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Rotor Currents Command of The Doubly Fed Induction Generator Used in The Wind Energy

Abdelali AARIB, Abdelhadi EL MOUDDEN, Widad DRIOUICH, Angel SCIPIONI

***Abstract*—The command of the doubly fed induction generator by the rotor currents plays a key role in the control of the stator active and reactive powers, So the concept of the command rests on the precise control of the rotor currents closed-loop, the implementation of this command allows to check the doubly fed induction generator used in the wind energy with the possibility of working in a loop of power open to the exit of this command which is represented by the exit of the doubly fed induction generator (DFIG), Regulators PI used are simple and precise regulators, this type of control of the rotor currents closed-loop adjusts the sliding of DFIG what gives a good adjustment of the stator powers and rotor powers generated by the DFIG, the compensation of the terms of coupling is made by the synthesis of all the regulators PI used in the command. The role of these regulators PI is the control of the stator active and reactive powers and the compensation of the cyclic rotor inductance and the cyclic stator inductance.**

***Index Terms* —Command, DFIG, grid, loads, Matlab-Simulink.**

I. Introduction

Wind energy is an expanding energy, geographically spread and especially in seasonal correlation (the electrical energy is widely more asked in winter and it is often in this period when the wind's average speed is the highest).

Furthermore,it is an energy that does not produce greenhouse gases; it is however random in the time and its harnessing remains rather complex, requiring matt and blades of big dimensions (until 60m for wind turbines of several megawatts) in zones geographically of turbulences. Furthermore, it is an energy which produces no air emission or radioactive waste; she is however random at the time and her harnessing remains rather complex, requiring matt and blades of big dimensions (until 60m for wind turbines of several megawatts) in zones geographically of turbulences[1]. The installations can be realized on earth but also at sea where the presence of the wind is more regular. A wind turbine can convert the kinetic energy of the wind into electrical energy. Its various elements are designed to maximize this energy conversion; since the use of the windmill, the technology of the wind sensors has not stopped evolving[2]. It is at the beginning of the forties when real prototypes of wind turbines with profiled blades were successfully used to generate some electricity.

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A wind turbine has to contain:

- A system which allows to check her electrically (electric machine associated with the command).
- A system which allows to control its mechanically (orientation of the landings of the wind turbine, the orientation of the nacelle).

The paper bellow deals with the wind turbine with the doubly fed induction generator, because it gets several characters as the adaptation has speeds of variable wind, the robustness of their command and the reduction of effort on the mechanical parts [3].

II. Vectorial Command of the Doubly Fed Induction Generator

The vectorial command is also field-oriented control, it's a separation between the command of the speed of the DFIGand the magnetic state stator-rotor.

Independently of the machine's speed, the couple changes the previous orientation and so the flow changes the previous orientation, but with the vectorial command the couple stays according to the direction in quadrature and the flow stays according to the direct direction [4].

The orientation of stator flow according to the axis allows to calculate the terms of coupling so the optimization of the power reactive stator and consequently the power factor of the wind system [5].

From the expression of these rotor flows, the equations of the rotor voltage could be deduced:
Because we are in three phases system, a tool to transform the tensions V_{rd} , V_{rq} in tensions V_{ra}, V_{rb}, V_{rc} of reference is needed, they will be injected in the converters of the power of the DFIG through these converters the machine absorbs the rotor energy, then, it produces the stator active powerP_s, and the reactive stator powerQ_s[6].

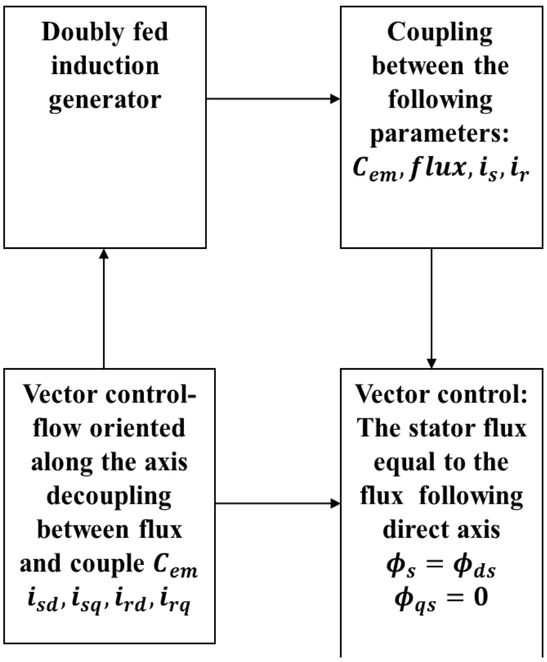

Fig.1 Vectorial command of the parameters of the DFIG.

III. MODULATION OF THE WIDTH OF THE IMPULSE

The modulation of the width of the impulse is realized by the comparison of a low-frequency modulated wave (reference tension) with a high-frequency expanding wave of triangular form [7].

The moments of switching are determined by the points' intersection between the carrier and the modulating.

In three-phases, three sinusoidal references disorientated of $\frac{2\pi}{3}$ with the same frequency f [8].

As at the exit of the inverter, the tension is not purely sinusoidal, thus it contains a harmonious, only responsible for parasites what engender additional losses. This PWM serves to solve these problems and it has the following advantages:

- As at the exit of the inverter, the tension is not purely sinusoidal, thus she contains harmonious, only responsible for parasites what engenders additional losses. This MLI serves to remedy these problems and it has the following advantages[9]:
- Variation of the frequency of the tension of the output
- Elimination of certain harmonious of tension

The reference tension V_{ra}, V_{rb}, V_{rc} will be modulated by a tension MLI this tension is called a carrier [10]:

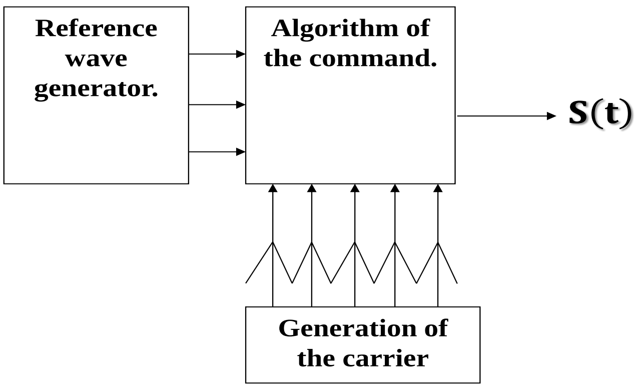

Fig.2 Plan of the modulation of width of impulse.

IV. Description of the Converters of the Power of the DFIG

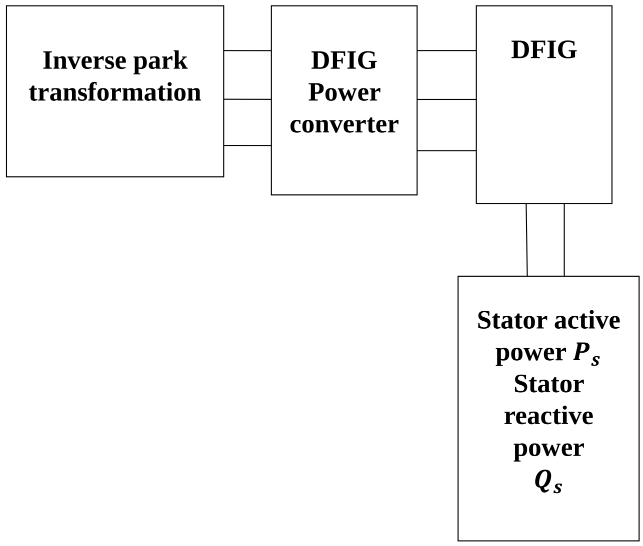

Fig.3 Plan of command of the converters of the DFIG (Matlab-Simulink).

The elaborated control considers the IGBT as switches in the case or the rotor tension of reference of the command is superior of the expandingtension, $V_{reference\ -rotor} > V_{porteuse}$ the switch is thus closed,the signal passes, in the case or the rotor tension of reference of the command is lower than the expanding tension $V_{reference\ -rotor} < V_{porteuse}$ the switch is opened, thus the signal is interrupted[11].

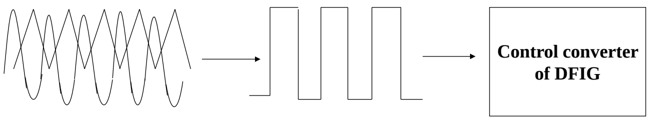

Fig.4Signal modulated by the tension introduces into the converters of power.

The modulation of width of impulse to allow us to pass of a low frequency to a high one and to decrease the harmonious on the modulated signal,the importance of modulated signal is to have a signal without harmonious capable of commanding the signal in a precise way without having a disorder in the functioning of the IGBT and their frequency of switching so the modulated signal is more preciseat the level of the passage of the IGBTof a state of switch opento astate of closed switch [12].

V. Open-Loop, Indirect Command of the System

The open-loop command is essentially based on the hypothesis of a stable network in tension and in frequency. It consists on enslaving either the powers, but also the rotor currents by not using either the powersmeasured as return on the comparator, but the rotor currents of axis d and q. This configuration remains reliable as long as the electricity networkremains stable in tension and in frequency[13].

This instability of the network is going to cause an erroron theinstructions of the active and reactive powers.

The open-loop command consists in overcoming either the powers, but also the rotorcurrents by using either the powers measured as return on the comparator but the rotor currents ofaxis d and q. These currents play a key role in the command of the stator active and reactive powers [14].

VI. Realization of the Objective $Q_s = 0$ by the Used Command

A wind turbine with a doubly fed induction generatoris used in Tangier's site.

The industrial problem of wind turbines is that it is very difficult to reach an almost Unitarian optimal power factor.The objective of the new command synthesized in this work is to return the value of the stator reactive power $Q_s = 0\ Var$ about is weather conditions [15].

