# Reactive Power Control of Doubly Fed Induction Generator based Wind Turbine

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***Abstract—*** Power generation utilizing renewable resources have been increasing worldwide very rapidly. When such resources have to be integrated with existing power system then operation becomes more challengeable particularly in terms of stability, security and reliability. So the recent grid codes particularly established for large scale integration of renewable power generation in the power system demand the network support similar to conventional generator in steady state and dynamic operations. The voltage instability is one of the major concerns with huge amount of wind power penetration in the existing power system which is due to insufficient amount of reactive power. Modern wind generators used in variable speed applications equipped with power electronics converters has capability to deliver/ consume reactive power similar to the conventional generator. In present work, First grid connected DFIG- based wind turbine system is analyzed to ensure the independent control of active and reactive power, then the reactive power control through RSC is ensured and Voltage control strategy is implemented that controls the voltage at point of common coupling effectively.

***Keywords****-Wind turbine; DFIG; Reactive power control; RSC; GSC; Voltage control;*

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## I. INTRODUCTION

Rapid depletion and Environmental concerns associated with fossil fuel attracted the attention worldwide towards the development of clean and sustainable energy technology. Among various renewable energy resources wind energy is most promising and fast developing one. India has forth position in the world in wind power generation with the total installed capacity of [1]. In some cases, power generation has reached to the power utility level. Due to increased wind power penetration, the operation of power system has become more challenging task particularly in terms security, stability, and reliability [2]. In order to integrate wind power generating system into the grid, different grid operators are developing new grid codes according to characteristics of their electric power grids [3]. It is require that large scale wind generating system must operate similarly to conventional power plant in steady state as well as in transient conditions. The frequency regulation, voltage regulation and fault ride-through (FRT) capability are the main requirements from wind power plants. variable speed wind turbine (VSWT) namely doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) equipped with power electronics converters have the capability to fulfill grid code requirements to greater extent [4]. In addition, DFIG based VSWT has the numerous advantages such as wide operating speed range below and above synchronous speed, more energy extraction, , independent control of active and reactive powers , reduced converter size [5]. Reactive power capability of DFIG based wind turbine has been determined under different operating conditions [6-7]. Reactive power control strategies are used in steady state and transient conditions. But voltage variation for different loading conditions is not considered [8]. In the present work, grid connected DFIG-based wind turbine system is considered. The maximum power point algorithm is used to obtain track the maximum power different wind speed operation. The Rotor side converter (RSC) is controlled in stator flux oriented control and the grid side converter (GSC) is controlled in voltage oriented control. The variation in voltage at the point of common coupling (PCC) occurs due to lagging power factor load variation. Voltage control strategy is implemented to control the voltage at PCC.

## II. DFIG BASED WIND TURBINE

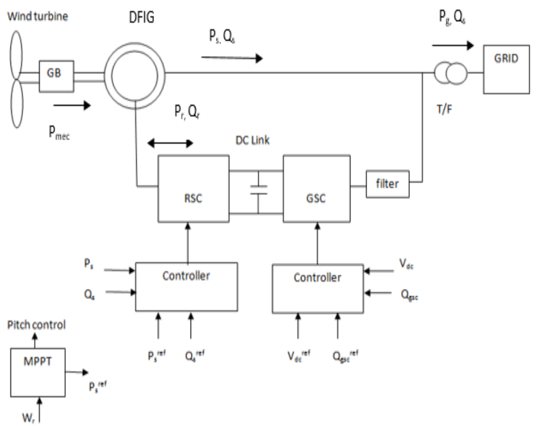


Figure 1. General structure of DFIG based wind turbine

The DFIG equipped wind turbine structure is shown in figure 1 that comprises of wind turbine, DFIG, two back to back connected voltage source converter and control system.

