

Fault Detection and Isolation in DFIG Driven by a Wind Turbine

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Abstract : This paper presents a new approach to detect and isolate the current sensor faults, a doubly fed induction generator (DFIG) for a wind turbine application. And to detect the variable resistance faults. A method using an unknown input of multiple observers described via Takagi-Sugeno (T-S) multiple models. A bank of multiple observers scheme (DOS) generates a set of residuals for detection and isolation of sensor faults which can affect a TS model. A decision system is used to the process the residual vector to detection and isolation faults. The stability and the performance of the multiple models are formulated in terms of Linear Matrix Inequalities (LMIs). The approach is validated using Matlab software to modeling and simulation of a DFIG..

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1. INTRODUCTION

Since many wind turbines are installed at remote locations, the introduction of fault diagnosis and fault-tolerant control is considered a suitable way of improving reliability of wind turbine and lowering cost of repairs. As many wind turbines are installed earth and offshore, a non-planned service can be highly costly, so it would be beneficial if diagnosis could help the turbines to produce some energy from the time a fault is detected to the next planned service. A considerable research has been done on the modeling and control of wind turbines with DFIG [1, 2, 3]. Since monitoring the generator requires processing the current and measuring voltage, the first step should be dedicated to sensor fault diagnosis. That is why this issue is addressed here.

In this paper, complete diagnosis system for stator current, as well as rotor sensors are designed. Wind turbines have nonlinear aerodynamics and this limits the use of a linear equation. Hence, an increase in interest in diagnosis wind turbines through nonlinear methods has been noticed in the last years to handle the nonlinearity of the generator speed. This is achieved either through the use of nonlinear models directly in the design or through the use of multiple models approaches [4,5]. It is known that nonlinear unknown input observer design and diagnosis are difficult problems because powerful design methods are lacking to deal with nonlinearities. Unknown input observer design for general nonlinear systems is still largely a problem, and thus a nonlinear unknown input observer based on fault diagnosis remains an area for further research [6,7].

Recently several researchers have explored a Takagi-Sugeno (TS) fuzzy observer to deal with nonlinearity in

problems detection and diagnosis. In [8] the authors proposed linear parameter-varying FTC systems for pitch actuator faults occurring in the full load operation. In [9] a T-S fuzzy observer based FTC design is proposed to achieve maximization of the power extraction. Other examples of this usage of the unknown input observers can be seen in [10] where the former reports similar schemes applied on fault detection of power plant coal mills and the latter estimate power coefficients for wind turbines, some examples can be found of fault detection and accommodation of wind turbines. An observer based scheme for detection of sensor faults for blade root torque sensor is presented in [11]. In [13] an unknown input observer based scheme was proposed to detect such faults in a wind turbine. The contribution of this paper focuses on the design of the unknown multiple observers to detect, isolate the current sensor faults and fault of variation resistance in the rotor circuit in DFIG, based on the wind turbine T-S models. This proposed scheme is based on the Dedicated Observers (DOS) method using a nonlinear unknown input observer scheme, each of the DOS is dedicated to each output of generator to generate a set of residual signals.

2. MODELING AND OBSERVER DESIGN

The model is derived from the voltage equations of the stator and the rotor. It is assumed that the stator and the rotor windings are symmetrical and symmetrically fed. The saturation of the inductances, iron losses, skin effect, and bearing friction is neglected.

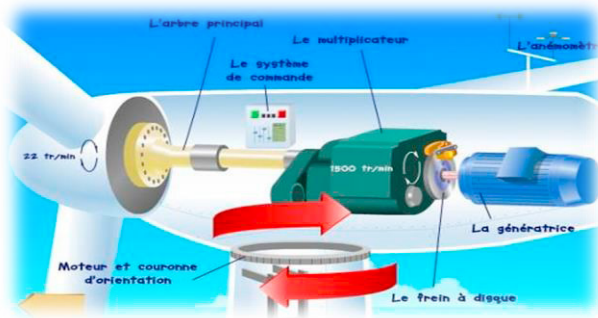


Fig. 1. Variable-speed wind system (Vestas)

The general state-space model is given in (1), (2) and (4), where $x(t)$ is the state system, $u(t)$ is the control vector input, $y(t)$ are measured and the output, $v(t)$ is the vector of unknown input. The matrices A , B , R and C are matrices known as the parameters of matrix which are defined in appendix, consistent with the dimension signals.

$$\dot{x}(t) = Ax(t) + Bu(t) + Rv(t), \quad y(t) = Cx(t) \quad (1)$$

Where

$$u(t) = [V_{dr} \ V_{qr}]^T, \quad v(t) = [V_{ds} \ V_{qs}]^T$$

$$x(t) = [i_{ds} \ i_{qs} \ i_{dr} \ i_{qr}]^T$$

and

$$\begin{cases} V_{ds} = R_s i_{ds} + \frac{d\phi_{ds}}{dt} - \omega_s \phi_{qs} \\ V_{qs} = R_s i_{qs} + \frac{d\phi_{qs}}{dt} + \omega_s \phi_{ds} \end{cases} \quad (2)$$

$$\begin{cases} V_{dr} = R_r i_{dr} + \frac{d\phi_{dr}}{dt} - \omega_r \phi_{qr} \\ V_{qr} = R_r i_{qr} + \frac{d\phi_{qr}}{dt} + \omega_r \phi_{dr} \end{cases} \quad (3)$$

where V stands for voltages (V), I stands for currents (A), R stands for resistors (Ω), ϕ stands for flux linkages (Vs). Indices d and q indicate direct and quadrature axis components, respectively, while s and r indicate stator and rotor quantities respectively. ω_s and ω_r are the stator and the (mechanical) rotor speed of the generator [12].