- Analytical Demonstration of $Q_s = 0\ Var$

Mathematically according to the vectorial command with oriented stator flow [16]:

$Q_S = V_s \frac{\phi_s}{L_s} - V_s \frac{M}{L_s} i_{dr}$ (1)

We have the stator flow becomes:

$\phi_s = \phi_{ds} = L_s i_{ds} + M\, i_{dr} = constante$ (2)

The stator tension according to the direct axis is equal has:

$V_{ds} = R_s i_{ds} - \frac{d}{dt}\phi_{ds} + \omega_s \phi_{qs}$ (3)

As:

$\phi_{ds} = constant$ and $\phi_{qs} = 0$ (4),(5)

Consequently:

$V_{ds} = 0$ and $V_{qs} = V_s$ (6),(7)

$V_{ds} = R_s i_{ds} \Rightarrow i_{ds} = \frac{V_{ds}}{R_s} = 0 \Rightarrow \phi_s = M\, i_{dr}$ (8),(9),(10)

Therefore:

$Q_s = 0\ Var$ (11)

VII. Results of the Simulation

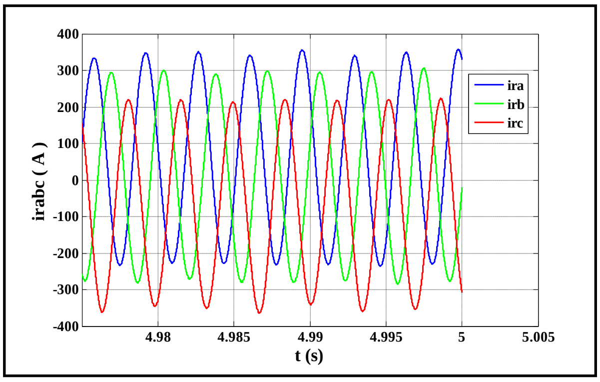

Fig. 5Rotor current i_{ra} (A), i_{rb} (A), i_{rc} (A) according to time (s).

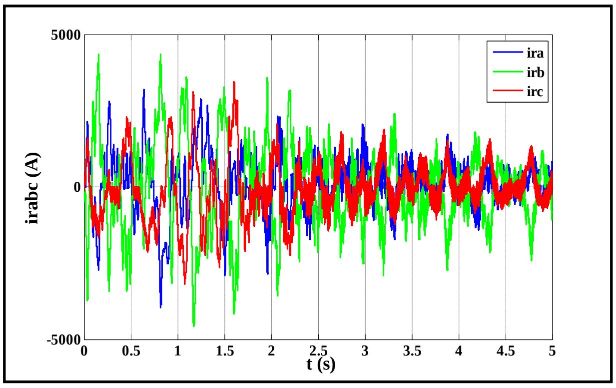

Fig.6Rotor current i_{ra} (A), i_{rb} (A), i_{rc} (A) according to time (s).

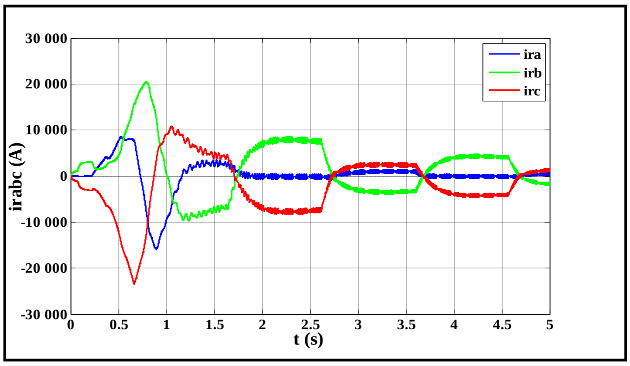

Fig. 7Rotor current i_{ra} (A) , i_{rb} (A), i_{rc} (A) according to time (s).

The rotor current is influenced by the variation of the reactive stator current absorbed by the DFIG, these currents i_{ra} (A), i_{rb} (A) and i_{rc} (A) vary approximately between–(30000 A) and (20000A), and they are independent from the profile of wind speed. The rotor currents depend on the variation of the speed of asynchronous machine with double feeding, and on the variation of the sliding of the machine according to the absorption or the supply of the rotor power.

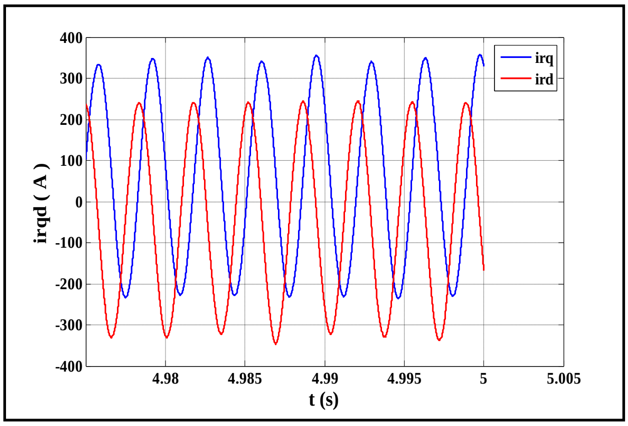

Fig. 8Rotor current according to i_{rqd} (A) to time (s).

