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Using a DFIG based wind turbine for grid current harmonics filtering

M. Kesraoui [a,*], A. Chaib [a], A. Meziane [b], A. Boulezaz [b]

[a] Laboratoire d'Automatique Appliquée, Université M'Hamed Bougara, Boumerdes, Algeria
[b] IGEE, Université M'hamed Bougara, Boumerdes, Algeria

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ABSTRACT

In this paper a variable speed doubly fed induction generator (DFIG) based wind energy conversion system (WECS) is employed for simultaneous power generation and grid harmonic current filtering. WECS active and reactive powers are controlled using vector control strategy. An improved harmonic isolator in the time domain, based on a new high selective signal detector or filter (HSF) has been used. Since the polluting currents contain direct and reverse harmonics of ($6k \pm 1$) order, the HSF can be used to isolate one particular harmonic or the whole harmonic components. The compensation technique of the whole harmonic components of the grid current is chosen. The rotor side converter (RSC) control structure has been modified in order to include the filtering task. Simulation for a 3 MW WECS with DFIG at two different wind speeds (8 m/s and 12 m/s) has been performed. Results showed that in addition to power generation, grid current harmonics filtering action is achieved by the WECS and a decrease by 4% of the total harmonic distortion is obtained.

1. Introduction

Grids are now dealing with a continuous increase of directly connected nonlinear loads such as power electronics converters and large AC drives, that loads inject harmonic currents in the network, which may potentially create voltage and current distortion problems. Nowadays, the most widely used wind power systems in wind farms is based on doubly fed induction generator (DFIG) due to noticeable advantages: the variable speed generation, decoupled control of active and reactive powers, reduction of mechanical stresses and acoustic noise, smaller converter power ratings and the improvement of the power quality [1,2]. The DFIG, even if it presents a less robust wound rotor and slip rings allows operation at variable speed of 30% around the synchronous speed. The control of rotor variables makes it possible to control the slip energy. The stator is directly connected to the network and the rotor is then dimensioned to be crossed by one third of the machine nominal power. For over synchronous speeds, the machine can also produce energy from the rotor to the grid up to 0.3 times the nominal power. In the greatest case, the machine can output 1.3 times its nominal power [6]. The wind power system can be used simultaneously to inject electric power into the grid and filter the existing current harmonics. Few authors have addressed this topic. Gaillard et al. proposed a new time domain harmonic detection method, based on a high selectivity filter (HSF) and requiring only current measurements [3]. A nonlinear hysteresis controller is also used. Soares et al. used instantaneous power p–q theory that consists of extracting harmonics from the load currents by the computation of instantaneous power p–q. But it does not allow selective detection of a particular harmonic and it requires both voltage and current measurements [4]. Papathanassiou and Papadopoulos used a high pass Filter (HPF) and/or low pass Filter (LPF) for reference harmonic currents generation [5]. In this paper a fixed frequency PWM current controller is used instead of a nonlinear hysteresis one. The studied system is presented in Fig. 1. In addition to the vector control power loop, it contains a harmonic measurement loop. First the harmonic currents drawn by the nonlinear load connected to the PCC and which are of orders 5, 7, 11, etc. are measured. A high selectivity filter HSF is then used to separate the whole harmonic components from the fundamental one. In the next section the power generation task of the WECS is first presented and simulated. Then the filtering capability is investigated and simulation results for two wind profiles are presented and improvements in grid current signal quality by a decrease of the total harmonics distortion are indicated.

2. Wind turbine for power generation

2.1. Wind power system

For the DFIG, the dynamic voltages of the stator (V_{ds} and V_{qs}) and those of the rotor (V_{dr} and V_{qr}) in the general d–q reference frame are respectively given by [6]:

* Corresponding author.
E-mail address: mkesraoui@umbb.dz (M. Kesraoui).

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Nomenclature

f	friction coefficient	R_r	per phase rotor resistance
v_{ds}, i_{ds}	stator direct voltage and current	R_s	per phase stator resistance
v_{qs}, i_{qs}	stator quadrate voltage and current	V_s	stator RMS voltage
v_{dr}, i_{dr}	rotor direct voltage and current	J	inertia of the induction machine
v_{qr}, i_{qr}	rotor quadrate voltage and current	P	pole pairs
ψ_{ds}, ψ_{qs}	stator direct and quadrate flux	p	operator d/dt
ψ_{dr}, ψ_{qr}	rotor direct and quadrate flux	ω_r	rotor speed
t_m	mechanical torque	ω_s	synchronous speed
t_e	electromagnetique torque	ω_m	mechanical speed
V_{dc}	DC link voltage	θs	stator field angle
M	mutual inductance	θr	rotor field angle
Ls	stator inductance per phase		
Lr	rotor inductance per phase		

$$\begin{cases} V_{ds} = R_s I_{ds} + p\psi_{ds} - \omega_s \psi_{qs} \\ V_{qs} = R_s I_{qs} + p\psi_{qs} + \omega_s \psi_{ds} \\ V_{dr} = R_r I_{dr} + p\psi_{dr} - \omega_r \psi_{qr} \\ V_{qr} = R_s I_{qr} + p\psi_{qr} + \omega_r \psi_{dr} \end{cases} \quad (1)$$

