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Model-Based Active Fault-Tolerant Cooperative Control in An Offshore Wind Farm

Hamed Badihi[a], Youmin Zhang[a,b,*], and Henry Hong[a]

[a] *Department of Mechanical and Industrial Engineering, Concordia University, Montreal, Quebec, H3G 1M8, Canada*
[b] *Xi'an University of Technology, Xi'an, Shaanxi, 710048, China*

Abstract

Given the importance of reliability and availability in wind farms, this paper focuses on the development of an integrated fault diagnosis and fault-tolerant control scheme in a cooperative framework at wind farm level against the decreased power generation caused by turbine blade erosion and debris build-up on the blades over time. More precisely, the paper presents a novel integrated fault detection and diagnosis (FDD) and fault-tolerant control (FTC) approach oriented to the design and development of an active fault-tolerant cooperative control (AFTCC) scheme for an offshore wind farm. The scheme employs a fault detection and diagnosis system to provide accurate and timely diagnosis information to be used in an appropriate automatic signal correction algorithm for accommodation of faults in the farm. The effectiveness and performance of the proposed scheme are evaluated and analyzed by different simulations on a high-fidelity offshore wind farm benchmark model in the presence of wind turbulences, measurement noises and realistic fault scenarios.

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Keywords: Fault Detection and Diagnosis (FDD); Fault-Tolerant Control (FTC); Fault-Tolerant Cooperative Control (FTCC); Wind Turbines; Wind Farm

1. Introduction

Wind energy is one of the fastest growing sources of renewable energy around the world. In order to reduce the average cost of this energy, large wind turbines are often installed in clusters called wind farms, particularly in offshore locations. As more and more offshore wind farms are developed, both the factors of complexity and limited accessibility together with harsh climate conditions come into play and result in higher failure rates and maintenance challenges. This motivates the design and development of advanced

* Corresponding Author (youmin.zhang@concordia.ca)

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fault detection and diagnosis (FDD) as well as fault-tolerant control (FTC) schemes not only in individual wind turbines but also in wind farms to improve their reliability and availability. In general, the FDD and FTC schemes can be applied at both individual wind turbine and entire wind farm levels. Recently, research works have been more focused on the application of such methods at wind turbine level (for example see, [1-5]). A recent review of the literature in [6] provides more references on FDD and FTC for wind turbines. Actually, some faults are easier to be detected, diagnosed, and accommodated at wind farm level through comparing the performance of turbines operating under almost the same wind conditions. With respect to a very recent field of research on the FDD and FTC at wind farm level, only a few research works are reported in the literature. Most of these works are focused on condition monitoring and fault detection in wind farms. In [7, 8], various data-mining algorithms are applied to develop models for predicting possible faults in wind farms. In [9], the relationship between the wind speed and the generated power in a wind farm is estimated using three different machine learning models. The models can detect anomalous functioning conditions of the wind farm. But, they are unable to isolate and identify faults. More recently, researchers have studied the FDD and FTC problems in a standard benchmark model presented in [10] that represents a wind farm with nine turbines subject to different fault scenarios. For example, authors in [11] present a fault detection and isolation approach based on a set of piecewise affine Takagi–Sugeno models that are identified from the noisy measurements. In [12], the fault diagnosis is conducted using interval nonlinear parameter-varying parity equations assuming unknown but bounded description of the noise and modeling errors. Moreover, an active FTC scheme based on a model-based FDD approach is also presented in [13]. The above cited works are common in two aspects. First, they have assumed that only one fault can occur at a time in a farm. Second, they mostly rely on wind speed or its estimation that itself, normally, depends on the layout of the wind farm and direction of the wind as well.

Given the importance of FDD and FTC at wind farm level, this paper presents a novel integrated FDD and FTC approach in a cooperative framework oriented to the design and development of an active FTC scheme for an offshore wind farm against decreased power generation fault caused by turbine blade erosion and debris build-up on the blades over time. The proposed scheme is based on a model-based FDD system that incorporates data-driven models developed using fuzzy modelling and identification (FMI) technique. Furthermore, an appropriate automatic signal correction (ASC) algorithm is designed that employs the provided accurate and timely FDD information for accommodating the possible faults in a wind farm. In fact, the proposed scheme not only provides necessary FDD information for condition monitoring purposes, but also provides the effective possibility of accommodation of faults. To further highlight the contribution of this paper compared to the other relevant works in the existing literature, the proposed scheme here is designed and developed in a way to be valid for any layouts of a wind farm with any directions of the wind while the considered fault may occur simultaneously in more than one turbine in the farm.

The effectiveness and performance of the proposed scheme are evaluated and compared by different simulations on a high-fidelity offshore wind farm benchmark model in the presence of wind turbulences, measurement noises and realistic fault scenarios.

The remainder of the paper is organized as follows: In Section 2, the wind farm benchmark model used in this paper is briefly described. The considered fault is described in Section 3. Section 4 presents an integrated FDD and FTC approach. The details of the FDD at wind farm level is presented in Section 5. Section 6 presents the simulation results. Finally, conclusions are drawn in Section 7.

2. Wind Farm Benchmark Model

This paper considers an advanced wind farm simulation toolbox called *SimWindFarm* [17]. The toolbox provides a realistic wind farm simulation benchmark model that allows control designers to develop, implement and investigate farm level control and diagnosis algorithms under different operating conditions. Fig. 1 shows the default layout for the considered wind farm with ten turbines. The overall structure of the simulation benchmark model under consideration is illustrated in Fig. 2. As it is shown in Fig. 2, the wind farm simulation benchmark model is composed of four major components in the top level that operate in a closed loop: