

Active and Reactive Power Control of a Doubly Fed Induction Generator

Zerzouri Nora, Labar Hocine

Department of Electrical Engineering, Badji Mokhtar University Annaba, Algeria

Article Info

Article history:

Received Jul 13, 2014

Revised Sep 14, 2014

Accepted Sep 30, 2014

Keyword:

Doubly Fed Induction

Generator (DFIG)

Wind Turbine

Active and Reactive Power

Control

ABSTRACT

Wind energy has many advantages, it does not pollute and it is an inexhaustible source. However, the cost of this energy is still too high to compete with traditional fossil fuels, especially on sites less windy. The performance of a wind turbine depends on three parameters: the power of wind, the power curve of the turbine and the generator's ability to respond to wind fluctuations. This paper presents a control chain conversion based on a double-fed asynchronous machine (D.F.I.G). To improve the transient and steady state performance and the power factor of generation, a stator flux oriented vector control scheme is used in this work. The vector control structure employs conventional PI controllers for the decoupled control of the stator side active and reactive power. The whole system is modeled and simulated using Matlab/Simulink and the results are analyzed.

Copyright © 2014 Institute of Advanced Engineering and Science.

All rights reserved.

Corresponding Author:

Zerzouri Nora

Departement of Electrical Engineering,

Badji Mokhtar University Annaba,

Université Badji Mokhtar -Annaba- B.P.12, Annaba, 23000 Algeria.

Email: Zerzouri_karima@yahoo.fr

1. INTRODUCTION

Wind energy is one of the most important and promising source of renewable energy all over the world, mainly because it reduces the environmental pollution caused by traditional power plants as well as the dependence on fossil fuel, which have limited reserves. Electric energy, generated by wind power plants is the fastest developing and most promising renewable energy source [1]. Off-shore wind power plants provide higher yields because of better conditions. With increased penetration of wind power into electrical grids, wind turbines are largely deployed due to their variable speed feature and hence influencing system dynamics. But unbalances in wind energy are highly impacting the energy conversion and this problem can be overcome by using a Doubly Fed Induction Generator (DFIG) [2]. Doubly fed wound rotor induction machine with vector control is very attractive to the high performance variable speed drive and generating applications. In variable speed drive application, the so called slip power recovery scheme is a common practice here the power due to the rotor slip below or above synchronous speed is recovered to or supplied from the power source resulting in a highly efficient variable speed system. Slip power control can be obtained by using popular Static Scherbius drive for bi directional power flow. Advantage of the DFIG is that the power electronic equipment used a back to back converter that handles a fraction of (20-30%) total system power. The back to back converter consists of two converters. Grid Side Converter (GSC) and Rotor Side Converter (RSC) connected back to back through a dc link capacitor for energy storage purpose [2].

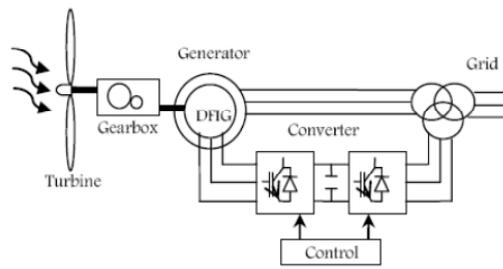


Figure 1. Wind energy conversion chain

2. WIND TURBINE MODEL RESEARCH

Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Wind passes over the blades, generating lift and exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotational speed to that which is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy.

The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time [3], [4].

$$P_{air} = \frac{1}{2} \rho S v^3 \quad (1)$$

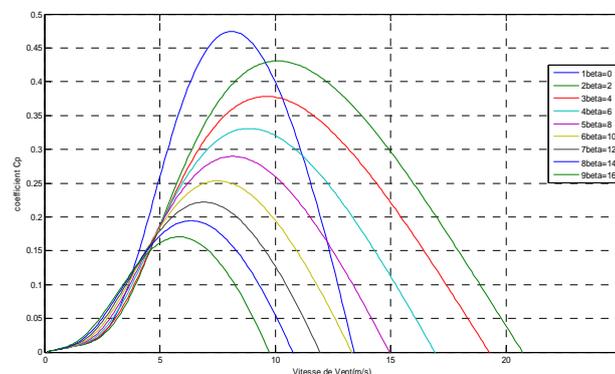
Where P_{air} the power contained in wind (in watts), ρ is the air density (1.225 kg/m³ at 15°C and normal pressure), S is the swept area in (square meter), and v is the wind velocity without rotor interference, ideally at infinite distance from the rotor (in meter per second). Although (1) gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the power coefficient C_p

$$C_p = \frac{P_{wind\ turbine}}{P_{air}} \quad (2)$$

A maximum value of C_p is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum C_p values in the range 25-45%. It is also conventional to define a tip speed ratio λ as [5], [6]:

$$\lambda = \frac{\omega R}{v} \quad (3)$$

Where ω is rotational speed of rotor (in rpm), R is the radius of the swept area (in meter). The tip speed ratio λ and the power coefficient C_p are the dimensionless and so can be used to describe the performance of any size of wind turbine rotor.

