Current Trends in Technology and Science
ISSN: 2279- 0535. Volume: 3, Issue: 4(June-July 2014)

Control and Optimization of the Energy Produced by a Chain of Wind Energy Conversion Controlled by a Double-fed Asynchronous Generator

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Nomenclature

S : The area swept by the blades of the turbine [m²]
ρ : The density of the air (= 1.225kg / m^3 in atmospheric pressure)
v : Wind speed [m/s]
C_p : Power coefficient
λ : The ratio of blade tip turbine speed and wind speed
β : The blade pitch angle
C_M, $\Omega_{méc}$: Torque and speed of the machine
C_t, Ω_t : Torque and speed of the turbine
C_{em}: Electromagnetic torque
v_{ds}, i_{ds} : Voltage and stator current along the axis d
$\emptyset_{ds}$, $\emptyset_{dr}$: Stator and rotor flow along the axis d
v_{qs}, i_{qs} : Voltage and stator current along the axis q
$\emptyset_{qs}$, $\emptyset_{qrs}$: Stator and rotor flow along the axis q
v_{dr}, i_{dr} : Rotor voltage and current along the axis d
ω_s, ω_r : Stator and rotor pulsation
v_{qr}, i_{qrs} : Rotor voltage and current along the axis d
$\Omega_{méc}$: Rotation speed of the machine
R_s, R_r : A stator and rotor phase resistance
L_s, L_r : Stator and rotor cyclic Inductance
i_s, i_r: Inductance own stator and rotor
M_s : Mutual inductance between two stator phases
M_r : Mutual inductance between two rotor phases
M: Magnetizing inductance.
p : Number of pair's pole
f : Friction coefficient
P_s, Q_s : Stator active and reactive power

Abstract — The aim of this paper is to study the conversion of wind energy in its entirety in order to optimize power output and improve the quality of energy supplied; therefore, we can extract the maximum power point : MPTT. For this, we are interested in modeling and simulation of a wind turbine, of a multiplier, and of a double feed induction generator (DFIG) wound rotor controlled with an indirect control of power. The adopted technique algorithm is developed using Matlab/Simulink/Sim-Power-Systems. Simulation results are presented and analyzed at the end of article.

Keyword — Turbine, DFIG, MLI, Converters, Maximum power, MPTT, Modeling, Matlab / Simulink.

1. INTRODUCTION

World energy demand becomes stronger; this is due to the industrial and economic development, to increased automobile fleet and to the proliferation of household appliances. So to satisfy the energy demand, the world has been directed to other energy sources. Among these sources, wind energy with very high energy potential and no greenhouse gas emissions. It is a "renewable" energy, geographically diffuse; especially with seasonal correlation (electrical energy is more widely applied in winter, when the average wind speed is higher). Therefore, the wind turbines have increased dramatically worldwide. Currently, the wind system with variable speed which it based on doubly fed induction generator: DFIG, is the most used in wind farms. Indeed, the double-feed asynchronous generator can operate over a wide

Current Trends in Technology and Science
ISSN: 2279- 0535. Volume: 3, Issue: 4(June-July 2014)

range of wind speeds, and gets the maximum possible power for each wind speed: MPPT. Its stator circuit is connected directly to the network. A second circuit is placed in the rotor, connected also to the network but via the power converters. Thus, DFIG offers several advantages: a very good energy efficiency, robustness and ease of operation and control, in addition to this, it allows an operation over a speed range of ± 30 % around the synchronous speed, ensuring a reduced dimensioning of the static converters.

The performance of production wind chain does not only depend on the asynchronous machine, but also to the manner in which the two parts of "back- to-back" converters are controlled. The power converter placed on the rotor is called "Rotor Side Converter" (RSC) and the second power converter is called "Grid Side Converter" (GSC).

The machine side power converter allows controlling the active power and reactive power produced by the system. Concerning the network side converter, it controls the DC bus voltage and power factor.

In this paper, we present a technique of indirect power control system, first, we'll start by the modeling and the simulation the blocks of the wind turbine, of the multiplier and induction generator, then a technique of maximum power point tracking (MPPT) will be presented. We analyze the dynamic performance of the system by simulations in Matlab/Simulink/Sim-Power-Systems.

2. Wind System

The wind system studded is composed by a turbine, a multiplier, DFIG, alternative-continuous converter, DC bus and a continuous-alternative converter placed between the rotor and the network [1].