$$A = \begin{bmatrix} \frac{-R_s}{\sigma L_s} & p \left(\omega_s + \frac{L_h^2}{\sigma L_r L_s} \omega_r \right) & \frac{L_h R_r}{\sigma L_r L_s} & \frac{P L_h}{\sigma L_s} \omega_r \\ -p \left(\omega_s + \frac{L_h^2}{\sigma L_r L_s} \omega_r \right) & \frac{-R_s}{\sigma L_s} & \frac{-P L_h}{\sigma L_s} \omega_r & \frac{L_h R_r}{\sigma L_r L_s} \\ \frac{L_h R_s}{\sigma L_r L_s} & \frac{P L_h}{\sigma L_s} \omega_r & \frac{-R_r}{\sigma L_r} & p \left(\omega_s - \frac{\omega_r}{\sigma} \right) \\ \frac{P L_h}{\sigma L_r} \omega_r & \frac{L_h R_s}{\sigma L_r L_s} & -p \left(\omega_s - \frac{\omega_r}{\sigma} \right) & \frac{-R_r}{\sigma L_r} \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ \frac{-L_h}{\sigma L_s L_r} & 0 \\ 0 & \frac{-L_h}{\sigma L_s L_r} \end{bmatrix} \quad R = \begin{bmatrix} \frac{-L_h}{\sigma L_s L_r} & 0 \\ 0 & \frac{-L_h}{\sigma L_s L_r} \\ \frac{1}{\sigma L_r} & 0 \\ 0 & \frac{1}{\sigma L_r} \end{bmatrix}$$

$$(\sigma) = 1 - \frac{L_h^2}{L_r L_s}: \quad \text{is the coefficient of Blondel} \quad (4)$$

Induction machines have a nonlinear nature, since the back EMF (electromotive force) depends on the rotational speed of the machine. This leads to a system matrix A that

depends on the rotational speed, which is a variable (A is the nonlinear matrix) that is linear with respect to the states (e.g., currents) and also linear with respect to the rotational speed. The system matrices are explicitly given in (4), where ω_r is the mechanical rotor frequency, p is the number of pole pairs, and ω_A is the rotational frequency of the reference frame. Using this description, it is easily possible to convert the system from a stator fixed into a synchronous reference frame or onto any other frame, since the influence of the rotation is described by ω_A . Explicitly, a stator fixed system is using $\omega_A = 0$, while a system oriented with the stator's voltage uses the stator's angular frequency $\omega_A = \omega_s = 2\pi 50 \text{ s}^{-1}$. Moreover, the nonlinear models influences the rotor's mechanical speed ω_r - see Figure 2.

3. MULTIPLE MODELS REPRESENTATION

The multiple models represent nonlinear systems in the form of an interpolation between models in generally linear space premises. Each local model is a dynamic LTI (Linear Time Invariant) valid around an operating point. In a practical way, these models are obtained by identification, linearization around different various working points or by polytopic convex transformation. The interpolation of these local models using standard activation function is used to model global nonlinear systems. This approach, known as multiple models, is inspired by Takagi-Sugeno fuzzy models (T-S).

3.1. Takagi-Sugeno Multiple models

The structure of the Takagi-Sugeno model is the most widespread, both in the analysis and in the synthesis of the multiple models. The fuzzy models of T-S consist of set of rules. The global models are obtained by the aggregation of local models. It is expressed in the following form.

$$\begin{cases} \dot{x}(t) = \sum_{i=1}^r hi(\xi(t)) (A_i x(t) + B_i u(t) + R v(t)) \\ y(t) = \sum_{i=1}^r hi(\xi(t)) (C_i x(t)) \end{cases} \quad (5)$$

where r is the number of submodels, $\xi(t)$ is the measurable premise's variable, $hi(\xi(t))$ are the membership functions verifying the convex sum's property $0 \leq hi(\xi(t)) \leq 1$ and $\sum_{i=1}^r hi(\xi(t)) = 1$, $x(t) \in \mathbb{R}^n$, $y(t) \in \mathbb{R}^p$ and $u(t) \in \mathbb{R}^m$ represent respectively the state, the output and input vectors $v(t)$ is the unknown input vector, $\{A_i, B_i, C_i, R\}$ are the sub models matrices.

3.2. Design of unknown input observers

In this section, we consider a nonlinear continuous time described by a multiple models, using activation functions that depend on the state of the system.

$$\begin{cases} \dot{z}(t) = \sum_{i=1}^r hi(\xi(t)) (N_i z(t) + G_i u(t) + L_i y(t)) \\ \hat{x}(t) = z(t) - E y(t) \end{cases} \quad (6)$$

$N_i \in \mathbb{R}^{n \times n}$, $G_i \in \mathbb{R}^{n \times m}$, $L_i \in \mathbb{R}^{n \times p}$ is the gain of the i^{th} local observer, E is a transformation matrix.

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