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SENSOR FAULTS DETECTION AND ESTIMATION FOR A DFIG EQUIPPED WIND TURBINE

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Abstract

Doubly Fed Induction Generator (DFIG) based on wind turbines demand a high degree of reliability and availability and they are characterized by expensive and safety critical maintenance work. This paper deals with a new strategy for detection and estimation of current sensor faults in the stator and rotor of a DFIG. First, a state space model of a DFIG is developed based on voltages and flux equations, which can be used in order to estimate states and to generate residuals by using a Luenberger observer. Then, the residuals results are exploited for faults detection and estimation. Finally, the effectiveness of the developed approach is validated through simulation tests performed by different faults scenarios.

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Keywords: Doubly-fed induction generator; Diagnosis faults; sensor faults states variables; estimation faults.

1. Introduction

Doubly Fed Induction Generators are largely the most popular electric machines employed in Wind Energy Conversion Systems (WECS). WECS based on DFIG has received increasing attention due to its remarkable advantages over other wind turbine systems [1]. The most important advantages of variable speed wind turbines

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compared with conventional constant speed systems are the improved dynamic behavior, resulting in the reduction of the drive train mechanical stress and electrical power actuations, and also the increase of power capture [2].

The DFIG is one of the most frequently deployed large grid connected wind turbines [3], due to their ability to operate at variable speed, the capacity to control the active and reactive powers. However, DFIG-based WTs are usually affected by various disturbances such as short-circuit in (abc) phases, current sensor faults caused by short-circuit, and voltage dips [4]. These disturbances have adverse many effects on the normal behavior of the real system and their estimates can be used to conceive systems of diagnostic and control systems [5]. Robust observers are proposed to simultaneously estimate states and actuator faults for different class of nonlinear and linear systems [6-10]. Diagnosis and faults estimation issues have been becoming one of increasing important to ensure a good supervision of the systems and guarantee the safety of human operators and equipment's, even if systems are becoming more and more complex. In this respect, a large number of diagnostic strategies for sensors of induction machines have proposed [11-13].

In the last two decades, a fault diagnosis and estimation (FDE) of induction machines has received extensive attention, as they are often used in practical control systems [14]. FDI in sensor faults of induction machines is necessary since control systems rely on the information provided by measured signals. In [15], authors have been studied the FDI problem of induction machines. DFIG can be subject by several kinds of faults as studied in [16]. Authors in [17-19], focus on current sensor fault detection and isolation (FDI) and control reconfiguration current for DFIG. In [20-21], the authors have studied the effect of current sensor fault on a doubly fed induction machine (DFIM).

The aim of this paper focuses on the design of the Luenberger observer in order to estimate both of the state variables of the DFIG and sensor faults. The simulation results will be given to demonstrate the superiority of the proposed method for faults detection and estimation.

Nomenclature

DFIG	Doubly Fed Induction Generator
FDE	Fault Diagnosis and Estimation
FDI	Fault Detection and Isolation
DFIM	Doubly Fed Induction Machine
WECS	Wind Energy Conversion Systems

2. System description and modeling

In a DFIG-based wind turbine, as shown in Fig. 1, the DFIG is coupled to the wind turbine rotor through a gearbox. The stator of the DFIG is directly connected to the grid and the rotor side is connected to a back-to-back converter via slip-rings [22].

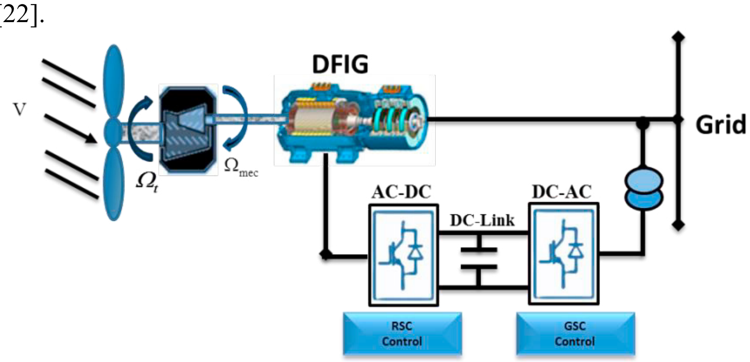

Fig. 1. Model of DFIG-based wind turbine.