### *A. Wind turbine modeling*

The mechanical power extract from the wind turbine expressed as [9]

$$P_w = \frac{1}{2}\rho\pi R^2 V_w{}^3 C_p(\lambda,\beta) P_w \qquad (1)$$

Where $\rho$ = Air density in Kg/m$^3$, $R$ = Radius of rotor blade, $V_w$ = wind speed in m/s , $C_p$ = power coefficient, $\lambda$ = tip speed ratio, $\beta$ = pitch angle in deg.The tip speed ratio, $\lambda$ is given by

$\lambda = \frac{R\Omega_t}{V_w}$, Where $\Omega_t$ = Angular speed of wind turbine.

$$C_p(\lambda,\beta) = c_1(\frac{c_2}{\lambda_i} - c_3\beta - c_4\beta^2 - c_5)e^{-c_6} \quad (2.a)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (2.b)$$

Where, $c_1 = 0.5, c_2 = 116, c_3 = 0.04, c_4 = 0, c_5 = 5, c_6 = \frac{21}{\lambda_i}$

The optimum electric power reference, $Ps^{ref}$ or electromagnetic torque reference, $Tem^{ref}$ is calculated taking into account the optimal rotor speed for the incoming wind speed considering the Cp-$\lambda$ curves [15-x].

### *B. Modeling of doubly fed induction generator*

The synchronously rotating reference is used to describe the equation of DFIGURE The advantage of transforming all the variables in synchronously rotating reference is that the d-q components of the variables are time invariant resulting in less computational time requirements for control aspects. The mathematical expression of doubly fed induction generator:

$$V_s^a = R_s i_s^a + \frac{d\Psi_s^a}{dt} + j\omega_s \Psi_s^a \quad (3.a)$$

$$\overrightarrow{V_r^a} = R_r i_r^a + \frac{d\Psi_r^a}{dt} + j(\omega_s - \omega_m)\Psi_r^a \quad (3.b)$$

$$\Psi_s^a = L_s i_s^a + L_m i_r^a \quad (4.a)$$

$$\Psi_r^a = L_m i_s^a + L_r i_r^a \quad (4.b)$$

The superscript ‘a’ denotes space vectors referred to synchronous reference frame.

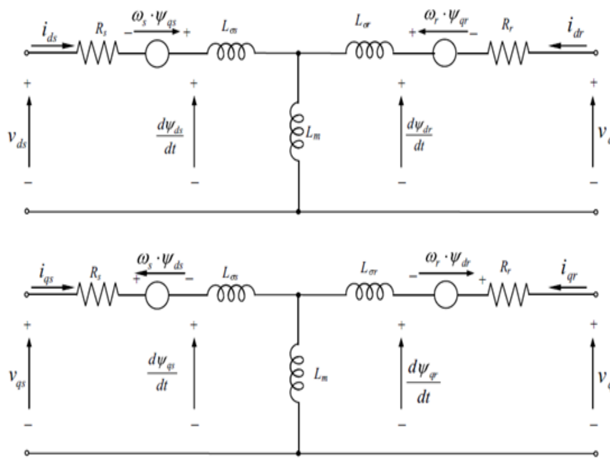

Figure 2. d-q model of DFIG in synchronously rotating reference fram

The stator and rotor mathematical equation of DFIG can be transformed to d-q components by using Park's transformations as follow:

$$V_{ds} = R_s i_{ds} + \frac{d\Psi_{ds}}{dt} - \omega_s \Psi_{qs} \quad (5.a)$$

$$V_{qs} = R_s i_{qr} + \frac{d\Psi_{qs}}{dt} + \omega_s \Psi_{ds} \quad (5.b)$$

$$V_{dr} = R_r i_{dr} + \frac{d\Psi_{dr}}{dt} - (\omega_s - \omega_m)\Psi_{ds} \quad (5.c)$$

$$V_{qr} = R_r i_{qr} + \frac{d\Psi_{qr}}{dt} + (\omega_s - \omega_m)\Psi_{ds} \quad (5.d)$$

$$\Psi_{ds} = L_s i_{ds} + L_m i_{dr} \quad (6.a)$$

$$\Psi_{ds} = L_s i_{qs} + L_m i_{qr} \quad (6.b)$$

$$\Psi_{dr} = L_r i_{dr} + L_m i_{ds} \quad (6.c)$$

$$\Psi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (6.d)$$

where, $\omega_s - \omega_m = \omega_r$

$$L_s = L_{\sigma s} + L_m$$

$$L_r = L_{\sigma r} + L_m$$

$$p_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs}) \quad (7.a)$$

$$p_r = \frac{3}{2}(V_{dr} i_{dr} + V_{qr} i_{qr}) \quad (7.b)$$

$$Q_s = \frac{3}{2}(V_{qs} i_{ds} - V_{ds} i_{qs}) \quad (7.c)$$

$$Q_r = \frac{3}{2}(V_{qr} i_{dr} - V_{qr} i_{dr}) \quad (7.d)$$

$$T_{em} = \frac{3}{2} p \frac{L_m}{L_s}(\Psi_{qs} i_{dr} - \Psi_{ds} i_{qr}) \quad (8)$$

### *C. Vector control strategy of DFIG*

Vector control (VC) technique being used for the independent control of active and reactive power [10] VC scheme is based on stator voltage orientation (SVC) [11] and stator flux orientation (SFO) [12]. In SFO vector control technique, the stator flux vector is aligned with d-axis of reference frame such that

$$V_{ds} = 0 \quad (9.a)$$

$$V_{qs} = V_s \approx \omega_s \psi_s \quad (9.b)$$

$$\psi_{ds} = \psi_s \quad (9.c)$$

$$\psi_{qs} = 0 \quad (9.d)$$

$$V_{ds} = 0 = R_s i_{ds} + \frac{d\Psi_{ds}}{dt} - \omega_s \Psi_{qs} \quad (10.a)$$

$$V_{qs} = V_s = R_s i_{qr} + \frac{d\Psi_{qs}}{dt} + \omega_s \Psi_{ds} \quad (10.b)$$

$$\Psi_{ds} = \psi_s = L_s i_{ds} + L_m i_{dr} \quad (11.a)$$

$$\Psi_{qs} = 0 = L_s i_{qs} + L_m i_{qr} \quad (11.b)$$

From above equation, we get

$$i_{ds} = \frac{\psi_s - L_m i_{dr}}{L_s} \quad (12.a)$$

$$i_{qs} = -\frac{L_m}{L_s} i_{qr} \quad (12.b)$$

$$i_{ms} = \psi_s / L_m \Leftrightarrow \psi_s = L_m i_{ms} \tag{13}$$

$$i_{ds} = \frac{L_m i_{ms} - L_m i_{dr}}{L_s} = \frac{L_m}{L_s}(i_{ms} - i_{dr}) \tag{14.a}$$

$$i_{qs} = -\frac{L_m}{L_s} i_{qr} \tag{14.b}$$

$$p_s = -\frac{3}{2}\frac{L_m}{L_s} V_s i_{qr} \tag{15.a}$$

$$Q_s = \frac{3}{2}\frac{V_s^2}{\omega_s L_s} - \frac{3}{2} V_s \frac{L_m}{L_s} i_{dr} \tag{15.b}$$

