

Indirect Control of a Doubly-Fed Induction Machine for Wind Energy Conversion

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ABSTRACT

In this paper, a grid connected wind power generation scheme using a doubly fed induction generator (DFIG) is studied. The aims of this paper are: The modelling and simulation of the operating in two quadrants (torque-speed) of a DFIG, the analysis employs a stator flux vector control algorithm to control rotor current, the system enables optimal speed tracking for maximum energy capture from the wind and high performance active and reactive power regulation using the PI regulator. The simulation calculations were achieved using MATLAB[®]-SIMULINK[®] package. Lastly, the obtained results are presented, for different operating points, illustrating the good control performances of the system

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1. INTRODUCTION

In order to meet power needs, taking into account economical and environmental factors, wind energy conversion is gradually gaining interest as a suitable source of renewable energy. The electromagnetic conversion is usually achieved by induction machines or synchronous and permanent magnet generators. Squirrel cage induction generators are widely used because of their lower cost, reliability, construction and simplicity of maintenance [2]. But when it is directly connected to a power network, which imposes the frequency, the speed must be set to a constant value by a mechanical device on the wind turbine. Then, for a high value of wind speed, the totality of the theoretical power cannot be extracted.

To overcome this problem, a converter, which must be dimensioned for the totality of the power exchanged, can be placed between the stator and the network. In order to enable variable speed operations with a lower rated power converter, doubly-fed induction machine (DFIM) can be used as shown on Figure 1. The stator is directly connected to the grid and the rotor is fed by a matrix converter.

In this paper, the control of electrical power exchanged between the stator of the DFIM and the power network by controlling independently the torque (consequently the active power) and the reactive power is presented. Several investigations have been developed in this direction using classical proportional-integral regulator [2]. In our case, after modelling the DFIM and choosing the appropriate d-q reference frame, active and reactive powers are controlled using respectively Integral-Proportional (PI) based on pole placement theory. Their performances are compared in terms of reference tracking, sensitivity to perturbations and robustness against machine's parameters variations.

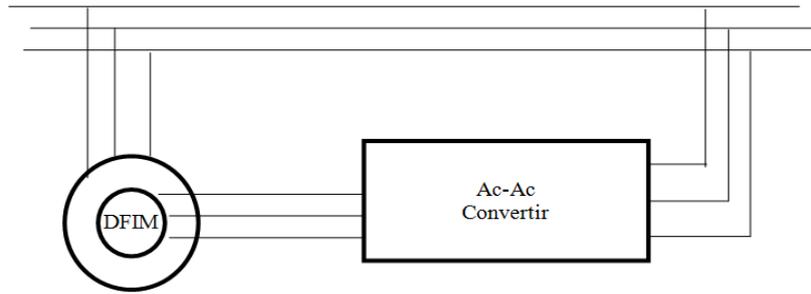


Figure 1. Doubly fed induction generator (DFIG)

2. RESEARCH METHOD

2.1. Turbine Modeling

The power capacity of being produced by a wind turbine P_t is dependent on the power coefficient C_p It is given by :

$$P_t = \frac{1}{2} C_p \rho . \pi . R^2 v^3 \tag{1}$$

The turbine torque is the ratio of the output power to the shaft speed:

$$C_t = \frac{P_t}{\Omega_t} \tag{2}$$

Power coefficient it is given by:

$$C_p = c_1 \left(\frac{c_2}{\lambda_i} - c_3 \beta - c_4 \right) \exp \left(-\frac{c_5}{\lambda_i} \right) + c_6 \lambda \tag{3}$$

With:

$C_1=0.5179, c_2=116, c_3=0.4, c_4=, c_5=21, c_6=0.0058$

λ_i called the tip speed ration:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta}$$

The simplified representation in the form of diagram blocks is given in Figure 2.