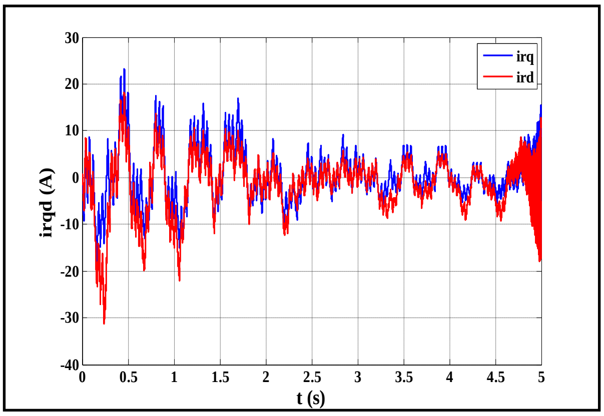

Fig. 9Rotor current i_{rqd} (A)according to time (s).

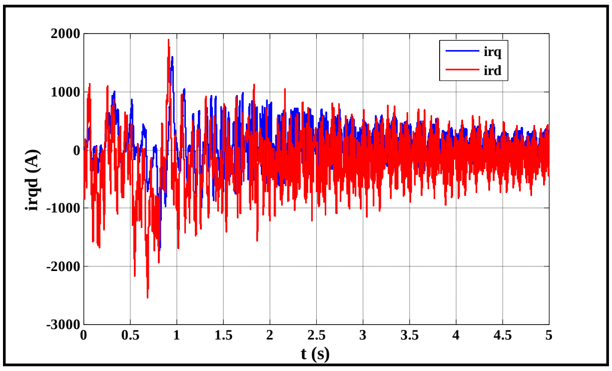

Fig. 10Rotor current i_{rqd} (A) according to time (s).

These curves show the evolution of rotor currents; these wave forms depend on the speed of the wind. The frequency of rotor currents depends on the sliding of the machine. For a zero sliding (synchronous mode), the rotor currents are constant. By performing a zoom on the rotor currents, we notice a dephasing between the latters. This can be explained by providing and/or absorbing the rotor reactive power according to the dephasing. These rotor currents vary between (-35 A) and (2000 A).

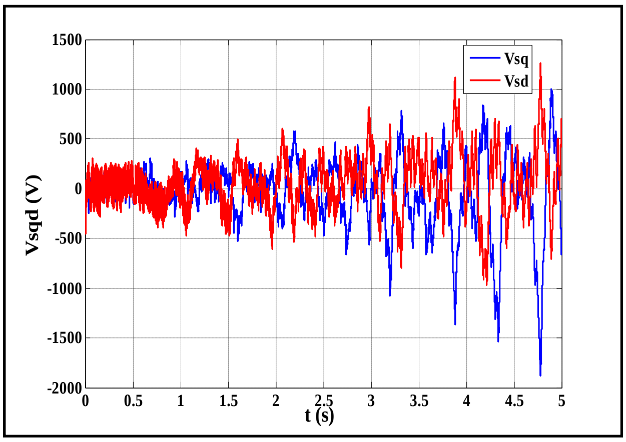

Fig. 11Stator voltage V_{sq} (V), V_{sd} (V) according to time (s).

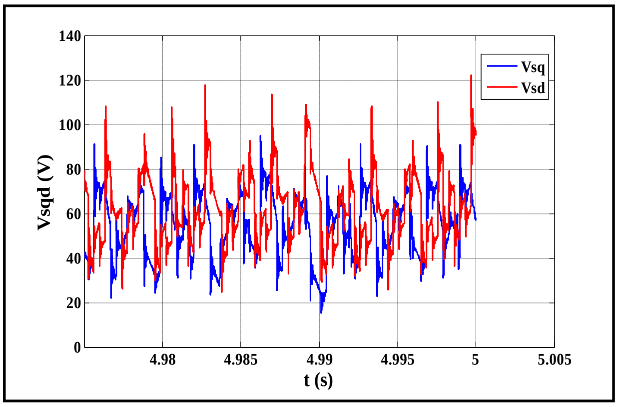

Fig. 12Stator voltage V_{sq} (V), V_{sd} (V) according to time (s).

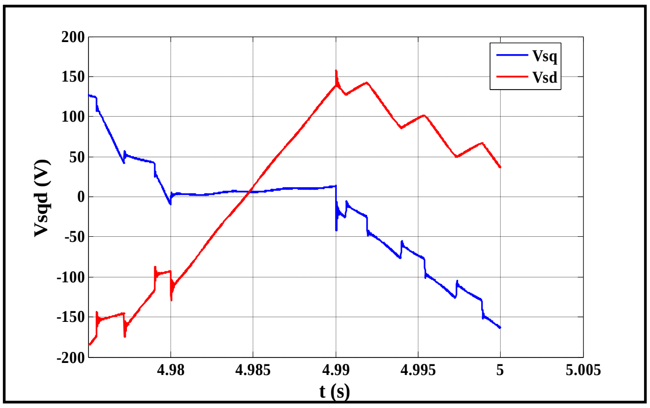

Fig. 13Stator voltage V_{sq} (V), V_{sd} (V) according to time (s).