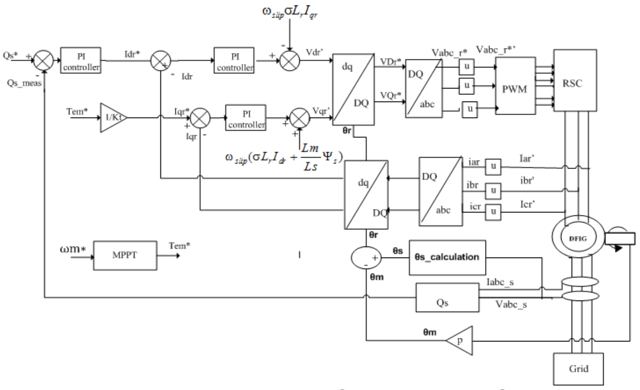


Figure 3. Rotor side converter control

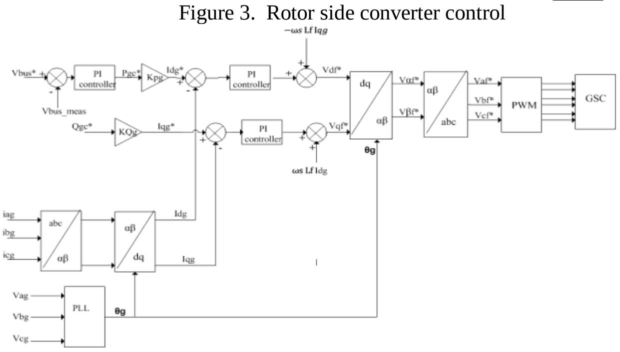


Figure 4. Grid side converter control

## III. ANALYSIS OF DFIG BASED WIND TURBINE UNDER VARIABLE SPEED CONDITIONS

### A. *Super synchronous speed operation*

The maximum power point tracking algorithm is used to obtain optimum torque reference in order to track maximum power corresponding to given wind speed. The wind speed is kept 10 m/s resulting in super synchronous operation of generator as shown in figure5. The stator active power is independently controlled by the q-axis rotor current component, Iqr, according to (15.a) whereas d-axis rotor current component, Idr, is zero as no reactive power control is considered at this moment. When the rotor speed reaches becomes more than synchronous speed, then q-axis rotor voltage changes its sign. So, in this mode of operation, generated power flow from stator as well as from rotor to grid via rotor side converter and grid side converter as is ensured by GSC d-axis rotor current as shown in figure 6.

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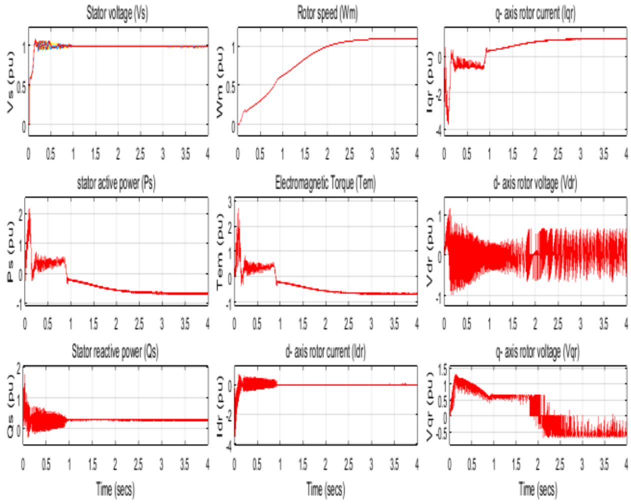


