*Editorial*

# Special Issue: "Wind Power Integration into Power Systems: Stability and Control Aspects"

**Lasantha Meegahapola** [1,*] and **Siqi Bu** [2,*]

1  Electrical and Biomedical Engineering, School of Engineering, RMIT University, Melbourne 3001, Australia
2  Department of Electrical Engineering, The Hong Kong Polytechnic University, Hong Kong 999077, China
*  Correspondence: lasantha.meegahapola@rmit.edu.au (L.M.); siqi.bu@polyu.edu.hk (S.B.)

Power network operators are rapidly incorporating wind power generation into their power grids to meet the widely accepted carbon neutrality targets and facilitate the transition from conventional fossil-fuel energy sources to the clean and low-carbon renewable energy sources. Complex stability issues, such as frequency, voltage, and oscillatory instability, are frequently reported in the power grid of many countries and regions (e.g., Germany, Denmark, Ireland, South Australia) with the substantially increased wind power generation. Control techniques, such as virtual/emulated inertia and damping controls, could be developed to address these stability issues, and additional devices, such as energy storage systems, can also be deployed to mitigate the adverse impact of high wind power generation on various system stability problems. This Special Issue includes 14 novel research articles mainly covering various stability analyses and associated control techniques of modern power systems as affected by high penetration of wind power generation.

Tu et al. [1] proposed a doubly fed induction generator (DFIG)–energy storage (ES) based hybrid system to improve the fast frequency response from wind farms. The ES system was designed to provide a similar inertial response as a synchronous generator of a similar rating as the wind farm. The authors have also proposed a coordinated virtual inertial response scheme for the DFIG-ES system to provide frequency response during frequency excursions. The proposed scheme was based on a fuzzy logic scheme, and it could improve the frequency nadir and also could alleviate the secondary frequency dip. Therefore, the proposed scheme is a very useful control scheme to improve the frequency response from wind farms.

Li et al. [2] proposed a multi-model predictive control algorithm based on a clustering approach to deal with the randomness and uncertainty of wind power generation. The authors developed the multi-model prediction model by first clustering the measured data and then applying the forgetting factor recursive least square method. The model predictive controller was developed to control the pitch-angle to vary the power output of the wind generator. The accuracy of the developed model was verified by using a DFIG-based wind farm in Western China by applying field-measured wind speed data. The proposed model predictive controller has shown a high prediction accuracy compared with the methods reported in the literature.

Jiao et al. [3] presented a sub-synchronous resonance (SSR) analysis and mitigation strategy for a DFIG operated as a virtual synchronous generator (VSG). Since the weak network phenomenon is more prominent in most of the present power grids, the VSG control method is used in power-electronic converter interfaced sources, such as the DFIG. Therefore, this paper presented an impedance-based analysis to characterise the sub-synchronous resonance (SSR) phenomenon for a DFIG-based wind farm controlled in VSG mode connected to the grid by a series-compensated line. According to the study, damping of reactive power plays a major role in mitigating the SSR phenomenon in DFIG wind generators controlled in VSG mode.

Wen et al. [4] presented a probabilistic assessment of the regional rate-of-change-of-frequency (RoCoF) for operational planning of high renewable penetrated power systems. Regional RoCoF is becoming an imperative factor in system planning and operation studies. Large-scale power-electronic converter interfaced generation sources are installed in regional areas of the power networks, which do not naturally respond to frequency excursions. This paper established an analytical sensitivity of regional RoCoF to the stochastic output of RES and subsequently, a linear sensitivity-based analytical method was proposed to calculate the regional RoCoF and the corresponding probabilistic distribution. The proposed method appears to be less time consuming than the existing methods.

Wang et al. [5] presented capacity planning of distributed wind power based on a variable-structure copula involving energy storage systems. Since some countries (e.g., China) require distributed wind power to be consumed within sub-transmission level, the distributed wind power capacity should be planned carefully while ensuring the entire distributed generation capacity is consumed within the network. Authors have developed a load and wind power prediction model based on the autoregressive moving average (ARMA) model, and subsequently, variable-structure copula models are established based on different time segment strategies to correlate the wind power and load. Finally, the capacity planning model was proposed based on the investment and operation cost, and environmental benefit and line loss cost. Subsequently, the model has been extended to a collaborative capacity planning model for distributed wind power and energy storage systems. The fidelity of the proposed model was validated using a modified IEEE-33 bus network.

Li et al. [6] presented a wind turbine wake model based on the modified Reynolds-averaged Navier–Stokes approach. The new model was proposed to improve the existing wake effect models' accuracy by proposing correction factors for the aerodynamic and turbulence models. The study has shown that the proposed model's velocity and turbulent fields are in close agreement with the data obtained from real wind turbines. In addition, the proposed mesh partition method has improved the computational efficiency, and hence the proposed model could be deployed to effectively assess the impact of the wake effect of wind turbines in power system studies.

