Preface

The development of environmentally compatible energy technologies has been accelerated in response to the growing concern of the impacts from climate change. Wind energy is rapidly emerging as a low carbon, resource efficient, cost-effective sustainable technology in the world. Due to the demand of higher power production installations with less environmental impacts, the continuous increase of the size of wind turbines and the recently developed offshore (floating) technologies have led to new challenges in the wind turbine systems.

Wind turbines are complex systems with large flexible structures that work under very turbulent and unpredictable environmental conditions for a variable electrical grid. The maximization of wind energy conversion systems, load reduction strategies, mechanical fatigue minimization problems, costs per kilowatt hour reduction strategies, reliability matters, stability problems, and availability (sustainability) aspects demand the use of advanced (multivariable and multi-objective) cooperative control systems to regulate variables such as pitch, torque, power, rotor speed, power factors of every wind turbine, etc. Meanwhile, the purpose of wind turbine monitoring and fault diagnosis systems is to detect and locate degradations and failures in the operation of wind turbine components as early as possible, so that maintenance operations can be performed in due time (e.g., during time periods with low wind speed). Therefore, the number of costly corrective maintenance actions can be reduced and consequently the loss of wind power production due to maintenance operations is minimized.

This book is mainly research-oriented, covers, and advances the current state-of-the-art of aforementioned subjects. It provides new understanding, methodologies, and algorithms of control and monitoring, and computer tools for modeling and simulation, along with several illustrative examples and practical case studies, and therefore includes extensive application features not found in solely academic textbooks. This book is primarily intended for researchers and postgraduates in the field of wind turbines, wind energy, and various disciplines ranging from electrical, mechanical to control engineering, and graduate and senior undergraduate students in engineering wishing to expand their knowledge of wind energy systems. The practicing engineers of wind technology will also benefit from the comprehensive coverage of all topics of this book for acquiring new knowledge on wind turbine systems.

This book is divided into five main parts: Power Converter Systems (Chaps. 1–3); Control (Chaps. 4–7); Monitoring and Fault Diagnosis (Chaps. 8–11); Vibration Mitigation (Chaps. 12–13); and Test-Bench for Research/Education (Chaps. 14–15).

Chapter 1 studies the variable speed permanent-magnetic synchronous generator with power electronic converters. The proposed supervisory reactive power control scheme can be applied to larger wind farms and network configurations. Chapter 2 proposes a higher-order sliding mode control strategy for the doubly-fed induction generators-based wind turbines. Simulations using the NREL FAST code have shown its effectiveness and attractiveness in terms of robustness (fault ride-through capability enhancement) and sensorless control. Chapter 3 deals with the problem of grid integration of the wind energy conversion systems by optimizing the power delivered to the grid in order to provide the voltage support ancillary service at the point of common coupling. Maximum power point tracking control algorithms are proposed for the variable speed wind energy conversion systems. Chapter 4 presents a robust pitch control design for variable speed wind turbines operating along the entire wind speed range. H_∞ and advanced antiwindup techniques are used to provide a high performance control solution for both low wind and high wind operating modes with optimum performance in the transition zone. Chapter 5 proposes a unified design procedure for different multivariable robust controllers. The designed feedback control strategies can reduce the wind effect in structural modes and consequently mitigate the fatigue loads in the wind turbine. Chapter 6 presents an individual pitch static output feedback controller for an offshore floating wind turbine system. By properly designing a constrained control gain matrix, the proposed control strategy is robust and fault tolerant to the pitch sensor failure. Chapter 7 focuses on investigations of different aspects related to a fault tolerant control approach to sustainable wind turbine systems. Fault tolerant control strategies based on the Takagi-Sugeno fuzzy framework are presented for offshore wind turbines. Chapter 8 studies the problem of the ice accumulation monitoring and active de-icing control of wind turbine blades. An optical ice sensing method is proposed for the direct detection of ice on the blade. An aero/thermodynamic model is developed to predict the heat flux locally needed for de-icing under variable atmospheric conditions. Chapter 9 provides a structural health monitoring solution for wind turbine blades. A fatigue damage detection system is developed by using high-spatial-resolution differential pulse-width pair Brillouin optical time-domain analysis sensing system. Chapter 10 presents new methods of single sensor based monitoring, and redundant sensors based fault detection/isolation, in which the analytical redundancy for sensor fault detection/isolation is considered and a decision system based on a recursive statistical change detection/isolation algorithm is used. Chapter 11 studies the structural loading effects of various pitch system faults in an offshore floating wind turbine. The considered faults include the bias and gain errors in pitch sensor measurements, the performance degradation of the pitch actuator, in addition to the actuator stuck and actuator runaway faults. Chapter 12 deals with the problem of vibration mitigation of wind turbine towers. Tuned mass damper and tuned liquid column damper are used to reduce the resonant tower vibrations induced by the soil-structure interaction and eventual seismic excitation, and thus to improve the fatigue life of wind turbines. Chapter 13 proposes the use of magnetorheological dampers to control the structural response of wind turbines. Based on the smart base restraint (a combination of the smooth hinge, elastic springs and magneto-rheological dampers), a semiactive control algorithm commands instantaneously the magnetorheological dampers during the motion, making them modulating the reactive force as needed to achieve the performance goals. Chapter 14 presents a new low-cost, flexible test-bench wind farm for advanced research and education in optimum wind turbine, which is useful for making experimental validation of wind farm design, modeling, estimation and multiloop cooperative control. Chapter 15 illustrates how to set up an inexpensive but effective hardware-in-the-loop platform for the test of wind turbine controllers.

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