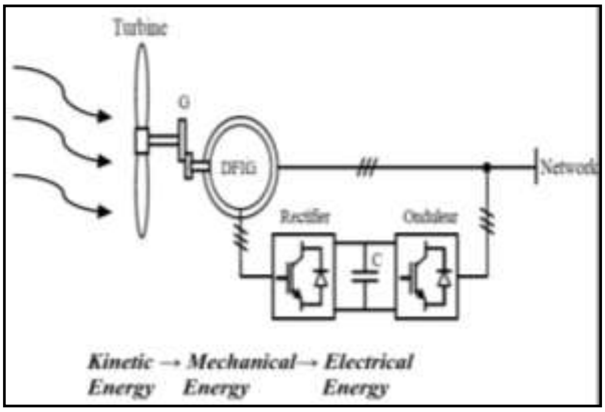

Fig. 1. Conversion of wind energy

3. Modeling and Simulation of Turbine

By applying the Bernoulli theorem, we can determine the incident power (the theoretical power), due to the wind

$$P_{incident}=\frac{1}{2}\,\rho.S.v^3 \qquad (1)$$

S = The area swept by the blades of the turbine;

ρ = The air density (ρ=1.225 kg/m3 in an atmospheric pressure);

v = wind speed [m/s].

In a turbine, the available power on the rotor turbine which we can extracted is less than the forward power :

$$P_{ext}=\frac{1}{2}\,\rho.S.C_p(\lambda,\beta).v^3 \qquad (2)$$

$C_p(\lambda,\beta)$ = The power coefficient, it expresses the efficiency of the turbine and it depends on the ratio λ, this ratio represents the ratio of the speed in extremity of the turbine blade and the wind speed, and the orientation angle β.

$$\lambda=R.\Omega_t/_v \qquad (3)$$

The maximum power coefficient C_p was determined by Albert Betz (1920) as follows :

$$C_p^{max}(\lambda,\beta)=\frac{16}{25}\approx 0{,}592 \qquad (4)$$

This coefficient depends on the constitution of the turbine. For a wind turbine of average power we have :

$$C_p(\lambda,\beta)=c_1.\left(c_2.\frac{1}{A}-c_3.\beta-c_4\right).e^{c_5\frac{1}{A}}+c_6.\lambda \qquad (5)$$

We observe in the figures 2.a and 2.b, that out the Betz limit is verified: $C_p^{max}\approx 0{,}59$.

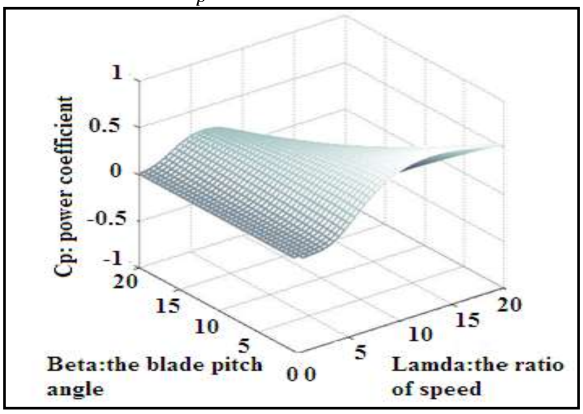

Fig. 2.a. Power coefficient $C_p(\lambda,\beta)$

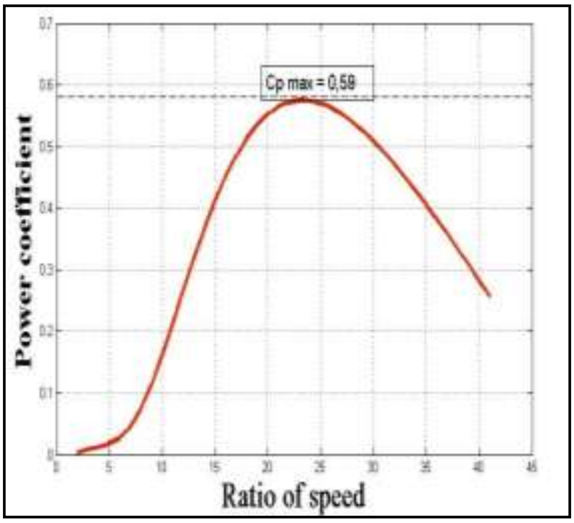

Fig. 2.b. Coefficient of power $C_p=f(\lambda)$ for $\beta=0°$

C_t is the torque on the slow axis of the turbine :

$$C_t = \frac{P_{ext}}{\Omega_t} = \frac{1}{2}\,\rho.S.C_p(\lambda,\beta).v^{3}.\frac{1}{\Omega_t} \quad (6)$$