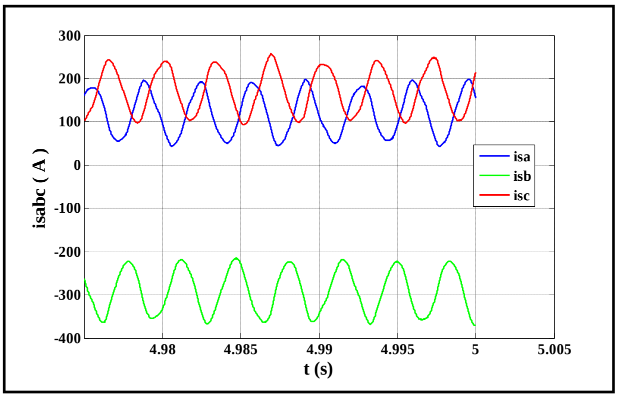

Fig. 14Stator current i_{sabc} (A) according to time (s).

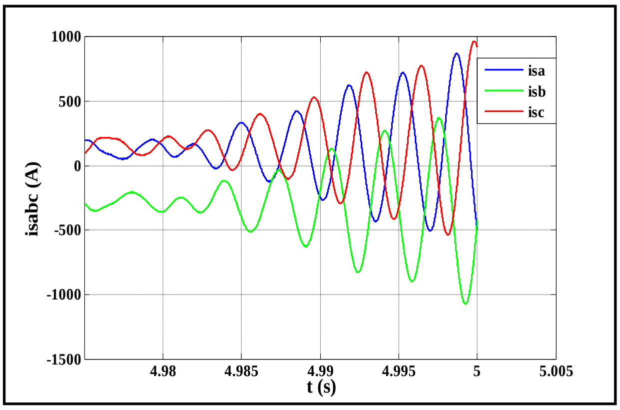

Fig. 15Stator current i_{sabc} (A) according to time (s).

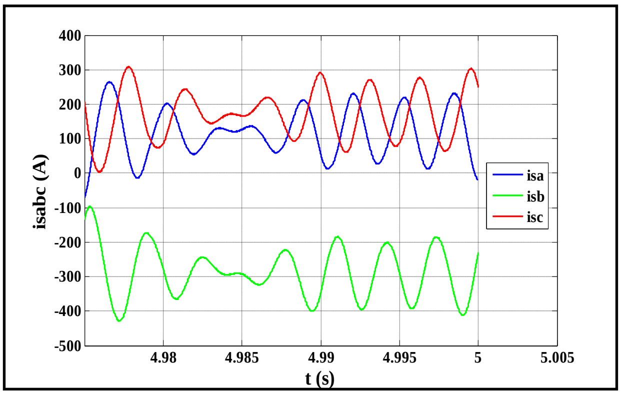

Fig. 16Stator current i_{sabc} (A) according to time (s).

The form of the wave of stator currents is linked to that of the stator active power and of the stator reactive power. This means that the stator active power is sent from the generator towards the grid. It is worth noting that the forms of the current are independent of the profile of the wind's speed. These curves vary in a sinusoidal way also there is some phase shift because of the constant of $\frac{2\pi}{3}$ which exists in the park's transformation, the value of these currents reached a maximum of (1000 A) and a minimum of (-420 A).

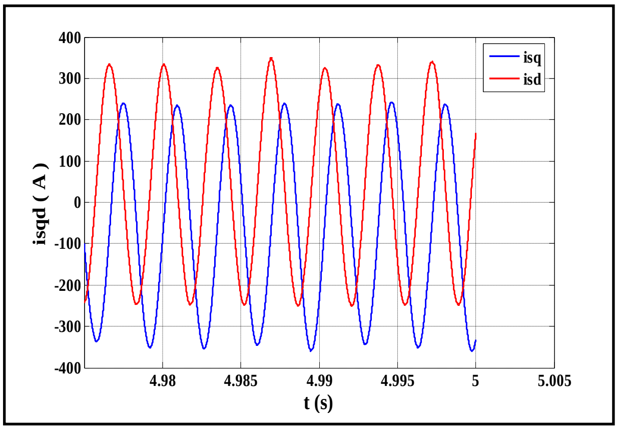

Fig. 17Stator current i_{sq} (A), i_{sd} (A) according to time (s).

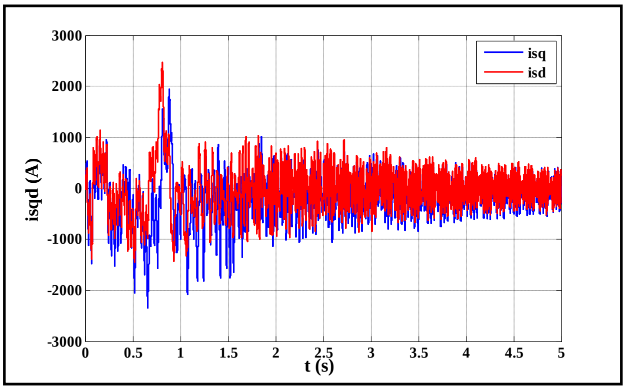

Fig. 18Stator current i_{sq} (A), i_{sd} (A) according to time (s).

