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Guest Editorial

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Introduction

In the last decade, renewable energy, in particular wind and solar energy, has experienced one of the most substantial growths of any power generation source. At present, in many areas across the world, wind and solar energy are providing substantial proportions of the total electrical demand, rising to over 50% in certain regions. However, many renewable energy sources, e.g. modern variable speed wind turbines and photovoltaic systems, are significantly different from conventional thermal and hydropower generating technologies, since they synchronize to the electricity grid via power electronics converters, and so are not directly responsive to system frequency transients. As a result, there are significant challenges for maintaining a reliable and secure power system, particularly in areas with high penetration of wind/solar energy. On the other hand, flexible control strategies can give modern wind turbines and solar generation units, as well as large scale wind/solar farms, the ability to provide active power support to the grid during frequency transients over a wide timeframe.

This Special Issue brings together papers focused on the recent advances and breakthroughs in the technology of active power control (APC) from wind and solar (including photovoltaic and solar thermal) energy generation systems, ranging from individual wind turbines and solar generation units to large wind/solar farms. 135 manuscripts were submitted to this Special Issue, and underwent a formal review process, after which only 24 papers were accepted for publication. The accepted papers are broadly classified into four themes: (I) inertia and primary frequency control of wind turbines; (II) grid integration of photovoltaic generations; (III) power system operation and stability with renewable energy generations; and (IV) Wind power predictions and other issues. A brief discussion of each paper and the authors' contributions are presented below.

1 Inertia, primary frequency, and pitch control of wind turbines

'Frequency regulation control strategy for PMSG wind-power generation system with flywheel energy storage unit ' by Yao *et al.* discusses the frequency control scheme for PMSG wind power system with flywheel energy storage unit (FESU) based on fuzzy proportional plus differential (PD) controller. To obtain the appropriate ranges of FESU's PD controller parameters, the eigenvalue loci of the system are investigated based on the developed small-signal model of the whole system. Simulation studies on a 2 MW PMSG-based wind power generation system with 400 kW FESU verify the validity of the proposed control strategy.

'Improved use of WT kinetic energy for system frequency support ' by Xu *et al.* discusses the amount of wind turbine (WT) kinetic energy used for system frequency control and minimum rotor speeds according to different WT operation states to avoid large drop of mechanical power during WT frequency control. Two methods for releasing kinetic energy are developed, one is to reduce the rate of change of frequency (ROCOF) whereas the other aimed to reduce both the ROCOF and frequency nadir. The performance of the proposed strategies is validated by simulations using MATLAB®/Simulink®.

'Frequency control by variable speed wind turbines in islanded power systems with various generation mix' by Persson *et al.* discusses the impact on power system frequency control in small power systems based on different generator topologies with a large penetration (50%) of variable speed wind turbines. The impact of a proposed controller is investigated versus various wind speeds.

'Speed recovery strategy for the inertia response control of DFIGs: extended state observer based approach ' by Wei *et al.* develops a novel rotor speed recovery strategy based on the extended state observer (ESO) technique so as to restore the rotor speed as quickly after an inertia response control action as possible. Simulations show that the proposed controller outperforms the traditional proportional-integral (PI) controller in the aspects of dynamical performance, the robustness to varying working conditions and the capability to prevent the system frequency from a second drop.

'Optimal tuning of multivariable disturbance-observer-based control for flicker mitigation using individual pitch control of wind turbine' by Imran *et al.* presents a multivariable disturbance accommodated observer based control (DOBC) scheme to mitigate loads generated due to wind shear and tower shadow using individual blade pitch for above-rated wind speed condition of wind turbine. New DOBC with individual pitch control (IPC) to mitigate the flickers is presented and linear state space model of wind turbine with tower dynamics is developed. The proposed controller is tuned using optimal control theory to reduce fatigue of drive-train, tower and to regulated output power.

'Integrated wind turbine controller with virtual inertia and primary frequency responses for grid dynamic frequency support' by Fu *et al.* discusses an integrated controller of wind turbines with both inertial response and primary frequency regulation (PFR) to provide complete dynamic frequency support for the grid with high wind power penetration. The wind turbine control governor contains two cross-coupled controllers: pitch controller and maximum power point tracking (MPPT) controller. A three-machine prototype system containing two synchronous generators and a DFIG based wind turbine with 30% of wind penetration is implemented to validate the proposed integrated control strategies on providing inertial response and subsequent load sharing in the event of frequency change.

2 Grid integration of photovoltaic generations

'Central energy management method for photovoltaic DC micro-grid system based on power tracking control' by Xie *et al.* discusses a power tracking control strategy and central energy management method (CEMM) for DC micro-grid with hybrid energy storages. A DC micro-grid emulation system is designed using LabVIEW software development environment. Simulation experiments were executed to verify the theoretical analysis.

