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Direct Active and Reactive Power Control of DFIG Based Wind Energy Conversion System

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***Abstract*—This paper presents a Direct Power Control (DPC) for the Rotor Side Converter (RSC) of Doubly-Fed Induction Generator (DFIG) connected to the wind energy conversion system, as an alternative to the classical vector control (FOC). In this work a simple but effective DPC is proposed to achieve quick response and acceptable steady state performance at reason of using a conventional switching table to select the appropriate voltage vectors to the Rotor Side Converter (RSC).**

Furthermore for controlling Grid-Side Converter (GSC) system a conventional Direct Power Control (DPC) strategy will be compared with Fuzzy Direct Power Control (F-DPC) for controlling Active and reactive power flow exchanged with grid.

Simulation results on a 2 MW DFIG system using MATLAB/Simulink are provided to demonstrate the effectiveness and robustness of the proposed control strategy during variations of active and reactive power, rotor speed, and converter dc link voltage.

***Index Terms*—back-to-back PWM converters (AC/DC/AC), Direct Power Control (DPC), Doubly-Fed Induction Generator (DFIG), Fuzzy logic controller (FLC), Vector Control (VC), Wind Energy.**

I. INTRODUCTION

Wind energy has become an important source for electricity generation in many countries. It is expected that wind energy will provide about 10% of the world's electrical energy in 2020. Nowadays, many wind farms are based on the doubly fed induction generator (DFIG) technology with converter rated at 20%-30% of generator rating [1]. Compared with other wind farm technologies DFIG offers several advantages such as lower converter cost, lower power losses, variable speed and four quadrants active and reactive power operation capabilities compared with the fixed-speed induction generators or synchronous generators with full sized converters [2]. A schematic diagram of the DFIG-based wind energy conversion systems is shown in Fig.1. [3].

Conventional design of DFIG control systems is based on rotor current vector control with d-q decoupling (FOC). The control system is usually defined in the synchronous d-q frame fixed to either the stator voltage, and it involves relatively complex transformation of voltages, currents and control outputs among the stationary, the rotor and the synchronous reference frames [4]. This conventional method requires accurate information of machine parameters such as stator, rotor resistance and inductance, and mutual inductance, etc. Consequently, the performance is degraded when the actual machine parameters change from those values used in the control system. Moreover, the rotor current controllers need to be carefully tuned to ensure system stability and suitable response within the whole operating range [5].

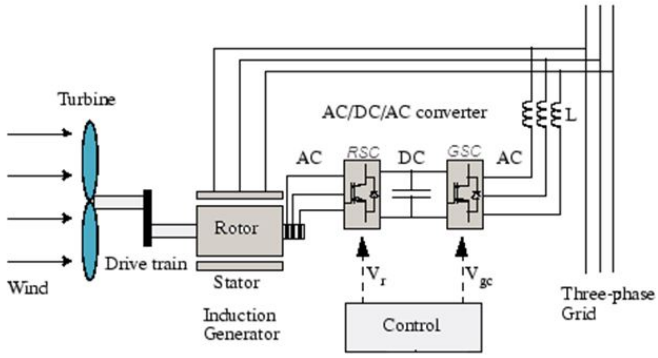

Fig. 1. Schematic diagram of a DFIG-based wind power system

Due to the advantages of simple structure and low dependency on the parameters, direct torque control (DTC) was widely used in cage-type induction motors, but less attention was paid to doubly-fed induction generators (DFIG) [2].

The DPC method directly controls the stator-side active and reactive powers by selecting voltage vectors from a lookup table using the information about the active and reactive powers of the stator. DPC of the DFIG is able to produce fast active and reactive power control with the hysteresis band and is robust with respect to the change of machine parameters and to perturbations [6].

Several modified DTC/DPC strategies[3], including space

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vector modulation (SVM), have been proposed to achieve a constant switching frequency for induction machine drives and grid-connected VSC. However, additional drawbacks are introduced by such control, such as complicated online calculation [7], additional PI controller parameters, and weak robustness to machine parameter variations. Several DPC strategies with constant switching frequency have also been proposed for the DFIG [7]. The switching states were initially selected based on conventional LUT in [8], whereas their durations were calculated based on the objectives of reduced active and reactive power oscillation [9].