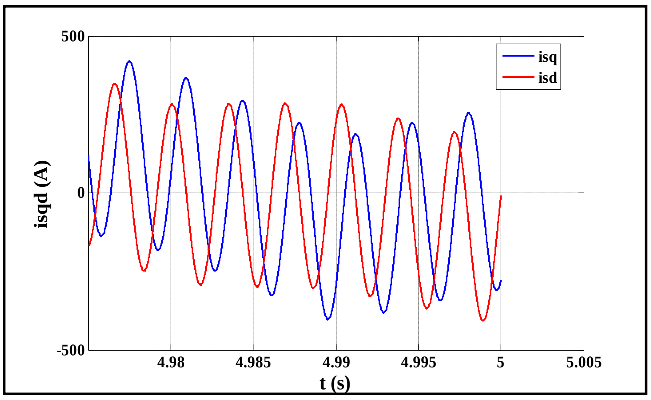

Fig. 19Stator current i_{sq} (A), i_{sd} (A) according to time (s).

The stator currents depend on the variation of the stator active power and the stator reactive power of the machine. These forms of waves depend on the speed of the rotation of the machine as well as on the rotor power according to the absorption or the supply. These curves vary in a sinusoidal way, and the value of this curves reached (2400 A).

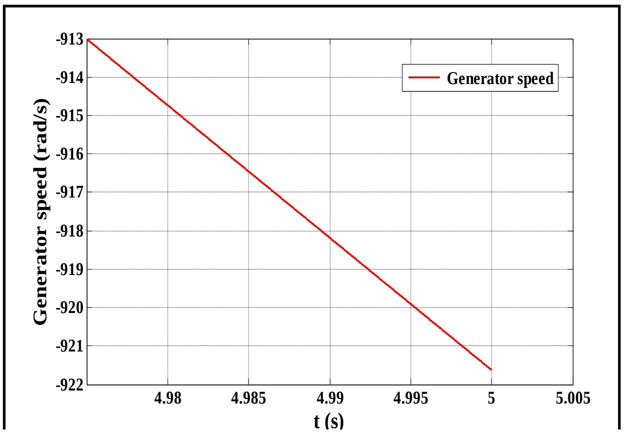

Fig. 20Generator speed (rad/s) according to time (s).

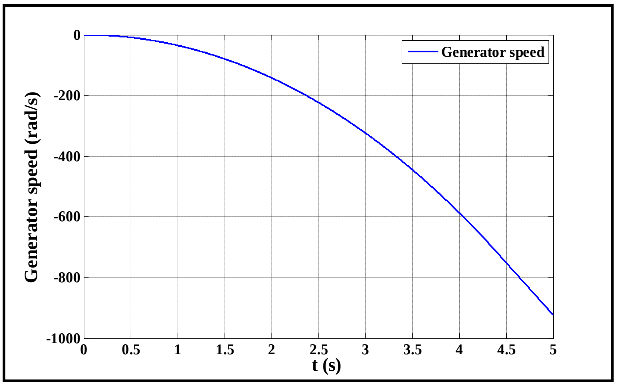

Fig. 21Generator speed (rad/s) according to time (s).

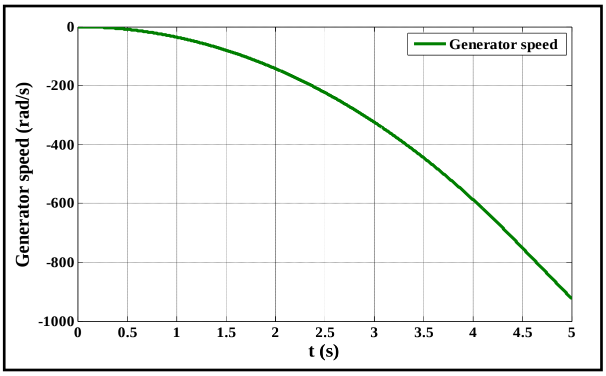

Fig. 22Generator speed (rad/s) according to time (s).

The mechanical speed on the slow tree multiplied by the coefficient of multiplying leads to a rapid mechanical couple on the asynchronous machine, and then to the increase in the speed of its rotation. The generator speed varies between $(-913\ \mathrm{rad/s})$ and $(-922\ \mathrm{rad/s})$ which is adequate to a DFIG used in wind turbines.

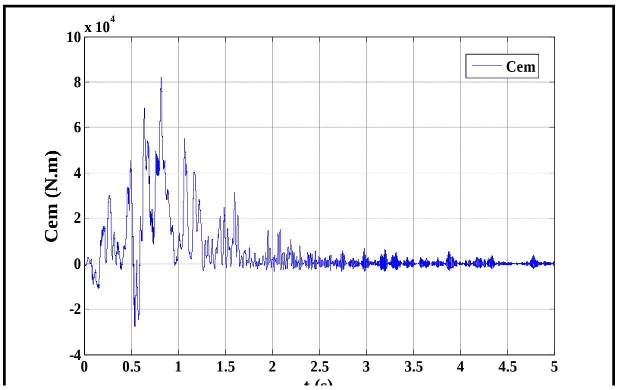

Fig. 23Electromagnetic couple C_{em} (N.m) according to time (s).

