Renewable Energy 107 (2017) 181–193

Contents lists available at ScienceDirect

Renewable Energy

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

Power control for wind power generation and current harmonic filtering with doubly fed induction generator

Adson B. Moreira [a, b, *], Tarcio A.S. Barros [b], Vanessa S.C. Teixeira [a, b], Ernesto Ruppert [b]

[a] *Federal University of Ceará, Campus de Sobral - UFC, Brazil*
[b] *University of Campinas - UNICAMP, Brazil*

A R T I C L E I N F O

Article history:
Received 12 July 2016
Received in revised form
5 January 2017
Accepted 27 January 2017
Available online 31 January 2017

Keywords:
Active power filter
Back-to-back converter
Controllers design
DFIG
Harmonic filter
Power generation

A B S T R A C T

This paper describes a wind power system which controls the active and reactive generated powers as well as it performs the function of filtering the harmonic components of the grid currents. From the grid side converter, the harmonic filtering is achieved by an algorithm proposed by compensation of harmonics. This technique ensures the improvement of power quality. The machine side converter controls the active and reactive powers that are delivered to the electric grid by the stator flux oriented control. The design methodology of the controllers used is presented. This paper is distinguished by three key contributions. The first contribution of this article is the tutorial character, it should assist in the development of future work. The second is the analysis of the harmonic filtering behavior for some operating points of the DFIG/APF system. The third is the application of the precise model of the DC link voltage dynamics, allowing verifying the stability of the system control for each DFIG/APF (active power filter) operating point. Simulation and experimental results confirm the effectiveness of the proposed research.

1. Introduction

Energy quality is an important aspect not only of wind power installation, but of all that use electronic power converters connected to the grid. The increase in applications of electronic devices such as variable speed drives, computer power source, among other things, they result in harmonic injection of current on the grid. This harmonic pollution distorts voltage and current waveforms in the grid with the presence of harmonic components, providing low power factor, possible warming, reactive power fluctuating, flicker, swell, among others.

Active power filter is a solution for reducing harmonics of electric current. The active power filter (APF) detects the harmonic electric current of nonlinear load and injects a compensation of electrical current to mitigate the harmonic components that go into the grid [1].

Applications on APF have been performed by means of changes in DFIG (Doubly Fed Induction Generator) converter control, which can improve the quality of electric power supplied and compensate the most harmonic currents [1–7]. Reference [2] proposes a control strategy by rotor side converter (RSC) that achieves reactive compensation and active filtering of harmonics grid currents of $5^{th.}$ and $7^{th.}$ orders. While [3] shows a similar system in Ref. [2], however the system manages the priority between the maximum power point tracking (MPPT) and improvement at power quality.

The works [1,4–6] propose a system that controls the active and reactive powers and performs compensation of harmonic current, by modifying the RSC control using the sliding mode controller type. In these studies [1,6], the current references for harmonic compensation are determined from the load current, calculated by the instantaneous power PQ theory [8].

Paper [4] proposes a wind power system and the mitigation of grid harmonic currents, using current controllers by hysteresis with constant switching frequency. It was obtained THD bigger than in Ref. [5], that used current controller by hysteresis with variable switching frequency. The authors, in Ref. [7], show the DFIG running with control delivery power to the electric grid, by using sensorless vector control, MPPT and mitigating grid harmonics currents.

Research on mitigation of grid harmonic currents from RSC control [1–7], using the harmonic currents injection in DFIG, and the electric machine is not designed for it, which increases losses and leads to a not adequate operation, which can cause a reduction

* Corresponding author. Federal University of Ceará, Campus de Sobral - UFC, Brazil.
E-mail address: adsonbmoreira@gmail.com (A.B. Moreira).

http://dx.doi.org/10.1016/j.renene.2017.01.059
0960-1481/

in its useful life.

Recently, other studies have implemented the current harmonic compensation based on grid side converter (GSC) [9–11]. In Ref. [10], the currents reference for harmonic current compensation are determined from the load current, calculated by the instantaneous power PQ theory [8]. In Refs. [10,11], the reference currents are determined using synchronous reference Frame (SRF) theory is based on the transformation of currents in synchronously rotating *dq* frame [12].

In the literature, most of the studies addressing the simulation results. Few studies present the experimental results [7,11]. The authors in Ref. [7] implement the functions of the system DFIG/APF using an experimental setup developed with microcontroller to include the filtering function from RSC control. However, the authors did not determine the THD of grid current, making the strategy analysis difficult. In Ref. [11], the operation of DFIG/APF system is implemented on the dSPACE system (DS1103). It is sold on the market and has a high cost. The authors present the simulation and experimental results of THD of grid current before and after filtering through GSC control, using a control technique with current controllers hysteresis.

The researches do not discuss the behavior filtering for the operation of the DFIG with grid current harmonics filtering in the literature, either for RSC control or for GSC control.