Figure 2. The typical curves of C_p versus λ for various values of the pitch angle β

3. DFIG MODELING AND POWER CONTROL

3.1. Principle of Operation

The machine stator winding is directly connected to the grid and the rotor winding is connected to the rotor-side VSC by slip rings and brushes. A wide range of variable speed operating mode can be achieved by applying a controllable voltage across the rotor terminals. This is done through the rotor-side VSC. The applied rotor voltage can be varied in both magnitude and phase by the converter controller, which controls the rotor currents. The rotor side VSC changes the magnitude and angle of the applied voltages and hence decoupled control of real and reactive power can be achieved.

3.2. Mathematical Model of DFIG

For a doubly fed induction machine, the Concordia and Park transformation's application to the traditional a,b,c model allows to write a dynamic model in a d-q reference frame as follows [7]:

$$\begin{cases} V_{ds} = R_s I_{ds} + \frac{d\phi_{ds}}{dt} - \phi_{qs} \omega_s \\ V_{qs} = R_s I_{qs} + \frac{d\phi_{qs}}{dt} + \phi_{ds} \omega_s \\ V_{dr} = R_r I_{dr} + \frac{d\phi_{dr}}{dt} - \phi_{qr} (\omega_s - \omega_r) \\ V_{qr} = R_r I_{qr} + \frac{d\phi_{qr}}{dt} + \phi_{dr} (\omega_s - \omega_r) \end{cases} \quad (4)$$

The flux equations are:

$$\begin{cases} \phi_{ds} = L_s I_{ds} + M I_{dr} \\ \phi_{qs} = L_s I_{qs} + M I_{qr} \\ \phi_{dr} = L_r I_{dr} + M I_{ds} \\ \phi_{qr} = L_r I_{qr} + M I_{qs} \end{cases} \quad (5)$$

Where

ω_s : synchronous angular frequency

ω_r : rotor angular frequency

R_s, R_r : equivalent resistances of stator and rotor windings, respectively

L_s, L_r, M : self and mutual inductances of stator and rotor windings, respectively

The motion equations are given as follows:

$$\frac{d\omega_r}{dt} = \frac{C_m - C_e}{J} \quad (6)$$

$$C_e = \frac{3}{2} PM (I_{qs} I_{dr} - I_{ds} I_{qr}) \quad (7)$$

$$\omega_g = s \omega_s = \omega_s - \omega_r \quad (8)$$

Where

ω_g : slip angular frequency

s : slip

C_m : mechanical torque provided to the wind turbine

C_e : electromagnetic torque

J : moment of inertia

3.3. Establishment of the Control Strategy

Neglecting the resistance of the generator stator winding, the phase difference between stator flux and stator voltage vector is just 90°. Therefore, utilizing the stator flux-oriented to align the stator flux vector position with d -axis, the flux equation is:

$$\begin{cases} \phi_{ds} = \phi_s \\ \phi_{qs} = 0 \end{cases} \quad (9)$$

To keep the stator flux ϕ_s constant, the voltage equations can be expressed as:

$$\begin{cases} V_{ds} \approx \frac{d\phi_{ds}}{dt} = 0 \\ V_{qs} \approx \frac{d\phi_{qs}}{dt} = V_s \end{cases} \quad (10)$$

Where V_s is the space vector amplitude of stator voltage. The active and reactive powers of stator can be derived as:

$$\begin{cases} P_s = \frac{3}{2}(V_{ds}I_{ds} + V_{qs}I_{qs}) \approx \frac{3}{2}V_sI_{qs} \\ Q_s = \frac{3}{2}(V_{qs}I_{ds} - V_{ds}I_{qs}) \approx \frac{3}{2}V_sI_{ds} \end{cases} \quad (11)$$

According to (10), while DFIG is connected to an infinite grid, the stator voltage is considered a constant. The stator current is the only controlled quantity. Therefore, the DFIG output power to grid can be controlled by the stator current, which achieves the goal of independent control for the DFIG active and reactive power output. Due to the stator windings are directly connected to the power systems and the effect of the stator resistance is very small.

