International Journal of Scientific Engineering and Technology ISSN : 2277-1581
Volume No. 6, Special Issue 3. PP : 183-186 22-23 Dec. 2017

Combined Vector and Direct Power Control of Doubly Fed Induction Generator-Based Wind Turbines: A Review Paper

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Abstract : In this paperanew innovative combined vector and direct power control (CVDPC) strategy is proposed for the rotor side converter (RSC) of doubly fed induction generators (DFIGs)-based wind energy generation system. The direct control of stator active and reactive power based strategy is used by selection of appropriate voltage vectors on the rotor side. It is observed that the initial rotor flux has no effect on the changes of the stator active and reactive power. The proposed method only makes use of the estimated stator flux in order to overcome the difficulties associated with rotor flux estimation. The proposed DPC method requires only one machine parameter i.e. .the stator resistance which has negligible impact on the system performance. Simulation results on a 9-MW wind farm consisting of six 1.5-MW DFIG-based wind turbines shows that the effectiveness and robustness of the proposed control strategy during variations of active and reactive power, rotor speed, machine parameters, and converter dc link voltage.

Keywords-Direct power control (DPC), doubly fed induction generator (DFIG), direct torque control, voltage source converter, voltage vector.

I. INTRODUCTION

Doubly fed induction generator (DFIG) is suitable choice for variable speed wind turbines. Due to the fact that the DFIG is controlled by the rotor circuit and the rotor circuit powerapproximately equal to 30% of the stator circuit power, DFIG need small-scale power electronic converter when compared with induction generators or synchronous generators. Therefore usage of the DFIG in variable speed wind turbine systems are more efficient [1].

DFIGs stator windings directly connected to the grid and rotor windings connected to the grid via a bi-directional backto-back converter as shown in Fig. 1. The bi-directional back-to-back converter consists of two converters called rotor-side converter (RSC) and grid-side converter (GSC). These two converters are connected to a common DC bus. The rotor side converter is used to control the active and reactive power of the DFIG and controls the power factor of the DFIG. On the other hand grid side converter keeps the DC bus voltage constant. During the operations between sub synchronous and super synchronous speed ranges, three phasevoltage source converter has to be used as GSC. If DFIG willoperate only a sub synchronous speed ranges, the GSC mightbe replaced with a three-phase uncontrolled rectifier In the past many years, a great increase in electrical power demand and depletion of natural resources have made environmental and energy crises. These have led to an increased need for production of energy from renewable sources so that the world wind energy production has grown significantly due to cleanness and renewability. Wind power generation is estimatedto be 10% of the world's total electricity by the year 2020 and is expected to be double or more by the year 2040 [1]. Wind turbines (WTs), which play a main role in wind energy, are basically divided into fixed and variable-speed technologies.

II. COMBINED VECTOR AND DIRECT POWER CONTROL

A. Vector Control

Vector control is the most popular method used in the Doubly Fed Induction Generator-based Wind Turbines. In this control method, the stator active and reactive powers are controlled through the rotor current Vector Control. The current vector is decomposed into the components of the stator active and reactive power in synchronous reference frame. This decouples the active power control from the reactive power control. The stator active and reactive power references are determined by the maximum power point tracking (MPPT) strategy and the grid requirements, respectively. The phase angle of the stator flux space vector is usually used for the controller synchronization. Although, if the stator flux-oriented frame (SFOF) is used, the overall performance of VC will be highly dependent on the accurate estimation of the stator flux position. This can be a critical problem under the distorted supply voltage condition or varying machine parameters. Therefore, in this paper, the stator-voltage-oriented frame (SVOF) is used for the controller synchronization. In order to extract the synchronization signal from the stator voltage signal, a simple phase locked- loop (PLL) system is used. The stator active and reactive powers are as [3].

$$P_S = \frac{3}{2}\mathrm{Re}(V_S i_s^*) = \frac{3}{2}(V_{ds}i_{ds} + V_{qs}i_{qs}) \text{ ----------(1)}$$

$$Q_S = \frac{3}{2}\mathrm{Im}(V_S i_s^*) = \frac{3}{2}(V_{qs}i_{ds} + V_{ds}i_{qs}) \text{ --------- (2)}$$