The total inertia j is composed by the inertia of the turbine j_t reported on the fast axis and the inertia of the generator j_g:

$$j = \frac{j_t}{G^2} + j_g \quad (7)$$

The fundamental equation of dynamic is written :

$$j\,\frac{d\Omega_{Mec}}{dt} = C_M = C_t - C_{em} - f.\Omega_{Mec} \quad (8)$$

3.1. Block Diagram of a Turbine

To remove the maximum power of the incident energy, we must constantly adjust the speed of the wind turbine.

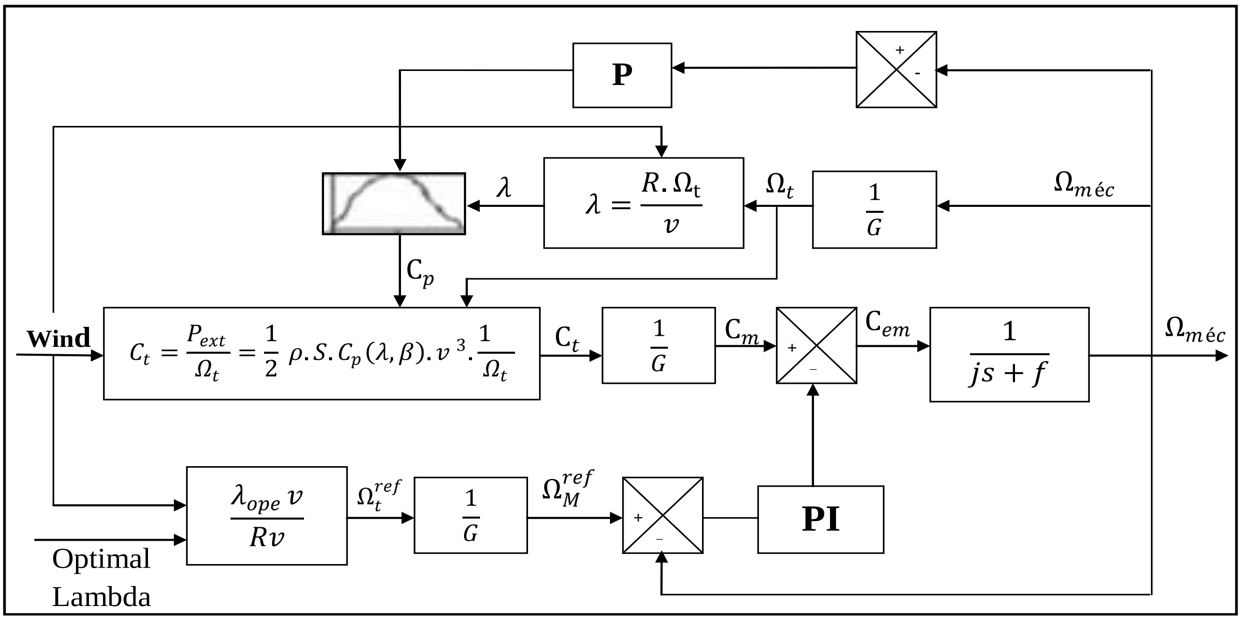