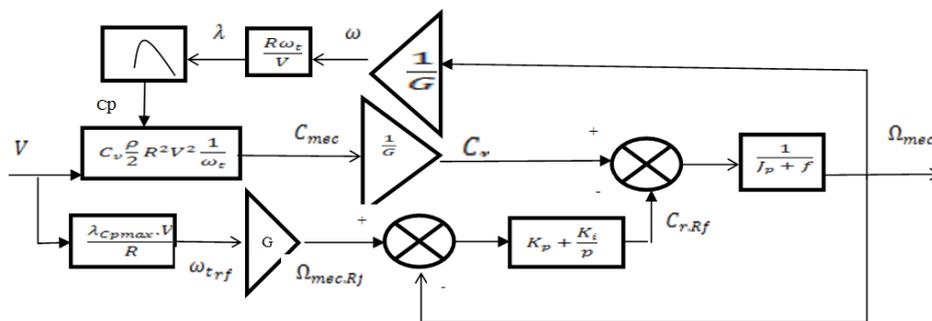


Figure 2. Device control with control speed

2.2. The DFIM Modeling

The classical electrical equations of the DFIG in the Park frame are written as follows:

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

The stator flux can be expressed as:

$$\begin{cases} \varphi_{ds} = L_s i_{ds} + L_m i_{dr} \\ \varphi_{qs} = L_s i_{qs} + L_m i_{qr} \end{cases} \quad (5)$$

The rotor flux can be expressed as:

$$\begin{cases} \varphi_{dr} = L_r i_{dr} + L_m i_{ds} \\ \varphi_{qr} = L_r i_{qr} + L_m i_{qs} \end{cases} \quad (6)$$

The active and reactive powers at the stator are defined as:

$$\begin{cases} P_s = v_{ds} i_{ds} + v_{qs} i_{qs} \\ Q_s = v_{qs} i_{ds} - v_{ds} i_{qs} \end{cases} \quad (7)$$

The active and reactive powers at the rotor are defined as:

$$\begin{cases} P_r = v_{dr} i_{dr} + v_{qr} i_{qr} \\ Q_r = v_{qr} i_{dr} - v_{dr} i_{qr} \end{cases} \quad (8)$$

The electromagnetic torque is expressed as:

$$C_{em} = P(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds}) \quad (9)$$

With P is the number of pair poles.

2.3. Contrôle Indirect

Le principe de cette méthode consiste à ne pas mesurer (ou estimer) l'amplitude de flux mais seulement sa position, l'idée est proposé par Hasse.

2.3.1.1. Active and Reactive Power Strategy of Control

When the DFIM is connected to an existing network, this connection must be done in three steps. The first step is the regulation of the stator voltages with the network voltages as reference. The second step is the stator connection to this network. As the voltages of the two devices are synchronized, this connection can be done without problem. Once this connection is achieved, the third step, is the transit power regulation between the stator and the network.

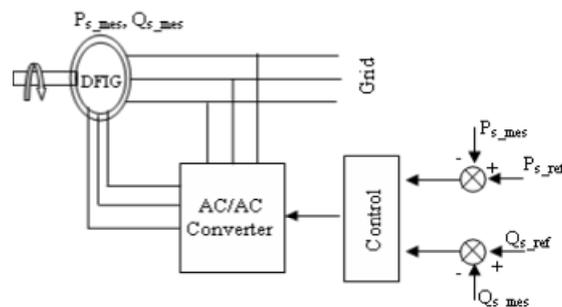


Figure 3. Power control between the stator and network

Stator current and rotor current can be rewritten as following:

$$\begin{cases} I_{ds} = \frac{\varphi_s}{L_s} - \frac{L_m}{L_s} I_{dr} \\ I_{qs} = -\frac{L_m}{L_s} I_{qr} \end{cases} \quad (10)$$

Stator power and rotor current can be rewritten as following:

$$\begin{cases} P_s = -v_s \frac{L_m}{L_s} I_{qr} \\ I_{qs} = -v_s \frac{v_s}{\omega_s L_s} - v_s \frac{L_m}{L_s} I_{dr} \end{cases} \quad (11)$$

Stator voltages and rotor current can be rewritten as following:

$$\begin{cases} V_{dr} = R_r i_{dr} + L_r \sigma \frac{di_{dr}}{dt} - \omega_r L_r \sigma i_{qr} \\ V_{qr} = R_r i_{qr} + L_r \sigma \frac{di_{qr}}{dt} + \omega_r L_r \sigma i_{dr} + \omega_r \frac{L_m}{L_s \omega_s} v_{qs} \end{cases} \quad (12)$$

Knowing the relations precedent, it is possible to design the regulators. The global block-diagram of the controlled system is depicted on Figure 4.