As the SVOF is used for the controller synchronization, Vqsdisperse and the stator active and reactive power equations are simplified to

$$P_s = \frac{3}{2}V_{ds}i_{ds} \text{ ---------- (3)}$$

$$Q_s = \frac{-3}{2}V_{ds}i_{ds} \text{ ---------- (4)}$$

According to the stator flux equations in the synchronous frame [3], in this condition, the stator currents can be written as

$$i_{ds} = \frac{-L_m}{L_s} i_{dr} \text{ --------------------------- (5)}$$

$$i_{qs} = \frac{-L_m}{L_s}(i_{qr} + \frac{V_{ds}}{\omega_s L_m}) \text{ ------------ (6)}$$

Substituting (5) and (6) into (3) and (4) yields

$$P_s = \frac{-3L_m}{2L_s} V_{ds} i_{dr} \text{ ------------------- (7)}$$

$$Q_s = \frac{3L_m}{2L_s} V_{ds} (i_{qr} + \frac{V_{ds}}{\omega_s L_m}) \text{ ---------- (8)}$$

So, the stator active and reactive powers are controlled through idr andiqr, respectively. The block diagram of the RSC-based Vector Control is shown in Fig. 1.

As shown in Fig. 1 schematic block diagram for the rotor-side converter control of the DFIG. The references q-axis rotor current $i_{qr}*$ can be obtained either from an outer speed control loop or from a torque imposed on the machine.

These two options may be termed a speed-control mode or torque-control mode for the generator, instead of regulating the active power directly. For speed-control mode, one outer Pl controller is to control the speed error signal in terms of maximum power point tracking Furthermore, another PI controller is added to produce the reference signal of the d-axis rotor current component to control the reactive power required from the generator. Assuming that all reactive power to the machine is feed by the stator, the reference value $i_{dr}*$ may set to zero. Rotor excitation current control is realized by controlling rotor voltage. TheI_{dr}andI_{qr}error signals are processed by associated PI controllers to give$V_{rd}$and V_{rq} respectively.

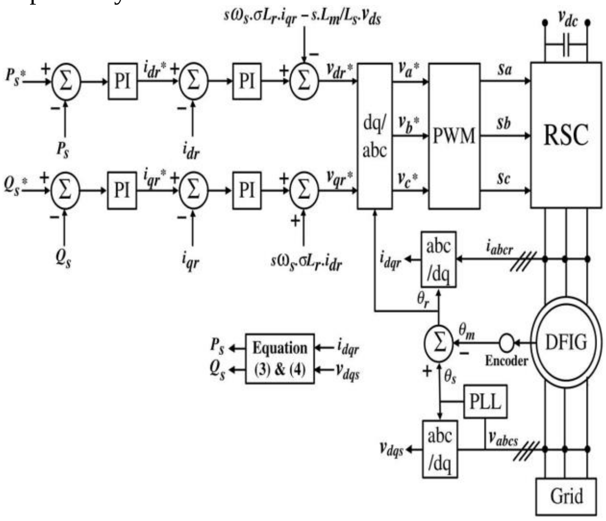


Figure 1. Block diagram of the vectorcontrol strategy of RSC.

B. Direct Power Control

In the Direct Power Control method, the stator active and reactive powers are controlled directly and the current control loop is eliminated. The principles of DPC can be explained by the following stator active and reactive power equations [7]

$$P_s = \frac{-3L_m\omega_s}{2\sigma L_s L_r} |\varphi_s||\varphi_r| \sin\delta \text{ -----------------------(9)}$$

$$Q_s = \frac{3\omega_s}{2\sigma L_s} |\varphi_s| \left[|\varphi_s| - \frac{L_m}{L_r} |\varphi_r| \cos\delta \right] \text{ ----------(10)}$$

By assuming constant magnitude for the stator and rotor flux, the derivative of (9) can be represented approximately as

$$\frac{dP_s}{dt} = \frac{-3L_m\omega_s}{2\sigma L_s L_r} |\varphi_s||\varphi_r| \cos\delta \text{ ------------------(11)}$$

Equation (11) shows that the stator active power dynamics depends on the variation of δ. Therefore, the fast-active power control can be achieved by rapidly changing δ. By assuming constant magnitude for the stator flux and δ the derivative of (10) can be represented approximately as

$$\frac{dQ_s}{dt} = \frac{-3L_m\omega_s}{2\sigma L_s L_r} |\varphi_s| \frac{d|\varphi_r|}{dt} \cos\delta \text{ ---------- (12)}$$

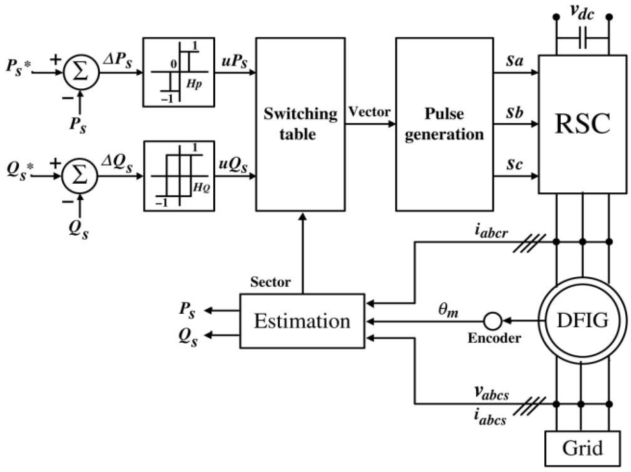


Figure 2. Block diagram of the direct power control strategyof RSC.

Equation (12) shows that the stator reactive power dynamics depend on the magnitude variation of the rotor flux. Therefore, the fast-reactive power control can be achieved by rapidly changing therotor flux magnitude. The variation in the rotor flux can be carried out by applying the appropriate inverter voltage vectors to the rotor windings to rotate the rotor flux linkage vector. The rotor voltage equation can be represented and approximated in a short interval of Δt as

$$\frac{d|\varphi_r|}{dt} = V_r - R_r i_r \approx V_r \Rightarrow \Delta\varphi_r = V_r \cdot \Delta t \text{ ---------- (13)}$$

The six inverter voltage vectors can be appropriately used to control the position and value of the rotor flux's by knowing the sector in which 'r is located. The block diagram of the direct power-controlled RSC is shown in Fig. 2.

III. Simulation and results

In this section simulation study, using MATLAB/Simulink, is simulated on a 9-MW wind farm consisting of six 1.5-MW DFIG-based WTs to compare the performance of the proposed CVDPC method with both Vector Control and Direct Power Control strategies. Fig. 5

ISSN : 2277-1581
22-23 Dec. 2017

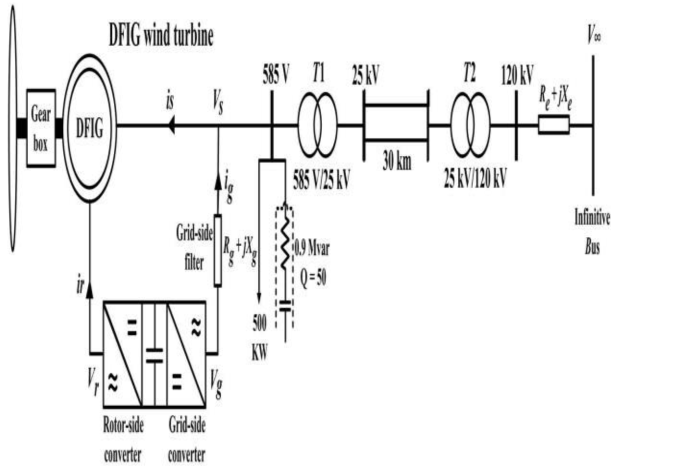


Figure 3. Schematic diagram of the proposed simulated system.

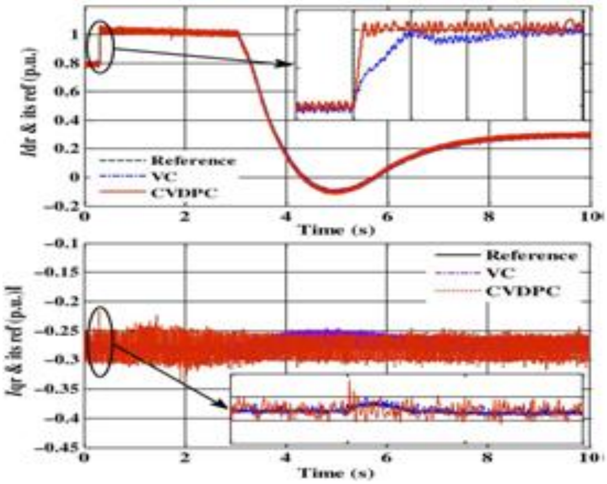
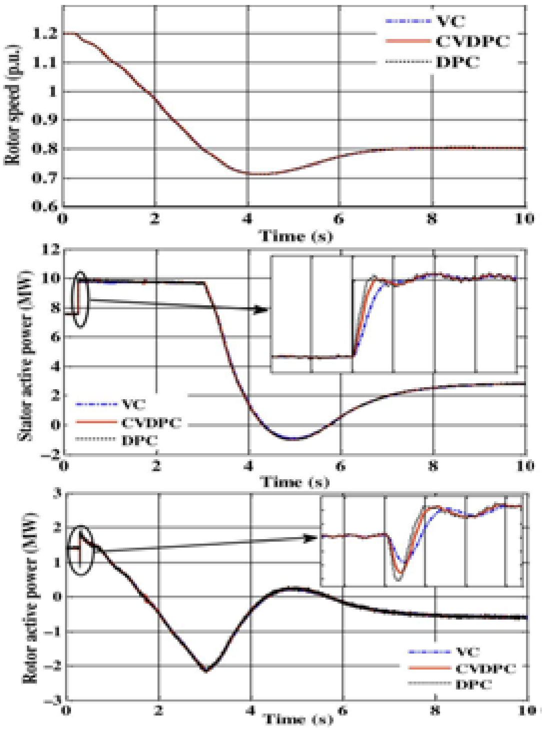


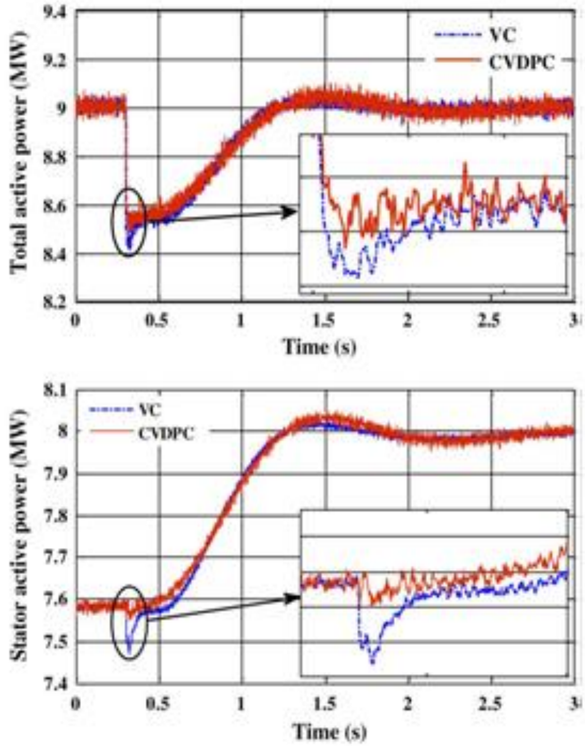
Figure 4. Simulation results when the wind speed changes from 15 to 10 m/s.

IV. Conclusion

In this paper, considering the vector control and direct power control method a new approach to combined control scheme based on the common basis of vector control method and direct power control method has been presented for the rotor side convertor of the doubly fed induction generator. In result, the proposed combined vector direct power control method gives a compromise of the advantages of these two methods.



In the FFT analysis results shows that VCDPC having less THD than the VC method. Also provides the decoupling and robustness against the variation of the machine parameter. By implementing CVDPC control method gives lower power ripple and also high dynamic response.



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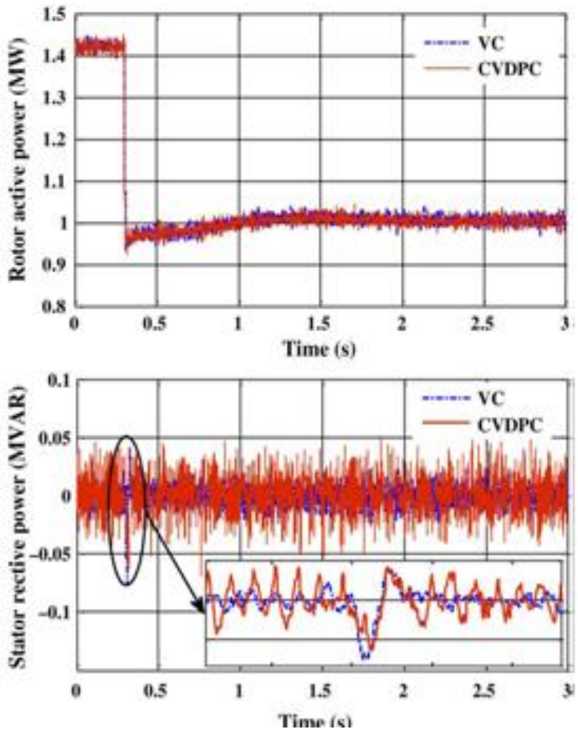

Figure 5. Simulation results when R_r is changed.

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