Liu et al. [7] proposed a deep learning approach for wind power forecasting based on a wavelet decomposition (WD)–long short-term memory (LSTM) neural network model. Uncertainty and intermittency associated with power generation add complexity to system operation, and inaccurate forecasts increase the power network's risk of instability. Thus, to address this pressing issue, this paper proposed a hybrid prediction model based on the combination of WD and LSTM neural network. In this model, the nonstationary time series is decomposed into multidimensional components to reduce the original time series' volatility and make them more stable and predictable by WD. Subsequently, it has been used as the input to the LSTM to predict wind power generation. The results showed that the proposed model predicts wind power generation much more accurately than the existing prediction models used in China.

Hao et al. [8] studied the impact of active power outputs and control parameters of full-converter wind farms on the damping characteristics of sub-synchronous oscillation in weak power grids. Eigenvalue and participation factor analyses were performed to identify the dominant oscillation modes of the system and investigate the damping characteristics. The analysis demonstrated that when the phase-locked loop (PLL) proportional gain is high, the sub-synchronous oscillation damping has worsened with the increase in the active power output. On the contrary, when the PLL proportional gain is small, the sub-synchronous oscillation damping is improved with the increase in the active power output. By adjusting the control parameters in the PLL and DC link voltage controllers, system sub-synchronous oscillatory stability can be improved.

Chien et al. [9] designed an artificial neural network (ANN)-based real-time supplementary frequency controller for a DFIG wind farm, as the optimal controller gain that gives the highest frequency nadir or lowest peak frequency is a complicated nonlinear

function and hence is not easy to be derived by conventional analytical methods, especially for an online environment. In this work, the load disturbance, wind penetration, and wind speed were used as the inputs and the desired controller gain was used as the output, and the ANN can be employed to yield the desired gain in a very efficient manner, even when the operating condition was not included in the training set. It was demonstrated in the paper that the proposed ANN-based frequency control could yield a better frequency response than the fixed-gain controller.

Zhang et al. [10] presented a model using modified LSTM to predict ultra-short-term wind power. The error following forget gate (EFFG)-based LSTM model was developed, which can update the output of the forget gate using the difference between the predicted value and the actual value, thereby reducing the impact of the prediction error at the previous moment on the prediction accuracy at this time and improving the rolling prediction accuracy of wind power. Study results revealed that the root mean square error of the wind power prediction model is less than 3%, while the accuracy rate and qualified rate are more than 90%. Hence, the EFFG-based LSTM model provides better performance than the support vector machine (SVM) and standard LSTM model.

Chen et al. [11] proposed two types of flexible kinetic energy release controllers for the DFIG to improve frequency nadir following a disturbance and avoid under-frequency load shedding. A deactivation function-based integral controller was firstly presented and a second flexible kinetic energy release controller was designed using a proportional-integral controller with the gains being adapted in real-time with the particle swarm optimisation algorithm. The design only releases a small amount of kinetic energy in the initial transient period and more kinetic energy would be released when the frequency dip exceeds a pre-set threshold. The paper concluded that the frequency nadir could be maintained around the under-frequency load shedding threshold of 59.6 Hz using the proposed controllers.

Mujcinagic et al. [12] presented a control scheme of the virtual inertia response of wind power plants based on the centre of inertia (COI) frequency of a control area for the inertia-insufficient power systems. The PSS/E user written wind inertial controller was developed using FORTRAN. The efficiency of the controller was tested and applied to the real interconnected power system of Southeast Europe. The performed simulations showed certain conceptual advantages of the proposed controller in comparison to traditional schemes that use the local frequency to trigger the wind inertial response.

Luo et al. [13] investigated the participation of full converter-based wind power generation (FCWG) in electromechanical dynamics and uncovered an unusual transition of the electromechanical oscillation mode (EOM). Modal analysis was employed to quantify the FCWG participation in electromechanical dynamics, with two new mode identification criteria proposed. The impact of different wind penetration levels and controller parameter settings on the participation of FCWG was studied. It was revealed that if an FCWG oscillation mode (FOM) has a similar oscillation frequency to the system EOMs, strong interactions between FCWG dynamics and electromechanical system dynamics of the external power systems might be induced, and an EOM can be dominated by FCWG dynamics instead, and hence becomes a quasi-EOM. Some key findings on the mechanism of this special phenomenon are finally summarised and discussed.

Yan et al. [14] presented a novel coordinated control scheme, i.e., overspeed-while-storing control for permanent magnet synchronous generator (PMSG)-based WTG to enhance its LVRT capability. The proposed control scheme regulated the rotor speed to reduce the input power of the machine-side converter (MSC) during slight voltage sags. When the severe voltage sag occurs, the coordinated control scheme sets the rotor speed at the upper-limit to decrease the input power of the MSC, while the surplus power is absorbed by the supercapacitor energy storage (SCES) to reduce its maximum capacity. Moreover, the specific capacity configuration scheme of SCES was detailed. The effectiveness of the overspeed-while-storing control in enhancing the LVRT capability was validated under different levels of voltage sags and different fault types in MATLAB/Simulink.

The papers mentioned above included in this Special Issue provide new and valuable insights, effectively representing ongoing research efforts and stimulating future research activities in the relevant field. As guest editors, we would like to thank all the authors and reviewers who contributed to this Special Issue.

**Conflicts of Interest:** The authors declare no conflict of interest.

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