Figure 5. Vaiable speed operation of DFIG in Super synchronous mode

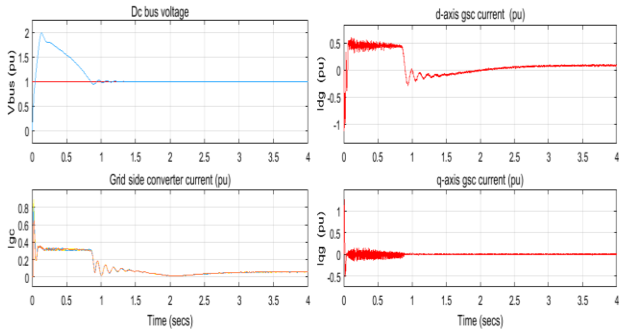


Figure 6. GSC control in super synchronous mode

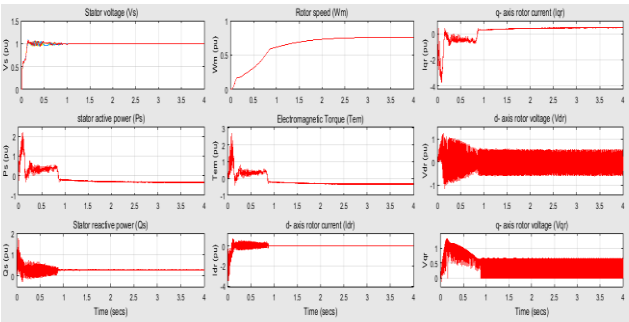


Figure 7. Vaiable speed operation of DFIG in sub synchronous mode

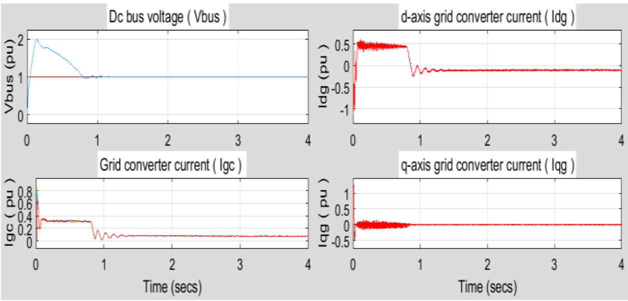


Figure 8. GSC control in sub synchronous mode

### B. *Sub synchronous speed operation*

The wind speed is kept 6 m/s and the rotor speed remain below the synchronous speed as shown in figure 7. As there is no change in the sign of q-axis rotor voltage, the generated power flows only from stator to grid and rotor takes the power from grid through the RSC and GSC. The dc link voltage is constant which ensure the smooth flow of power through dc link in either direction as shown in figure 6 and figure 8.

## IV. Reactive Power Control

The stator reactive power (Qs) is controlled through RSC. The d- axis rotor current component, Idr control the reactive power. From the figure 9, Idr current is zero and stator is magnetized by absorbing the reactive power from the grid. At time 2s, Idr control the reference value of stator reactive power, Qs which is kept zero. The reactive power reference is kept -500 KVAR and +500 KVAR at time 2s and 3s respectively. The rotor current component,Idr track the reference value of Qs as shown in figure 10. The stator active power (Ps) and rotor current component, Iqr remain constant during the whole operation ensuring the independent control of stator active and reactive power.