Substituting (9) into (5), d - q axis stator current can be calculated as:

$$\begin{cases} I_{ds} = \frac{M I_{dr} - \phi_{ds}}{L_s} \\ I_{qs} = \frac{M}{L_s} I_{qr} \end{cases} \quad (12)$$

Substituting “(12)” into “(4)”, the rotor voltage can be express as:

$$\begin{cases} V_{dr} = R_r I_{dr} + \delta L_r \frac{dI_{dr}}{dt} - \omega_g \delta L_r I_{qr} \\ V_{qr} = R_r I_{qr} + \delta L_r \frac{dI_{qr}}{dt} + \omega_g \delta L_r I_{dr} + \frac{M}{L_s} \phi_{ds} \end{cases} \quad (13)$$

Where $\delta = 1 - \frac{M^2}{L_r L_s}$ is the leakage factor.

The control variables V_{dr} and V_{qr} of the rotor voltage can be obtained from “(13)”. The influence of the cross-coupling between the d - q axis components of rotor current on system performance is small, which can be eliminated by adopting some control law. The model of the vector control of the rotor-side converter obtained from the above analysis is shown in Figure 3.

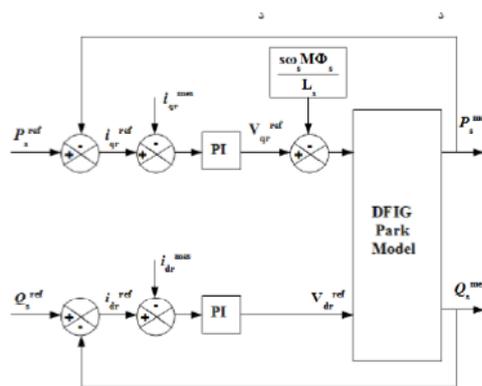


Figure 3. Power control of the DFIG

4. SIMULATION RESULTS

The structure of the DFIG wind energy system is illustrated in Figure 1. The DFIG connected directly to the grid through the stator, and its speed is controlled via a back-to-back PWM converter. The parameters of the DFIG are given in Table 1. A speed wind profile is applied to the system Figure 4.

Table 1. 3MW WTG Induction Machine Parameters

<i>Parameter</i>	<i>Value</i>
Rotor resistor per phase	2,97mΩ
Rotor resistor per phase	3,82mΩ
Inductance of the stator winding	121 mH
Inductance of the rotor winding	57,3 mH
Mutual Inductance	12,12 mH
Number of pole pairs	2
inertia	114 kg.m ²
Rated power	3MW
Rated voltage	690V