2.1. Physical model of DFIG

In a stationary reference frame ($\alpha-\beta$), The DFIG electrical equations written in the state-space can be expressed as follows [23-24]:

$$\begin{cases} V_{\alpha s} = R_s I_{\alpha s} + \frac{\mathrm{d}}{\mathrm{d}t}\Phi_{\alpha s} - \omega_s \Phi_{\beta s} \\ V_{\beta s} = R_s I_{\beta s} + \frac{\mathrm{d}}{\mathrm{d}t}\Phi_{\beta s} + \omega_s \Phi_{\alpha s} \end{cases}, \begin{cases} V_{\alpha r} = R_r I_{\alpha r} + \frac{\mathrm{d}}{\mathrm{d}t}\Phi_{\alpha r} - \omega_r \Phi_{\beta r} \\ V_{\beta r} = R_r I_{\beta r} + \frac{\mathrm{d}}{\mathrm{d}t}\Phi_{\beta r} + \omega_r \Phi_{\alpha r} \end{cases} \tag{1}$$

The stator and rotor ($\alpha-\beta$) fluxes, $\varphi_{\alpha s}$, $\varphi_{\beta s}$, $\varphi_{\alpha r}$ and $\varphi_{\beta r}$ are given by [14]:

$$\begin{cases} \Phi_{\alpha s} = L_s i_{\alpha s} + L_m i_{\beta r} \\ \Phi_{\beta s} = L_s i_{\beta s} + L_m i_{\beta r} \end{cases}, \begin{cases} \Phi_{\alpha r} = L_r i_{\alpha r} + L_m i_{\alpha s} \\ \Phi_{\beta r} = L_r i_{\beta r} + L_m i_{\beta s} \end{cases} \tag{2}$$

The rotor and stator angular velocities are expressed by the following relation:

$$\omega_r = \omega_s - \omega \tag{3}$$

Where, $V_{\alpha s}$, $V_{\beta s}$, $V_{\alpha r}$, $V_{\beta r}$ stator and rotor in ($\alpha-\beta$) voltages, $I_{\alpha s}$, $I_{\beta s}$, $I_{\alpha r}$, $I_{\beta r}$ stator and rotor in ($\alpha-\beta$) currents; $\psi_{\alpha s}$, $\psi_{\beta s}$, $\psi_{\alpha r}$, $\psi_{\beta r}$ stator and rotor in ($\alpha-\beta$) fluxes; R_s , R_r stator and rotor per phase resistance; L_s , L_r cyclic stator and rotor inductances.

2.2. State space model

The model of the DFIG developed in this work is derived from the voltage equations of the stator and rotor (for more details see ([17-19]). Based on (1), (2) and (3), the general state space model of the DFIG is expressed as:

$$\begin{cases} \dot{x}(t) = A(\Omega_m)x(t) + B\,u(t) \\ y(t) = C\,x(t) \end{cases} \tag{4}$$

Where, Ω_m is the mechanical speed of the rotor, P is the number of pole pairs, and the matrices $A(\Omega_m)$, B and C are expressed as follows:

$$A(\Omega_m) = \begin{bmatrix} -(\frac{R_s}{\sigma L_s} I_2 + (\omega_s + \frac{L_m^2 P}{\sigma L_s L_r}\Omega_m)J) & (\frac{L_m R_r}{\sigma L_s L_r} I_2 - \frac{L_m P}{\sigma L_s}\Omega_m J) \\ (\frac{L_m R_s}{\sigma L_s L_r} I_2 + \frac{L_m P}{\sigma L_r}\Omega_m J) & -(\frac{1}{\sigma L_r} I_2 + (\omega_s - \frac{P}{\sigma}\Omega_m)J) \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{L_m}{\sigma L_s L_r} I_2 & -\frac{1}{\sigma L_s} I_2 \\ -\frac{1}{\sigma L_r} I_2 & \frac{L_m}{\sigma L_s L_r} I_2 \end{bmatrix}, \; J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}, C = eye(4)$$

The state vector $x = \left[I_{\alpha s} \; I_{\beta s} \; I_{\alpha r} \; I_{\beta r} \right]^T$, consists of the stator currents and rotor current components. The control inputs $u = \left[u_{\alpha s} \; u_{\beta s} \; u_{\alpha r} \; u_{\beta r} \right]^T$ are the stator and rotor voltage components. It is clear from the representation as in (4), that the system matrix A is varying time and depends on the mechanical rotor speed Ω_m . In this paper, let's consider that the DFIG operates at a fixed-speed ($\Omega_m = \Omega_{mec}$).

3. Estimation problem

In this section, we will design a Luenberger observer to estimate the immeasurable states and sensor faults in the stator and rotor of a DFIG. The block scheme of a Luenberger observer for the state and faults estimation is illustrated in Fig. 2.

