Control of DFIG Wind Turbine With Direct-Current Vector Control Configuration

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***Abstract*—The doubly-fed induction generator (DFIG) wind turbine is a variable speed wind turbine widely used in the modern wind power industry. At present, commercial DFIG wind turbines primarily make use of the technology that was developed a decade ago. But, it is found in this paper that there is a limitation in the conventional vector control technique. This paper presents a direct-current vector control method in a DFIG wind turbine, based on which an integrated control strategy is developed for wind energy extraction, reactive power, and grid voltage support controls of the wind turbine. A transient simulation system using SimPowerSystem is built to validate the effectiveness of the proposed control method. The conventional control approach is compared with the proposed control technique for DFIG wind turbine control under both steady and gust wind conditions. The paper shows that under the dc vector control configuration, a DFIG system has a superior performance in various aspects.**

***Index Terms*—DC-link voltage control, direct-current vector control, doubly-fed induction generator (DFIG) wind turbine, grid voltage support control, maximum power extraction, reactive power control.**

I. Introduction

At THE present time, wind turbines based on doubly-fed induction generators (DFIGs) are used in most large wind power plants in North America [1]. There are several reasons for using DFIG wind turbines; among those are possibilities to increase turbine energy capture capability, reduce stresses of the mechanical structure, diminish acoustic noise, and make the active and reactive power controllable for better grid integration [1], [2].

However, the energy captured and converted from the wind by a DFIG wind turbine depends strongly on how the wind turbine is controlled under variable wind conditions. Presently, commercial DFIG wind turbines mainly use the technology that was developed a decade ago [2]–[4] based on the standard decoupled $d-q$ vector control mechanism. This paper shows that there is a limitation in the conventional vector control approach for the grid-side converter of the DFIG wind turbine. The weakness is more evident when the converter operates beyond its linear modulation limit. This situation has also been reported recently by many studies in different applications. In [5], it is found through both theoretical and experimental studies that the conventional control technique is sensitive to model uncertainties. In [6]–[8], it is reported that wind farms periodically experience high unbalance and harmonic distortions that have resulted in a large number of trips. In [9], it is pointed out that it is difficult to tune PI parameters for the conventional vector control technique in a STATCOM application. In [10], it is pointed out that it is the critical to be able to estimate the grid system parameter changes so as to enhance the performance of the conventional control method for a microgrid application.

This paper develops a mechanism for improved control of a DFIG wind turbine under a direct-current vector control configuration. Then, based on the proposed control structure, the integrated DFIG system control is developed, including maximum wind power extraction control, reactive power control, and grid voltage support control. In the sections that follow, the paper first introduces the general configuration of a DFIG system and overall control structure in Section II. Then, Section III presents the direct-current and conventional standard vector control approaches for a DFIG grid-side converter (GSC). The control of the rotor-side converter (RSC) is presented in Section IV. Section V shows the control integration of the GSC and RSC for DFIG maximum power extraction, reactive power, and grid voltage support controls. Simulation studies are conducted in Section VI to compare the performance of DFIG wind turbine using the direct-current and traditional vector control configurations for steady and variable wind conditions. Finally, the paper concludes with the summary of the main points.

II. DFIG Mechanical/Electrical Systems and Integrated Controls

A DFIG wind turbine primarily consists of three parts: a wind turbine drive train, an induction generator, and a power electronic converter (Fig. 1) [2], [4]. In the wind turbine drive train, the rotor blades of the turbine catch wind energy that is then transferred to the induction generator through a gearbox. The induction generator is a standard, wound rotor induction machine with its stator windings directly connected to the grid and its rotor windings connected to the grid through a frequency converter. The frequency converter is built by two self-commutated voltage-source converters, the RSC and the GSC, with an intermediate dc voltage link.

The control in a DFIG wind power plant has three levels: the generator level, the wind turbine level, and the wind power

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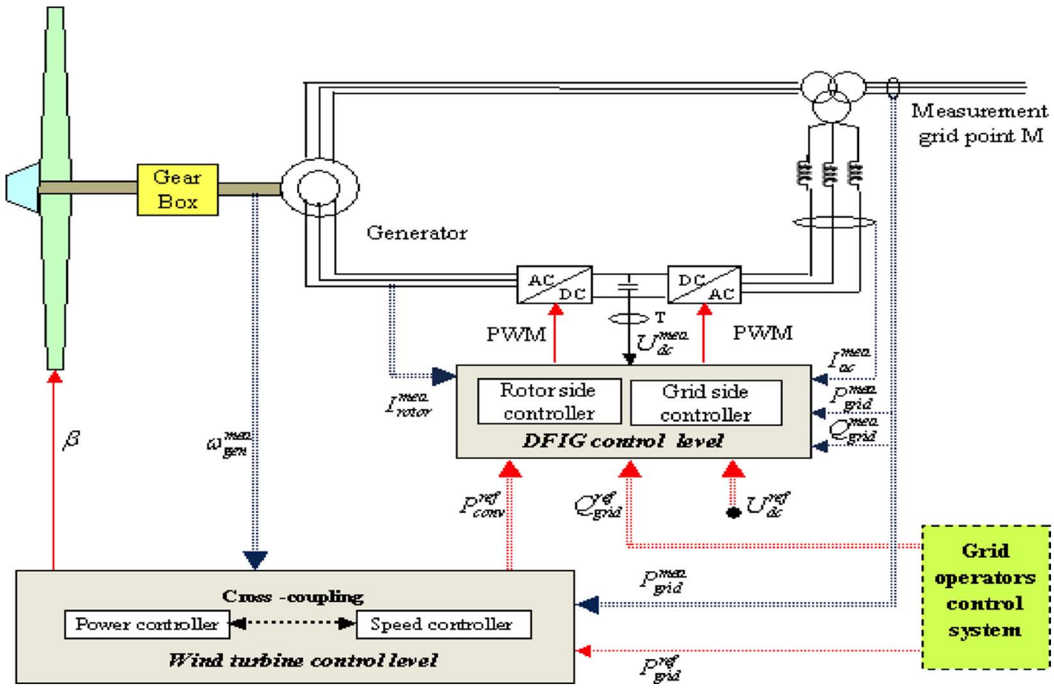

Fig. 1. Configuration of a DFIG system.

plant level (Fig. 1) [4]. At the generator level, the RSC controller regulates the DFIG to achieve one of the following two goals: 1) maximum energy extraction from the wind or 2) compliance with a wind plant control demand; the GSC controller maintains a constant dc-link voltage and adjusts reactive power absorbed from the grid by the GSC. At the turbine level, there are a speed controller and a power limitation controller. At a low wind speed, the speed controller gives a power reference to the RSC based on the principle of maximum energy extraction. At a high wind speed, the power limitation controller increases or decreases the pitch angle of the turbine blades to prevent the wind turbine from going over the rated power. At the wind power plant level, the power production of the entire plant is determined based on a grid requirement. The central control system sends out power references to each individual turbine, while the local turbine control system ensures that the power reference from the central control level is reached.

III. Conventional and Direct-Current Vector Control of GSC

In a DFIG wind turbine, the GSC controls the dc-link voltage and contributes to the reactive power or grid voltage support control of the overall DFIG system as well.

A. GSC Transient and Steady-State Models

Fig. 2 shows the schematic of the GSC, in which a dc-link capacitor is on the left and a three-phase voltage source, representing the voltage at the point of common coupling (PCC) of the ac system, is on the right.

In the $d-q$ reference frame, the voltage balance across the grid filter is

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = R_f \begin{bmatrix} i_d \\ i_q \end{bmatrix} + L_f \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega_s L_f \begin{bmatrix} -i_q \\ i_d \end{bmatrix} + \begin{bmatrix} v_{d1} \\ v_{q1} \end{bmatrix} \quad (1)$$

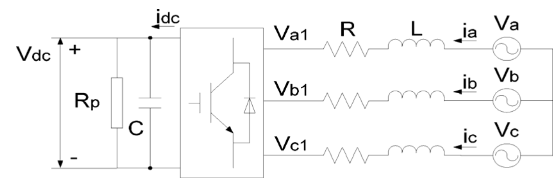

Fig. 2. Grid-connected converter schematic.

where ω_s is the angular frequency of the PCC voltage, and L_f and R_f are the inductance and resistance of the grid filter. Using space vectors, (1) is expressed by a complex (2) in which v_{dq}, i_{dq}, and v_{dq1} are instantaneous space vectors of the PCC voltage, line current, and converter output voltage. In the steady-state condition, (2) becomes (3), where V_{dq}, I_{dq}, and V_{dq1} stand for the steady-state space vectors of PCC voltage, grid current, and converter output voltage

$$v_{dq} = R_f \cdot i_{dq} + L_f \frac{d}{dt} i_{dq} + j\omega_s L_f \cdot i_{dq} + v_{dq1} \quad (2)$$

$$V_{dq} = R_f \cdot I_{dq} + j\omega_s L_f \cdot I_{dq} + V_{dq1}. \quad (3)$$

In the PCC voltage oriented frame [3], [11], the instant active and reactive powers absorbed by the GSC from the grid are proportional to grid d- and q-axis currents, respectively, as shown by (4) and (5)

$$p(t) = v_d i_d + v_q i_q = v_d i_d \quad (4)$$

$$q(t) = v_q i_d - v_d i_q = -v_d i_q. \quad (5)$$

In terms of the steady-state condition, $V_{dq} = V_d + j0$ if the d-axis of the reference frame is aligned along the PCC voltage position. Assuming $V_{dq1} = V_{d1} + jV_{q1}$ and neglecting the grid filter resistance, then, the current flowing between the PCC and the GSC according to (3) is

$$I_{dq} = (V_d - V_{d1})/(jX_f) - V_{q1}/X_f \quad (6)$$

in which X_f stands for the grid filter reactance.