'MOPSO-based optimal control of shunt active power filter using a variable structure fuzzy logic sliding mode controller for hybrid (FC-PV-wind-battery) energy utilisation scheme' by Elgammal *et al.* discusses a variable structure fuzzy logic sliding mode controller utilizing MOPSO for shunt active power filter for standalone hybrid FC-PV-wind-battery energy utilization scheme. The developed MOPSO algorithm is used to continuously search for effective and optimized gains of the fuzzy logic sliding mode controller to ensure minimum harmonic distortion of the hybrid FC-PV-wind-battery current. The performance of the shunt active power filter with proposed control scheme has been verified through computer simulation studies using MATLAB®/Simulink®.

'Battery and supercapacitor for photovoltaic energy storage: a fuzzy logic management' by Cabrane *et al.* presents an approach of the voltage regulation of DC bus for the photovoltaic energy storage by using a combination of batteries and supercapacitors. The energy management strategy is developed to manage the power flows between the storage devices by choosing the optimal operating mode, thereby to ensuring the continuous supply of the load by maintaining the state of charge of supercapacitors (SoCsc) and the state of charge of the batteries (SoCbat) at acceptable levels.

'Simplified swarm optimisation for the solar cell models parameter estimation problem' by Yeh *et al.* discusses an improved simplified swarm optimization (SSO) algorithm, known as iSSO, to optimize the newest solar energy problem with a comprehensive comparative study of its performance for two well-known benchmarks, i.e., the solar cell single diode model (SDM) benchmark and the solar cell double diode model (DDM) benchmark.

'Grid integration of 3P4W solar PV system using M-LWDF-based control technique' by Singh *et al.* discusses a multitasking 3P4W (three phase four wire) SPV (solar photovoltaic) system using an M-LWDF (modified lattice wave digital filter) based control technique. For effective utilization of SPV array, an INC (incremental conductance) based MPPT (maximum power point tracking) approach is used to obtain the peak power. The M-LWDF based control technique is implemented under various working modes at nonlinear loads.

'Low-voltage ride-thorough capability of photovoltaic grid-connected neutral-point-clamped inverters with active/reactive power injection' by Tafti *et al.* discusses the performance of medium-scale grid-connected PVPPs during low voltage ride through operations. An algorithm for the calculation of the *dq*-axis current references during voltage sags is introduced, which considers the inverter current limitation, grid code requirements and the amount of extracted power from photovoltaic strings. The proposed algorithm uses the full current capacity of the inverter in injecting active or reactive powers to the grid during voltage sags, which leads in a better grid voltage enhancement.

3 Power system operation and stability with renewable energy generations

'Small-signal stability of power system integrated with ancillary-controlled large-scale DFIG-based wind farm' by Geng *et al.* discusses the small-signal stability of the power system integrated with ancillary controlled large-scale doubly fed induction generator based wind farm (WF). It is shown that the ancillary controller deteriorates power system low frequency oscillations and/or induces new lightly damped oscillation modes especially in a weak grid. The principle of the influence on the small-signal stability with different grid weakness and ancillary control schemes is evaluated in the paper by eigenvalue analysis and verified with time-domain simulations.

'Design guidelines for MPC-based frequency regulation for islanded microgrids with storage, voltage, and ramping constraints' by Liang *et al.* discusses the frequency regulation for a microgrid under islanded mode with variable renewables. Some critical and realistic considerations are identified and modelled, and the guidelines for battery energy storage system (BESS) sizing are thus obtained by a non-linear model predictive control (MPC) controller. Simulation results show that the effectiveness of the proposed MPC controller and design guidelines can be generalized for microgrids in islanded mode with two kinds of controllable operating resources, which are represented by diesel generators and BESS.

'Instantaneous penetration level limits of non-synchronous devices in the British power system' by Yu *et al.* discusses the instantaneous penetration level (IPL) limits of non-synchronous device (NSD) connected to a model power system in terms of steady-state stability beyond which the system condition becomes unstable. The paper introduces a set of system 'viability' criteria relating to locking signal in converter phase-locked loop, frequency, rate of change of frequency and voltage magnitude, which are used to determine the IPL limits. Further, a frequency domain visualization method is introduced to provide additional insight into contributions of individual generators.

'Dynamic power flow algorithm considering frequency regulation of wind power generators' by Wang *et al.* discusses the operational traits and frequency regulation characteristics of major types of wind turbines, including fixed speed wind turbines and variable speed wind turbines with integrated control strategy combining over-speed control and droop control. With the primary frequency regulation characteristics of wind turbines, a simplified dynamic power flow algorithm is proposed for power systems integrating wind power generation. The IEEE 30-bus system is modified to verify the proposed method considering different levels of wind power penetration.