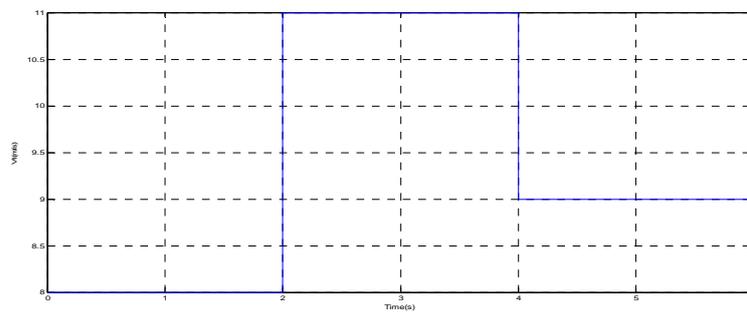


Figure 4. Wind speed profile

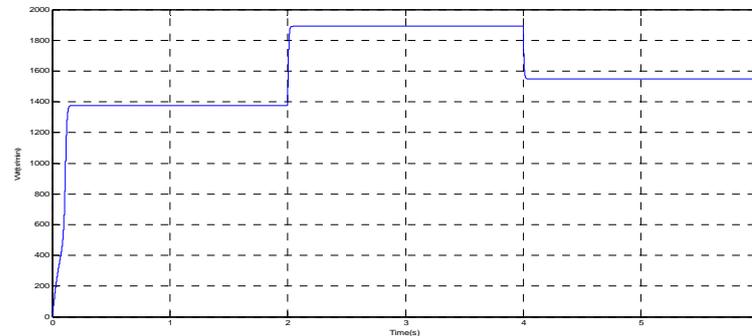


Figure 5. Mechanical speed of the DFIG

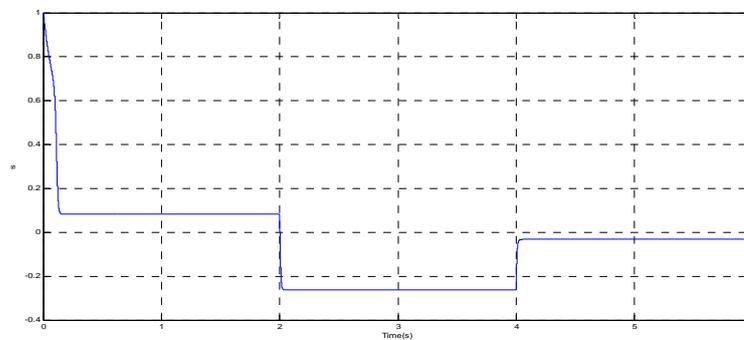


Figure 6. Rotor slip

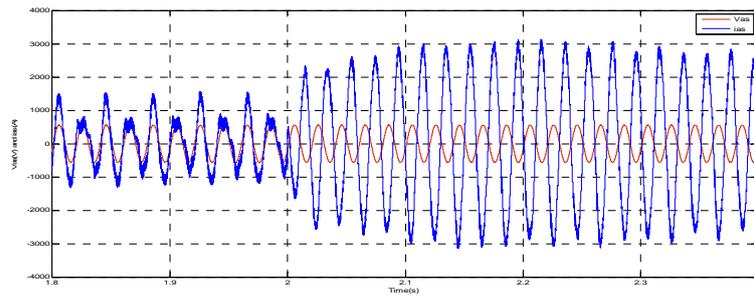


Figure 7. Stator current and voltage

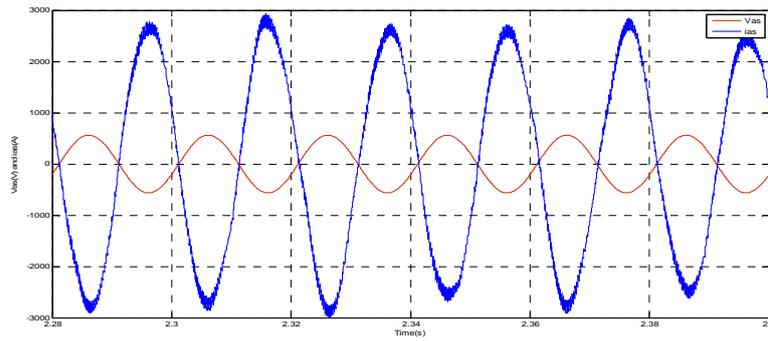


Figure 8. Zoom stator current and voltage

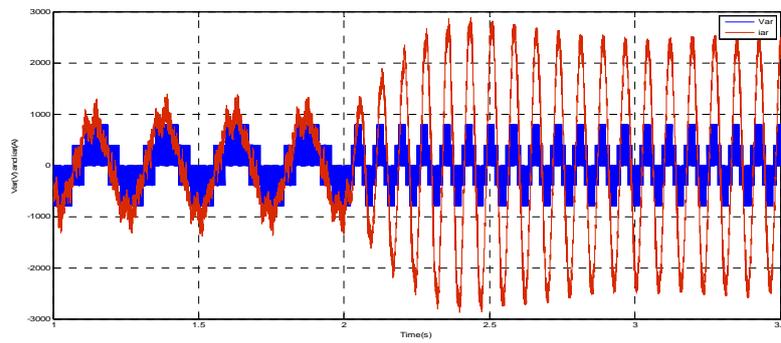


Figure 9. Rotor current and voltage

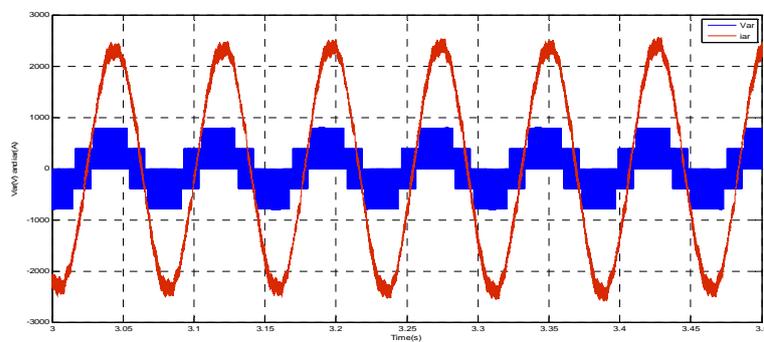


Figure 10. Zoom rotor current and voltage

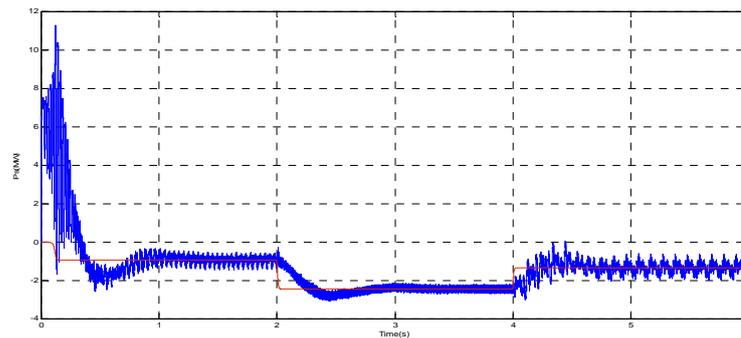


Figure 11. Stator active power

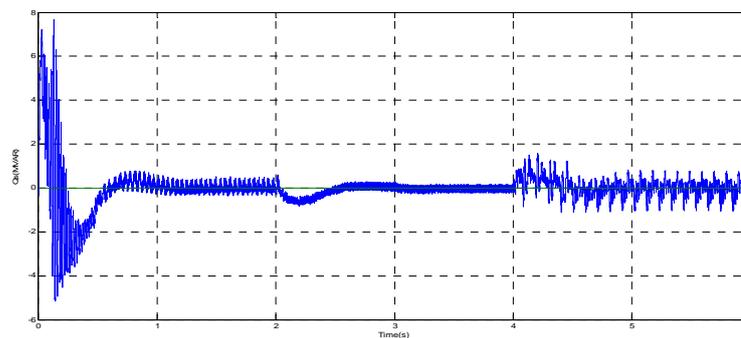


Figure 12. Stator reactive power

Figure 7 shows the zoom of the waveform of the stator voltage and current are in phase opposition. This confirms that the DFIG is sending active power to the grid. We can see that the current and voltage are in phase when the machine acts the motor. Figure 6 shows the generator slip, below synchronous speed the slip is positive and the machine acts as motor, above synchronous speed the slip is negative and machine acts as generator. Figures 11 and 12 illustrate respectively the stator active power and reactive power. We can see the robustness of the power control of the DFIG. Figures 9 and 10 show the rotor voltage and current waveforms. The frequency of these voltage and current, vary according to the slip s .

The active power of DFIG increase from 1MW to the power 2.5MW and the reactive power remains 0Mvar, which signified the reactive power output is not affected. The simulation result indicates that the active and reactive power decoupled control is achieved and the performance is good.

5. CONCLUSION