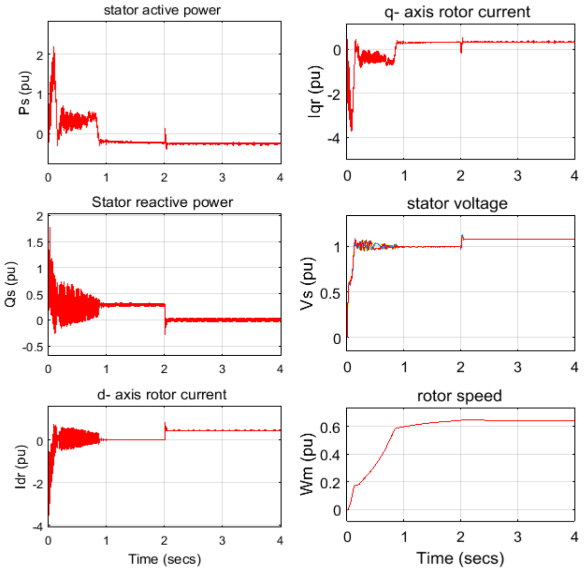


Figure 9. Stator magnetization through grid and RSC

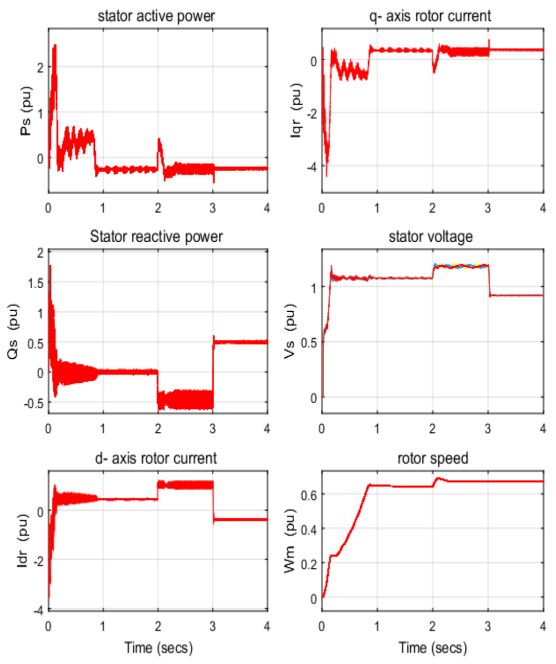


Figure 10. Stator reactive power control

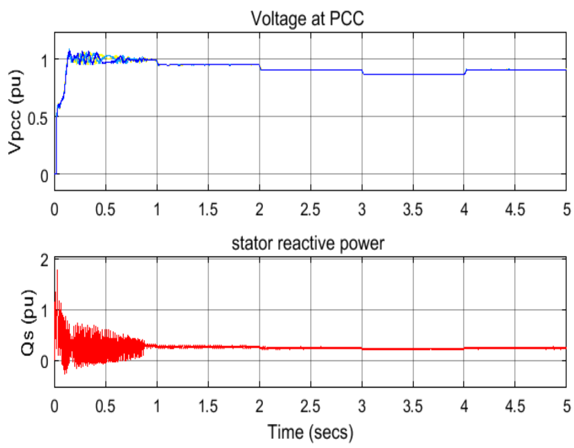


Figure 11. Volatge at pcc and reactive power without voltage control

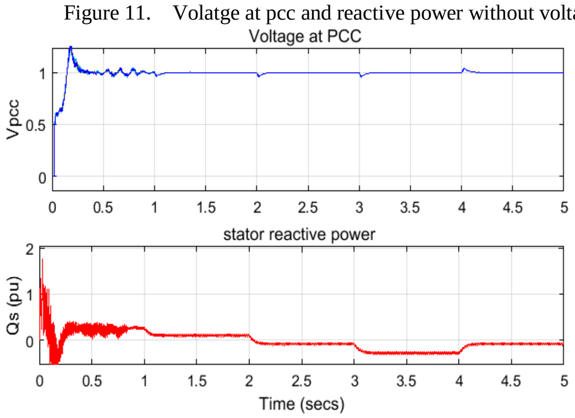


Figure 12 Volatge at pcc and Reactive power with voltage control

## V. Voltage Control at PCC

### A. *Voltage at PCC without voltage control strategy*

The variation of voltage at the PCC is due to the variation in lagging power factor load that increases at time 1s, 2s,and 3s and decreases at time 4s as shown in figure 11. The stator reactive power is zero as no voltage control is considered.

### *B. Voltage at PCC without voltage control strategy*

Voltage control through RSC is implemented to control the voltage at PCC. The figure 2 shows that voltage at PCC controlled effectively by controlling the stator reactive power.

TABLE 1.

| Parameters | PARAMETERS OF DFIG | |
|---|---|---|
| | ***Description*** | ***value*** |
| Ps | Nominal stator active power | 2 MW |
| Vs | Nominal stator voltage | 690 V |
| f | Nominal frequency | 50 Hz |
| Rs | Stator resistance | 0.026 Ω |
| Rr | Rotor resistance | 0.029 Ω |
| Lls | Stator leakage inductance | 0.087 mH |
| Llr | Rotor leakage inductance | 0.087 mH |
| Lm | Magnetizing inductance | 2.5 mH |
| p | Pole pair | 2 |
| u | Stator to rotor turns ratio | 1/3 |

## VI. CONCLUSION

In the present scenario, the penetration of renewable energy resources increased to such large scale posing more challenges to the power utility. Voltage instability is one among the various challenges that need to be control. Modern variable speed wind turbine has the capability to generate/absorb reactive power through power electronics converter along with flow of active power. In the present work, independent control of active and reactive power is ensured in grid connected DFIG-based wind turbine system. Then the reactive power control is ensured for different reference values of reactive power. Also a voltage control strategy using reactive power control through RSC is implemented that results in the effective control of voltage at PCC.

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