ENERGY SERIES

Electrical and Mechanical Fault Diagnosis in Wind Energy Conversion Systems

Edited by
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Introduction

Wind energy plays a vital role in meeting the Paris Agreement's goal of 1.5°C global warming and to accelerate the energy transition. In fact, wind energy is a renewable and sustainable source of energy, which does not contribute to greenhouse gas emissions, making it an important tool in combating climate change. As the cost continues to decrease significantly and technology improves, wind energy is becoming more competitive with other sources of energy an increasingly important part of the global energy mix.

According to the Global Wind Energy Council (GWEC), the cumulative capacity of wind power installed worldwide reached 841 GW at the end of 2022. The growth of wind power capacity installation is expected to continue in the coming years as more countries implement policies and invest in renewable energy to reduce their carbon footprint and combat climate change.

A wind energy conversion system is an important technology for generating clean renewable energy and reducing our dependence on fossil fuels. The operating mode of this system consists on capturing the power of the wind and converts it into usable electrical energy. The system typically consists of several key components, including wind turbines composed of blades that capture the kinetic energy of the wind and convert it into rotational motion, the generator that converts the rotational motion of the rotor blades into electrical energy, the power electronic system including inverters, rectifiers and other components that convert the AC power

Introduction written by Monia BEN KHADER BOUZID and Gérard CHAMPENOIS.

produced by the generator into a form that can be used by the grid or stored in batteries and the control system responsible for regulating the speed and direction of the rotor blades to optimize the efficiency of the wind turbine.

However, wind energy conversion systems are subject to various types of faults which can impact their reliability and efficiency. These faults can be electrical or mechanical faults. Electrical faults can occur in generators, transformers, power converters and cables. These faults can result in reduced power output, increased maintenance requirements and potentially dangerous situations such as electrical arcing. Mechanical faults can occur in blades, bearings and gears. These faults can result in increased vibration, noise and wear and can ultimately lead to component failure if not addressed.

Therefore, fault detection in wind energy conversion systems is of great important to ensure their reliability, safety and efficiency. Regular maintenance and monitoring can also help to detect them before they lead to downtime or major repairs. Additionally, advanced control and monitoring systems can help to optimize the performance of wind energy conversion systems and reduce the risk of faults occurring.

Thus, this book is an opportunity for readers to deepen their understanding of the theories and concepts related to the topic of electrical and mechanical fault detection and diagnosis in the different components of a wind energy conversion system, as well as to gain insight into the practical applications and the results achieved in the field. To this end, many researchers from the scientific community have contributed to this book in order to share their research results. This book is organized into an Introduction and five chapters.

Chapter 1, *Accurate Electrical Fault Detection in the Permanent Magnet Synchronous Generator and in the Diode Bridge Rectifier of a Wind Energy Conversion System*, written by Monia **Ben Khader Bouzid** and Gérard **Champenois**, proposes an efficient symmetrical component-based method, able to detect, locate and discriminate between an inter-turns short-circuit fault in the permanent magnet synchronous generator and an open-circuit diode fault in the diode rectifier of a small-scale wind conversion energy system. The first part of this chapter will be dedicated to an original analytical study of the negative sequence voltage under the different considered faults, where novel expressions of the negative sequence voltage are developed. Afterward, as a second part, an analytical study of the different proposed indicators of faults will be presented to investigate the behavior of the proposed indicators under the different faulty modes. Then, the third part of this chapter will be focused on the experimental validation of the behavior of the proposed indicators of fault and the novel developed expressions of the negative sequence voltage. Finally, a detailed description of the proposed method will be introduced in the fourth part of this chapter.

Chapter 2, *Control and Diagnosis of Faults in Multiphase Permanent Magnet Synchronous Generators for High-Power Wind Turbines*, written by Sérgio **Cruz** and Pedro **Gonçalves**, presents a general overview of the existing control systems and diagnostic methods available for diagnosing faults in multiphase PMSM drives applied in wind energy conversion systems. After a general overview of the modelling of multiphase PMSM machines, the most common control algorithms of multiphase PMSM drives are presented, including field oriented control, direct torque control and model predictive control (MPC). Special emphasis is given to MPC algorithms due to their increasing popularity and adequacy in the control of this category of drives. Following this, recent diagnostic methods are presented to detect different types of machine and converter faults, including inter-turn short-circuits, high-resistance connections, open-phase faults in the machine and in the power switches, permanent magnet faults, mechanical faults and sensor faults.

Chapter 3, *Gearbox Faults Monitoring Using Induction Machine Electrical Signals*, written by Khmais **Bacha** and Walid **Touti**, first presents the theoretical basis of the AM-FM effect of gear faults on the driven machine stator current using the machine current signal analysis technique (MCSA). Then, the MCSA is compared to various recent methods such as the extended Park vector approach (EPVA) and the discrete cosine/discrete sine transform used for the gear fault diagnosis purpose. Based on the experimental results, these methods are investigated in terms of fault sensitivity to frequency levels.

Chapter 4, *Control of a Wind Distributed Generator for Auxiliary Services Under Grid Faults*, written by Youssef **Kraiem** and Dhaker **Abbes**, presents an intelligent control strategy based on fuzzy logic technology for a renewable distributed generator (RDG) integrated into power electrical system in order to keep the frequency and the voltage of the power grid in an allowable range, while ensuring the continuity of the power supply in the event of a grid fault. The RDG comprises a wind system, as a principal source and a hybrid storage system consisting of battery (BT) and supercapacitors (SC). RDG is associated with loads and a fluctuating power grid. The structure of the proposed control strategy is mainly composed of a fuzzy logic supervisor, a fuzzy detector of the standalone operation mode and an adaptive fuzzy droop control. The fuzzy supervisor is developed to manage the power flows between different sources by choosing the optimal operating mode, while ensuring the stability of the power grid and the continuous supply of loads by maintaining the state of charge of the BT and SC in acceptable levels to improve their lifespans. The fuzzy islanding detector is used to detect the standalone mode in the event of power grid failure. The adaptive fuzzy droop control allows for controlling active and reactive powers exchanged with the power grid, ensuring its stability by maintaining frequency and voltage within optimal margins.

Chapter 5, *Fault-Tolerant Control of Sensors and Actuators Applied to Wind Energy Systems*, written by Elkhatib **Kamal** and Abdel **Aitouche**, proposes an observer-based actuator or sensor detection scheme for TS (Takagi-Sugeno) type fuzzy systems subject to sensor faults, parametric uncertainties and actuator faults. The detection system provides residuals for detecting and isolating sensor faults that may affect a TS model. The fuzzy TS model is adopted for fuzzy modeling of the uncertain nonlinear system and establishing fuzzy state observers. Sufficient conditions are established for robust stabilization in the sense of Lyapunov stability for the fuzzy system. The sufficient conditions are formulated in the form of linear matrix inequality (LMI). The effectiveness of the proposed controller design method is finally demonstrated on a DFIG-based wind turbine to illustrate the effectiveness of the proposed method.