Fig. 3.a. Diagram of the multiplier and the turbine with control of the speed

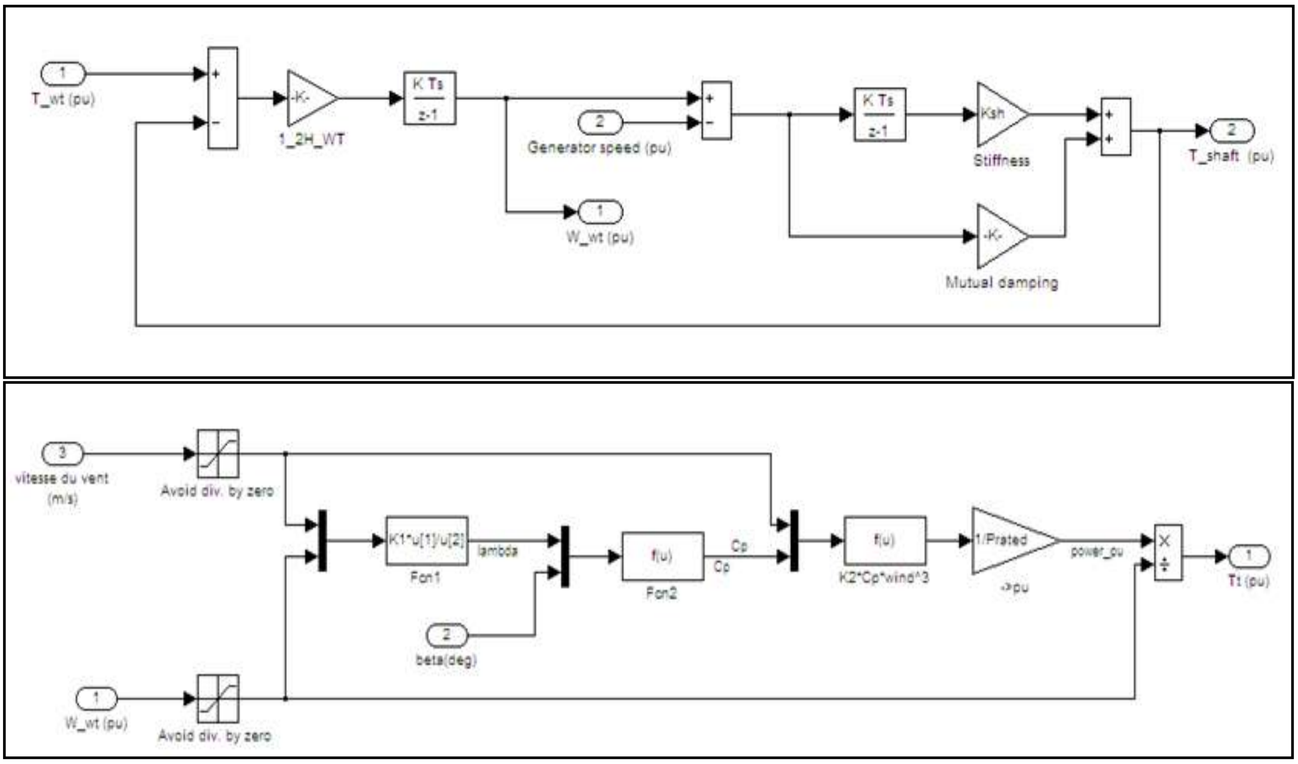

Fig. 3.b. Blocks implemented for simulation of turbine

3.2. The results of Simulation

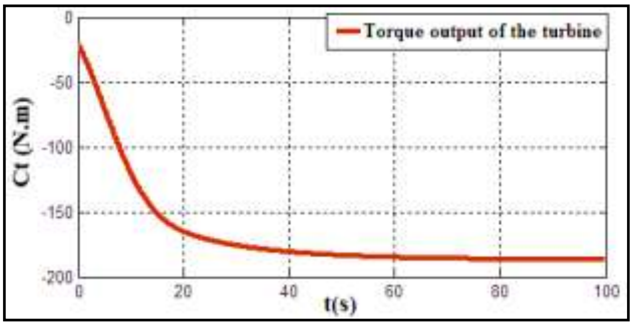

Fig. 4.a. Torque for $\beta = 60°$ and $v = 5\ m/s$
$\Rightarrow C_t \approx -180\ N.m$

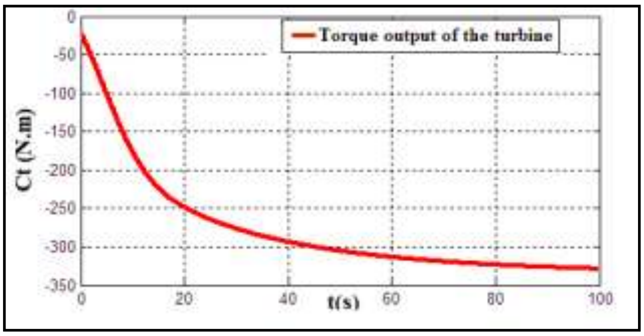

Fig. 4.b. Torque for $\beta = 40°$ and $v = 5\ m/s$
$\Rightarrow C_t \approx -325\ N.m$

