Guest Editorial
Electric Machines in Renewable Energy Applications

THE USE of renewable energy resources for production of electricity is increasing rapidly worldwide. As of 2015, a majority of countries have set renewable electricity targets in the 10%–40% range to be achieved by 2020–2030, with a few notable exceptions aiming for (or having already achieved) 100% generation by renewables. We are experiencing a truly unprecedented transition away from fossil fuels, driven by environmental, energy security, and socio-economic factors.

Electric machines can be found in a wide range of renewable energy applications, such as wind turbines, hydropower and hydrokinetic systems, flywheel energy storage devices, and low-power energy harvesting systems. Hence, the design of reliable, efficient, cost-effective, and controllable electric machines is crucial in enabling even higher penetrations of renewable energy systems in the smart grid of the future. In addition, power electronic converter design and control is critical, as they provide essential controllability, flexibility, grid interface, and integration functions. The main objective of this special issue is to collect and disseminate publications that highlight recent advances and breakthroughs in this domain.

We have followed a two-tier process. First, we invited authors to submit extended abstracts. We received more than 70 abstracts, from which 48 were invited for full paper submission, based on scope and suitability for this special issue. The submitted manuscripts underwent a formal review process. Finally, ten papers were accepted for publication: seven papers related to wind energy, proposing new generator designs, power electronic converter controls for low voltage ride-through, and aggregate wind power plant modeling; one paper on generator design for hydro applications; one paper on the design and analysis of an electric machine for a flywheel energy storage application; and one paper describing a low-power energy harvesting device. In the next paragraphs, we present a brief discussion of each paper, ordered alphabetically by last name of first author.

The paper "Optimisation of Magnetic Circuit for Brushless Doubly Fed Machines (BDFMs)" by Abdi *et al*. presents novel design methods for optimizing the magnetic circuit of BDFMs. The BDFM is an attractive electrical machine particularly for wind power applications as a substitute for doubly fed slip-ring generators. It is shown that the peak flux density in the rotor magnetic circuit including rotor back iron varies with angular position, independent of the rotor speed. Therefore, some parts of the rotor back iron do not contribute in the machine magnetic circuit and hence can be removed. The proposed method leads to designs with substantial weight reduction.

The paper "Optimizing Air-Core Permanent-Magnet-Based Energy Harvest in Free-Rotating Devices" by Brovont and Pekarek details the analysis and design of an energy harvest system for use within an in-pipe mobile water-quality sensor. The sensor is a free-moving/free-rotating device of which the energy harvest system occupies an appreciable volume. Therefore, the electrical and mechanical dynamics of the device are strongly coupled, which poses a modeling challenge. To address this challenge, a rigorous electromechanical model is established to determine the expected energy harvest, given the geometric/material parameters and electrical/mechanical inputs.

The paper "Design Requirements of Generators Applied to Low Head Hydro Power Plants" by Garcia *et al*. discusses the design of bulb generators commonly used in low head hydro applications. To improve the hydraulic performance, the generator should be confined in the free space of a bulb, which leads to various electromagnetic and mechanical design challenges. Limited bulb dimensions and runner low speed result in a series of consequences that distinguish the bulb generator design from the conventional vertical-shaft hydro generators. The narrow stator bore diameter limits the rated voltage, rated power factor, short-circuit ratio, machine reactance, and stability. The small bulb case constrains the size of the components, the unit inertia, heat exchange, and structure support.

The paper "Dynamic Equivalent Model of Wind Power Plant using Aggregation Technique" by Kim and El-Sharkawi develops a reduced-order dynamic model of a wind power plant. The turbines are clustered into several groups depending on their types and operational conditions. Models of aerodynamic, mechanical, and electrical dynamics are integrated to represent the equivalent turbines for the groups, where fast dynamics are eliminated. The obtained slow dynamic models are interconnected through an equivalent network model. The proposed model order reduction method is useful for wind power plant design and for power system dynamic studies.

The paper "Enhanced Dynamic Voltage Control of Type 4 Wind Turbines during Unbalanced Grid Faults" by Neumann *et al*. describes three alternative voltage control options during unbalanced grid faults, with emphasis on the analysis of negative sequence current control schemes. The paper demonstrates that the simultaneous injection of both positive and negative sequence currents is advantageous because it leads to an elimination of overvoltages that may occur if only positive sequence current is injected.

