Vector Control of Wind Turbine Conversion chain Variable Speed Based on DFIG Using MPPT Strategy

Becheri Houcine  
Department of Electrical Engineering, Faculty of Technology,  
University Tahri Mohammed of Bechar, B.P 417, Bechar 08000, Algeria.

Bousserhane Ismail.K  
Smart Grids & Renewable Energies Laboratory, Faculty of Technology,  
University Tahri Mohamed of Bechar, B.P 417, Bechar 08000, Algeria.

Bouchiba Bousmaha  
Smart Grids & Renewable Energies Laboratory, Faculty of Technology,  
University Tahri Mohamed of Bechar, B.P 417, Bechar 08000, Algeria.

Harrouz Abdelkader  
Department of Hydrocarbon and Renewable Energy, Faculty of Science and Technology,  
University Ahmed Draïa of Adrar, National Street N°06, Adrar 01000, Algeria.

Belbekri Tahar  
Department of Technologie, Faculty of Science and Technology,  
University Ahmed Draïa of Adrar, National Street N°06, Adrar 01000, Algeria.

Abstract

Wind energy has many advantages, no polluting gases are produced, no fuel cost besides it is an inexhaustible source. However, its cost is still too high to compete with traditional fossil sources. The yield of a wind turbine depends on three parameters: the power of the wind, the turbine power curve and the ability of the generator to respond to fluctuations in the wind. This paper presents the simulation of MPPT of a wind turbine system equipped with double fed Induction Generator (DFIG) under Matlab Simulink program, first time we simulated all the conversion chain with complete model of DFIG and vector control in second step then the extracted maximum power MPPT strategy is applied, this command is effective and has several advantages. Its offered to maximize kept the power delivered to network despite all the changed parameter.

Keywords: Wind energy, DFIG, Power supply, Vector control, MPPT

INTRODUCTION

Electrical energy is crucial to any socio-economic development [1]. The demand for electricity is very important to this dilemma, it is necessary to appeal to new energy sources that will be without consequence for humans and environment. Wind energy represents a sizeable potential for bearing damping demand increasingly rampant, after centuries of evolution and further research in recent decades and some wind power projects developed by major central wind turbines provide electricity in parts of the world at a competitive price than the energy produced by conventional plants [2].

Today, the development and proliferation of wind turbines have led researchers in Electrical Engineering to conduct investigations in order to improve the efficiency of electromechanical conversion and quality of the energy supplied [3]. In this context, this paper present a study and using of double fed Induction Generator (DFIG) in wind system. Initially modeling and conversion system simulation (turbine and DFIG) Then the stator vector control of active and reactive powers are proposed; in the last step the improved system with extracted maximum power MPPT strategy and the simulation results is discussed.

The objective of this paper is to develop the model and vector control of variable speed wind turbine and their simulation under the MATLAB/SIMULINK environment using MPPT strategy.
WIND POWER SYSTEM MODELING

Wind turbine model
The wind turbine collects the kinetic energy of the wind and converts it into a torque, which turns the blades of the rotor [3, 6]. In our study, the system used a wind turbine based on DFIG, which supplies to generate the torque required to the load, (Figure 1).

Wind modeling
In our case, the wind speed will be modeled as a sum of several harmonics [4]:

\[ V(t) = A + \sum_{k=1}^{i} a_k \sin(\omega_k t) \]

(1)

\( a_k \) : Harmonics amplitudes ; \( \omega_k \) : Harmonics frequency.

The wind speed is represented by the function:

\[ V(t) = 10 + 0.2\sin(0.1047t) + 2\sin(0.2665t) + \sin(1.2930t) - 0.2\sin(3.6645t) \]

(2)

Aerodynamic power
The rotation of the blades creates a mechanical power \( P_t \) on the shaft of the turbine:

\[ P_t = \frac{1}{2} C_p(\lambda, \beta) \cdot p \cdot S \cdot v^2 \]

(3)

Which \( \lambda \) is defined by:

\[ \lambda = \frac{\Omega_t \cdot R}{v} \]

(4)

The power coefficient \( C_p \) represents the aerodynamic efficiency of the wind turbine. We will use an approximate expression of the power coefficient given by [6]:

\[ C_p(\lambda, \beta) = (0.35 - 0.00167(\beta - 2)) \cdot \sin\left[\frac{\pi(1.0 + 0.01)}{14.24 - 0.5(\beta - 2)}\right] - 0.000184(\lambda - 3)(\beta - 2) \]

(5)

The simulation of the power coefficient is shown in Figure 2:

![Figure 2: Cp (\lambda, \beta) Characteristics for various values of pitch angle \beta[13].](image)

The mechanical energy translated aerodynamic torque \( C_t \) rotating the rotor at a speed \( \Omega_t \) The (Figure 3); aerodynamic torque is expressed as follows:

\[ C_t = \frac{\Omega_t}{\Omega} = \frac{\pi}{2\lambda} R^3 \cdot v^2 \cdot C_p(\lambda, \beta) \]

(6)

![Figure 3: Wind turbine Aerodynamic model [4, 6].](image)

For the mechanical part is presented by a simple mechanical model (Figure 4). The dynamic behavior of the generator can be represented by the following equation [6, 13]:

\[ J \frac{d^2 \omega}{dt^2} = C_m - C_{em} - f_v \cdot \omega \]

(7)

Where \( J \) is the inertia rotational moment of the rotor and the generator kg.m², \( \omega \) is the angular velocity of the rotor in rad / s, \( C_m \) is the mechanical torque applied to the alternator shaft in Nm, \( C_{em} \) is the electromagnetic torque developed by the generator in Nm and \( f_v \) is the viscous friction coefficient in Nm.
**DFIG modeling**

We modeled the DFIG with the implementation of the transformation of the park following Repository related rotating field. This repository called system of axes (X, Y), it rotates with the speed of the electromagnetic field [9]:

\[
\begin{align*}
\frac{du_{d}}{dt} &= R_{s} i_{d} + \frac{d\varphi_{d}}{dt} - \omega_{e} \varphi_{q}, \\
\frac{du_{q}}{dt} &= R_{s} i_{q} + \frac{d\varphi_{q}}{dt} + \omega_{e} \varphi_{d}, \\
\frac{du_{o}}{dt} &= R_{o} i_{o} + \frac{d\varphi_{o}}{dt}
\end{align*}
\]

The stator:

\[
\begin{align*}
\varphi_{d} &= L_{q} i_{q} + M_{d} \varphi_{q} \\
\varphi_{q} &= L_{q} i_{q} + M_{q} \varphi_{d}
\end{align*}
\]

For stator:

\[
\begin{align*}
\varphi_{d} &= L_{q} i_{q} + M_{d} \varphi_{q} \\
\varphi_{q} &= L_{q} i_{q} + M_{q} \varphi_{d}
\end{align*}
\]

And rotor:

\[
\begin{align*}
\varphi_{d} &= L_{r} i_{d} + M_{d} \varphi_{q} \\
\varphi_{q} &= L_{r} i_{d} + M_{q} \varphi_{d}
\end{align*}
\]

The equations of flow and after the simplification are:

\[
\begin{align*}
\dot{\varphi}_{d} &= L_{q} \dot{i}_{q} + M_{d} \dot{\varphi}_{q} \\
\dot{\varphi}_{q} &= L_{q} \dot{i}_{q} + M_{q} \dot{\varphi}_{d}
\end{align*}
\]

Double Fed Induction Generator model of the landmark Park in the form of state:

\[
\begin{align*}
\frac{d\varphi_{d}}{dt} &= \frac{-\sigma}{L_{q}} \left(\varphi_{d} - R_{s} i_{d} + \frac{M_{d}}{L_{r}} i_{d} + \frac{M_{q}}{L_{q}} i_{q} + \frac{\omega_{e} P_{o}}{L_{q}} \sigma_{p}\right) \\
\frac{d\varphi_{q}}{dt} &= \frac{-\sigma}{L_{q}} \left(\varphi_{q} - R_{s} i_{q} + \frac{M_{d}}{L_{r}} i_{d} + \frac{M_{q}}{L_{q}} i_{q} + \frac{\omega_{e} P_{o}}{L_{q}} \sigma_{p}\right)
\end{align*}
\]

Where: \(\sigma = 1 - \frac{M_{d}^{2}}{L_{r} L_{q}}\) is the dispersion coefficient.