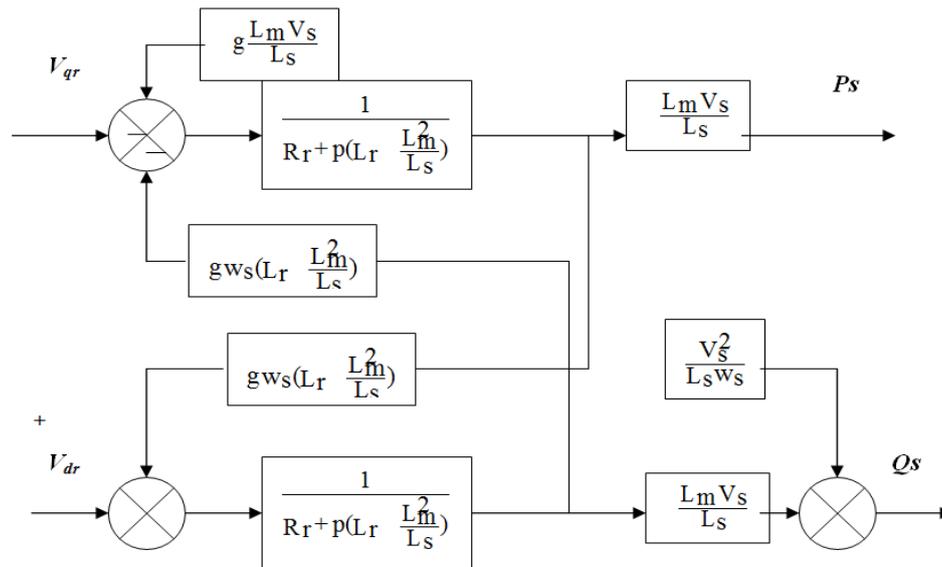


Figure 4. Block diagram of DFIG power control

3. RESULTS AND ANALYSIS

The DFIM is driven at speed 1450 tr/min of vacuum

at $t = 1$ s: level of active power (Pref from 0 to -1500W).

at $t = 2$ s: level of active power (Pref from -1500 to -10000W).

For reactive power:

The setpoint of the reactive power is varied from -8000 VAR to -5000 VAR along simulation

Figure 5(a) represents the active power and the Figure 5(b) represents the reactive power of the stator, the Figure 5(c) is quadratic in the live and fixed speed rotor currents interpretation of simulation results. We note a good continuation of active and reactive power of the stator that is either fixed or variable speed (see Figure 5(a, b)). It is observed the static error is zero. The currents of the rotor have faster dynamics.