The electromagnetic couple depends on the evolution of thestator flux ϕ_s (Wb), and on the rotor current irq (A). It is independent from the speed of wind, The value of this couple vary approximately between (-30000 N.m) and (+80000 N.m) in the beginning of the simulation and it becomes very adequate to the function of high power wind turbines in the end of the simulation, it fluctuates between 4.98 seconds and 4.99 seconds, and it depends from the stator inductance.

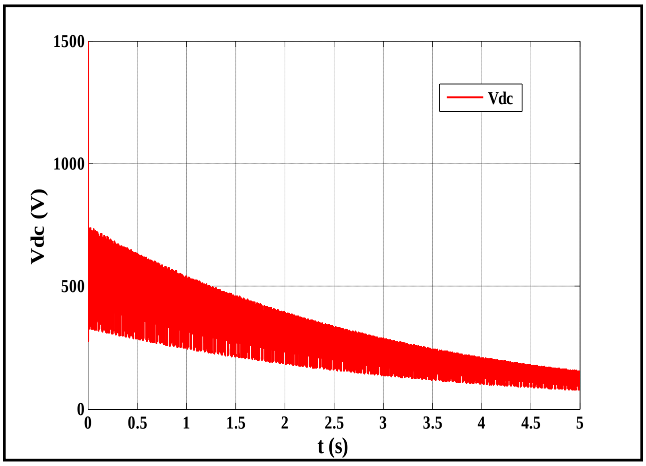

Fig. 24Voltage of continuous bus V_{dc} (V) according to time (s).

The Voltage of continuous bus V_{dc}, which allows us to control the active power injected in the grid, it has a maximum of (1500 V), and a minimum of (90 V).

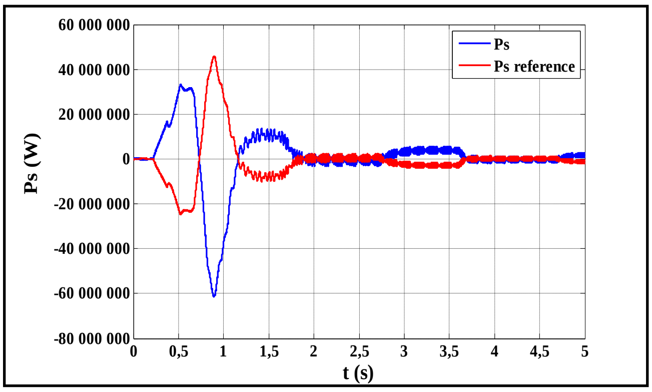

Fig. 25Stator active powers Ps (W) according to time (s).

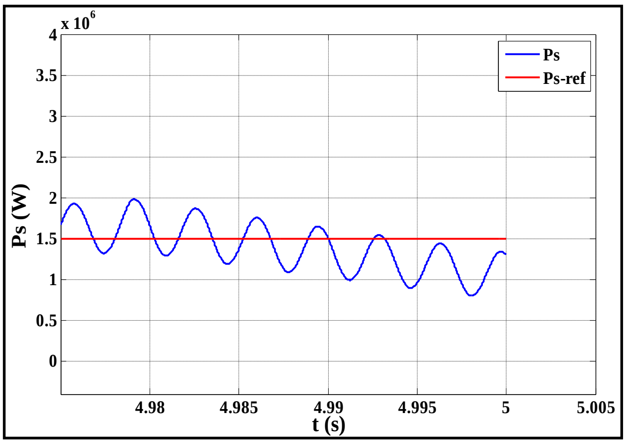

Fig. 26Stator active powers Ps (W) according to time (s).

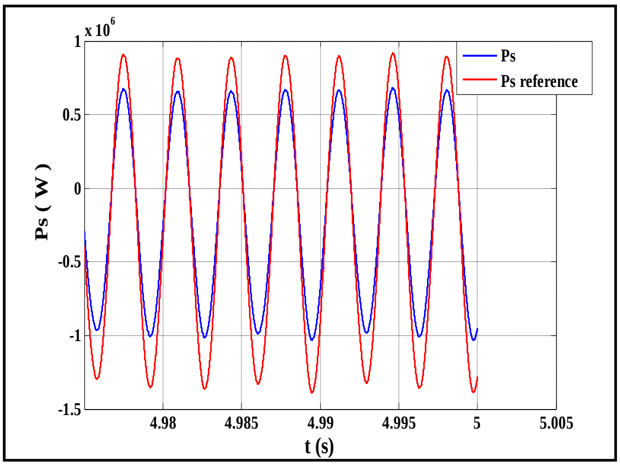

Fig. 27Stator active powers Ps (W) according to time (s).

