Renewable Energy 88 (2016) 40–50

Contents lists available at ScienceDirect

Renewable Energy

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

# Design and real time implementation of type-2 fuzzy vector control for DFIG based wind generators

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ARTICLE INFO

*Article history:*
Received 17 May 2015
Received in revised form
22 October 2015
Accepted 2 November 2015
Available online 19 November 2015

*Keywords:*
DFIG
Grid integration
Hardware in loop
Interval Type-2 fuzzy logic control
RTDS
Type-1 FLC

ABSTRACT

Doubly fed induction generator is very sensitive to voltage variations in the grid, which pose limitation for wind power plants during the grid integrated operation. Handling the uncertainity in wind speed and grid faults is a major challenge to fulfill the modern grid code requirements. This paper proposes a new control strategy for Rotor side converter using Interval type-2 fuzzy sets which can model and handle uncertainties in the system parameters. The presence of third dimension in the membership function, offers an additional degree of freedom in the design of the controller to counter the effects of fluctuations in wind speed and low voltage during severe grid fault conditions. A 2 MW DFIG connected to the grid is modelled in simulation software RSCAD and interfaced with Real time digital simulator (RTDS) to perform the simulations in real-time. The RTDS platform is considered by many research laboratories as real-time testing module for controller prototyping and also for hardware in the loop (HIL) applications. The controller performance is evaluated in HIL configuration, by performing the real-time simulations under various parameter uncertainties. The proposed controller can improve the low voltage ride through capability of DFIG compared to that of PI and type-1 fuzzy controller.

## 1. Introduction

In response to the increasing energy demands and environmental pollution the need for alternate energy sources, forcing energy researchers to focus on the renewable energy field. In many countries, wind energy has become a major source of Renewable energy generation due to the many advantages [1,2]. In the preliminary days, wind energy conversion systems with fixed speed induction generators have contributed a significant portion in the renewable share of energy production. Recently, the use of doubly fed induction generators in wind power generation has received an increasing attention, because of its ability to control active and reactive powers and also support variable speed operation. Other advantages of the doubly fed induction generator (DFIG) topology are the converters required are rated at only 20%–30% of the generator rated power, efficient power capture and reduced mechanical stresses [3].

The schematic diagram of wind turbine coupled to DFIG is shown in Fig. 1. The rotor side converter controls the rotor voltages to track the reference power inputs and the grid side converter is used for maintaining the dc link voltage. The drawback of the DFIG based wind turbine is that, it is very sensitive to voltage variations, which are caused by grid faults and other load disturbances. The network faults cause a voltage dip at the connection point, which leads to an increased current in the stator windings. The magnetic coupling between stator and rotor reflects the stator current in the rotor windings which leads to damage of the rotor side converter and DC link capacitor. In general, for the safety of the converter system, the wind generators have been designed to get disconnected fast from the grid if a grid fault causes a large voltage drop. However, the sudden disconnection during faults, poses serious challenges to reliable and stable operation of the grid, when the penetration levels of wind farms are very high.

Therefore, for reliable grid integration of wind energy sources, the wind power generators must be able to withstand network disturbances that are successfully eliminated. The recent grid codes also demand low voltage ride through capability from wind turbines to export power to the grid. In the existing literature distinct control schemes are suggested for grid integrated operation of variable speed wind generators and most of those schemes are based on conventional PI controllers [4–7]. In Refs. [8,9], the converters are controlled by employing direct feedback of torque and

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http://dx.doi.org/10.1016/j.renene.2015.11.006
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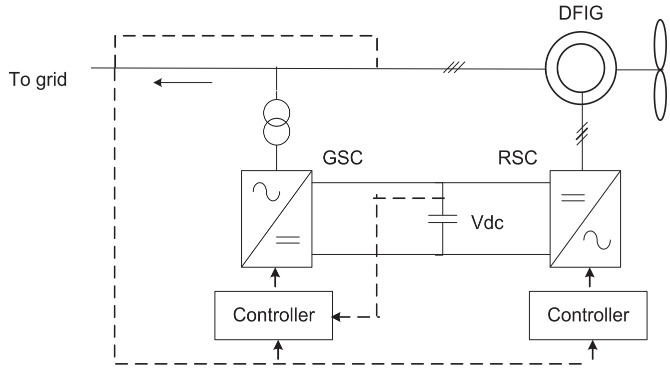

**Fig. 1.** Schematic diagram of the DFIG and converters.

power in the cascaded control loops for enhancing the reliability of grid operation. The problem of reactive power control during grid faults is addressed using different energy storage devices and by varying the number of control loop parameters [10]. Application of FACTS devices for enhancing the LVRT capability has been investigated in literature [11]. Most of these control schemes are based on either stator flux or voltage oriented control and uses conventional PI controllers accessing, references from the stator and rotor parameters. However, in all the above schemes, tuning the PI gains is a challenging task when the plant is nonlinear and parameters are uncertain, also requires the knowledge of dynamic modelling and behaviour of the DFIG.

Recent reviewing studies on DFIG shows that type-1 fuzzy logic controllers presents a better performance than the traditional PI controllers in terms of tracking terminal voltage, active and reactive power during network disturbances [12,13]. In general, the rules and membership functions of FLC are chosen based on experience and knowledge of experts. However, the type-1 fuzzy sets cannot take account of uncertainty in membership functions and rules which vary from case to case.

