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Fuzzy model-based faults diagnosis of the wind turbine benchmark

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Abstract

Modern Wind turbines are complex systems which can be affected by malfunctions, regarding actuators, sensors, and components. An early faults detection and isolation are then highly required. For this aim, in the present paper, a robust fault detection and isolation (FDI) scheme is developed for a 4.8 MW wind turbine described via Takagi–Sugeno (T–S) multiple models. The FDI method is developed by using Fuzzy sliding mode observer as residual generators. Regarding the evaluation task, a set of pre-defined thresholds designed to indicate the occurrence of faults. Following that, a bank of residual generators is employed appropriately to determine fault type and location. Finally, the wind turbine benchmark is used to evaluate the performances of the proposed method against a set of realistic fault scenarios.

Keywords: Fault detection and isolation; Sensor and Actuator faults; T–S fuzzy systems; Observers; Wind Turbine Benchmark.

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1. Introduction

Electrical energy plays an integral part in human's daily life. However, the primary energy resources, fossil, and fuels based energy source are not inexhaustible. Therefore, due to the several causes; the lack of the principal energy resources and to environmental consequences, there has been significant research focusing on the development of a clean and renewable energy resources such as the case for wind and solar energy [1].

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As an alternative energy source, the wind turbine is an aeroelastic mechanical device that converts kinetic energy from the wind into mechanical energy to produce electricity. A wind turbine needs to operate with a high degree of reliability and availability at all times, despite the possible occurrence of malfunctions in the system. Hence, the main challenges to achieving a proper functioning of the system are in the design of a fault detection and accommodation techniques.

Several fault detection and isolation (FDI) schemes investigated in the literature for wind turbine [2-3]. The existing FDI techniques subdivided into two main FDI methods. Signal processing based methods, which make use of the measured data from the process under investigation [4-5]. And model-based methods which employ the mathematical models [6].

Two major problems encountered in the design of an FDI scheme for the wind turbine. The high noise level in the wind speed measurement, and the non-linearities in the aerodynamics of the turbine.

In this paper, fuzzy sliding-mode observers are designed to deal with the FDI problem. Taking advantage of the TS representation of the wind turbine, the proposed technique consists of estimating the system state vector by the observer, used as a residual generator. The residual signals are generated as the difference between the measured (the real output) and the estimated output of the observer. Finally, a decision making on the technical state of the diagnosed part of the system is performed using some pre-defined thresholds for the generated residual signals to distinguish faults with disturbances, noise or modeling errors

The next section presents the fuzzy T-S model of the nonlinear wind turbine benchmark together with the different types of faults affecting the model.

2. Benchmark model of the Wind Turbine

The wind turbine model is three blades horizontal variable speed turbine of 4.8MW rated power. This benchmark model [7], mainly consists of three parts: blade & pitch system, generator & converter, and drive-train. The state space model of the wind turbine established by combining the individual systems is given by

$$\begin{cases} \dot{x}(t) = A\,x(t) + B\,u(t) + E\,T_a(t) \\ y(t) = C\,x(t) \end{cases} \tag{1}$$

where

$$A = \begin{bmatrix} 1/\tau_g & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & I & 0 & 0 & 0 \\ 0 & -\omega_n^2 I & -2\xi\omega_n I & 0 & 0 & 0 \\ 0 & 0 & 0 & -\dfrac{(B_{dt}+B_r)}{J_r} & \dfrac{B_{dt}}{n_g J_r} & -\dfrac{K_{dt}}{J_r} \\ -\dfrac{1}{J_g} & 0 & 0 & \dfrac{B_{dt}}{n_g J_g} & -\dfrac{(B_{dt}+n_g B_g)}{n_g^2 J_g} & \dfrac{K_{dt}}{n_g J_g} \\ 0 & 0 & 0 & 1 & -\dfrac{1}{n_g} & 0 \end{bmatrix}, \quad B = \begin{bmatrix} \dfrac{1}{\tau_g} & 0 \\ 0 & 0 \\ 0 & \omega_n^2 I \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad E = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \dfrac{1}{J_r} \\ 0 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}, \quad x = \begin{bmatrix} T_g \\ \beta \\ \dot{\beta} \\ \omega_r \\ \omega_g \\ \theta_\Delta \end{bmatrix}, \quad u = \begin{bmatrix} T_{gr} \\ \beta_r \end{bmatrix}$$

J_r is the rotor inertia, ω_r is the rotor speed B_r is the rotor external damping, J_g is the generator inertia, ω_g and T_g are the generator speed and torque, B_g is the generator external damping, n_g is the gearbox ratio, K_{dt} is the torsion