Guest editorial: special section on applications of power electronics in power systems

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Power transformers and steam turbines were the key drivers in the development of the AC power system paradigm at the dawn of the 20th century, characterized by huge synchronous generators feeding millions of passive loads through large interconnected systems, all of them supervised and controlled from a centralized energy management system (EMS). In the same way, thyristor valves and IGBTs, introduced in the seventies and nineties of the past century, respectively, are called to play a similar role in the decarbonized power systems of the 21st century, where distributed generators will compete to a large extent with centralized ones to deliver mostly renewable energy to smarter loads through more flexible and hybrid (i.e., AC-DC) networks, operated in a hierarchical and partly distributed fashion with the help of ubiquitous digital technologies.

Power electronics first appeared in transmission power systems in the form of high voltage DC (HVDC) lines, and soon after as static var compensators (SVC), whose terrific success and reliability quickly led to a whole and growing family of flexible AC transmission system (FACTS) devices. Later on, power electronics also entered the distribution business arena, in the form of active filters, distribution flexible AC transmission system (DFACTS) for voltage regulation, interface for renewable sources, etc. Nowadays, power electronics, particularly the successful voltage source converter (VSC) building block, has become an indispensable component of modern power systems, where multi-terminal DC grids will complement or supersede existing point-to-point HVDC lines, and renewable generators (mostly asynchronous, with low or null mechanical inertia) will replace conventional fossil-fuel generators faster than expected.

This special section aims at addressing the way power electronics will help facing the big challenges arising in this upcoming paradigm, in terms of both power infrastructure (grid-related and converters architectures) and "intelligence" (supervision and control of AC-DC transmission and distribution systems), in order to keep current standards of efficiency and reliability. The call for papers invited original submissions dealing with a diversity of applications of power electronics in future power systems, with the emphasis placed preferably on the system-wide perspective.

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Out of a pool of 175 initial submissions, eleven papers coauthored by researchers from six different countries have successfully passed the double-blind, peer-review process and been finally accepted for publication. Taxonomically, the eleven papers accepted for this special section can be broadly classified in four groups:

1) Review papers. The first paper, entitled "Overview of power electronics technology and applications in power generation, transmission and distribution", can be considered as an introductory preamble for this special section, providing a bottom-up perspective of the different power electronics technologies and applications arising in power systems. The authors argue that the traditional separation between FACTS and HVDC systems has become blurred with the advent of the VSC, the all-round and unique workhorse of future power systems. One of the goals of the paper is to somehow fill the gap existing between power electronics specialists, who frequently lack a deep enough knowledge of how power systems are operated, and power system engineers, who are not always fully aware of the plethora of mature technologies and advanced control methods which can be resorted to for the system benefit. The second paper, entitled "Multi-terminal DC grids: challenges and prospects", presents an overview of multi-terminal DC (MTDC) systems, nowadays one of the most exciting avenues of research in power systems. The authors perform an analysis of the most critical challenges and prospects for such emerging technology, and discuss a foreseeable technology development roadmap, paying special attention to crucial control and operational issues associated with MTDC grids.

2) Converter topologies. The next two papers are devoted to novel power converter configurations. The paper "Neutral-point-clamped hybrid multilevel converter with DC fault blocking capability for medium-voltage DC transmission" presents a hybrid arrangement that combines the features of both the neutral-point clamped converter and the modular multilevel converter. The topology, operation principle, modulation scheme and inner energy balance are presented, and its DC fault blocking capability is also investigated. A comparison with other multilevel converters is made, showing that the proposed scheme can be the right choice for medium-voltage DC transmission with overhead lines. The fourth paper, entitled "High step-up quasi-Z-source DC-DC converters with single switched capacitor branch", combines the advantages of switched-capacitor and quasi-Z-source converters to provide a DC-DC converter with higher output voltage gain, lower current stress across the switches and lower voltage stress across the output diodes, while at the same time using a similar number of active and passive components. As in the previous case, the topology, operating principle and design parameters are discussed, while both simulation and experimental results are presented confirming the theoretical analysis and advantages with respect to other DC-DC converters.