The expression of the electromagnetic torque of the DFIG in reference Park [10]. The general form of electromagnetic torque is:

\[
C_{em} = \frac{2 \rho_{o}}{s} \left(\varphi_{d} i_{q} - \varphi_{q} i_{d}\right)
\]

**DFIG power Modeling**

**Phase rectifier diodes modeling**

If we neglect the effect of encroachment, the rectifier output voltage will be defined as following:

\[
V_{\text{req}}(t) = \text{Max} \left[ V_{g}(t), V_{b}(t), V_{c}(t) \right] - \text{Min} \left[ V_{g}(t), V_{b}(t), V_{c}(t) \right]
\]

**DC bus modeling**

To reduce the ripple of the voltage source adding a low pass filter LC Their operation is governed by the following equations:

\[
\begin{align*}
\frac{dV_{dc}}{dt} &= \frac{V_{\text{req}} - V_{dc}}{L_{f}} \\
\frac{dV_{dc}}{dt} &= \frac{V_{dc} - V_{b}}{c_{f}}
\end{align*}
\]

**VDC to DFIG Association**

We will have the following system:

\[
\begin{align*}
\frac{V_{d}}{V_{c}} &= \frac{V_{dc}}{\frac{1}{\frac{1}{L_{f}} + s \frac{1}{c_{f}}}}
\end{align*}
\]

In our case, the control of the switches of the inverter is performed by use of the command modulation or PWM pulse width.

**Maximum power extraction technique**

In this part, we will present the power optimization strategy with mechanical speed to control the electromagnetic torque and to regulate the mechanical speed and as result maximize the electrical power generated (Figure 5). This method is known under the terminology Maximum Power Point Tracking (M.P.P.T.) and corresponds to zone 2 of the operating characteristic of the wind turbine [7].

Figure 5 : Maximization of power extracted without speed control.
An erroneous speed measurement therefore inevitably leads to degradation of the power captured by the first extraction technique. This is why most wind turbines are controlled without control of the speed. The second control structure based on the assumption that the wind speed varies very little in steady state.

Application of vector control

Vector control is based on the choice of a reference mark. We can choose the reference axes according to one of the flows of the machine. We consider the DFIG works in hypersynchronous mode, the principle is to direct the stator flux along the axis of the rotating frame [6, 9].

So we have: \( \phi_{ds} = \phi_s \) and we have: \( \phi_{dq} = 0 \).

The technical guidance of stator flux is applied to the couple:

\[
C_{q} = -\frac{2}{3}P_{im}\left(\phi_{2d}, I_{r}\right)
\]

(17)

With neglecting the stator winding resistance \( R_s \); voltage expressions become:

\[
\begin{align*}
V_{sd} &= 0 \\
V_{sq} &= V_s = \omega_s\phi_{sd} \\
\phi_s &= \phi_{2d} = L_r I_{r} + L_m I_{r}
\end{align*}
\]

(18)

(19)

Relations between stator, rotor currents and powers:

From this equation, we can write the equations linking the stator currents to the rotor currents:

\[
\begin{align*}
I_{sd} &= \frac{\omega_s}{L_s} I_{r} \\
I_{sq} &= -\frac{L_m}{L_s} I_{r}
\end{align*}
\]

(20)

The stator active and reactive power of an asynchronous machine are written:

\[
\begin{align*}
P_s &= V_{sd} I_{sq} + V_{sq} I_{sd} \\
Q_s &= V_{sq} I_{sd} - V_{sd} I_{sq}
\end{align*}
\]

(21)

The adaptation of these equations to simplifying assumptions made in this case given:

\[
\begin{align*}
P_s &= V_{s} I_{r} I_{r} \\
Q_s &= V_{s} I_{r} I_{r}
\end{align*}
\]

(22)

Relations between rotor and rotor currents tensions:

One could express the rotor voltages depending on rotor currents, we can write:

\[
\begin{align*}
V_{rd} &= \frac{L_r}{L_s} I_{r} + g\omega_2 \left(L_r - \frac{L_m}{L_s}\right) I_{r} \\
V_{rq} &= \frac{L_r}{L_s} I_{r} + \frac{d}{dt} I_{rq} + g\omega_2 \left(L_r - \frac{L_m}{L_s}\right) I_{r} + g \frac{L_m V_s}{L_s}
\end{align*}
\]

(23)

In steady state, the terms involving derivatives disappear, we can write:

\[
\begin{align*}
V_{rd} &= \frac{L_r}{L_s} I_{r} - g\omega_2 \left(L_r - \frac{L_m}{L_s}\right) I_{r} \\
V_{rq} &= \frac{L_r}{L_s} I_{r} + g\omega_2 \left(L_r - \frac{L_m}{L_s}\right) I_{r} + g \frac{L_m V_s}{L_s}
\end{align*}
\]

(24)

There are two control modes applied to DFIG direct and indirect method of power control. In this paper we are interested to the indirect method of Vector control in stator wind power system based on a PI controller [7, 13]:

Indirectly Vector control

In indirect method the flow is controlled in open loop. It is not measured or estimated. The quantities (voltage or current) ensuring the flow direction are evaluated and decoupled from the equations of the machine transient.