'Coordinated frequency control from offshore wind power plants connected to multi terminal DC system considering wind speed variation' by Sakamuri *et al.* discusses a coordinated fast primary frequency control (FPFC) scheme from offshore wind power plants (OWPPs) integrated to a three-terminal high voltage DC (HVDC) system. The removal of active power support from OWPP after the frequency control action may result in second frequency (and DC voltage) dips. Three different methods to mitigate these secondary effects are presented, and the effectiveness is demonstrated on a wind power plant integrated into a three terminal HVDC system developed in DIgSILIENT PowerFactory.

'Optimal operation of hybrid power systems including renewable sources in the sugar cane industry' by Marcelo *et al.* discusses a control structure, based on Model Predictive Control, applied to energy management optimization in a sugar cane processing plant including renewable sources. The proposed control algorithm has the task of performing the management of which energy system to use (combined heat and power generation systems, boilers or others), maximize the use of renewable energy sources, maximize the gains of the boilers (that vary according to the biomass mixture used), manage the use of energy storages and supply the defined amount of energy. Simulation results show the satisfactory operation of the proposed control structure

'Active and reactive power control of wind farm for enhancement transient stability of multi-machine power system using UIPC' by Firouzi *et al.* discusses the connection of wind farms (WFs) to power system through unified inter-phase power controller (UIPC) for enhanced transient stability of the power system. Based on the UIPC model and low-voltage ride-through (LVRT) requirements of the new grid codes, a control system for active and reactive powers control is proposed for enhancement transient stability of power system. The proposed approach is validated in a 4-machine 2-area test system in PSCAD/EMTDC.

'Networked distributed automatic generation control of power system with dynamic participation of wind turbines through uncertain delayed communication network' discusses by Bijami *et al.* discusses a new distributed networked control scheme and its stability analysis framework for automatic generation control (AGC) in networked interconnected power systems with participation of wind turbine. A model is proposed for large scale distributed networked control system consisting of subsystems in which the states of each subsystem have their own time varying delay, and a linear matrix inequality (LMI) based method is further proposed to design the distributed controller for better system performance. Simulation results show the capability of the proposed approach to enhance the performance of networked power system.

4 Wind power predictions and other issues

'Optimisation of time window size for wind power ramps prediction' by Ouyang *et al.* discusses a new long-term wind power prediction approach based on time windows to improve the accuracy and efficiency of wind power ramp prediction. An optimization model is built to select the optimal time window size, which is the key point of the wind power forecasting. The variables, parameters, and constraints of the model are

investigated, and a kind of genetic algorithm is utilized to achieve the optimal solution.

'Research on wind power ramp events prediction based on strongly convective weather classification' by Xiong *et al.* discusses a forecasting model for wind power ramps based on strongly convective weather classification. A parameter templates method is used to identify the ramps weather in strongly convective weather library, and the original wind speed data is modified to obtain more accurate wind speed. Further, a new wind power ramps definition is proposed based on the ramp character itself and its impact on the power grid. Compared with the existing wind power ramps forecasting algorithms, the proposed prediction method gets into meteorologic essence of triggering great fluctuation of wind speed.

'Adequacy of frequency reserves for high wind power generation' by Das *et al.* discusses a new methodology to assess the adequacy of frequency reserves to handle power imbalances caused by wind power forecast errors. An algorithm is proposed and developed to estimate the power imbalances due to wind power forecast error following activation of different operating reserves. Frequency containment reserve requirements for mitigating these power imbalances are developed through this methodology. Wind power generation for 2020 and 2030 scenarios for Continental Europe network are investigated, based on which recommendations are made for requirements of frequency reserves in these scenarios.

'Self-adaptive inertia control of DC microgrid based on fast predictive converter regulation' by Wang *et al.* discusses an adaptive inertia control strategy for DC microgrid combined with fast predictive control of corresponding converter. Coordinated inertia control of wind power system, AC power grid and energy storage system of the microgrid is designed according to the characteristics of corresponding micro-sources in the system. In addition, to avoid control hysteresis and adjustment error, a fast converter local control method based on model predictive approach is proposed to cooperate with the rapid inertia adjustment strategy.

## Acknowledgments

Author biographies

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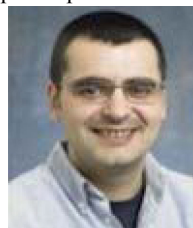
Nicolaos A. Cutululis is a Senior Researcher at DTU Wind Energy, Technical University of Denmark. His work is mainly related with integration of wind power, with a special focus on offshore wind power and grids, involving a variety of technical disciplines including modeling and control of wind turbines and farms, wind power variability and ancillary services from wind power.

Professor **Yongning Chi** is with China Electric Power Research Institute as the chief engineer of renewable energy research center. He is an IEEE member, secretary of IEC SC 8A 'Grid Integration of renewable energy generation', expert member of IEA GIVAR Advisory Group, and also a member of CIGRE. His research interests are modeling, control and grid integration of renewable energy generation. He was also responsible for formulating the Chinese wind power & PV grid codes.