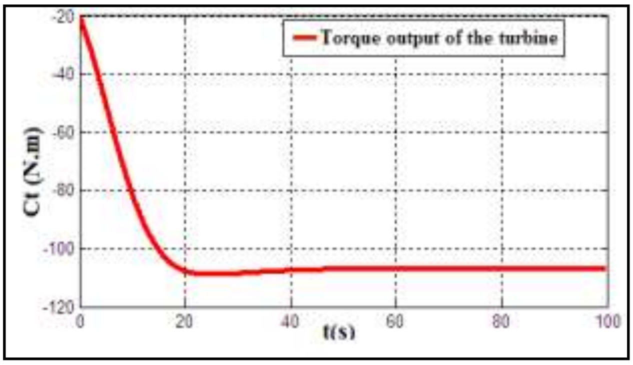

Fig. 4.c. Torque for $\beta = 80°$ and $v = 5\ m/s$
$\Rightarrow C_t \approx -106\ N.m$

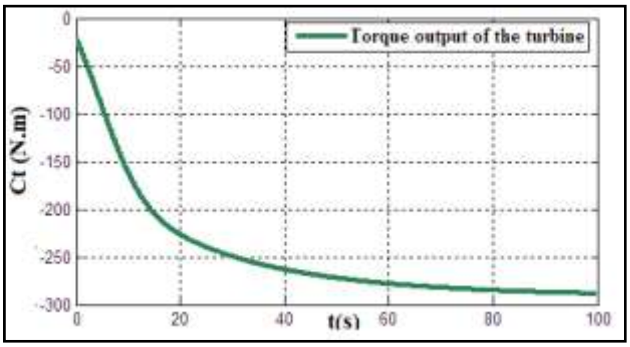

Fig. 4.d. Torque for $\beta = 80°$ and $v = 7\ m/s$
$\Rightarrow C_t \approx -280\ N.m$

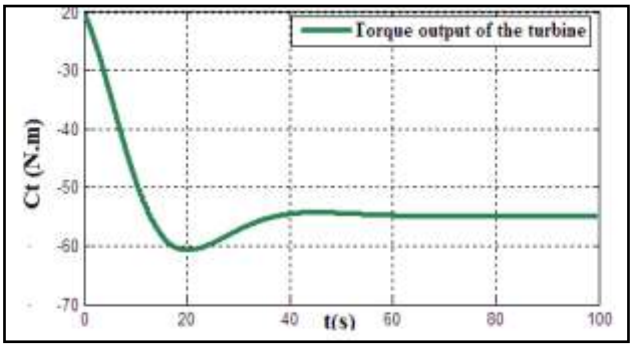

Fig. 4.e. Torque for $\beta = 80°$ and $v = 4\ m/s$
$\Rightarrow C_t \approx -55\ N.m$

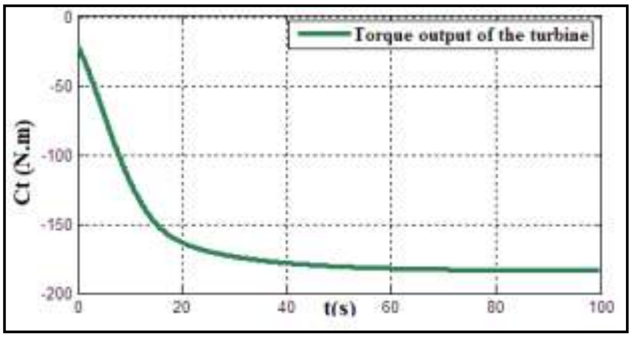

Fig. 4.f. Torque for $\beta = 80°$ and $v = 6\ m/s$
$\Rightarrow C_t \approx -160\ N.m$

3.3. Comment and Conclusion

We have used the "Stall control" technique which is a passive technique that allows natural aerodynamic stall.
We have noted that the torque developed by the turbine increases when the angle β decreases and it increases when the wind speed v increases, this is explained by the theory.
Finally, the torque output of the turbine is constant during the steady state and the simulated model is convenient for our study.