In [10] a sensorless integrated doubly fed electric alternator/active filter (IDEA) for variable speed wind energy conversion systems (WECS) is proposed.

This paper presents DPC control strategy for a DFIG based wind energy conversion system. A comparative study between DPC and F-DPC to control the rotor side converter is implemented. Simulation results on a 2 MW DFIG generation system are presented to demonstrate the performance of the proposed control strategy during variations of rotor speed, active and reactive power, and converter dc link voltage.

II. Mathematical Model of DFIG

The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator. All stator and rotor quantities are in the arbitrary two-axis reference frame (*dq frame*) [4].

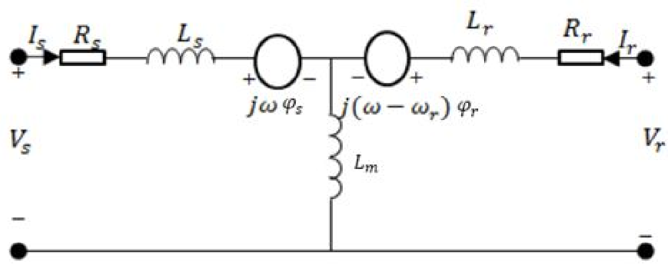

Fig. 2. DFIG electric equivalent model

A. Electrical System

$$V_{qs} = R_s I_{qs} + \frac{d}{dt}\varphi_{qs} + \omega\varphi_{ds} \tag{1}$$

$$V_{ds} = R_s I_{ds} + \frac{d}{dt}\varphi_{ds} - \omega\varphi_{qs} \tag{2}$$

$$V_{qr} = R_r I_{qr} + \frac{d}{dt}\varphi_{qr} + (\omega - \omega_r)\varphi_{dr} \tag{3}$$

$$V_{dr} = R_r I_{dr} + \frac{d}{dt}\varphi_{dr} - (\omega - \omega_r)\varphi_{qr} \tag{4}$$

$$T_e = \frac{3}{2}p(\varphi_{ds}I_{qs} - \varphi_{qs}I_{ds}) \tag{5}$$

B. Mechanical System

$$\frac{d}{dt}\omega_m = \frac{1}{j}(T_e - F\omega_m - T_m) \tag{6}$$

$$\frac{d}{dt}\theta_m = \omega_m \tag{7}$$

where

$$\varphi_{qs} = L_s I_{qs} + L_m I_{qr} \tag{8}$$

$$\varphi_{ds} = L_s I_{ds} + L_m I_{dr} \tag{9}$$

$$\varphi_{qr} = L_r I_{qr} + L_m I_{qs} \tag{10}$$

$$\varphi_{dr} = L_r I_{dr} + L_m I_{ds} \tag{11}$$

$$L_s = L_{ls} + L_m \tag{12}$$

$$L_r = L_{lr} + L_m \tag{13}$$

III. Control Algorithms

The AC/DC/AC converter is divided into two components: the rotor-side converter (RSC) and the grid-side converter (GSC). RSC and GSC are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor is used to connect GSC to the grid. The three-phase rotor winding is connected to RSC by slip rings and brushes and the three-phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generates the voltage command signals V_r and V_{gc} for RSC and GSC respectively in order to control the power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid terminals.

A. Direct Power Control of RSC

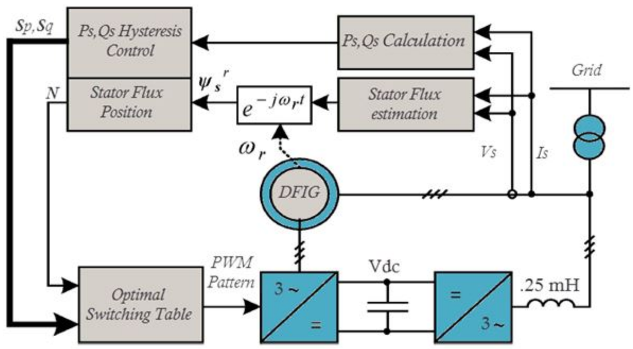

Fig. 3. DPC scheme for DFIG grid connection

Connection of DFIG to grid requires the adjustment of stator voltage to be synchronized with the grid voltage. The objective of RSC control is meeting the synchronization conditions. These conditions are equality in phase, frequency and magnitude between the grid and stator voltage vector.