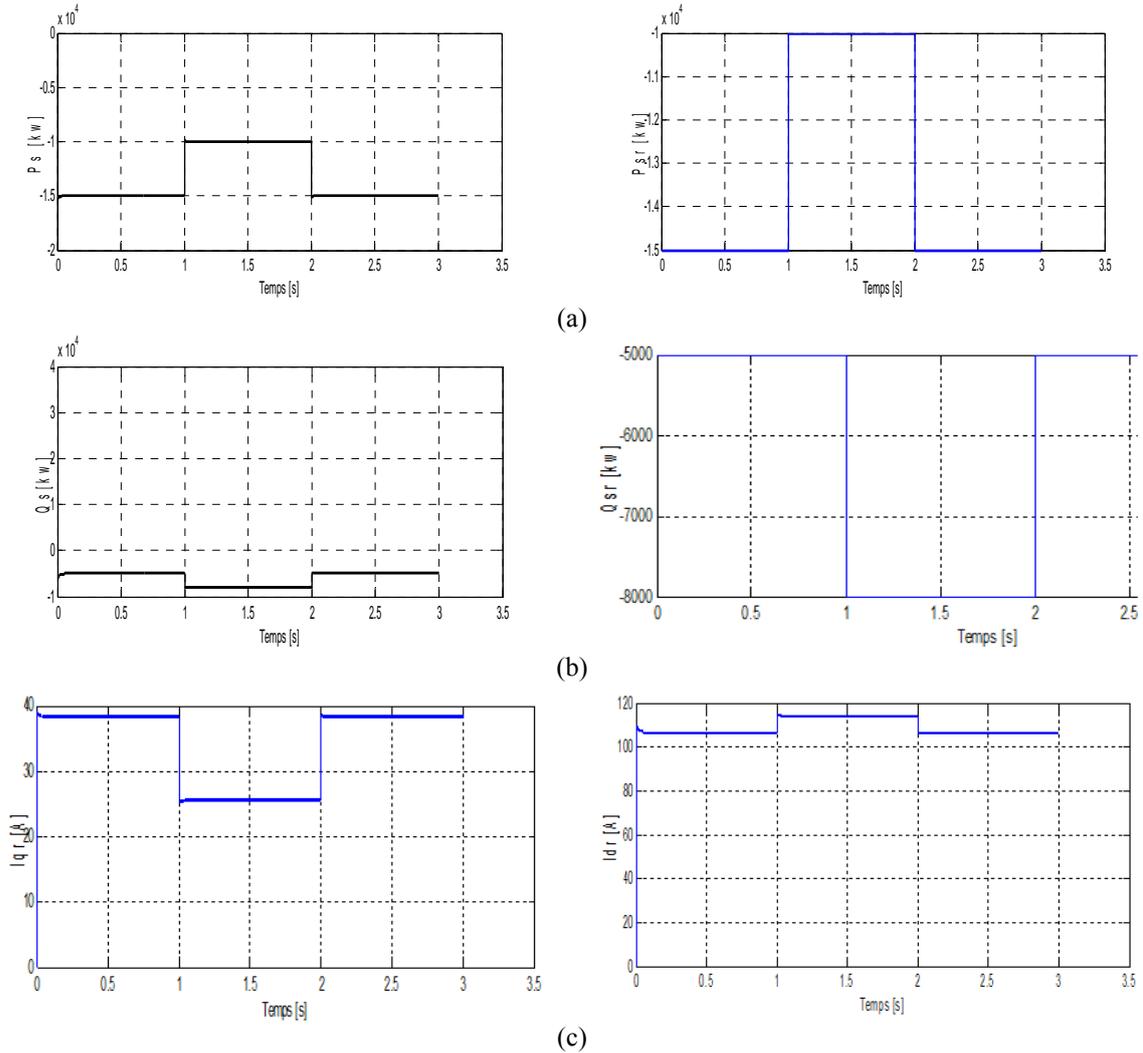


Figure 5. Reference tracking

4. CONCLUSION

In this paper, we have presented a system to produce Electrical energy with a doubly-fed induction machine by the way of a wind turbine. The studied device is constituted of a DFIM with the stator directly connected to the grid and the rotor connected to the grid by the way of an AC-AC converter.

The control of the machine inverter has been presented first in order to regulate the active and reactive powers exchanged between the machine and the grid.

The method of control is based on the calculated active and reactive powers from the rotor currents measurements (indirect control). The impact on the active and reactive powers values is important for PI controller A robustness test has also been investigated where the machine's parameters have been modified. These changes induce time-response variations with PI controller.

The PT controller is more efficient when the speed is suddenly changed (which happens frequently in wind energy conversion systems) and is more robust under parameters variations of the DFIM.

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Mansouru Smail obtained Licencer in electronic 1993 from university of oran, algeria, after that, Magister 'Automatique': Advanced dynamics command systems from Bechar University on 2012, Algeria. He worked assecandary schooles from 1993 to 2012. Presently he is working as assistant professor on Departement of Hydrocarbon and Renewable Energy, Adrar University, Algeria. His areas of interest are metering Systems, Power Systems, and Automation. He is member of Laboratory of Energy Environment and System Information (LEESI). He has published 2 papers in International Journals and presented several papers in national and international



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