4. Modeling and Simulation of Asynchronous Generator

The double feed asynchronous generator is modeled in the benchmark Park by the following equations [6] [7] [8] [9]:

$$v_{ds} = R_s\, i_{ds} + \frac{d}{dt}\emptyset_{ds} - \omega_s \emptyset_{qs} \quad (9)$$

$$v_{qs} = R_s\, i_{qs} + \frac{d}{dt}\emptyset_{ds} + \omega_{\ s} \emptyset_{ds} \quad (10)$$

$$v_{dr} = R_r\, i_{dr} + \frac{d}{dt}\emptyset_{dr} - \omega_{\ r} \emptyset_{qr} \quad (11)$$

$$v_{qs} = R_r\, i_{qr} + \frac{d}{dt}\emptyset_{qr} + \omega_{\ s} \emptyset_{dr} \quad (12)$$

where $\omega_r = \omega_s - p\Omega$ (13)

$$\begin{cases} \emptyset_{ds} = L_s\, i_{ds} + M\ i_{dr} \\ \emptyset_{qs} = L_s\, i_{qs} + M\ i_{qr} \\ \emptyset_{dr} = L_r\, i_{dr} + M\ i_{ds} \\ \emptyset_{qr} = L_r\, i_{qr} + M\ i_{qs} \end{cases} \qquad (14), (15), (16), (17)$$

$$L_s = l_s - M_s \text{ and } L_r = l_r - M_r \qquad (18)$$

4.1. Independent control of active and reactive power

To adequately control the electricity production of the wind, we will realize independent control of active and reactive powers Ps and Qs stator [2] [3] [4] [5] [6]. The reference (dq) is oriented so that :

$$\emptyset_{ds} = \emptyset_s \ \text{ and } \ \emptyset_{qs} = 0 \qquad (19)$$

Assuming that the stator flux ϕ_s is constant (constant electric network) and ignoring the stator resistance, we obtain for P_s and Q_s :

$$P_s \ = -\upsilon_s \frac{M}{L_s} i_{qr} \qquad (20)$$

$$Q_s = \ -\upsilon_s \frac{M}{L_s} i_{dr} + \frac{{V_s}^2}{L_s \omega_s} \qquad (21)$$

The currents i_{qr} and i_{dr} are such that :

$$\upsilon_{dr} = R_r\, i_{dr} + (L_r - \frac{M^2}{L_s}) \frac{di_{dr}}{dt} + g\omega_s \left(L_r - \frac{M^2}{L_s}\right) i_{qr} \qquad (22)$$

$$\upsilon_{qr} = R_r\, i_{qr} + (L_r \ - \frac{M^2}{L_s}) \frac{di_{qr}}{dt} + g\omega_s \left(L_r - \frac{M^2}{L_s}\right) i_{qr} + g \frac{MV_s}{L_s} \qquad (23)$$

We can then establish the block diagram of the machine :

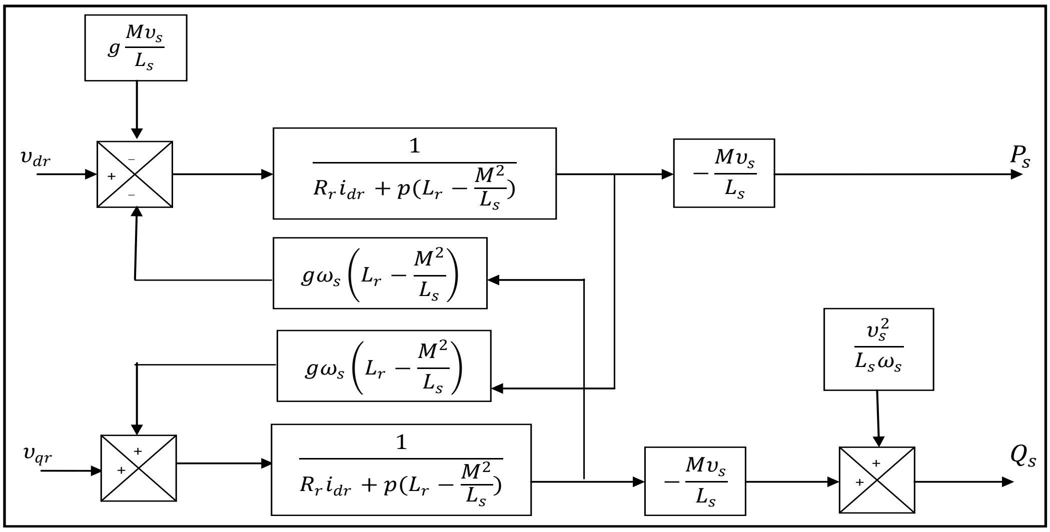

Fig. 5. The block diagram of the DFIG

Indirect control can be performed on two different axes (Axis q - Active Power / Main Lines - Reactive power) taking into consideration the coupling and compensation [1] [2].