The stator and rotor d–q fluxes, ψ_{ds}, ψ_{qs}, ψ_{dr} and ψ_{qr}, are related to corresponding d–q currents, I_{ds}, I_{qs}, I_{dr} and I_{qr} by:

$$\begin{cases} \psi_{ds} = L_s I_{ds} + M I_{dr} \\ \psi_{qs} = L_s I_{qs} + M I_{qr} \\ \psi_{dr} = L_r I_{dr} + M I_{ds} \\ \psi_{qr} = L_r I_{qr} + M I_{qs} \end{cases} \quad (2)$$

And the electromagnetic torque t_e is defined by:

$$t_e = P\frac{M}{L_s}(\psi_{qs} I_{dr} - \psi_{ds} I_{qr}) \quad (3)$$

where L_s, L_r, M, R_s and R_r are the stator and rotor phase inductances, magnetizing inductances and resistances respectively. The stator field speed is $\boldsymbol{\omega_s}$. The generator mechanical and electromagnetic torques (t_m and t_e) are related, if the viscous friction coefficient $\mathbf{f_{visc}}$ is taken into account, as follows:

$$t_m = t_e + J\omega_r + f_{visc}\theta_r \quad (4)$$

Fixing a link for the reference frame, for example the flux vector of the stator linked to the d-axis, that is:

$$\psi_{ds} = \psi_s \text{ and } \psi_{qs} = 0 \quad (5)$$

The electromagnetic torque becomes:

$$t_e = -p\frac{M}{L_s}\psi_s I_{qr} \quad (6)$$

Therefore, the torque and hence the active power will depend only on the q-axis rotor current component $\mathbf{I_{qr}}$. If the stator resistance $\mathbf{R_s}$ is neglected, a realistic approximation for medium power machines used in wind energy [7], and applying Eq. (5) that is:

$$V_{ds} = 0 \text{ and } V_{qs} = V_s = \omega_s \psi_s \quad (7)$$

where $\mathbf{V_s}$ is the stator RMS voltage. Using, Eq. (6), the stator active (P) and reactive (Q) powers, expressed only by the rotor currents are given by:

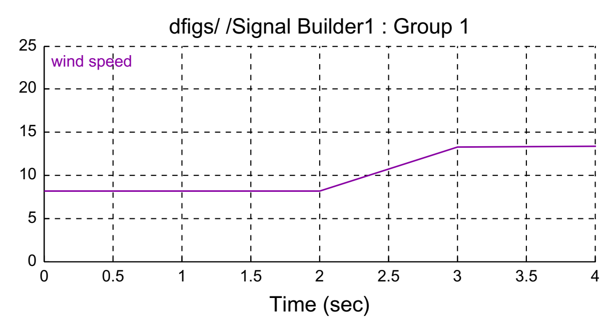

Fig. 2. Wind speed [m/s].

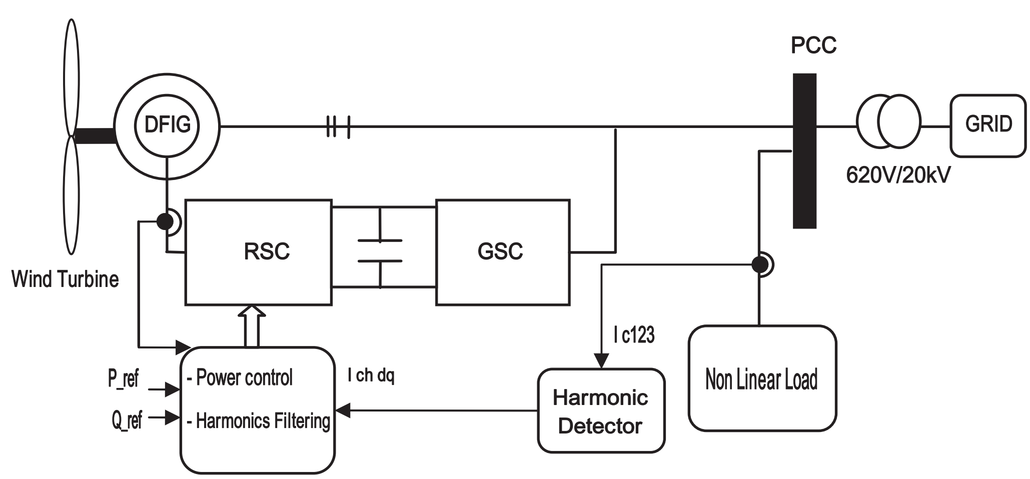

Fig. 1. DFIG based WECS with current harmonics filtering capability.