Condition Monitoring, Diagnosis, Prognosis, and Health Management for Wind Energy Conversion Systems

CONDITION monitoring, diagnosis, prognosis, and intelligent health management are effective means to reduce the downtime and the maintenance cost, and to improve the reliability, capacity factor, and lifespan of wind energy conversion systems. These important issues have drawn more and more attention during the last decade, and significant research effort is being taken by both the academia and the industry to advance the technologies for the condition monitoring, diagnosis, prognosis, and health management of wind energy conversion systems. This Special Section aims to provide a platform for academic and industrial communities to report the most recent findings in this field.

Through a strict peer-review process supported by highly qualified experts, 11 (approximately 27%) high-quality contributions to this "Special Section on Condition Monitoring, Diagnosis, Prognosis, and Health Management for Wind Energy Conversion Systems" have been selected for publication in the IEEE Transactions on Industrial Electronics. The selected contributions cover a wide range of interesting and important topics related to wind turbine condition monitoring and fault diagnostics. For example, the condition monitoring, fault diagnosis, and reliability of major wind turbine components and subsystems, such as blades [3], drivetrains [4], power converters [5], gearboxes [6], [7], and bearings [8], [9], were well covered by the selected contributions. Moreover, this Special Section covers the most commonly used sensors/signals for wind turbine condition monitoring, such as electrical signals [1], [2], strain sensors [3], [6], vibration [3], [4], [7], [9], acoustic emission [8], and supervisory control and data acquisition (SCADA) data [10], [11].

This Special Section is opened by a comprehensive survey on the state-of-the-art condition monitoring and fault diagnostic technologies for wind turbines [1], [2]. Part I of the survey [1] discussed the existing literature surveys on the subject, the common failure modes in major wind turbine components and subsystems, the condition monitoring and fault diagnostic techniques for these components and subsystems, and the issues of condition monitoring and fault diagnosis for offshore wind turbines. Part II of the survey [2] provided a comprehensive and critical review on the signals and signal processing methods used for wind turbine condition monitoring and fault diagnosis.

In [3], a new condition monitoring method for detecting incipient defects occurring in long wind turbine blades was developed. The method is based on the concept of the transmissibility of frequency response functions. The method jointly utilizes the condition monitoring signals measured by a number of neighboring sensors, such as fiber Bragg grating strain gauges or accelerometers. This offers the method a unique capability of both damage detection and location.

In [4], a real-time condition monitoring technique was developed for wind turbine drivetrains based on an improved spline-kernelled chirplet transform (SCT). The improved SCT is able to detect the instantaneous amplitude of a lengthy nonlinear and nonstationary (NNS) multicomponent condition monitoring signal at a fault-related frequency of interest. This enables the improved SCT to detect faults in wind turbines operating in time-varying conditions.

A universal method was described in [5] to calculate the lifetime of machine-side converters for low-speed (direct-drive) and medium-speed (one-stage) permanent-magnet synchronous generators. Based on the method, the reliability metrics of the machine-side converters for the two generators were assessed and compared. The conclusion is that, although the low-speed permanent-magnet synchronous generator is able to eliminate the gearbox, the lifespan of its machine-side converter is lower than that of the one-stage medium-speed generator.

In [6], a new method using a single piezoelectric strain sensor for the fault diagnosis of planetary gearboxes, which are widely used in wind turbine drivetrains, was presented. The method provides an attractive alternative to the traditional vibration monitoring approaches for wind turbine gearboxes.

In [7], a convex optimization-based method for the simultaneous identification of multiple features in superimposed signals was proposed. The method exploits the underlying prior information that multiple faults having similar frequency spectra but different morphological waveforms can be sparsely represented over the union of redundant dictionaries. The method was successfully applied for the diagnosis of multiple faults in wind turbine gearboxes.

In [8], an acoustic emission signal was used to evaluate the size of a single spall in a rolling element bearing. Based on the hypothesis that an acoustic emission signal is composed of two events for each passage of the rolling element across the spall, an analytical dual-impulse response model was developed to describe the acoustic emission signal. Then, an averaged dual-impulse interval-determining method was proposed to evaluate the spall size in the bearing.

In [9], a complete data-driven method to automatically generate system health indicators without the need of *a priori* knowledge on the system being monitored or the signals acquired was

Digital Object Identifier 10.1109/TIE.2015.2464785

proposed. The method consists of two steps. First, the spectral peaks of each acquired signal are identified and then grouped into a more complex spectral structure as harmonic series or modulation sidebands. Then, a time–frequency tracking operation is applied to track the spectral peaks and the spectral structures over time to construct spectral structure trajectories, which are used to generate wind turbine health indicators for the condition monitoring of wind turbines.

A method that uses SCADA data to monitor the wind turbine power generation performance was proposed in [10]. In the method, the profiles that statistically capture the curvatures and shapes of a wind turbine's power curve over consecutive time intervals are constructed by fitting appropriate SCADA data sets with a least square method. Multivariate and residual approaches are then applied to monitor the variations of the power curve profiles over time. That information can be used for the condition monitoring of wind turbines.

In [11], the potential of using SCADA data for the condition monitoring of wind turbines was explored. The power curve of each individual wind turbine in a wind farm is produced by a machine learning method using the SCADA data collected from the wind turbine. The constructed power curve of each wind turbine is then used to predict the power curves of other wind turbines. The residual error between the actual and predicted power produced was then used for the condition monitoring of wind turbines.

In summary, the contributions included in this Special Section have focused on reliability analysis, condition monitoring, and fault diagnosis. However, little exploration has been given to the prognosis and health management (e.g., fault-tolerant operation and condition-based maintenance) of wind energy conversion systems. The Guest Editors anticipate that this Special Section will stimulate such exploration and attract more attention from the academia and the industry to further develop condition monitoring and fault diagnostic technologies to make wind energy a more competitive and reliable energy source for clean and renewable power production.

Acknowledgment

The Guest Editors would like to thank all the authors that have submitted their valuable contributions and the numerous and highly qualified anonymous reviewers. They think that the selected contributions, which represent the current state of the art in the field, will be of great interest to the industrial electronics community. The Guest Editors would also like to thank Prof. C. Cecati, Editor-in-Chief of the IEEE Transactions on Industrial Electronics (TIE), for giving them the opportunity to organize this Special Section and for all the encouragement, help, and support given throughout the process, and Mrs. S. McLain, who is part of the TIE staff, for her professional support and assistance during the whole preparation of this Special Section.

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