The studied system is then represented by the principle following diagram :

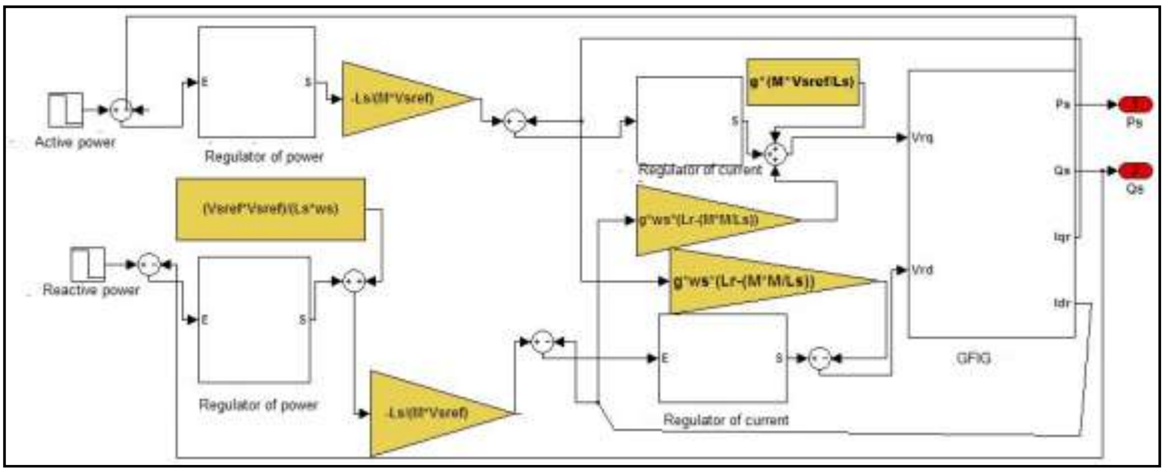

Fig. 6. The bloc diagram of the independent control of active and reactive power

4.2. Results of simulation of the generator with its indirect power control

The machine model and indirect control were implemented in the MATLAB environment to test the control. We therefore subjected the system to varying values of active and reactive power in order to observe the behavior of its regulation.
The double feed induction generator studied is characterized by the parameters given in Table (1) [1].

Table (1) Parameters of the asynchronous generator

Rotor resistance	0.19 Ω
Rotor inductance	0.0213 H
Mutual inductance	0.034H
Number of pairs of poles	2
Stator resistance	0.455 Ω
Stator inductance	0.07 H
Nominal active power	150kW

The gain correction are calculated by the method of compensation poles and identification to a first order system (system response time of about 10 ms) and were refined after simulation.
To improve the indirect control, we will incorporate two control loops, one at the level of rotor currents and the other at the level of powers to eliminate the static error while keeping the system dynamics.

