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# Direct Power Control for AC/DC/AC Converters in Doubly Fed Induction Generators Based Wind Turbine

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**ABSTRACT**

In this paper direct power control (DPC) strategy is applied to control a doubly fed induction generator (DFIG) based wind energy generation system. A AC/DC/AC converter is controlled by direct power control method. The rotor side converter is controlled by selects 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 direct power control based a grid voltage position to ensures a constant DC voltage, Simulation results demonstrate robust, precise, and fast dynamic behavior of system.



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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 decupled 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 are required and nonlinear operation of converter for tuning current controllers is not considered. So 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 mid 1980s. DTC is based on decoupled torque and flux control which have very fast and precise dynamic without using 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]. The Grid side converter (GSC) is used to maintain DC link voltage at desired reference level for all operation conditions of DFIG. The conventional voltage-oriented control (VOC) is used to control GSC. In this method two decoupled current control loops are used to control DC voltage and reactive power which result in complex algorithm and dependency of system response on system parameters and operation condition. Because of dependence of rotor active power on generator speed, it has fast dynamic and in order to have constant DC voltage the GSC must transmit the active power between rotor and grid with a fast response. In this paper the direct power control DPC is proposed to control the ac/dc/ac converter. The effectiveness of the technique and the improvement of the whole system performance are proved by simulation software.

## 2. DIRECT POWER CONTROL

The Direct Power Control (DPC) is based on the instantaneous active and reactive power control loop. There are no internal current control loop and no PWM modulator block. The switching state is determined with a switching table based on the instantaneous errors between the commanded and estimated values of active and reactive power.

Based on the theory of the direct self control and the direct torque control respectively, the goal of every direct control strategy is to minimize the errors between reference and actual values in each sampling step. This is done by selecting the appropriate converter output voltage vector to push the state of the system towards the reference values. In this case the controlled values are the instantaneous active and reactive power components of the stator and the grid, respectively. The instantaneous active and reactive power components for a three phase system can be calculated as

$$P_s = \frac{3}{2}(v_{sd} i_{sd} + v_{sq} i_{sq}) \tag{1.a}$$

$$Q_s = \frac{3}{2}(v_{sd} i_{sq} - v_{sq} i_{sd}) \tag{1.b}$$

The power reference values are provided from outer control loops, like the dc-link (voltage or speed) controller. Due to the calculation is done continuously, a direct control algorithm needs no modulator and it is able to reach the maximum dynamic capability of the system. Furthermore, no coordinate transformations are required. The control loops are based on hysteresis regulators. The appropriate voltage vector is selected from a précalculated switching table. The block diagram of a ac/dc/ac PWM converter controlled py direct power control in DFIG is shown in Figure 1. The control consists of two parts, the grid side and machine side.

## 3. GRID SIDE DIRECT POWER CONTROL

The DPC method is similar to Direct Torque Control (DTC) for induction motor. Instead of torque and stator flux the instantaneous active and reactive powers are controlled. The grid side DPC controls the amplitude of the dc link voltage (active power flow). Based on the equivalent circuit of the grid side converter and the inductive filter connected to the grid, the voltage equation is given as

$$\overrightarrow{v_g} = R_f \overrightarrow{\iota_g} + L_f \frac{d\overrightarrow{\iota_g}}{dt} + \overrightarrow{e_g} \tag{2}$$

With

$$\overrightarrow{e_g} = \begin{cases} U_{dc} e^{\frac{j(k-1)\pi}{3}} & for\ k = 1 \ldots .6 \\ 0 & for\ k = 0,7 \end{cases} \tag{3}$$

$\overrightarrow{e_g}$ the grid side converter output voltage. The change of current can be calculated by neglecting the filter resistance as follows

$$\overrightarrow{\Delta\iota_g} \approx \frac{1}{L_f}\int_0^{T_s} (\overrightarrow{v_g} - \overrightarrow{e_g})\, dt \tag{4}$$

By changing into $d$–$q$ reference frame, which is oriented with the grid voltage vector (thus $v_{gq}= 0$), the change of the instantaneous active and reactive power can be simplified to

$$\Delta P_g \approx u_{gd}.\Delta i_{gd} \tag{5.a}$$

$$\Delta Q_g \approx -u_{gd}.\Delta i_{gq} \tag{5.b}$$

Equation (4) indicates that the grid current change $\Delta i_g$ is directly controlled by the applied voltage vector $e_g$. Since the power is linear to the current, it is possible to control both active and reactive power components. The selection of the voltage vector depends on the location of the grid voltage in the $\alpha$–$\beta$ plane. Therefore this plane is divided into $k$ = 12 sectors as shown in Figure 2.

