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Control of a wind energy conversion system equipped by a DFIG for active power generation and power quality improvement

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ABSTRACT

The aim of this paper is to improve the reactive power compensation and active filtering capability of a Wind Energy Conversion System (WECS). The proposed algorithm is applied to a Doubly Fed Induction Generator (DFIG) with a stator directly connected to the grid and a rotor connected to the grid through a back-to-back AC-DC-AC PWM converter. The control strategy of the Rotor Side Converter (RSC) aims, at first, to extract a maximum of power under fluctuating wind speed. Then, depending on the rate power of the RSC, the power quality can be improved by compensating the reactive power and the grid harmonics current due to nonlinear loads. Hence, the RSC is controlled in order to manage the WECS function's priorities, between production of the maximum active power captured from the wind, and power quality improvement. The main goal of the proposed control strategy is to operate the RSC at its full capacity, without any over-rating, in terms of reactive power compensation and active filtering capability. Elsewhere, the Grid Side Converter (GSC) is controlled in such a way to guarantee a smooth DC voltage and ensure sinusoidal current in the grid side. Simulation results show that the wind turbine can operate at its optimum power point for a wide range of wind speed and power quality can be improved. It has been shown also that the proposed strategy allows an operating full capacity of the RSC in terms of reactive power compensation and active filtering.

1. Introduction

Due to its clean and renewable nature, wind energy is becoming one of the important renewable sources of energy in the world. Through its collaboration with other renewable sources of energy, such as solar energy, the world energy crises can be solved in the future [1]. Comparatively with the past and due to the progressive integration of the nonlinear loads in the grid, the principal role of a WECS is not only to capture the maximum power from the wind but, also, to improve the quality of power [1], Consequently, with the development of the wind farms which are integrated in the grid, power quality could be better improved in the future. Variable speed wind generators are frequently used and are more attractive than fixed-speed systems because of their efficient energy production, improved power quality and dynamic performance during grid faults. Recently, the most of the wind energy conversion systems are equipped with a variable speed DFIG [2]. Many works are done about power generation and power quality improvement using a WECS. In [1,2], Gaillard et al., have studied the grid reactive power compensation and active filtering of the nonlinear loads harmonics by controlling the RSC. In this work a selective pass band filter is used to extract harmonic current components with taking advantage of the high amplification effect of the RSC to mitigate harmonic currents. In [3], a sensorless field oriented control of a doubly fed induction electric alternator/active filter for WECS capable of simultaneously capturing maximum variable wind power and improving power quality by eliminating the most significant and trouble-some harmonic currents of nonlinear loads has been studied. In this contribution, reactive power compensation and over-rating of the RSC are not discussed. In [4], the GSC is used as a shunt active filter in order to control the power factor and ensure harmonics compensation. In [5], Jain et al. have used the GSC as a shunt active filter in a stand-alone grid. In [6], the grid side converter is actively controlled to feed generated power as well as to supply the harmonics and reactive power demanded by the non-linear load at the point of common coupling (PCC). In [7], Chen et al. have studied reactive power and harmonic compensation schemes including passive filters, active filters and hybrid compensation

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Nomenclature

v	Wind speed (m/s)
V_g	PCC voltage (V)
i_r	Rotor current (A)
i_p	Linear load current (A)
i_l	Nonlinear load current (A)
i_G	Grid current (A)
ψ_s	Stator flux (Wb)
T_{em}	Electromagnetic torque (Nm)
T_L	Turbine torque (Nm)
P_s, Q_s	Stator active (W) and reactive (VAr) powers
Q_{PCC}	PCC reactive power (VAr)
L_s, L_r	Stator and rotor per phase winding inductance (H)
M	Magnetizing inductance (H)
R_s, R_r	Stator and rotor per phase winding resistance (Ω)
R_g	Line resistance (Ω)
L_g	Line inductance (H)
C	DC bus capacitor (F)
J	Total inertia constant (DFIG and turbine) (kg m^2)
f	Total friction factor (DFIG and turbine) (Nm s)
ω_s	Synchronous angular speed (rd/s)
ω_r	Rotor angular speed (rd/s)
ω_t	Turbine speed (rd/s)
Ω_g	DFIG speed (rd/s)
δ	Gear box ratio
R	Turbine radius (m)
P	Pole pairs number

methods for a converter interfaced with permanent magnet generator based variable speed wind turbine. In [8], Engelhardt et al. have discussed the steady state reactive power loading capability of DFIG based WECS by tacking into account the most important physical phenomena restricting the reactive power supply of DFIG-based wind turbine systems. In [9], Different combinations of reactive power control of RSC and GSC are investigated for DFIG. In [10], Machmoum et al. have studied flicker mitigation in a doubly fed induction generator for wind turbine system based on RSC control. In general, the full capacity of the RSC, in terms of active filtering, has not been exploited for different operating conditions of the WECS.

In this paper, a control strategy is proposed to achieve the filtering full capability of the RSC which is used to manage the WECS function's priorities, between production of the maximum active power and power quality improvement. The top priority is given to the active power production over power quality improvement. Then, priority is given to power factor correction over harmonics compensation. Finally, the filtering capability of the RSC is exploited at its maximum (when it is needed) without any over-rating by using a proposed procedure. Moreover, the GSC is controlled in such a way to guarantee a smooth DC voltage by using a fuzzy logic controller. A sinusoidal current is ensured between GSC and the grid.

2. Description and modelling of the wind energy conversion system

The synoptic scheme of the studied system is shown in Fig. 1. It is composed of a WECS, a linear load and a nonlinear load. These elements are coupled together at the PCC.

2.1. Turbine model

The mechanical power captured by the turbine from the wind is given by the following expression:

$$p_t = \frac{1}{2}\rho c_p(\lambda, \beta) s v^3 \quad (1)$$

Where ρ is the air density, s is the area of the wind wheel (m^2), v is the wind speed (m/s), c_p (λ, β) is the power coefficient of the turbine, λ is the tip speed ratio and β is the pitch angle.

The tip speed ratio is given by the following equation:

$$\lambda = \frac{R\omega_t}{v} \quad (2)$$

Fig. 2 shows the variation of the power coefficient versus λ for a constant value of the pitch angle β. In the case of a variable speed

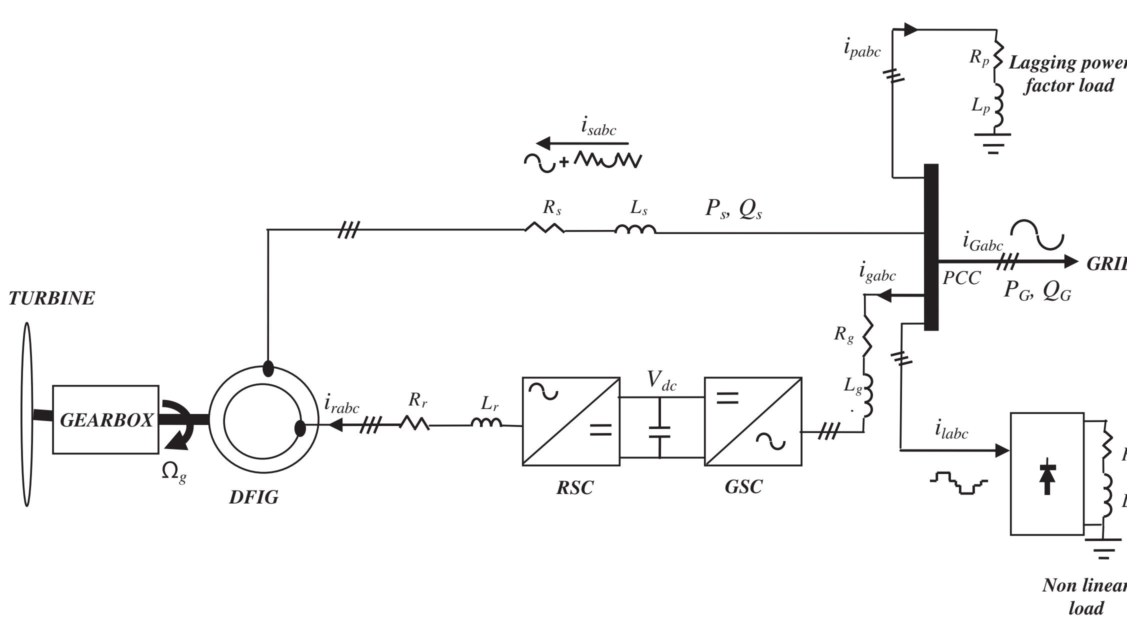

Fig. 1. Synoptic scheme of the studied WECS.