The active stator powers depends on the variation of the stator currents, of the machine and of the sliding of the machine, it vary between (-60 MW) and (40MW). Which isadapted to high power wind turbine, the simulation time is 5 seconds.

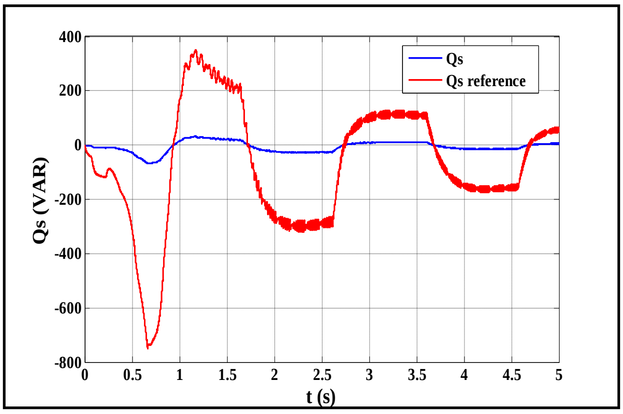

Fig. 28Stator reactive powers Qs (VAR) according to time (s).

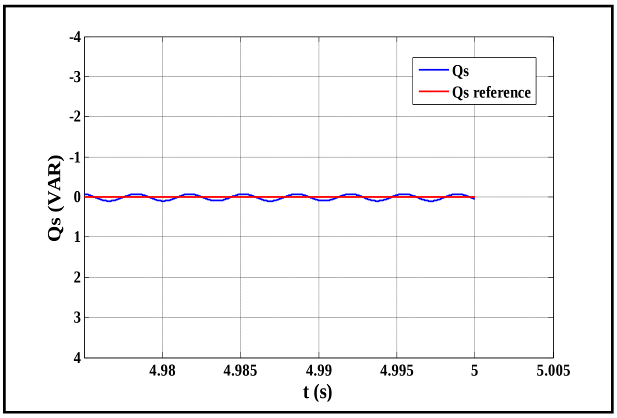

Fig. 29Stator reactive powers Qs (VAR) according to time (s).

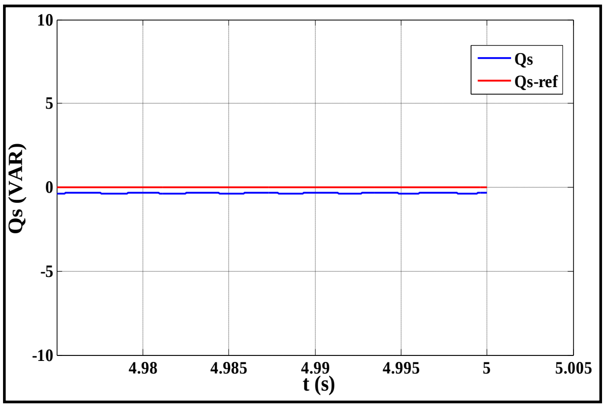

Fig. 30Stator reactive powers Qs (VAR) according to time (s).

These curves vary between (-700VAR) and (800VAR), which shows the robustness of the indirect command of the DFIG used in wind energy and it depends on the rotor current i_{dr} (A), it's not related to the profile of wind turbine, the simulation time is 5 seconds.

P_s: Active power output from stator (W);
Q_s: Reactive power output of stator (VAR);
V_{dc}: DC link voltage (V);
Φ_{ds}: The stator flux following axis d (Wb);
Φ_{qs}: The stator flux following axis q (Wb);
P: The number of pole pairs;
L_m: Magnetizing inductance (H);
L_s: Stator inductance (H);
V_{ds}: The stator voltage following axis d (V);
V_{qs}: The stator voltage following axis q (V);
I_{dr}: The rotor current following axis d (A);
I_{ds}: Stator current following axis d (A);
w_s: Stator pulsation (rad/s) ;
V_{rd} : Rotor voltage following the direct axis (V);
V_{rq} : Rotor voltage following the quadrature axis (V);
Φ_s : Stator flux (Wb);
V_s : Stator voltage (V) ;
R_s : Stator resistance(Ω).

VIII. Conclusion

From the results obtained, we can conclude that the use of the indirect control in opened loop is well adapted for this kind of system. The behavior of the asynchronous machine with double feeding was studied, when the indirect open looped command of the DFIG is applied, and the indirect command in power remains the robust and suitable command for a DFIG used in the wind energy. The algorithm based on a traditional (PI) controller can be used under every circumstance without variations on the control hardware of the actual wind generators [17]. The one based on an indirect opened control presents a better performance for trajectory tracking applications, with error minimization characteristics but with the need for more computational operations[18]. On the other hand, even if both algorithms present a correct dynamic performance in the developed tests, only the (PI) controller has really been implemented in a wind farm, It can be used to implement and develop various studies such as interaction of wind farm with an energy storage system [19], interaction of model with a solar system, applying protection system technology and developing new advanced control schemes, Considering the results it can be said that doubly fed induction generator proved to be more reliable and stable system when connected to grid side with the proper converter control systems [20]-[21].

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