This paper presents the doubly fed induction generator used in variable-speed wind power generation. And a control structure using standard proportional integral PI controller and a field-oriented control strategy based on a reference frame rotating synchronously with the rotor flux for variable speed wind turbines using doubly fed induction generator and for obtaining injected rotor voltages is described and simulated. Hence results are determined sub-synchronous and super synchronous speeds and the active and reactive power control is achieved by the RSC and GSC. For the purpose of future extension instead of standard PI controllers fuzzy controllers etc. can be used.

REFERENCES

- [1] A Babaie Lajimi, S Asghar Gholamian, M Shahabi. Modeling and Control of a DFIG-Based Wind Turbine During a Grid Voltage Drop. *ETASR - Engineering, Technology & Applied Science Research*. 2011; 1(5): 121-125.
- [2] MA Mossa. Field Orientation Control of a Wind Driven DFIG Connected to the Grid. *Wseas Transactions On Power Systems*. 2012; 4(7).
- [3] Hachemi Glaoui, Harrouz Abdelkader, Ismail Messaoudi, Hamid Saab. Modeling of Wind Energy on Isolated Area” *International Journal of Power Electronics and Drive System (IJPEDS)*. 2014; 4(2): 274~280.

- [4] Yu Ling, Xu Cai. Rotor current dynamics of doubly fed induction generators during grid voltage dip and rise. *Electrical Power and Energy Systems*. 2013; 44: 17–24.
- [5] Srinath Vanukuru, Sateesh Sukhavasi. Active & Reactive Power Control Of A Doubly Fed Induction Generator Driven By A Wind Turbine. *International Journal of Power System Operation and Energy Management*. ISSN (PRINT): 2011; 1(2): 2231–4407.
- [6] Sai Sindhura K, G Srinivas Rao. Control And Modeling Of Doubly Fed Induction Machine For Wind Turbines. *Int. Journal of Engineering Research and Applications*. 2013; 3(6): 532-538.
- [7] Belabbas Belkacem, Tayeb Allaoui, Mohamed Tadjine, Ahmed Safa. Hybrid Fuzzy Sliding Mode Control of a DFIG Integrated into the Network. *International Journal of Power Electronics and Drive System (IJPEDS)*. 2013; 3(4): 351~364.