The values of the rotor voltages depending on power are as follow:

\[
\begin{align*}
V_{dr} &= g\omega_2 \left(L_r + \frac{L_m}{L_s}\right) P - \left(\frac{L_r}{L_s} - \frac{L_m}{L_s}\right) Q \\
+ g \omega_2 \left(L_r - \frac{L_m}{L_s}\right) S \\
V_{qr} &= - g\omega_2 \left(L_r + \frac{L_m}{L_s}\right) P + g \omega_2 \left(L_r - \frac{L_m}{L_s}\right) Q \\
+ g \omega_2 \left(L_r - \frac{L_m}{L_s}\right) S
\end{align*}
\]

(25)

The figure 6 show the method of control with power. In this method, the isolation is carried out at the outputs of the rotor current regulators with a return of the system. Which allows the adjustment of the powers.

![Figure 6: Indirect control with power loop.](image)

It is important to emphasize that the indirect method is the simplest to carry out and the most used that the direct method.
RESULTS
To evaluate and test the indirect control technique for a complete model of DFIG with power loop of active and reactive power by the PI controllers, a simulation was performed under the MATLAB / Simulink. In this case, the gains of the PI controllers are based to a method of design, which is based on the compensation of the time constant of the regulator with the process of the quantity to be regulated, and were refined after simulation:

✓ For the power loop: \( kp = 75.75; \) \( Ki = 5354.55 \).
✓ For the current loop: \( kp = 75.75 \times 10^{-1} \); \( Ki = 5354.55 \times 10^{-1} \).

Figure 7: Stator current.

Figure 8: Rotor current.

Figure 9: Wind speed.

Figure 10: Rotor Speed.

Figure 11: Stator active power.
DISCUSSION

Good results are obtained in dynamic handling and response to regulations imposed. The fluctuations in the power due to the PWM inverter and the dependence of these powers slip.

The figure 7 and 8 show the results of the stator current and rotor current that have the same paces with the trend of the wind and the power. Are sinusoidal, implying a clean energy without harmonics supplied or absorbed by the DFIG.

The results obtained in figure 13 confirm the technique that we used to maximize speed and extract the maximum power in zone two of system operation.

The results obtained in figures 11, 12 and 14, we can conclude that this type of control is more efficient than direct control in terms of a variable speed operation, since it is able to provide a decoupled control of active power and responsive regardless of the drive speed.

CONCLUSION

This paper presents the modelling of the various components of a wind system for distributed generation of electricity and the study of different double fed Induction Generator control systems (DEIG) representing the production of this energy.

In the second part, we start with the maximum power extraction technique in the operation of the wind; this method proves and gives good results for the maximum generated power to the grid.

Subsequently, we developed stator vector of control reactive power in the stator level, the proper follow instructions for the two powers by the real powers debited by the stator of the machine showed the effectiveness of the applied control.

ABBREVIATIONS:

DFIG  Doubly Fed Induction Generator
ρ    Air density
S    turbine area
v    Wind Speed
PC   power extraction coefficient
s (R) index of the stator (rotor)
d, q  indices Park repository
V (I) voltage (current)
P (Q) active power (reactive)
φ    Magnetic flux
Cem () electromagnetic torque
Cr   mechanical torque
R    Resistance
L (M) Inductance (mutual)
σ    Coefficient leaks
θr (θs)  
Position of the rotor (stator)

ωr (ωs)  
Electric speed rotor (stator)

Ω  
Mechanical speed

g  
Slip

f  
Friction

J  
Inertia

P  
Number of pole pairs

PARAMETERS OF SYSTEM

Vs=220/381; Vr=18/31 V; E=220 V; f=50 Hz; fr=14 Hz; 
Ls=0.094 H; Lr=0.088 H; Lm=0.082 H; Rs=0.095; Rr=1.8; 
R=0.3 Ω; L=0.014 H; C= 2 e^{-3} F; Udc=260 V; R =35.25 m; 
G= 90 m; J=0.1Kg.m²;

REFERENCES


