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), is 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 an 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, an 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 stand-alone 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 the 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 [items 1)–7) in 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) in 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, thereby proposing a solution to a long-standing research challenge. In [item 2) in the Appendix], an adaptive cascaded delayed signal cancelation 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) in 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 sliding mode controller for the dc-link voltage is proposed to enhance system behavior under both internal and external disturbances. In [item 4) in 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 power quality events with MoVS is for the first time determined and statistically proved. In [item 5) in the Appendix], an extended Kalman filter based control strategy for fault ride-through operation in two-stage grid-connected photovoltaic (PV) system is proposed. The proposed strategy does not compromise with power quality improvement features in the system while enabling ride-through operation. In [item 6) in the Appendix], an innovative design and experimental validation of disturbance-observer-based control for grid-tied PV 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, Agrawal *et al.* [item 7) in the Appendix] capitalize on the fact that islanding or nonislanding events in grid-connected DG bring along a typical distinguishable transient signature in its frequency profile and propose a new islanding protection approach, which is based on the estimation of frequency waveform parameter (transient's frequency) by matrix-pencil method.

Second category [items 8)–17) in 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) in the Appendix], a two-degrees-of-freedom control algorithm based on uncertainty and disturbance

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estimator (UDE), aimed to minimize the total harmonic distortion of inverter output voltage, is proposed. 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 harmonics. In [item 9) in 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) in 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) in 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. Yang *et al.* [item 12) in the Appendix] capitalize on the fact that submodule 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 modular multilevel converter (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) in the Appendix], new leaky least logarithmic absolute difference algorithm based maximum power point tracking algorithm, for grid-integrated solar PV system, is proposed. It is actually an improved form of incremental conductance (InC) algorithm, where inherent problems of traditional InC techniques, such as steady-state oscillations, slow dynamic responses, and fixed step size issues, are successfully mitigated. Similarly, Kumar *et al.* [item 14) in the Appendix] propose an improved version of the perturb and observe algorithm. It uses a maximize-M Kalman filter to mitigate problems of traditional perturb and observe such as steady-state oscillation, slow dynamic responses, and fixed step size issues. Giri *et al.* [item 15) in the Appendix] propose to use adaptive theory based momentum least mean square 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. Zhou *et al.* [item 16) in the Appendix] propose a harmonic voltage distortion damping method, which includes a direct output voltage control and the parallel virtual-admittance control. Finally, Rodriguez-Cabero *et al.* [item 17) in the Appendix] present 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 [items 18)–22) in 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. Wang *et al.* [item 18) in the Appendix] look at the dual-active-bridge (DAB) converter connected to a dc link that is tied to an ac grid via single-phase inverter. It proposes a method to reduce the second harmonic current 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 control. The proposed idea is to incorporate virtual impedance to the output impedance of the front-end converter. In [item 19) in the Appendix], an application of the interconnection and damping assignment passivity based control approach to the port-controlled Hamiltonian model of DAB source-side converters in an medium voltage DC MG is proposed. Its effectiveness is demonstrated when stabilizing constant power loads. In [item 20) in the Appendix], a coordinated droop control method through virtual voltage axis is proposed for voltage restoration and energy management of dc MGs. To solve the problems of conventional droops, the voltage compensation term is defined as the virtual axis voltage value. In [item 21) in the Appendix], decentralized nonlinear model and intelligent control are proposed using adaptive output-feedback controller to stabilize the dc MGs burdened by constant power loads. Finally, in [item 22) in the Appendix], a new control strategy for the dual active bridge is proposed, i.e., it is modified for zero circulating power flow operation. Power management and coordination control used in this paper ensures the power supply reliability of the zonal hybrid dc–ac MG 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.

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Appendix
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