The paper "Effects of Rotor Winding Structure on the BDFM Equivalent Circuit Parameters" by Oraee *et al*. studies different rotor structures and arrangements for a BDFM. The equivalent circuit parameters are extracted using the winding factor method and the coupled circuit model. The rotor equivalent circuit parameters are optimized with the aim of minimizing rotor impedance while keeping the turns ratio close to its optimum

Digital Object Identifier 10.1109/TEC.2015.2494639

value. Design objectives and constraints are investigated further for MW-scale wind turbine generators.

The paper "Magnetic Equivalent Circuit Modeling of the AC Homopolar Machine for Flywheel Energy Storage" by Severson *et al*. investigates the design and optimization of the synchronous ac homopolar machine. This type of machine is of particular interest in the application of grid-based flywheel energy storage, where it has the potential to significantly reduce self-discharge associated with magnetic losses. The complex geometry and flux paths of the ac homopolar machine make it particularly difficult to design. The main contribution of this paper is a model that is both sufficiently accurate and has a short enough solve-time so that it can be used in the design process.

The paper "Transient Reconfiguration and Coordinated Control for Power Converters to Enhance the LVRT of a DFIG Wind Turbine with an Energy Storage Device" by Shen *et al*. proposes a method to improve the low voltage ride-through operation of doubly fed induction generator turbines. During a grid fault, the grid-side converter is reconfigured such that it is connected to the rotor circuit in parallel with the rotor-side converter to provide an additional route for the rotor current, while an energy storage device is responsible for dc-link voltage regulation. A coordinated demagnetizing and reactive current control strategy is designed for the reconfigured DFIG during transient conditions.

The paper "On Inertial Dynamics of Virtual-Synchronous-Controlled DFIG-Based Wind Turbines" by Wang *et al.* investigates a method to enhance power system frequency stability through synthetic inertia support by doubly fed induction generators. The proposed virtual synchronous control method attempts to mimic the equation of motion of synchronous generators, which have a natural inertial response that does not require phase-locked loops. Furthermore, an approach is proposed to deal with the variations of input mechanical power caused by the changes of rotational speed or pitch angle during the inertial response process.

The paper "Development of a Magnetless Flux Switching Machine for Rooftop Wind Power Generation" by Yu and Niu presents the design of a novel, low-cost, single-phase generator for residential applications. The machine can be regarded as an integration of an outer-rotor and an inner-rotor flux switching machine sharing a common stator yoke, on which the armature coils and field coils are alternately wound. Important design details, such as machine speed constraint, field MMF calculation, and field and armature winding gauges are discussed.

ACKNOWLEDGMENT

The Guest Editorial Board thanks the IEEE Power and Energy Society for sponsoring this special issue. We sincerely thank the distinguished Guest Editors and all paper Referees for their invaluable comments, insight, and time. All paper authors are commended for their contributions. Many thanks to Prof. J. Jatskevich, Editor-in-Chief of the IEEE TRANSACTIONS ON ENERGY CONVERSION, for his support throughout the development of this special issue, and to R. Scholnick-Philippidis and K. Capaldo of the PES Executive Office, for their technical guidance and support.

Guest Editor-in-Chief
DIONYSIOS ALIPRANTIS
Purdue University
West Lafayette, IN 47907 USA
dionysios@purdue.edu

Guest Editors
MOHAMED EL-SHARKAWI
University of Washington
Seattle, WA 98195 USA

EDUARD MULJADI
National Renewable Energy Laboratory
Golden, CO 80401 USA

Guest Associate Editors
IAN BROWN
Illinois Institute of Technology
Chicago, IL 60616 USA

AKIRA CHIBA
Tokyo Institute of Technology
Tokyo 152-8550, Japan

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Ultimo, N.S.W. 2007, Australia

ISTVÁN ERLICH
University of Duisburg–Essen
Duisburg 47057, Germany

ISIDOR (IZZY) KERSZENBAUM
Izzytech
Irvine, CA 92619-0636 USA

EMIL LEVI
Liverpool John Moores University
Liverpool L3 2AJ, U.K.

KEVIN MAYOR
Alstom Power
Birr 5242, Switzerland

OSAMA MOHAMMED
Florida International University
Miami, FL 33174 USA

STAVROS PAPATHANASSIOU
National Technical University of Athens
Athens 15780, Greece

MIRCEA POPESCU
Motor Design Ltd.
Ellesmere SY12 0EG, U.K.

WEI QIAO
University of Nebraska–Lincoln
Lincoln, NE 68588 USA

DEZHENG WU
ABB Electrical Machines Ltd.
Shanghai, 200245, P.R.C.