid-integrated solar PV (Photovoltaic) system is proposed. It is actually an improved form of Incremental Conductance (InC) algorithm, where inherent problems of traditional InC technique like steady-state oscillations, slow dynamic responses and fixed step size issues, are successfully mitigated. Similarly, [item 14) of the Appendix] proposes an improved version of the perturb and observe algorithm. It uses a maximize-M Kalman filter (MMKF) to mitigate problems of traditional P/O like steady-state oscillation, slow dynamic responses and fixed step size issues. [item 15) of the Appendix] proposes to use adaptive theory based momentum least mean square (M-LMS) algorithm to operate the power converter with enhanced power quality. This control is also responsible for keeping constant frequency and voltage at the point of common coupling under mechanical and electrical transients. [item 16) of the Appendix] proposes a harmonic voltage distortion damping method, which includes a direct output-voltage control and the parallel virtual-admittance control. Finally, [item 17) of the Appendix] presents a differential and common-current (power)-based state-feedback control for back to back converters. This controller features a fast control of active and reactive powers, and a stiff regulation of the dc-link voltage.

The third category [item 18]–[22) of the Appendix] focuses on developing new advanced control techniques for power converters that are operated within the dc subgrids. These subgrids can be operated either in completely isolated mode or be a part of the overall energy conversion process of a grid-tied power electronics system. [item 18) of the Appendix] looks at the dual-active bridge converter connected to a dc-link which is tied to an ac grid via single phase inverter. It proposes a method to reduce the second harmonic current (SHC) caused by the pulsating power of the downstream single-phase inverter, which may increase the battery's degradation and the component stress of the front-end converter. Method uses a load current feedforward (LCFF) control. The proposed idea is to incorporate virtual impedance to the output impedance of the front-end converter. In [item 19) of the Appendix], an application of the Interconnection and Damping Assignment Passivity Based Control (IDA-PBC) approach to the Port-Controlled Hamiltonian (PCH) model of Dual Active Bridge (DAB) source-side converters in a MVDC Microgrid is proposed. Its effectiveness is demonstrated when stabilizing constant power loads. In [item 20) of the Appendix] a coordinated droop control method through virtual voltage axis is proposed for voltage restoration and energy management of dc microgrids. To solve the problems of conventional droops, the voltage compensation term is defined as the virtual axis voltage value. In [item 21) of the Appendix] decentralized nonlinear model and intelligent control are proposed using adaptive output-feedback controller to stabilize the dc microgrids burdened by constant power loads. Finally, in [item 22) of the Appendix], a new control strategy for the dual active bridge is proposed, i.e. it is modified for zero circulating power flow (ZCPF) operation. Power management and co-ordination control used in this paper ensures the power supply reliability of the zonal Hybrid dc/ac Microgrid (HMG) integrated through the solid state transformer.

We hope this special section serves as a reference and update for academics, researchers, and practicing engineers in order to inspire new research and developments that can pave the way for the next generation of advanced control strategies for power electronic converters.

TOMISLAV DRAGIČEVIĆ, *Guest Editor*
Aalborg University
Aalborg, 9220, Denmark

SERGIO VAZQUEZ, *Guest Editor*
Universidad de Sevilla
Seville, 41092, Spain Spain

PATRICK WHEELER, *Guest Editor*
University of Nottingham
Nottingham, NG7 2RD, UK

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APPENDIX
RELATED WORK

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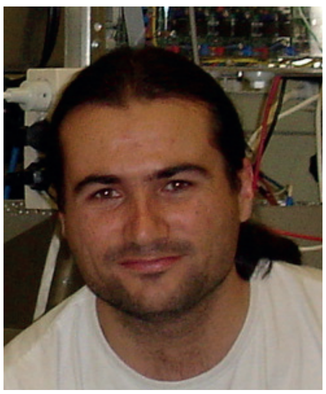
Tomislav Dragičević (S'09-M'13-SM'17) received the M.Sc. and the industrial Ph.D. degrees in Electrical Engineering from the Faculty of Electrical Engineering, Zagreb, Croatia, in 2009 and 2013, respectively. From 2013 until 2016 he has been a Postdoctoral research associate at Aalborg University, Denmark. From March 2016 he is an Associate Professor at Aalborg University, Denmark where he leads an Advanced Control Lab.

He made a guest professor stay at Nottingham University, UK during spring/summer of 2018. His principal field of interest is design and control of microgrids, and application of advanced modeling and control concepts to power electronic systems. He has authored and co-authored more than 155 technical papers (more than 70 of them are published in international journals, mostly IEEE Transactions) in his domain of interest, 8 book chapters and a book in the field.

He serves as Associate Editor in the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, in IEEE Emerging and Selected Topics in Power Electronics and in IEEE Industrial Electronics Magazine. Dr. Dragičević is a recipient of the Končar prize for the best industrial PhD thesis in Croatia, and a Robert Mayer Energy Conservation award.



Sergio Vazquez (S'04, M'08, SM'14) was born in Seville, Spain, in 1974. He received the M.S. and PhD degrees in industrial engineering from the University of Seville (US) in 2006, and 2010, respectively.

Since 2002, he is with the Power Electronics Group working in R&D projects. He is an Associate Professor with the Department of Electronic Engineering, US. His research interests include power electronics systems, modeling, modulation and control of power electronics converters applied to renewable energy technologies..

Dr. Vazquez was recipient as coauthor of the 2012 Best Paper Award of the IEEE Transactions on Industrial Electronics and 2015 Best Paper Award of the IEEE Industrial Electronics Magazine. He is involved in the Energy Storage Technical Committee of the IEEE industrial electronics society and is currently serving as an Associate Editor of the IEEE Transactions on Industrial Electronics.

Patrick Wheeler (M'99-SM'11) received his BEng [Hons] degree in 1990 from the University of Bristol, UK. He received his PhD degree in Electrical Engineering for his work on Matrix Converters from the University of Bristol, UK in 1994. In 1993 he moved to the University of Nottingham and worked as a research assistant in the Department of Electrical and Electronic Engineering. In 1996 he became a Lecturer in the Power Electronics, Machines and Control Group at the University of Nottingham, UK. Since January 2008 he has been a Full Professor in the same research group. He was Head of the Department of Electrical and Electronic Engineering at the University of Nottingham from 2015 to 2018. He is currently the Head of the Power Electronics, Machines and Control Research Group and is the Li Dak Sum Chair Professor in Electrical and Aerospace Engineering at the University of Nottingham, China. He is a member of the IEEE PELs AdCom and was an IEEE PELs Distinguished Lecturer from 2013 to 2017. He has published 500 academic publications in leading international conferences and journals.