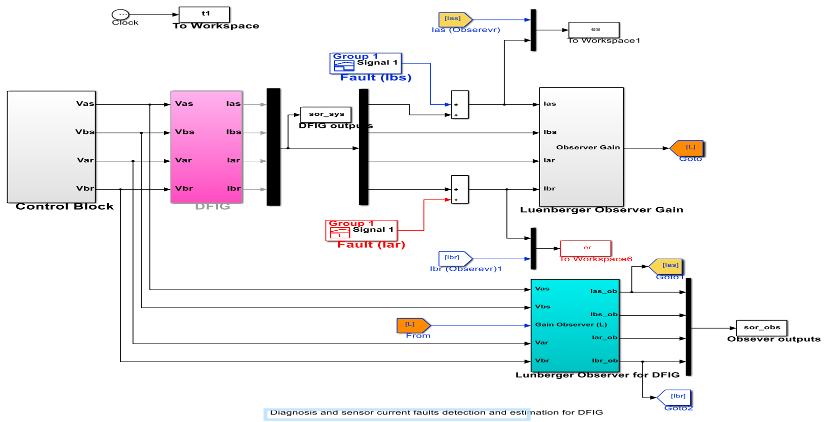

Fig. 2. Luenberger Observer scheme for a DFIG.

Luenberger observer goal is used to estimate the states and sensor electrical faults of a DIFG. The Luenberger observer for a DFIG system is constructed as:

$$\begin{cases} \dot{\hat{x}}(t) = A_n \hat{x}(t) + B u(t) + L(y - \hat{y}) \\ \hat{y}(t) = C \hat{x}(t) \end{cases} \tag{5}$$

Where $\hat{x}(t)$ is the state of the observer, $\hat{y}$ the output victor, u the known input vector, and the matrix gain L of the observer is the matrix of the observer feedback gains that is designed to provide the required performance of the observer.

In order to establish the conditions for the asymptotic convergence of the observer (5), let us define the state estimation errors as:

$$e(t) = x(t) - \hat{x}(t) \tag{6}$$

By using (5) and (6), the error dynamics can be described as follows:

$$\begin{pmatrix} \dot{e}_{I_{\alpha s}} \\ \dot{e}_{I_{\beta s}} \\ \dot{e}_{I_{\alpha r}} \\ \dot{e}_{I_{\beta r}} \end{pmatrix} = (A_{nom} - LC) \begin{pmatrix} e_{I_{\alpha s}} \\ e_{I_{\beta s}} \\ e_{I_{\alpha r}} \\ e_{I_{\beta r}} \end{pmatrix} \tag{7}$$

The Luenberger Observer matrix gain matrix L is defined by placing the eigenvalues of matrix (A-LC) to impose an observer dynamic faster than system. The feedback matrix L can be calculated using the function (*place*) in MATLAB.

4. Results and discussion

In order to validate the proposed method, the model (4) with the parameters in [9-10] is used as a controlled system in the simulation studies. The studies are conducted in Matlab using 4th-order Runge-Kutta method with the fixed step size of 0.01 s.

4.1. Simulations results in fault free case

Fig. 4 represents the measured stator and rotor currents of the DFIG and their estimated based on the use of Luenberger observer, and in Fig. 5 is represented the dynamic errors of the states.

It can be clearly observed from the simulation results that the states estimation generated from the Luenberger observer converge rapidly to those simulated by the real system (DFIG). Furthermore, we can observe in Fig. 5, that the estimation errors are very weak, which confirm an ideal estimation by using this observer.

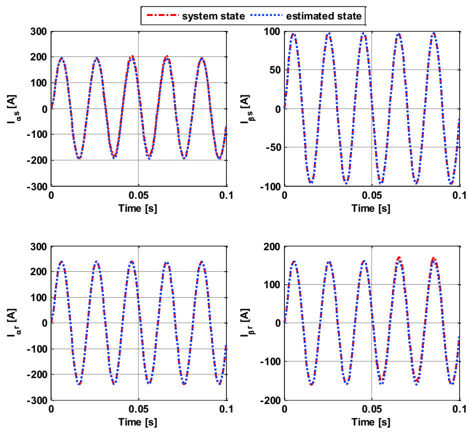

Fig. 4. Original states and their estimated.

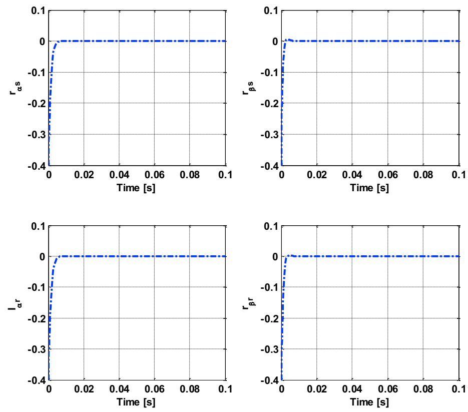

Fig. 5. Errors between states and their estimates.

4.2. Simulation with stator bias fault

The system (4) is subjected of an additive sensor current fault in the stator between the times t = 0.03 s and t = 0.07 s, according to;

$$f_s(t) = \begin{cases} 10, & 0.03 \le t \le 0.07s \\ 0\ , & otherwise \end{cases} \tag{8}$$

Fig. 6 represents the real states, estimated states, sensor original fault and it's estimated. Fig. 7 shows in zoom of the original fault and its estimated in the stator.

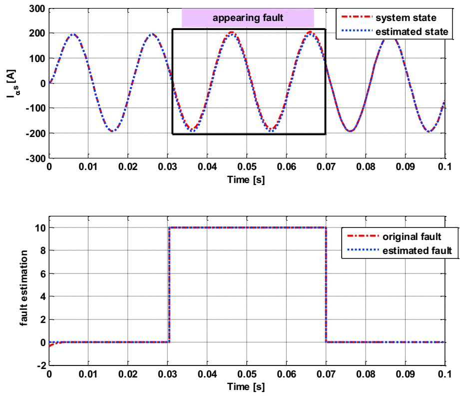

Fig. 6. Results for a fault in the stator.

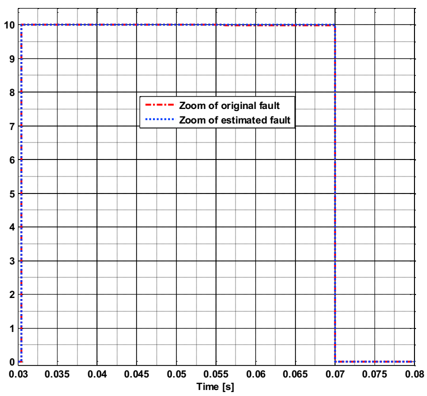

Fig. 7. Zoom of original fault and estimated fault (stator).

4.3. Simulation with rotor bias fault

The system (4) is subjected of an additive sensor current fault in the rotor between the times t = 0.052 s and t = 0.092 s, according to;

$$f_r(t) = \begin{cases} 10, & 0.052 \le t \le 0.092s \\ 0\ , & otherwise \end{cases} \tag{9}$$

Fig. 8 represents the state, state estimated, sensor original fault and it's estimated in the rotor. Fig. 9 shows in zoom of the original fault and it's estimated.

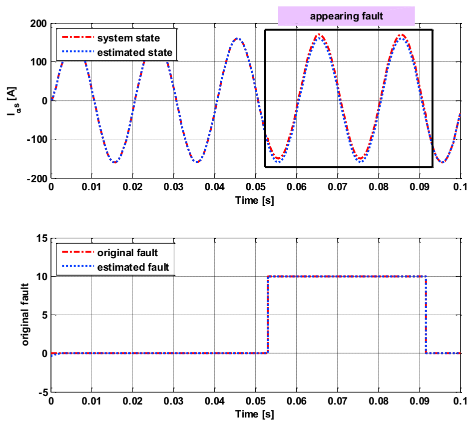

Fig. 7. Simulation results for the rotor sensor fault.

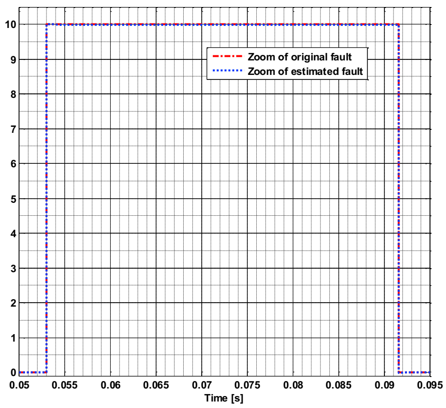

Fig. 9. Zoom of original fault and estimated fault (rotor).

From the above simulation results, it has shown that the Luenberger observer is effective for estimating the fault behavior, in cases of the DFIG subject to electrical faults in the stator and rotor.

5. Conclusions

In this paper, we presented a liner Luenberger observer to solve the problem of fault detection and estimation of faults those appearing in the stator and rotor current sensors for a DFIG, which is most used generator nowadays.

The state space of a DFIG is derived from the voltage equations of the stator and rotor, with considering that the DFIG operates at a slowly variable speed. Estimate states converge rapidly to the real states (stator and rotor currents). We can also conclude that the presented approach offer a good estimation of electrical faults which are appearing in the stator and rotor of a DFIG.

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