

Variable speed DFIG wind energy system for power generation and harmonic current mitigation

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ABSTRACT

This paper presents a novel approach for simultaneous power generation and harmonic current mitigation using variable speed WECS with DFIG. A new control strategy is proposed to upgrade the DFIG control to achieve simultaneously a green active and reactive power source with active filtering capability. To ensure high filtering performance, we studied an improved harmonic isolator in the time-domain, based on a new high selectivity filter developed in our laboratory. We examined two solutions for harmonic current mitigation: first, by compensating the whole harmonic component of the grid currents or second, by selective isolation of the predominant harmonic currents to ensure active filtering of the 5th and 7th harmonics. Simulation results for a 3 MW WECS with DFIG confirm the effectiveness and the performance of the two proposed approaches.

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1. Introduction

Wind energy is becoming one of the most important renewable energy sources. Recently, power converter control has mostly been studied and developed for WECS integration in the electrical grid. The use of power electronic converters allows variable speed operation of the wind turbine where the WECS extracts maximum power from the turbine.

Although WECS uses an electric generator that could be coupled directly to the electrical grid, the power electronics interface is commonly used nowadays. One can take advantage of the power electronic interface to provide some of the ancillary services such as harmonic current mitigation, simultaneously with power generation [1]. These services are provided in addition to active power

generation, reactive absorption and injection to achieve voltage control, regulation and correction to meet load variations [2–4].

Electric utility grid systems cannot accept further connection of new generation plants without strict conditions of power quality. In fact, IEEE Standard 1547-2003 (Standard for Interconnecting Distributed Resources with Electric Power Systems) is under final construction [5]. Power quality becomes a major aspect in integrating WECS to grids. Furthermore, grids are now dealing with a continuous increase of directly connected non-linear loads such as power electronics converters and large AC drives. As far as the authors know, only a few groups of researchers have addressed the issue of making use of the built-in WECS converters to improve grid power quality and achieve harmonic current mitigation. However, active power filtering function can also be achieved thanks to the WECS power electronics interface. Barbosa et al. proposed a control strategy for grid connected DC–AC converters with load power factor correction [6]. Macken et al. studied the compensation of distorted currents through multiple converter-interfaced renewable generation units [7]. Recently, Abolhassani et al. presented a sensorless field oriented control of an integrated electric alternator capable of controlling the amount of harmonic compensation [8]. More recently, Jain and Ranganathan studied a wound rotor induction generator with sensorless control and integrated active filter for feeding non-linear loads in a stand-alone grid [9]. In the DFIG case, one can also think of using a suited rotor side control to cancel the most significant and troublesome harmonic currents of the utility grid.

Abbreviations: AC, alternating current; DC, direct current; DFIG, doubly fed induction generator; FFT, fast Fourier transform; GSC, grid side converter; HSF, high selectivity filter; IGBT, insulated gate bipolar transistor; MPPT, maximum power point tracking; PCC, point common of coupling; PLL, phase locked loop; PWM, pulse width modulation; RSC, rotor side converter; THD, total harmonic distortion; WECS, wind energy conversion system.

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Nomenclature	
$V_{ds}, V_{qs}, V_{dr}, V_{qr}$	stator and rotor voltages in the (d-q) reference frame (V)
$I_{ds}, I_{qs}, I_{dr}, I_{qr}$	stator and rotor currents in the (d-q) reference frame (A)
θ_s, θ_r	stator and rotor field angles (rad)
$\varphi_{ds}, \varphi_{qs}, \varphi_{dr}, \varphi_{qr}$	stator and rotor flux in the (d-q) reference frame (Wb)
R_s, R_r	stator and rotor resistances (Ω)
L_s, L_r	cyclic stator and rotor inductances (H)
M	cyclic mutual inductance (H)
V_s	RMS value of the grid voltage (V)
ω_s	grid pulsation (rad/s)

In this paper, we study simultaneous power generation and harmonic current mitigation using variable speed WECS with DFIG. Since rotor currents are controlled, it is possible to offer other services than active power supply, i.e. active filtering. In next section, we will present the operating principle. Harmonic current loops are added to the RSC current control so that harmonic current components can be injected into the grid at the PCC. These currents compensate the harmonics of the non-linear load and the current drawn from the AC grid becomes quasi-sinusoidal. Thus, to implement active filtering capability, changes must be made to the rotor side current controller only. This control is achieved by using a three-phase modulated hysteresis current controller to satisfy a fixed switching frequency for the IGBTs. In Section 3, the DFIG rotor side control is described and the active and reactive power control is examined. Special focus is made on harmonic current mitigation detailed in Section 4 where harmonic current isolation is considered and harmonic current loops studied. Simulation results are presented and performances are analyzed in the last section.