In this research, we propose a control strategy for a wind-power system with DFIG, shown in Fig. 1. Besides the power control, the proposed system improves the energy quality by using the converter connected to the grid to perform active filtering in the point of common coupling (PCC) of the electric grid in the presence of three-phase full bridge rectifier with L_{iL} feeding a resistive load. The control of active and reactive powers of the generator is accomplished through field vector control by stator. The active filtering function is performed by the grid side converter, using dq reference frame. The power control and filtering function occur simultaneously. In harmonic identification, the extraction of the fundamental component is based on the SRF theory. Also, this paper presents a design methodology of the controllers employed in these techniques. The proposed control of DFIG/APF improves the electric power quality in the electric grid. Simulation and experimental results are presented to demonstrate the idea of this study.

The paper contributions are: (1) the tutorial character, assisting in the development of future researches; (2) the analysis of the harmonic filtering behavior for some operating points of the DFIG/APF system; (3) the application of the precise model of the DC link voltage dynamics, allowing evaluating the stability of the system control for each DFIG/APF operating point.

The paper is organized as follows: Section 2 describes the studied the power control of the generator. Section 3 contains the technique proposed of harmonic current filtering. Section 4 and 5 contain the design methodology of the controllers. Section 6 shows simulation results and Section 7 shows experimental verifications. Section 8 presents stability analysis of the system and Section 9 presents feasible application of the wind turbine converter in range of MVA up to 15 kHz. Conclusions are summarized in Section 10.

2. Power control of the doubly fed induction generator - DFIG

The generator is controlled in the reference of synchronous rotation with the stator flux directed along the axis d. Thus, the active and the reactive powers of the stator are decoupled. The mathematical model of a DFIG in the *d-q* reference frame is described from (1) to (6) [13],

$$v_{sd} = r_s i_{sd} + \frac{d\psi_{sd}}{dt} - \omega_e \psi_{sq}$$
$$v_{sq} = r_s i_{sq} + \frac{d\psi_{sq}}{dt} + \omega_e \psi_{sd} \quad (1)$$

$$v_{rd} = r_r i_{rd} + \frac{d\psi_{rd}}{dt} - \omega_{sl} \psi_{rq}$$
$$v_{rq} = r_r i_{rq} + \frac{d\psi_{rq}}{dt} + \omega_{sl} \psi_{rd} \quad (2)$$

$$\omega_{sl} = \omega_e - \omega_r \quad (3)$$

$$\psi_{sd} = L_s i_{sd} + L_m i_{rd}$$
$$\psi_{sq} = L_s i_{sq} + L_m i_{rq} \quad (4)$$

$$\psi_{rd} = L_r i_{rd} + L_m i_{sd}$$
$$\psi_{rq} = L_r i_{rq} + L_m i_{sq} \quad (5)$$

$$T_e = 3\frac{p}{2} L_m (i_{sq} i_{rd} - i_{sd} i_{rq}) \quad (6)$$

where v_{sd}, v_{sq} and v_{rd}, v_{rq} are stator and rotor voltages in the *d-q* reference frame, r_s and r_r are the stator and rotor per phase electrical resistances, i_{sd}, i_{sq} and i_{rd}, i_{rq} are stator and rotor currents in the *d-q* reference frame, ψ_{sd}, ψ_{sq} and ψ_{rd}, ψ_{rq} are stator and rotor fluxes in the *d-q* reference frame, L_s, L_r and L_m are stator, rotor and magnetizing per phase inductances, ω_e and ω_r are the synchronous and rotor speeds, T_e is the electromagnetic torque, and p is the number of poles.

The speed generator is given by (7):

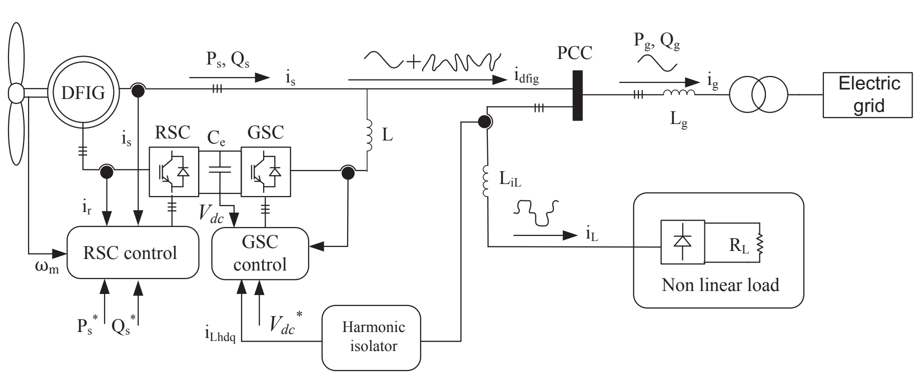

Fig. 1. Proposed DFIG/APF operation diagram.