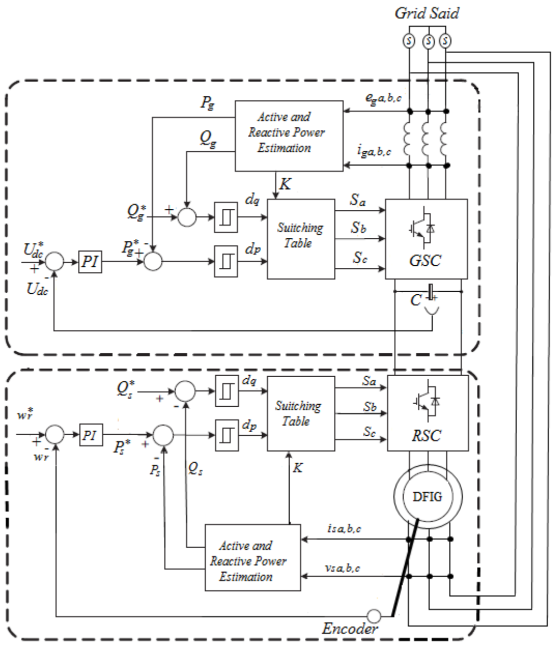
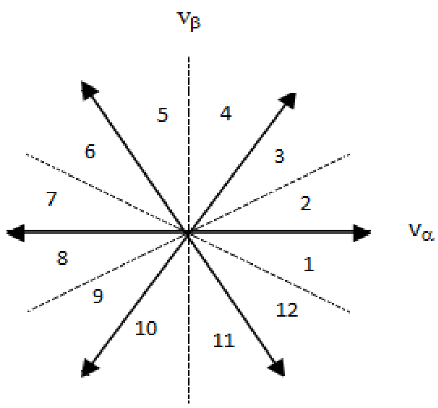
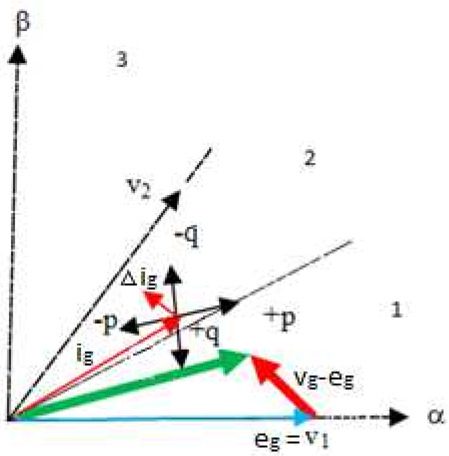



Figure 1. Conventional switching table based direct power control for ac/dc/dc converter in DFIG




a)




b)

Figure. 2 a space vector in ab plane, b.controled the *p* and *q* pay the applied voltage vector $e_g$

Figure2.a shows that the application of $v_1$, the active power will be decreased and the reactive power will be increased. Also the same synthesis is applied of the other vectors. The resulting switching table is shown in Table 1.

Table.1 Optimal switching table for direct power control of GSR

| dp | dq | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | $V_5$ | $V_6$ | $V_6$ | $V_1$ | $V_1$ | $V_2$ | $V_2$ | $V_3$ | $V_3$ | $V_4$ | $V_4$ | $V_5$ |
| 1 | 1 | $V_7$ | $V_7$ | $V_0$ | $V_0$ | $V_7$ | $V_7$ | $V_0$ | $V_0$ | $V_7$ | $V_7$ | $V_0$ | $V_0$ |
| 0 | 0 | $V_6$ | $V_1$ | $V_1$ | $V_2$ | $V_2$ | $V_3$ | $V_3$ | $V_4$ | $V_4$ | $V_5$ | $V_5$ | $V_6$ |
| 0 | 1 | $V_1$ | $V_2$ | $V_2$ | $V_3$ | $V_3$ | $V_4$ | $V_4$ | $V_5$ | $V_5$ | $V_6$ | $V_6$ | $V_1$ |

## 4. DIRECT POWER CONTROL FOR ROTOR SIDE CONVERTER (RSC)

After connecting the stator of the DFIG to the grid terminals, the DPC strategy is applied at the Rotor side Converter. In the DPC scheme, the RsC is controlled by two hysteresis controllers: one of them is controlling the stator active power Ps and the other, the stator reactive power Qs. The outputs of these comparators for the power errors, together with the position of the rotor flux vector, are the inputs of an optimal switching table to select appropriately the instantaneous voltage vector to apply for the inverter in order to make the desired action on the active and reactive powers. It makes six active possible rotor voltage vectors and two inactive ones that are not applied. This switching state is fixed until the next time step $T_0$ of the algorithm. The relation between the rotor flux and the rotor voltage vectors is given by

$$\overrightarrow{v_r} = Rr\overrightarrow{\iota_r} + \frac{d\overrightarrow{\Psi_r}}{dt} \tag{6}$$

The rotor flux variation that takes place along the applied rotor voltage vector:

$$\overrightarrow{\Psi_r} = \overrightarrow{\Psi_{r\iota}} + \int \overrightarrow{v_r} dt \tag{7}$$

The rotor flux change (increment) falls opposite to the applied voltage vector's direction, as the generator association of signs was adopted. But, the rotor flux is as follows:

$$\overrightarrow{\Psi_r} = \frac{l_m}{l_s}\overrightarrow{\Psi_s} + l_r\overrightarrow{\iota_r} \tag{8}$$

The active and reactive stator powers Ps, Qs (with zero stator losses) are

$$P_s = -\frac{3}{2}p\omega_s Im\left(\overrightarrow{\Psi_r}.\overrightarrow{\iota_r}^*\right) \tag{9.a}$$

$$Q_s = -\frac{3}{2}p\omega_s Re\left(\overrightarrow{\Psi_r}.\overrightarrow{\iota_r}^*\right) \tag{9.b}$$

With Equation (8), and introducing a flux power angle γ between and Ps and Qs become

$$P_s = \frac{3}{2}p\omega_s \frac{l_m \Psi_s \Psi_r}{l_s l_r} \sin\gamma \tag{10.a}$$

$$Q_s = \frac{3}{2}p\omega_s \frac{l_m}{l_s l_r}(\Psi_r - \Psi_s \cos\gamma) \tag{10.b}$$

Equations (10.a) and (10.b) express that the stator active and reactive powers can be controlled by adjusting amplitude of stator and rotor flux space vectors and angle between them.

Disinviting (10.a) and (10.b) yields:

$$\frac{dP_s}{dt} = -\frac{3\omega_s}{2\sigma l_s}\left|\Psi_s^r\right| \frac{d(|\Psi_r^r| sin\gamma)}{dt} \tag{11.a}$$

$$\frac{dQ_s}{dt} = \frac{3\omega_s}{2\sigma l_s}\left|\Psi_s^r\right| \frac{d(|\Psi_r^r| cos\gamma)}{dt} \tag{11.b}$$

So by changing $\Psi_r sin\gamma$ and, $\Psi_r cos\gamma$ stator active and reactive power can be varied, as depicted in Figure 2.

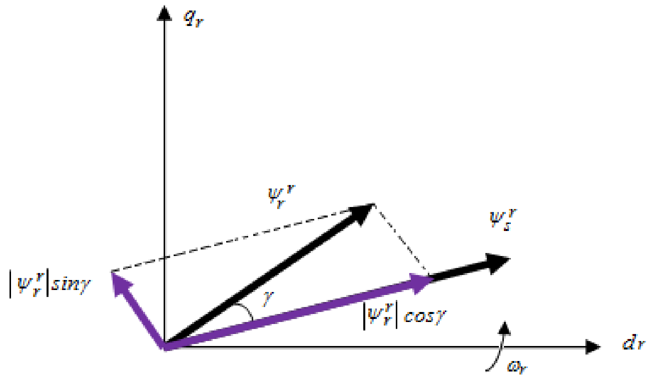



Figure 3. Stator and rotor flux vectors in rotor reference frame

So, by variation of rotor flux vector in same and vertical directions into rotor flux vector, the active and reactive power change, respectively Rotor converter output voltage space vectors in rotor reference frame for a two level converter is depicted in Figure 4. It can be divided in zero voltage vectors ($V_0$ and $V_7$) and active voltage vectors ($V_1$ –$V_6$).

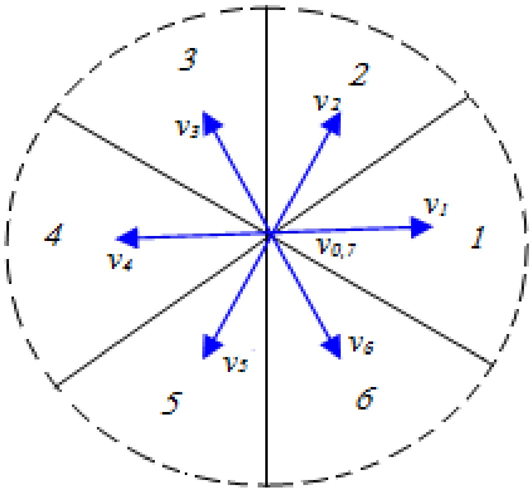



Figure 4. Rotor converter output voltage space vectors for a two level converter

Based on the sign of active and reactive power errors, with rotor flux vector in sector K, the application of voltage vectors *V(K +1)* and *V(K +2)* would increase the delivered stator active power, while the vectors *V(K −1)* and *V(K −2)* would reduce it. Moreover, the application of *V(k), V(K −1),* and *V(K −2)* would decrease the delivered reactive power, while *V(k), V(K+1), V(K+2),* and *V(K+3)* would increase it. The reactive power control is the same in motor and generator operation modes. Table 2 illustrates the selection of voltage vector by (Equation 11) and the sector.