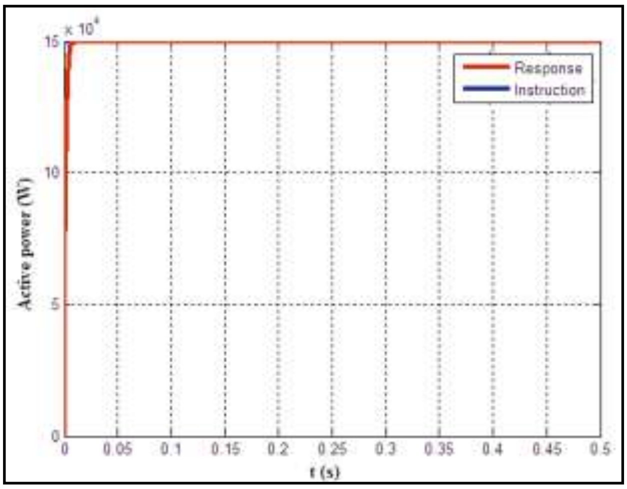

Fig. 7. Active power with power Reference equal to reference equal to : 150kW

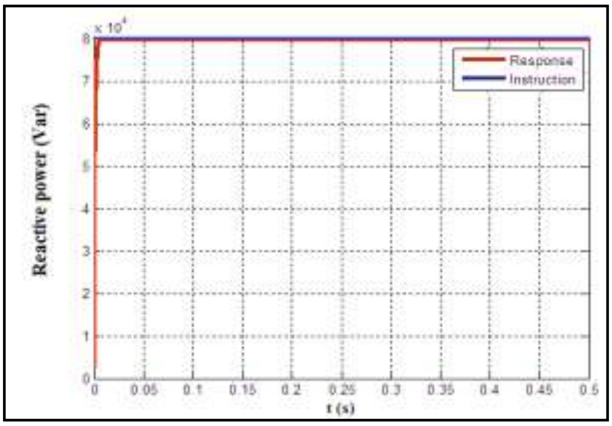

Fig. 8. Reactive power with power reference equal to : 80kVAR

Figures 7 and 8, show that our system has a satisfactory dynamic, which reacts rapidly with almost zero static error, either for active or reactive power.
It is observed that the powers of reference are followed. This wouldn't cause a problem for the exploitation of the machine model.
To demonstrate the interest of the proposed control, simulation results were compared those with other techniques (direct and indirect control command without power control).
We have noticed that having an indirect control with two control loops improves the robustness of the system, something that remains an important issue especially for systems with large variations in parameters (meteorological factors). If we had changed the instructions, the response of the system would have been controlled with indirect control.

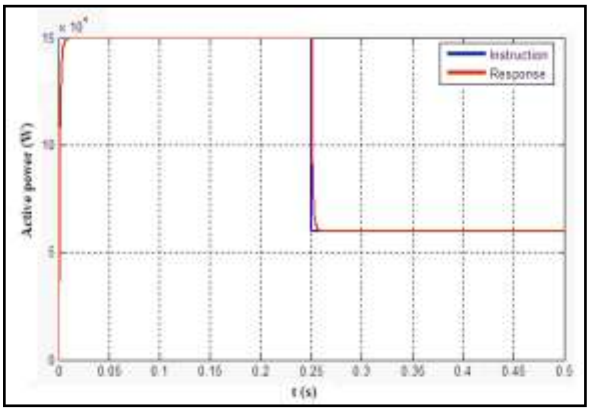

Fig. 9. Active power variation, the reference is between : 150kW and 60kW

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ISSN: 2279- 0535. Volume: 3, Issue: 4(June-July 2014)

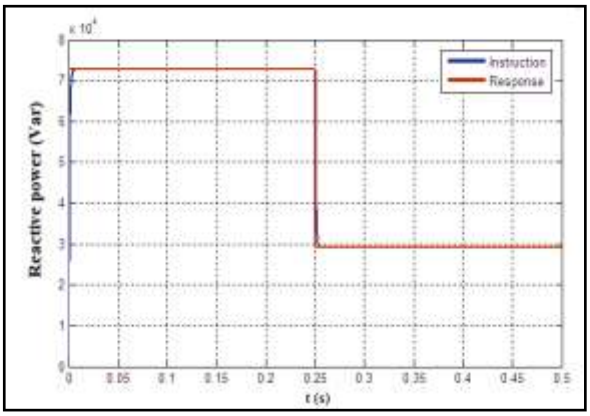

Fig. 10. Reactive power variation, the reference is between : 72.8kVAR and 29.2kVAR

Figures 9 and 10 show the evolution of the power at a reference power variation. Note that this change does not affect the system which still manages to ensure control powers. Also, through the response characteristics, good performance is observed even in the presence of instructions variations.

5. Conclusion and Outlook

In this study, we have addressed the modeling and control of the turbine, of the multiplier and the double-fed asynchronous generator operating machine with an indirect power control.

The simulation results have allowed us to evaluate the quality of the control strategy adopted.

We have noticed that the indirect control provides a powerful and robust system with very good simulation results.

We retain indirect control for the rest of our work, which would study the overall operation of a wind generator while ensuring constant power supplied to the network via two converters and DC bus.

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On June 2013, I got an engineering diploma specialized in electrical energy in ENSEM. My doctoral thesis is about direct and fuzzy-logic control systems of the double-feed induction generator wind turbine. I've submitted my first technical paper to (AMT) scientific conference (22/04/2014).

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