3) Analysis and modeling issues. The following two papers deal with one of the major pending issues of HVDC systems, namely the need to properly protect increasingly more complex systems against faults. Unlike earlier approaches based on time-domain simulations, the paper "Frequency domain based DC fault analysis for bipolar HVDC grids" proposes a frequency-domain methodology to analyze the influence of HVDC configuration and parameters on the travelling waves arising during a DC fault. The first travelling wave for meshed HVDC grids is characterized in the Laplace domain through voltage and current wave transfer functions with

respect to the incident voltage wave. Then, the step responses obtained from those transfer functions are validated by comparison with detailed simulations performed with PSCAD. The sixth paper, "Application of new directional logic to improve DC side fault discrimination for high resistance faults in HVDC grids", proposes a simple way to determine the direction of a fault in a multi-terminal HVDC grid, by comparing the rate of change of voltage values at both sides of the d*i*/d*t* limiting inductors. The local measurements, supervised by a directional element, allow a fast protection method to be implemented, which can be used for detecting high resistance faults. The protection scheme is applied to a three-terminal HVDC grid and its performance is evaluated through electromagnetic transient simulations.

4) Converter control schemes. The last five papers are devoted to the broad and critical issue of duly controlling power converters to attain the required performance for each specific application. The paper "Impact of phase-locked loop on stability of active damped LCL-filter-based grid-connected inverters with capacitor voltage feedback" investigates the effect of PLL dynamics on the small-signal stability of grid-connected inverters with actively damped LCL filter. Indeed, in weak grids, the dynamic interaction between the PLL and the controller may compromise the stability of the inverter. Based on the overall closed-loop transfer function, the system stability boundary is related to the PLL bandwidth and current regulator gain, and the accuracy of the identified stable ranges is verified by both simulation results and experimental tests.

Closely related to the earlier contribution, the paper "Stability of LCL-filtered grid-connected inverters with capacitor current feedback active damping considering controller time delays" addresses the controller design to optimize the dynamic response of LCL filtered, grid-connected inverters. In this work, the focus is on the impact of time-delays on the active damping and its equivalent virtual impedance. A critical value of active damping coefficient is proposed and necessary conditions to ensure system stability are identified. Simulation and experimental results confirm the proposed methodology.

The paper "Decentralized control of two DC microgrids interconnected with tie-line", considers the stable operation of two DC interconnected microgrids, fed by PV modules and battery units. For this purpose, the DC bus voltages are used to monitor the supply-demand balance of each microgrid, and hence to control the power flow across the tie-line. A decentralized control approach is proposed to keep the bus voltage fluctuations within an allowable range, while at the same time allowing a seamless transition between microgrid operation modes.

The tenth work included in this special section, "Comprehensive control for unified power quality conditioners", presents a control strategy for the so-called unified power quality conditioner (UPQC) to compensate waveform quality problems. Like the unified power flow controller reviewed in the first paper of this special section, the UPQC is composed of a shunt and a series VSC. Three controlling blocks are considered: (a) the main controller, dealing with the fundamental-frequency active and reactive power flow; (b) the harmonic controller, which ensures zero-error tracking while compensating voltage and current harmonics; (c) the module that generates the set-points in accordance with the different control objectives. The proposed strategy can be implemented by measuring only four variables, and has been experimentally validated under different conditions, including grid-frequency variations.

Last but not least, the paper entitled "Optimized and coordinated model predictive control scheme for

DFIGs with DC-based converter system" proposes a model predictive control scheme to coordinate the rotor and stator converters of doubly-fed induction generators. The objective is to improve the efficiency and dynamic performance of wind generators when connected to a DC grid. Optimized trajectories for rotor flux and stator current are the control targets in order to minimize the Joule losses, which is particularly advantageous at low and moderate torque. Simulations and experimental results are provided showing the steady-state and dynamic performance of the DFIG.

To summarize, besides two review papers, this special section comprises two papers proposing novel converter topologies and a total of seven papers dealing with different power system applications. Those applications include fault detection and protection of HVDC systems, stability enhancement and control of grid-connected converters, including DC microgrids, power quality improvement and efficient operation of wind generators.

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