Table-2 Optimal switching table for direct power control of DFIG

| dp | dq | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | 1 | $V_5$ | $V_6$ | $V_1$ | $V_2$ | $V_3$ | $V_4$ |
| 0 | 1 | $V_3$ | $V_4$ | $V_5$ | $V_6$ | $V_1$ | $V_2$ |
| 1 | 0 | $V_6$ | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ |
| 0 | 0 | $V_2$ | $V_3$ | $V_4$ | $V_5$ | $V_6$ | $V_1$ |

## 5. SIMULATION RESULTS

The simulated system parameters are shown in table 4. The simulation is performed by Matlab/Simulink software

Table 4. Parameters of simulation of DFIG

| | | |
|---|---|---|
| Generator | Rated Power | 2MW |
| | Stator voltage | 690 V |
| | Rs | 0.0108 pu |
| | Rr | 0.0121 pu |
| | Lls | 0.102 pu |
| | Llr | 0.11 pu |
| | Lm | 3.362 pu |
| | H | 0.5 |
| | Pole paires | 2 |
| Converter | DC link voltage | 1200V |
| | DC link capacitor | 16mF |
| | Grid side inductance | 0.4mf |

The simulation of the proposed control scheme has been performed under two different operating conditions.

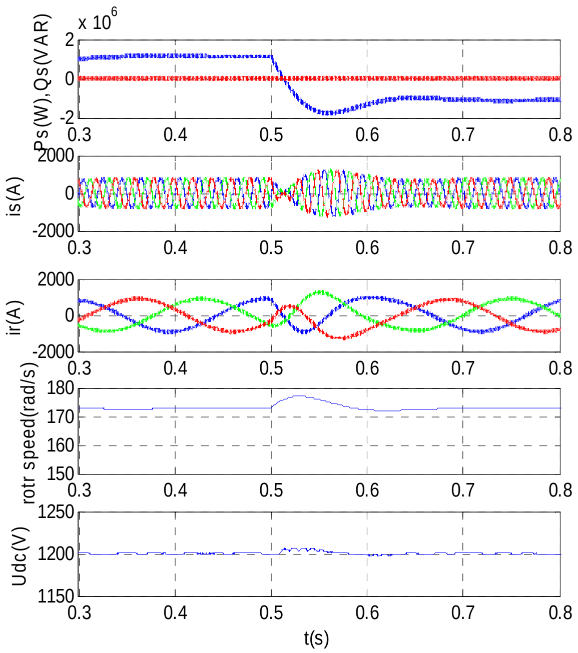



Figure 6. The simulation results under hypersynchronous speed: 175 rad/s active power step from $1.6.10^6$ W (motor mode) to $-1.6.10^6$ W. (generator mode).

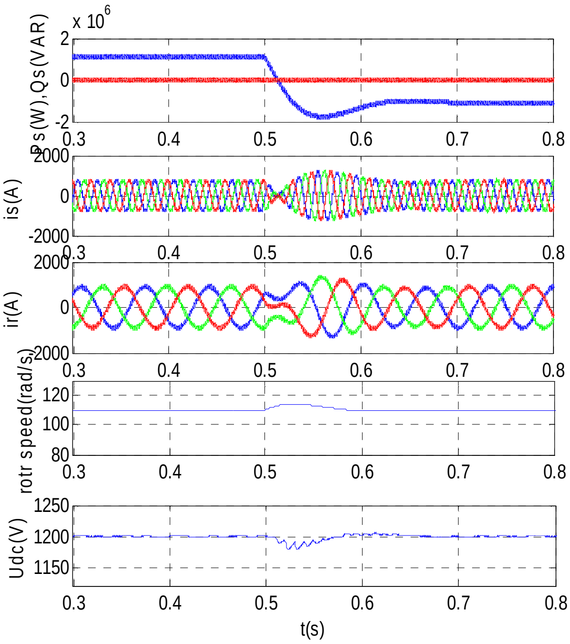



Figure 7. the simulation results under subsynchronous speed: 110 rad/s active power step from 1.6.10$^6$ W (motor mode) to -1.6.10$^6$ W (generator mode)

## 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 DPC technique is applied for the tow side (Grid and rotor side). The proposed scheme has the advantages of simple algorithm, good dynamic performances, especially, can obtain stable dc-bus voltage at desired reference level, in all operation conditions.

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