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A Combined Vector and Direct Power Control for AC/DC/AC Converters in DFIG Based Wind Turbine

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Abstract

In this paper Combined Vector and direct power control (CVDPC) strategy is applied to control a doubly fed induction generator (DFIG) based wind energy generation system. AC/DC/AC converter is controlled by Combined Vector and direct power control method. The rotor side converter is controlled by selecting appropriates voltage vector based on the instantaneous errors between the reference and estimated values of active and reactive powers and rotor flux position. Also the Grid side is controlled by Combined Vector and direct power control based a grid voltage position to ensure a constant DC voltage, Simulation results demonstrate robust, precise, and fast dynamic behavior of the system.

Keywords: Doubly Fed Induction Generator, Vector Control, Direct Power Control, VCDPC.
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1. Introduction

The doubly-fed generators (DFIG) have clear superiority for the applications of large capacity and limited-range speed control case due to the partially rated inverter, lower cost and high reliability. These characteristics enable the doubly-fed wound rotor induction machine to have vast applications in wind-driven generation [1-3]. One of the most conventional control methods for DFIG is vector control in which rotor currents are decoupled into stator active power (or torque) and reactive power (or flux) and these two currents are controlled in the reference frame fixed to stator flux (or voltage) [4] - [5]. In this method accurate value of machine parameters such as resistances and inductances is required and non-linear operation of the converter for tuning current controllers is not considered. So the performance of vector control method is affected by changing machine parameters and operation condition. Direct torque control (DTC) of induction machine drives was developed in the mid1980s. DTC is based on decoupled torque and flux control which have very fast and precise dynamic without using an inner control loop. The control of DFIG in which the rotor flux is estimated and an optimal switching table is used based on rotor flux position, based on DTC strategy, direct power control (DPC) is developed to control the DFIG [4].

In this paper, it focused on comparison of VC and DPC by looking for similarities between their principles and searching for a fundamental common basis. From this common basis, in order to enjoy the benefits of VC and DPC and to avoid some of the implementation difficulties of either of two methods, the CVDPC method is proposed for the RSC of the DFIG. The proposed CVDPC has several advantages in comparison with VC, including fast dynamic response, robustness against the machine parameter variations, lower computation, and simple implementation. On the other hand, it has benefits in comparison with DPC, including less harmonic distortion and lower power ripple. The rest of this paper is organized as follows. In Section II, the VC and DPC methods are described and the common basis of them is investigated. In Section III, the proposed control system and its basic idea are discussed. In Section IV, simulation results are shown, and finally, in Section V, the conclusion is presented.

2. Vector control (VC)

The dynamic stator, active and reactive power quotations of DFIG in a synchronously (ω_s)

rotating d-q reference frame can be expressed by the following equations [5]:

$$P_s = \frac{3}{2}\left(V_{ds}I_{ds} + V_{qs}I_{qs}\right) \quad (1)$$

$$Q_s = \frac{3}{2}\left(V_{qs}I_{ds} - V_{ds}I_{qs}\right) \quad (2)$$

The stator voltage vector is aligned with the d axis, therefore V_{qs} is equal to zero and $V_{ds} = V_s$, so the stator active and reactive power equation is simplified to:

$$P_s = \frac{3}{2}V_{ds}I_{ds} \quad (3)$$

$$Q_s = -\frac{3}{2}V_{ds}I_{qs} \quad (4)$$

3. Direct power control (DPC)

The equations of active and reactive power in DPC method can be expressed as follows [6]:

$$P_s = \frac{3}{2}\frac{L_m}{\sigma L_s L_r}\omega_s\left|\vec{\lambda}_s\right|\left|\vec{\lambda}_r\right|\sin\delta \quad (5)$$

$$Q_s = \frac{3}{2}\frac{\omega_s}{\sigma L_s}\left|\vec{\lambda}_s\right|\left[\frac{L_m}{L_r}\left|\vec{\lambda}_s\right| - \left|\vec{\lambda}_r\right|\cos\delta\right] \quad (6)$$

$$\delta = \rho_s - \theta_r \quad (7)$$

Where L_s, L_r are the stator and rotor self-inductance, L_m is the mutual-inductance, σ is leakage coefficient, ω_s is the stator angular frequency, δ is the angle between the stator and rotor flux linkage space vector, P_s and θ_r are the angle between σ axis (rotating at electrical angular speed of the rotor ω_m) and their flux linkage as shown in Fig.1. λ_s and λ_r are the stator and rotor flux linkage.

