Measurement 91 (2016) 680–691

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

A novel scheme for current sensor faults diagnosis in the stator of a DFIG described by a T-S fuzzy model

Samir Abdelmalek [a,b,*], Linda Barazane [a], Abdelkader Larabi [a], Maamar Bettayeb [c]

[a] Industrial and Electrical Systems Laboratory, Faculty of Electronics and Computer, University of Sciences and Technology Houari Boumediene, B. P. 32 El-Alia, 16111 Bab-Ezzouar, Algiers, Algeria

[b] Unité de Développement des Equipements Solaires, UDES, Centre de Développement des Energies Renouvelables, CDER, 42415 Tipaza, Algeria

[c] Department of Electrical and Computer Engineering, University of Sharjah, United Arab Emirates

ARTICLE INFO

Article history:
Received 8 March 2015
Received in revised form 26 May 2016
Accepted 30 May 2016
Available online 31 May 2016

Keywords:
Doubly-fed induction generator (DFIG)
Current sensors fault (CSF)
Takagi-Sugeno (T-S) fuzzy modeling
Fault detection and isolation
Linear Matrix Inequalities (LMIs)

ABSTRACT

Diagnosis of current sensor faults (CSF) for doubly fed induction generators (DFIGs) is of paramount importance for the reliable power generation of DFIG-based wind turbines (WT). In this paper, a new scheme is developed for current sensors faults diagnosis in the stator of a DFIG-based WT. The nonlinear model of the DFIG is first transformed into an equivalent Takagi-Sugeno (T-S) fuzzy model. Secondly, using this model, a novel fault detection and isolation (FDI) algorithm is proposed. This algorithm is based on a bank of Luenberger observers for residuals generation combined with a new proposed residual vector. Furthermore, a new binary decision logic is used for CSF isolation. Stability analysis of the observer bank is analyzed using a Lyapunov theorem, which allows deriving sufficient stability conditions by solving a system of Linear Matrix Inequalities (LMIs). A simulation study is carried out to assess the performance and the effectiveness of the new FDI scheme.

1. Introduction

Nowadays, many modern wind farms use DFIG-based on WECS to allow variable rotor speed. This latter is one of the most habitually deployed large grid connected wind turbines [1]. In addition, this kind of generators has gained more interest due to its various advantages over other generators [2], such as full power control capability, high energy efficiency, and reduced inverter costs [3,4]. However, fault diagnosis of a DFIG constitutes a big challenge, because of its highly coupled nonlinear multivariable system, its fast dynamics, and its higher sensitivity to: disturbances, noise, sensor faults, and especially to voltage dips during grid faults [5].

Several techniques were developed in the scientific literature in order to approximate nonlinear systems by applying the so-called linear parameter varying (LPV) transformation that can be employed to represent nonlinear multivariable systems, for winding induction machine as presented in [6], and [7] for a twin rotor nonlinear system. Among these techniques, the sector nonlinearity approach proposed in [8,9] allows an exact representation of a nonlinear model by Takagi-Sugeno (T-S) model [10–14]. Furthermore, the obtained model precisely represents the original nonlinear system. However, to the author's knowledge, no work exists in the scientific literature on the T-S fuzzy modeling for current dynamics of DFIG (electrical model). Hence, we propose a new T-S fuzzy model representing the current dynamics in the operating Region (2) of a DFIG-based WT by applying the sector nonlinear approach.

During the past decade, the safety and reliability of DFIG in WECS have drawn the attention of many authors, since they have become an important component of global WECS, fault diagnosis of these machines is very essential to reduce the down time, minimize maintenance costs, and improve power quality. DFIG is subject to different kind of faults, such as open-phase failure, short-circuit, voltage sensors faults, and speed sensors faults [15]. In fact, certain faults may occur in one or more sensors, which may reduce the overall system performance and may cause instability. Further, DFIG sensor faults are among the major common problems in WECS [16]. Therefore, fault detection and isolation (FDI) of these sensors is of great importance since their failure can cause serious damage to the generator.

Several approaches concerned with the diagnosis of electrical faults in a DFIG were proposed [17–28]. Authors in [17] have

* Corresponding author at: Industrial and Electrical Systems Laboratory, Faculty of Electronics and Computer, University of Sciences and Technology Houari Boumediene, B. P. 32 El-Alia, 16111 Bab-Ezzouar, Algiers, Algeria. Unité de Développement des Equipements Solaires, UDES, Centre de Développement des Energies Renouvelables, CDER, 42415 Tipaza, Algeria.