Acknowledging the limitations of conventional PI and type-1fuzzy controllers, the authors have recommended a new control strategy with type-2 fuzzy sets which can address the above issues.Type-2 fuzzy logic sets (FLS) are characterized by a three dimensional fuzzy membership function (MF) that includes a footprint of uncertainty (FOU). The FOU and the third dimension of MFs provide an additional degree of freedom in the controller design that makes it possible to directly model and handle parameter uncertainties caused by network disturbances. The above special features of the type-2 fuzzy sets can avoid frequent retuning of the controller parameters when there is an uncertainty in the operating conditions.

In this work, at first, mathematical modelling of the DFIG is derived. The system model shown in Fig. 1 is designed using software package RSCAD and interfaced with RTDS for real time simulations. Afterwards, the type-2 fuzzy logic controller is proposed for the rotor side converter (RSC) of DFIG. To evaluate the feasibility of the controller for real-time applications, at first, the reference error signals in RSCAD model are converted to analogue signals as controller input, then processed through type-2 controller with HIL configuration, and fed back to the RTDS as an actuating input. The performance of the type-2 controller is compared with that of PI and type-1 controller for a three phase short circuit fault. Furthermore, the validity of the proposed controller for parameter uncertainties is confirmed by performing the simulations for an unbalanced fault and variable wind speed conditions.

The rest of the article is organized as follows: Section 2 describes how the mathematical modelling of the DFIG is developed. Section 3 and 4 introduces the Type-2 fuzzy logic systems and controller design steps. Simulation results are discussed in Section 5 and the contribution of this work is concluded in Section 6.

## 2. Modelling of DFIG

The mathematical modelling equations of DFIG, expressed in the space vector form, referring to stationary reference frame, results in Refs. [14,15].

$$\begin{cases} v_{ds} = -R_s I_{ds} - \omega_s \lambda_{qs} + \dfrac{d\lambda_{ds}}{dt} \\ v_{qs} = -R_s I_{qs} + \omega_s \lambda_{ds} + \dfrac{d\lambda_{qs}}{dt} \end{cases} \tag{1}$$

$$\begin{cases} v_{dr} = R_r I_{dr} - (\omega_s - \omega_r)\lambda_{qr} + \dfrac{d\lambda_{dr}}{dt} \\ v_{qr} = R_r I_{dr} + (\omega_s - \omega_r)\lambda_{dr} + \dfrac{d\lambda_{qr}}{dt} \end{cases} \tag{2}$$

where, $v_s$ and $i_s$ are the stator voltages and currents; $R_s$ and $R_r$ are the stator and rotor resistances; $\omega_s$ and $\omega_r$ are the stator and rotor electrical frequencies; $\lambda_s$ and $\lambda_r$ are the stator and rotor flux linkages, respectively. The subscripts $d$ and $q$ denote the direct and quadrature axis components of the reference frame.

The flux linkage in (1) and (2) can be expressed as

$$\begin{cases} \lambda_{ds} = -L_{ss} I_{ds} + L_m i_{dr} \\ \lambda_{qs} = -L_{ss} I_{qs} + L_m i_{qr} \end{cases} \tag{3}$$

$$\begin{cases} \lambda_{dr} = L_{rr} I_{dr} - L_m i_{ds} \\ \lambda_{qr} = L_{rr} I_{qr} - L_m i_{qs} \end{cases} \tag{4}$$

where $L_{ss}$ , $L_{rr}$, and $L_m$ are the stator, rotor, and mutual inductances respectively. By neglecting the stator transients, the machine model is represented by a simple voltage source behind a transient reactance for the sake of power system stability studies. Using the equations (1)–(4), the new relation between stator voltages and currents with the voltage behind a transient reactance can be derived as

$$\begin{cases} v_{ds} = -R_s I_{ds} + X' \lambda_{qs} + e_d \\ v_{qs} = -R_s I_{qs} - X' \lambda_{ds} + e_q \end{cases} \tag{5}$$

$$\begin{cases} \dfrac{de_d}{dt} = -\dfrac{1}{T_o}\left[e_d - \left(X - X'\right) i_{qs}\right] + s\omega_s e_q - \omega_s \dfrac{L_m}{L_{rr}} v_{qr} \\ \dfrac{de_q}{dt} = -\dfrac{1}{T_o}\left[e_q - \left(X - X'\right) i_{ds}\right] + s\omega_s e_d - \omega_s \dfrac{L_m}{L_{rr}} v_{dr} \end{cases} \tag{6}$$

Here, $X$ is the reactance of open circuit, represented by $\omega_s L_{ss}$, $X'$ is the blocked rotor reactance, represented by $\omega_s (L_{ss} - L_m^2 / L_{rr})$ , $e_d$ and $e_q$ are the direct and quadrature axis voltages behind transient reactance respectively and $T_o$ is the open circuit time constant of the rotor, given by $L_{rr}/R_r$ .

The swing equation describes the dynamic behaviour of the machine which provides state variables for rotor parameters. To analyse the mechanical behaviour of the system, it is necessary to describe the relation of electrical voltages and currents with swing equation. It is derived as

$$\frac{d\omega_r}{dt} = \frac{1}{J}(T_m - T_e) \tag{7}$$