2. Operation principle

The electrical WECS studied in this paper uses a DFIG, one of the most used wind turbine generators in recently built wind farms [10]. For a DFIG, both stator and rotor terminals are available for power flow (Fig. 1). The stator is directly connected to the grid. A DC common bus for both bi-directional converters is used. DFIG is the only variable speed wind turbine generator that does not require a full-size rated rotor side power converter, typically rated about 30% of the total power system. Consequently, the power devices switching frequency can be higher than for other WECS topologies.

With the new control presented in this paper, the WECS in Fig. 1 is simultaneously capable of capturing maximum energy from fluctuating wind, controlling the active and reactive powers and compensating the grid harmonic currents. A suited dynamic excitation of the DFIG wound rotor side circuitry is made by the current regulated voltage source IGBT converter. This control is based on an "indirect" field oriented control for which both fundamental and harmonic currents are controlled. To achieve harmonic current

mitigation, the harmonic currents absorbed by the non-linear load connected to the PCC are measured. It is well known that those currents drawn from the grid are rich in harmonics with the orders of $(6k \pm 1)$, that is 5, 7, 11, ... To extract one particular current harmonic or the whole harmonic component of the measured load currents, we used a high selectivity harmonic isolator developed in our laboratory and based on HSF. Consequently, one can choose for compensating a particular harmonic current, several or all harmonics. In the following, we study the simultaneous compensation of the 5th and 7th harmonic currents (the most dominant ones) and the compensation of the whole harmonic component.

The control of the RSC mainly manages the DFIG speed Ω , the stator reactive power Q_s and the harmonic current mitigation while the control of the GSC manages the active power flow between the DC bus and the grid.

3. Vector control of the DFIG

3.1. Modeling of the DFIG

We used the classical modelization of the induction generator in the (d-q) Park reference frame [11,12]. The voltages and flux equations of the DFIG are:

$$\begin{cases} V_{ds} = R_s I_{ds} + \frac{d}{dt} \varphi_{ds} - \dot{\theta}_s \varphi_{qs} \\ V_{qs} = R_s I_{qs} + \frac{d}{dt} \varphi_{qs} + \dot{\theta}_s \varphi_{ds} \\ V_{dr} = R_r I_{dr} + \frac{d}{dt} \varphi_{dr} - \dot{\theta}_r \varphi_{qr} \\ V_{qr} = R_r I_{qr} + \frac{d}{dt} \varphi_{qr} + \dot{\theta}_r \varphi_{dr} \end{cases} \quad \begin{cases} \varphi_{ds} = L_s I_{ds} + M I_{dr} \\ \varphi_{qs} = L_s I_{qs} + M I_{qr} \\ \varphi_{dr} = L_r I_{dr} + M I_{ds} \\ \varphi_{qr} = L_r I_{qr} + M I_{qs} \end{cases} \quad (1)$$

The electromagnetic torque is expressed by:

$$T_{em} = p(\varphi_{ds} I_{qs} - \varphi_{qs} I_{ds}) \quad (2)$$

And the electro-mechanical equation is:

$$T_{em} - T_r = J \frac{d\Omega}{dt} + f\Omega \quad (3)$$

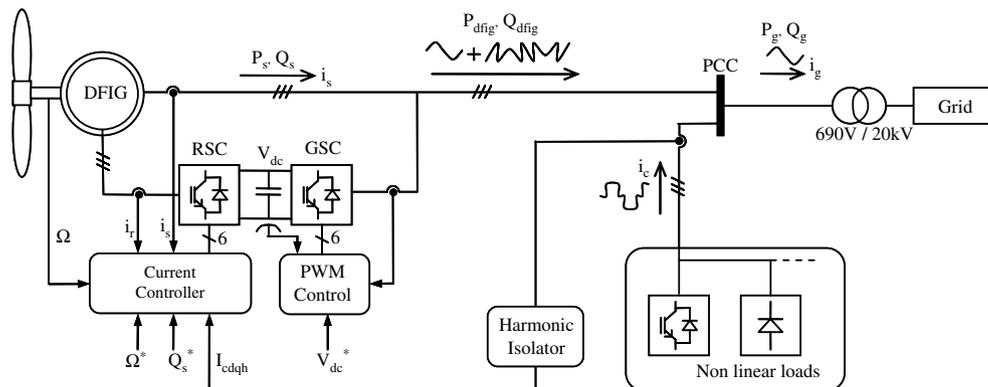


Fig. 1. Principle of simultaneous power generation and harmonic current mitigation.

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