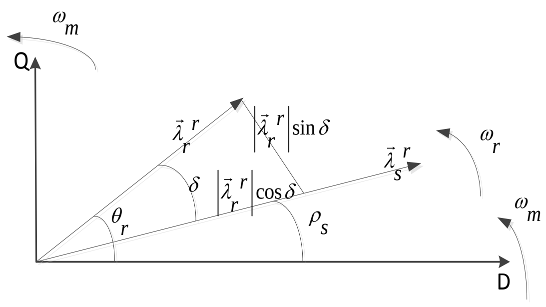

Fig. 1. Flux space vector in rotor reference frame (OQ)

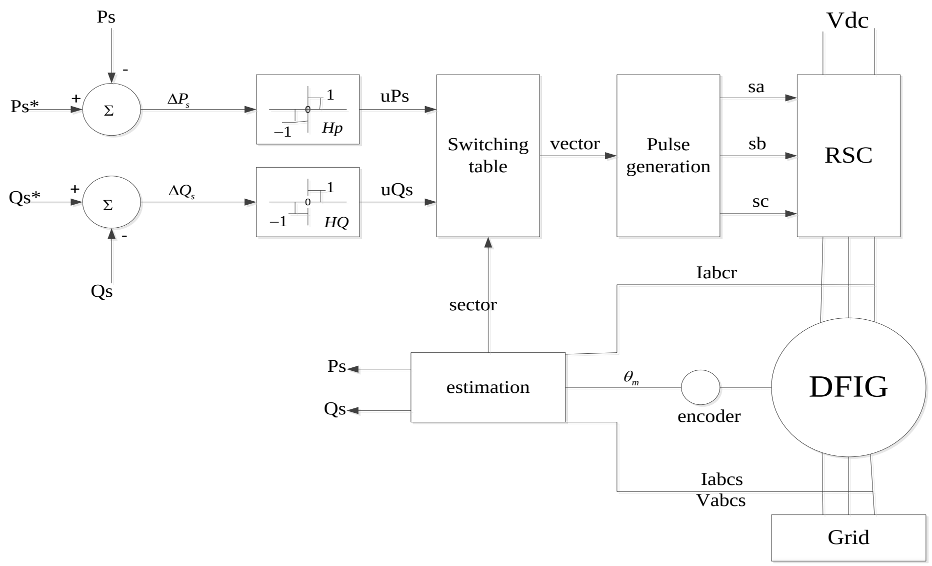

Fig. 2. Block diagram of a DPC for DFIG

The stator windings of DFIG are directly connected to the grid. So under normal conditions, the stator voltage is constant and by neglecting the stator resistance; the stator flux linkage is constant too, so the stator active and reactive power can be written as:

$$P_s = A\left|\vec{\lambda}_r\right|\sin\delta \quad (8)$$

$$Q_s = B\left[C - \left|\vec{\lambda}_r\right|\cos\delta\right] \quad (9)$$

Where A, B and C are constant value. From the above equations, it can be seen stator active power is related to magnitude of rotor flux linkage and sinus of the angle between the stator and rotor flux linkage, as well stator reactive power is related to magnitude of rotor flux linkage and Cosine of the angle between stator and rotor flux linkage, as shown in Fig.1. In direct power control, the stator active and reactive power directly controlled by comparing the reference power with estimated power. The power error is compared with a hysteresis band wide and flags of the hysteresis band wide are specified. The block diagram of this method is shown in Fig.1. Optimal voltage vector can be selected by knowing rotor flux sector, and the flags of hysteresis comparators. This optimal switching table is shown in Table. l. For example, if the rotor flux linkage vector located in sector I and v2 selected, this voltage vector makes active and reactive power to decrease (the active power will be more negative) and if V3 selected, makes the active power to decrease and reactive power to increase.

4. Proposed combined vector control and direct power control

Due to the vector control, a phase locked loop (PLL) for the stator voltage used, therefore the stator voltage space vector gets along the d axis that rotates at slip speed ($\omega_r = \omega_s - \omega_m$) in the d-q reference frame. So, by neglecting the stator resistance, the stator flux linkage space vector lags the stator voltage space vector by 90 degrees. The location of stator voltage vector and d-q axis in the d-q reference frame is shown in Fig.3 [7-8].

Due to the equations (8) and (9), the related variations of active power and reactive power are shown by red lines in Fig.3. As shown in this figure, variation of active power is along the d axis, and the variation of reactive power is along the q axis. From equations (3) and (4) and Fig.1 it is concluded:

$$\begin{aligned} \Delta P_s &\propto \Delta I_{ds} \\ \Delta Q_s &\propto -\Delta I_{qs} \end{aligned} \tag{10}$$

It means that the variation of active power is proportional to the variation of d axis stator current and variation of reactive power is proportional to negative variation of q axis stator current. So, d-q axis stator currents can be directly controlled like DPC by a switching table. However, because of the negative relative of reactive power and q axis stator current, the switching table became as Table 2. Fig.4 shows the block diagram of the proposed method which the d --q axis stator currents errors have been compared with a hysteresis band wide. The flags of this comparator and the sector of rotor flux select the voltage vector from Table 2.

5. Simulation Results

Using Matlab/Simulink to build the entire VSCF doubly fed wind power generation system simulation model, as shown in Fig. 5 the wind turbine simulation module which uses Matlab7. 5.0 inherent in wind turbine module (Simulink / Sim power systems / application libraries / distributed resources / wind turbine). Doubly-fed generator parameters are given in Appendix 1. Generally, in order to evaluate the VCDPC method, the evaluation is divided into two parts: the first part is related to the steady-state conditions and the second part is regarding the transient conditions.

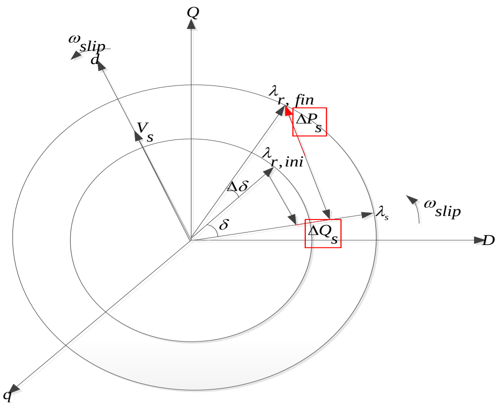

Fig. 3. Stator voltage and flux in DQ reference frame and the relation of direct power to d-q axis currents

Table.1.
Switching table for DPC method

uQ$_s$	***uP***$_s$	***sector***					
		1	***2***	***3***	***4***	***5***	***6***
1	1	V5	V6	V1	V2	V3	V4
	0	V0	V7	V0	V7	V0	V7
	-1	V3	V4	V5	V6	V1	V2
-1	1	V6	V1	V2	V3	V4	V5
	0	V0	V7	V0	V7	V0	V7
	-1	V2	V3	V4	V5	V6	V1

Table.2.
Switching table of proposed method for RSC and GSC

uQ$_s$	***uP***$_s$	***sector***					
		1	***2***	***3***	***4***	***5***	***6***
1	1	V6	V1	V2	V3	V4	V5
	0	V0	V7	V0	V7	V0	V7
	-1	V2	V3	V4	V5	V6	V1
-1	1	V5	V6	V1	V2	V3	V4
	0	V0	V7	V0	V7	V0	V7
	-1	V3	V4	V5	V6	V1	V2

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6. Conclusion

A new control scheme for (ac/dc/ac) converter to control doubly-fed asynchronous generator is proposed and evaluated by simulation in this paper. The VCDPC technique is applied for the tow side (Grid and rotor side). In the steady-state conditions, the VCDPC has power ripple as low as that of DPC. The ripple is significantly lower in comparison with that of DPC. Furthermore, an FFT analysis shows that VCDPC has a suitable THD as which is less than that of DPC. Moreover, the VCDPC-like DPC outperforms VC in providing proper decoupling and robustness against the machine parameters variation. Consequently, the proposed VCDPC not only enjoys lower power ripple as good as VC.

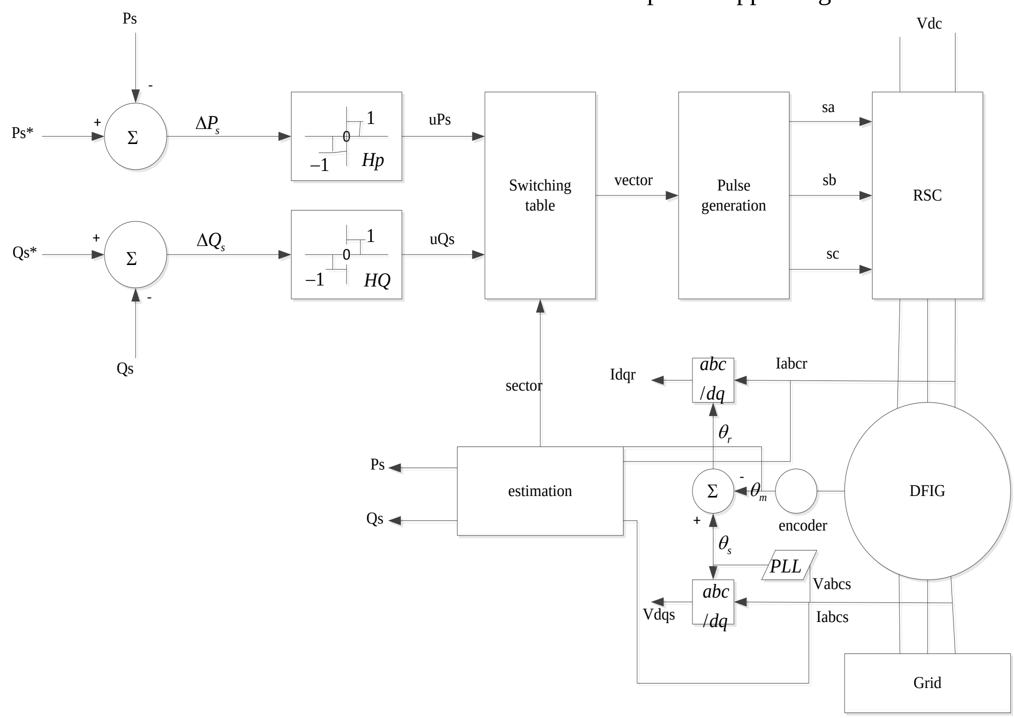

Fig. 4. The block diagram of proposed method for RSC and GSC

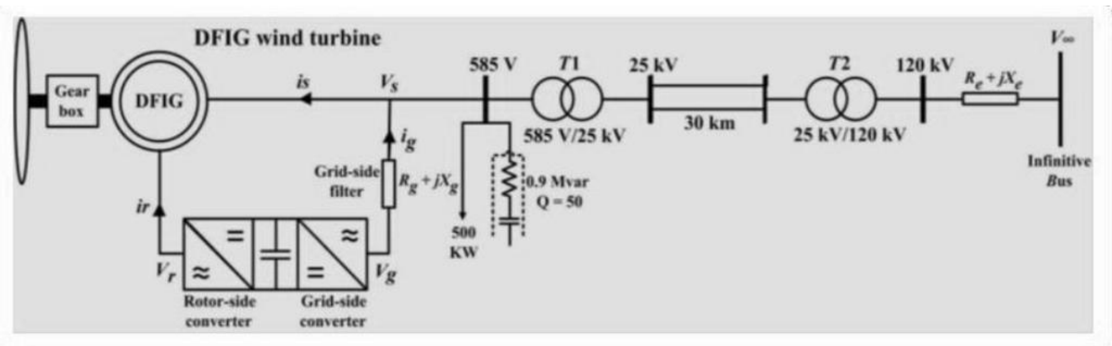

Fig. 5. Schematic diagram of the simulated system

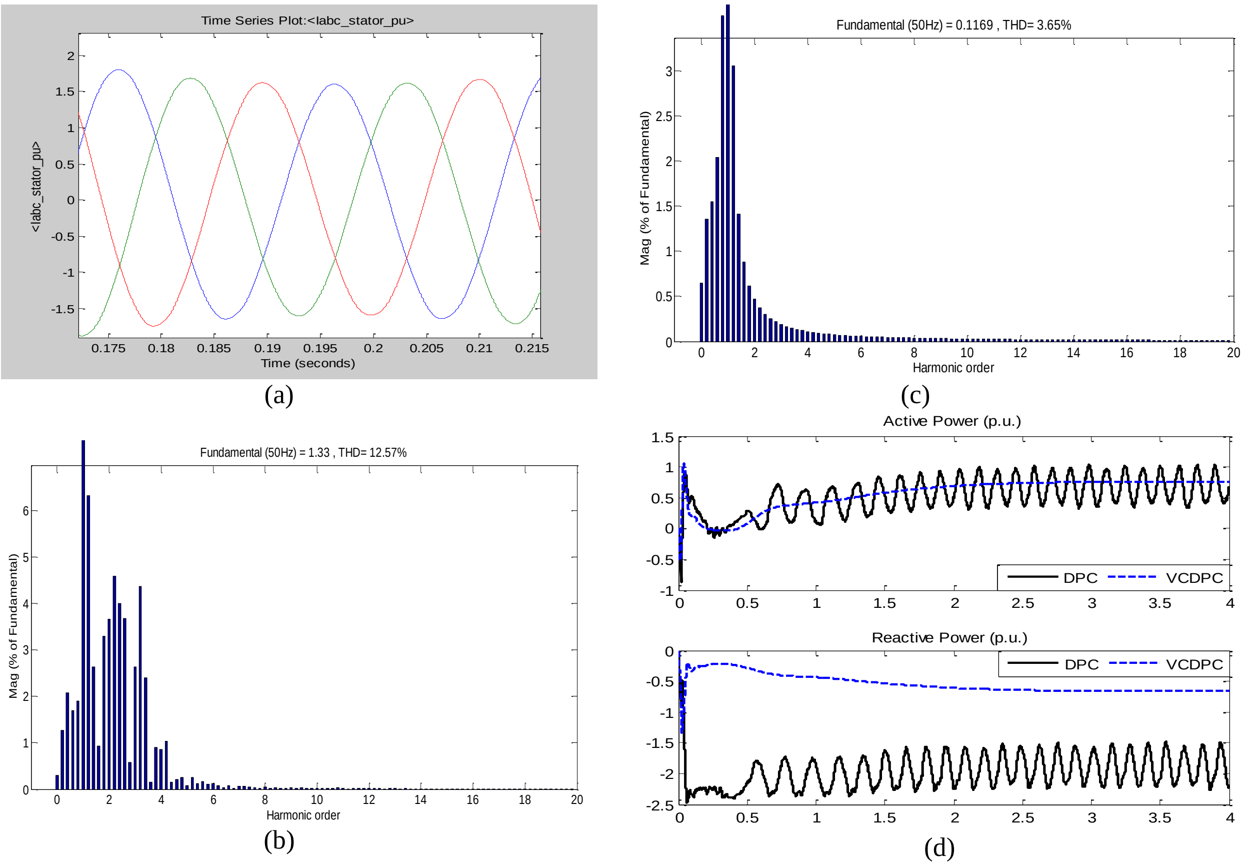

Fig. 6. (a) Stator output current in steady-state conditions and (b) – (c) THD of DPC and VCDPC (d) Active and reactive power of DPC and VCDPC.

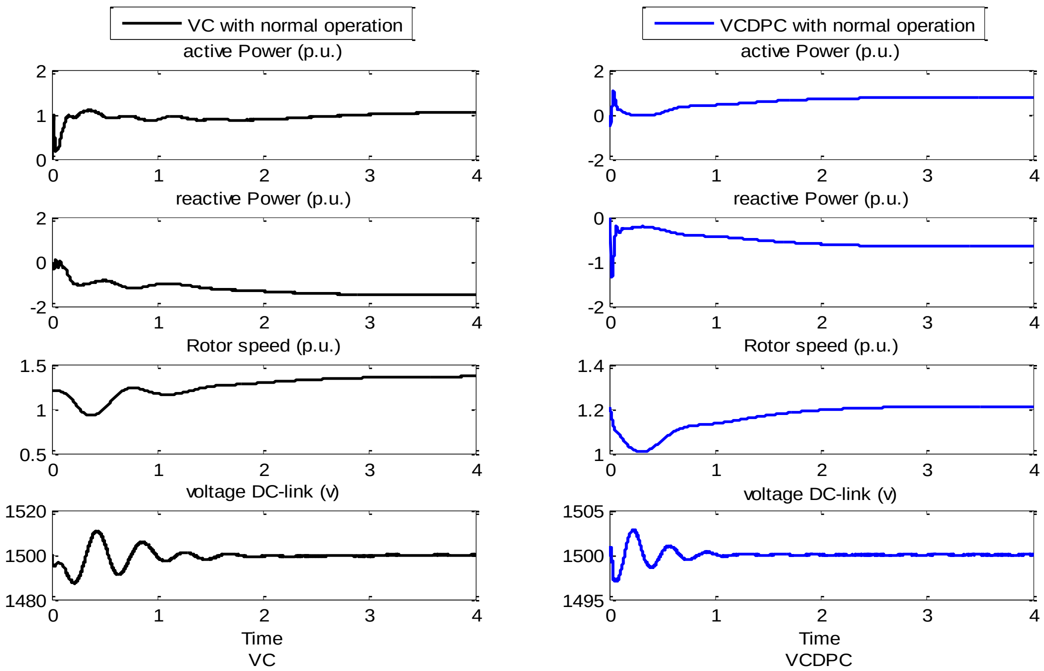

Fig. 7. System simulation results during normal operation.

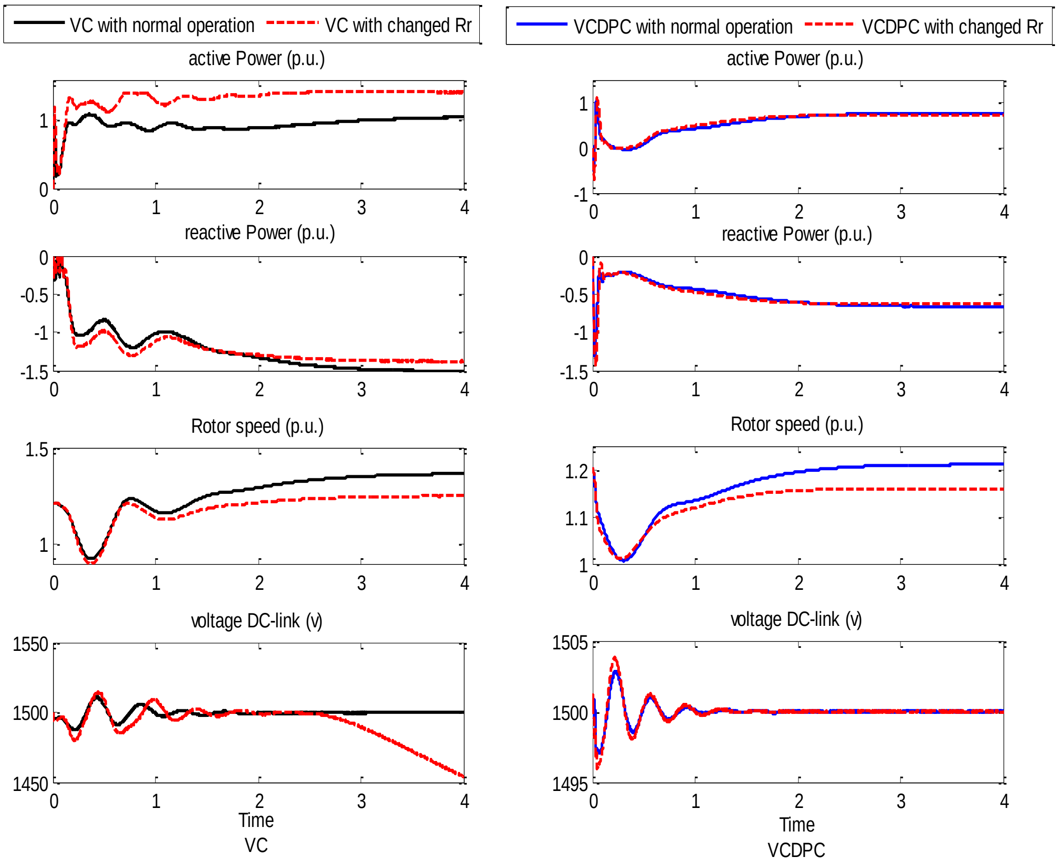

Fig. 8. Simulation results when is Rr changed.

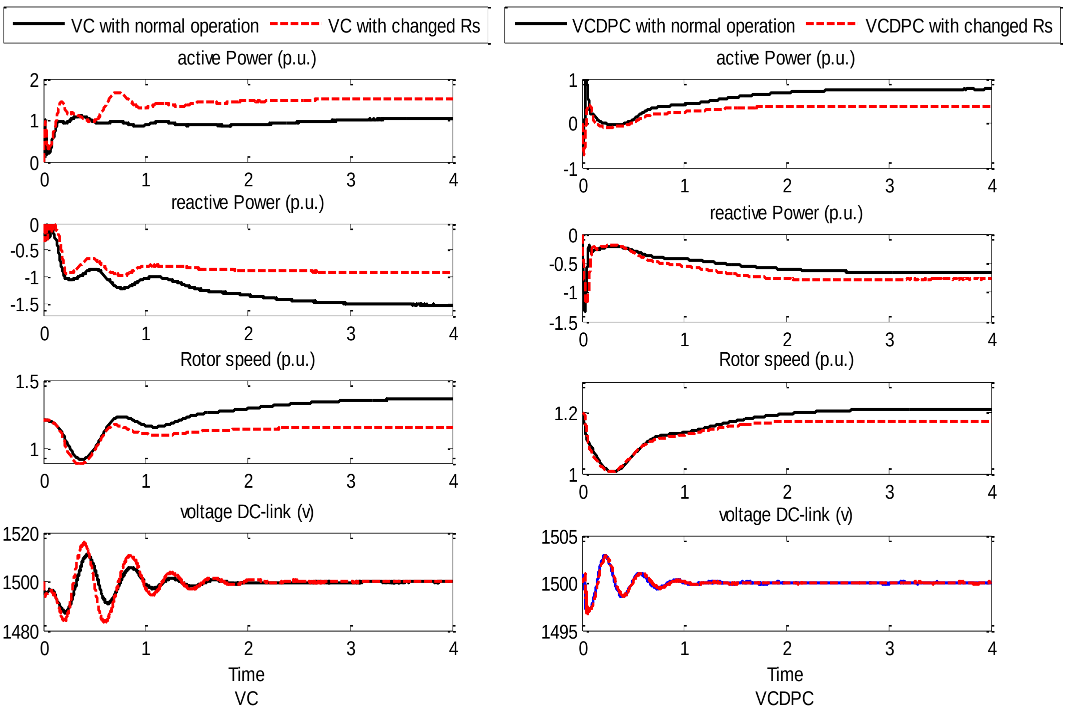

Fig. 9. System simulation results when is Rs changed.

Appendix 1

Parameters of the simulated DFIG:

- Rated power: 2MW
- Rated voltage (phase to phase): 690 v
- Stator resistance (Rs): 1.162 mΩ
- Rotor resistance (Rr): 1.3072 mΩ
- Stator inductance (Ls): 3.1 mH
- Rotor inductance (Lr): 3.1 mH
- Mutual inductance (Lm): 3mH
- Number of pole (P): 4
- DC link capacitor (Cf): 16000μF
- Grid frequency: 50 Hz

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