E-mail address: samir_aut@yahoo.fr (S. Abdelmalek).

http://dx.doi.org/10.1016/j.measurement.2016.05.102
0263-2241/

Nomenclature

V_w	wind speed (m s^{-1})
ρ_1	air density (kg m^{-3})
R	rotor radius (m)
P_a	aerodynamic power (W)
T_a	aerodynamic torque (Nm)
T_g	driving torque of the generator (Nm)
λ	tip speed ratio
C_p	power coefficient
β_1	pitch angle
Ω_t	wind turbine rotor mechanical speed (rad s^{-1})
Ω_m	generator mechanical speed (rad s^{-1})
T_{em}	generator electromagnetic torque (Nm)
d, q	synchronous reference frame index
α, β	synchronous rotation reference frame index
s, (r)	stator (rotor) index
R	resistance (m)
L (L_m)	inductance (mutual inductance)
σ	leakage coefficient
ω_r (ω_s)	angular speed (synchronous speed)
g	slip
P	pole pair number
v (i)	voltage (current)
ϕ	Flux

Abbreviations

DFIG	doubly fed induction generator
DTC	Direct Torque Control
EMF	Electromotive Force
FTC	Fault Tolerant Control
FDI	Fault Detection and Isolation
FDD	Fault Detection and Diagnosis
FOC	Field Oriented Control
GSC	Grid Side Converter
LPV	Linear Parameter Varying
LMI	Linear Matrix Inequalities
IWECS	Isolated Wind Energy Conversion System
RSC	Rotor Side Converter
SEIG	Self-Excited Induction Generator
CSF	Current Sensors Fault
T-S	Takagi-Sugeno
TSR	Tip Speed Ratio
WECS	Wind Energy Conversion Systems

presented an online monitoring system based on mathematical logic algorithms for fast fault diagnosis in power generators. In [18], a new simple algorithm was developed based on an improved current observer to detect both soft and hard faults in current sensors for a DFIG. Diagnosis of electrical faults for a Self-Excited Induction Generator (SEIG) based on the use of a proposed FFT algorithm was presented in [19], the aim was to analysis the current sensors faults in the stator. In [20], a novel theoretical methodology was presented for the analysis of CSF in the rotor in a DFIG-based WT, while in [21] the authors reported a signal-based method for the faults detection and isolation of current and voltage sensors in the stator of a DFIG. In [22], an algorithm for detection and isolation CSF was developed in the rotor of a DFIG for WT applications. Also, in [23] an advanced technique was proposed for designing a fault diagnosis and FTC scheme for a WT using fuzzy logic modeling.

More recently, some model- based diagnosis methods of a DFIG were proposed for sensor faults [24–28]. In fact, the authors in [24] presented a bilinear observer that provides residuals to detect faults and to reconfigure the current sensors signal, in [25–28], the authors were focused on CSF detection and isolation, and control reconfiguration current signals of the DFIG. Two observers Luenberger are employed in parallel in order to generate structural residuals for detecting the faults in current sensors. Also, an algorithm for fault identification has been proposed to isolate the detected faults in the stator and the rotor. However, all of the cited model-based methods: (*i*) The authors considered only that DFIG operates at a fixed speed (only one speed) in order to avoid the complexity of the nonlinear model, while the power for a variable speed turbine changes as the wind's speed changes. (*ii*) The nonlinearity of the DFIG model was not treated up to now. (*iii*) The problem of simultaneous CSF were not fully investigates yet. Therefore, the purpose of the proposed work is to deal with the above mentioned problems. The main contributions of this paper are summarized as follows:

(i) Nonlinear state space model of the DFIG is developed,
(ii) A T-S fuzzy model in the operating Region (2) of the DFIG-based WT is proposed in order to solve the nonlinearity problem of the DFIG,
(iii) A novel FDI scheme is designed, which exhibits single as well as multiple and simultaneous CSF detection and isolation,
(iv) This scheme is simple and can be easily implemented in real time.

The rest of the paper is organized as follows: Section 2 presents the modeling of DFIG-based WT. Section 3 introduces the DFIG dynamics model and its linearized model using the T-S fuzzy representation. Section 4 focuses on the proposed fault diagnosis and isolation of the CSF in the stator of a DFIG. Section 5 presents simulation results to validate and demonstrate the effectiveness of the proposed FDI scheme. Finally, Section 6 gives a conclusion and further research work.

2. Modeling of DFIG-based WT

The DFIG-based WT under study with the proposed current sensors FDI scheme are shown in Fig. 1. The stator winding of DFIG is directly connected to the grid, while the rotor is connected via a back-to-back converter. These converters are inserted between the rotor of the DFIG and the grid to permit power exchange between the grid and the generator. So, the Grid Side Converter (GSC) controls the DC-link voltage and reactive power, and the Rotor Side Converter (RSC) operates to control the DFIG independently of active and reactive powers, more details are given in [29].

2.1. Wind turbine model

The aerodynamic power extracted from the wind is given by [29,30]:

$$P_a = \frac{1}{2} C_p(\lambda, \beta) \rho_1 \pi R^2 V_w^3 \tag{1}$$

The tip speed ratio is described as follows:

$$\lambda = \frac{R\Omega_t}{V_w} \tag{2}$$

The turbine torque is defined as the ratio of the output power to the shaft speed and is given by the following relation: