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A proposal for a wind system equipped with a doubly fed induction generator using the Conservative Power Theory for active filtering of harmonics currents[☆]

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ABSTRACT

This study describes a strategy that allows the addition of active filtering functionality to a doubly fed induction generator (DFIG) wind power system. The active filtering is performed through an algorithm that uses the mathematical formulation of Conservative Power Theory (CPT) applied into the electric current control loop on grid side converter. The wind power system that uses the CPT to mitigate harmonic currents, allows the improvement of the power quality in electrical power systems where non-linear loads are connected. The active and reactive power control of the DFIG are presented, performed using the stator magnetic flux vector orientation technique. In addition to the detailed description of the back-to-back converter control loops, the controllers design realized by frequency response is presented. The simulation results confirm the possibility of adding the active filtering function in DFIG wind energy systems using the CPT, reducing the THD of the electric current in the grid to less than 5% and improving the power quality in order to comply with the recommendations of the IEEE standardization 519.

1. Introduction

Wind power systems designed to extract maximum power at different wind speeds are known as variable speed wind systems. In Refs. [1] and [2] the modeling and control of variable speed systems employing the doubly fed induction generator (DFIG) were studied. Variable speed wind systems are more advantageous than fixed speed systems for installed power above 1 MW [3].

Fig. 1 shows a schematic of a wind power system using a DFIG connected to the power grid. In this system, the turbine is connected to the DFIG by means of a gearbox that provides mechanical power in the speed range for which the electric generator was designed. The back-to-back converter has rated power from 20% to 30% of DFIG nominal power reducing the costs with electronic power converters. The main function of the static back-to-back converter is to control the active and reactive power that the wind system delivers to the power grid. As the amount of wind power systems connected to the electric grid grows each year [4], the use of these electricity generation plants to perform auxiliary functions to support the electric systems has motivated several research works. In Refs. [5–12] some methods are studied to integrate to the wind power systems, with DFIG, functionalities that help in the improvement of parameters related to the power quality, such as: reactive power compensation and harmonic current filtering.

The harmonic currents compensation can be realized from power filters, which can be passive, active and hybrid [13]. Thus, among the several topologies presented in Ref. [14], the parallel active filtering by electronic power converters is in line with the energy conditioning coming from renewable resources in distributed generation, since those converters use the same topology of power electronic converters.

Recently, different contributions have been made about harmonic current compensation strategies. The instantaneous power theory p–q [15] and Conservative Power Theory (CPT) [16], two of some power theories that are used to measure and compensate electric power disturbances, deserve to be highlighted, because of the amount of publications and research using these approaches. In Refs. [17] and [18] harmonic current compensation techniques based on the p–q theory are presented. In Refs. [19] and [20] the CPT was applied to a parallel power active filter.

The active filtering function can be added to wind power systems equipped with DFIG using different methodologies. In Refs. [5], [8] and

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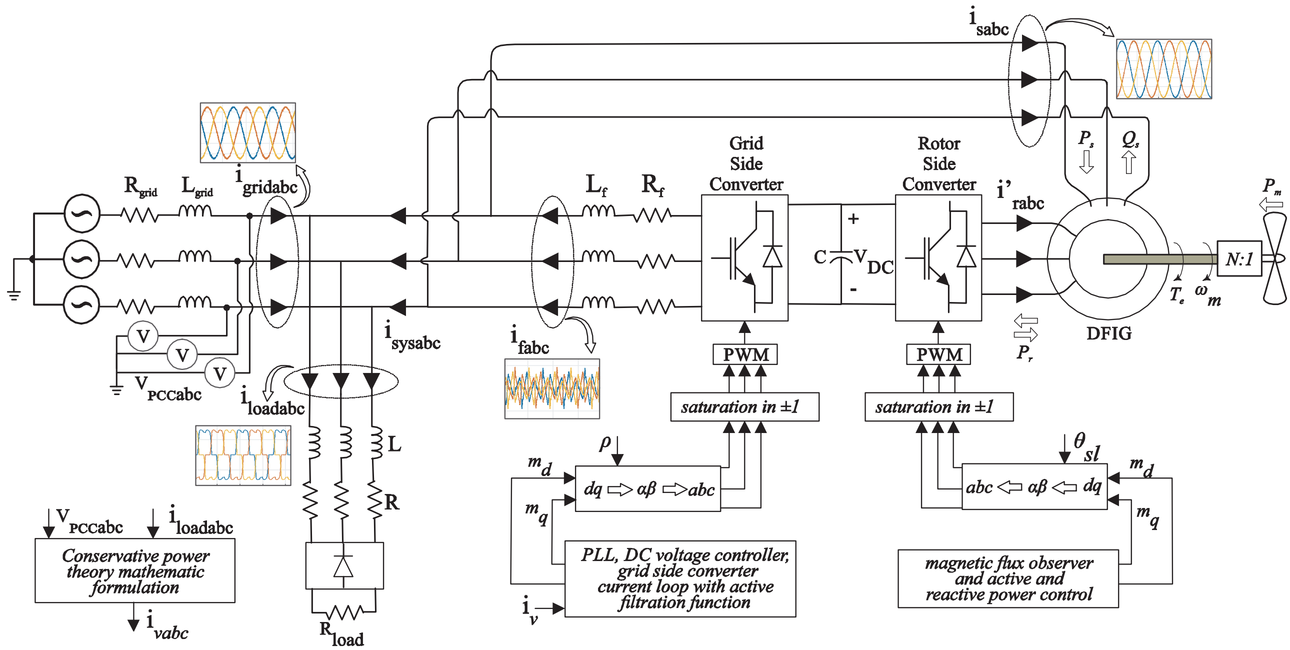

Fig. 1. Schematic diagram proposed for a wind system with active filtering function.

[11] the active filtering functionality was added to the control algorithm of the GSC in wind power systems with DFIG, results of simulations and experimental results show the effectiveness of the employed methods.

During this research, we did not find studies that use CPT as methodology for the decomposition of the electric current and generation of references for harmonic currents compensation in wind power systems with DFIG. Thus, the main contribution of this research is the application of CPT to the addition of the active filtering function in the GSC, as can be observed in Fig. 1. For this purpose, the elementary mathematical formulation of the theory is presented.

The authors in Ref. [21] proposed harmonic mitigation techniques using the time-domain harmonic detection method (HSF) with modulated hysteresis current controller where the switching frequency is not constant. In Ref. [22] the HSF method was also used with a fixed switching frequency PWM controller was applied. The techniques presented in Refs. [21] and [22] included the active filtering function in the control loop of the converter connected to the DFIG rotor achieving good results. The modification of the rotor side control loop should be performed with care because the injection of harmonic currents into the rotor circuit of the DFIG can cause increased losses due to heating and mechanical wear.

This study presents a way to add the active filtering function to a wind power system with DFIG, in order to compensate harmonic currents required by nonlinear loads. Following the recommendations of IEEE Standard 519 [23], THD (Total Harmonic Distortion) limits on transmission systems must be less than 5%. The simulation results show that wind power plants with the active filtering function using the CPT can compensate harmonic currents in the electric grid with the presence of nonlinear loads, so that the electric grid current presents THD lower than 5% recommended by IEEE Standard 519.

Section 2 describes the dynamic mathematical modeling of the DFIG and the control of active and reactive powers; Section 3 explains the control structures of the grid side converter (GSC); Section 4 presents the mathematical formulation of the CPT and the description of the proposed method; Section 5 describes the controller design; finally, in Section 6 the simulations results for a wind system of 1.5 MW are presented.

2. Active and reactive power control of doubly fed induction generator — DIFG

The control of the doubly fed induction generator is carried out by means of its dynamic mathematical modeling, which was obtained by the three-phase circuits of the stator and the rotor in synchronously rotating reference frame as defined in Ref. [24]:

$$v_{ds} = (d\psi_{ds}/dt) - \omega_e \psi_{qs} + r_s i_{ds} \quad (1)$$

$$v_{qs} = (d\psi_{qs}/dt) + \omega_e \psi_{ds} + r_s i_{qs} \quad (2)$$

$$v'_{dr} = d\psi'_{dr}/dt - (\omega_e - \omega_r)\psi'_{qr} + r'_r i'_{dr} \quad (3)$$

$$v'_{qr} = d\psi'_{qr}/dt + (\omega_e - \omega_r)\psi'_{dr} + r'_r i'_{qr} \quad (4)$$

$$\psi_{ds} = L_s i_{ds} + L_m i'_{dr} \quad (5)$$

$$\psi_{qs} = L_s i_{qs} + L_m i'_{qr} \quad (6)$$

$$\psi'_{dr} = L_r i'_{dr} + L_m i_{ds} \quad (7)$$

$$\psi'_{qr} = L_r i'_{qr} + L_m i_{qs} \quad (8)$$

$$T_e = 1.5(p/2) L_m (i'_{dr} i_{qs} - i'_{qr} i_{ds}) \quad (9)$$

$$\omega_r = p\omega_m \quad (10)$$

where v_{ds}, v_{qs} represent the stator voltages in dq coordinates; v'_{dr}, v'_{qr} represent the rotor voltages; r_s, r'_r are the electrical resistances of the stator and rotor windings per phase; i_{ds}, i_{qs} represent the stator electric currents in dq coordinates; i'_{dr}, i'_{qr} represent the rotor electric currents in dq coordinates; ψ_{ds}, ψ_{qs}, represent the components of the stator magnetic flux in dq coordinates; ψ'_{dr}, ψ'_{qr} represent the components of the rotor magnetic flux in dq coordinates; L_s and L_r are the self-inductances of the stator and rotor windings; L_m represents the magnetizing inductance per phase; ω_e and ω_r are the synchronous and rotor angular velocities; T_e is the electromagnetic torque developed by the electric generator and p is the number of poles pairs.

The dynamic behavior of the mechanical part of the wind power system is expressed by:

$$d\omega_m/dt = (1/2H)(T_m - T_e - F\omega_m) \quad (11)$$

where H is the combined inertia moment of the rotor and turbine; F is