ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING
YEAR : 2008
VOLUME : 8
NUMBER : 2
(633-641)

Comparison of PI and Direct Power Control with SVM of Doubly Fed Induction Generator

C. Belfedal[1], S.Moreau[1], G.Champenois[1], T.Allaoui[2], M.Denai[3]

ABSTRACT

The present paper proposes the control of powers, independently of each other, of the active and reactive of a DFIG (Doubly Fed Induction Generator) used generally in the production of the electric energy and more especially in wind turbines.
The machine is connected to a public network and works as a generator. Its rotor is fed by a two levels inverter. We propose to control the DFIG by two strategies, the first one is based on the use of classic PI controller and the second one is based on the use of DPC (Direct Power Control). Then we will end up by a comparison of the performances obtained by the two control strategies.

***Keywords**: DFIG, wind turbine, PI controller, DPC controller, SVM.*

I. Nomenclature

$d-q$	Field oriented reference frame
V_{ds}, V_{qs}	Stator voltage components
V_{dr}, V_{qr}	Rotor voltage components
I_{ds}, I_{qs}	Stator current components
I_{dr}, I_{qr}	Rotor current components
Φ_{ds}, Φ_{qs}	Stator fluxes components
Φ_{dr}, Φ_{qr}	Rotor fluxes components
R_s, R_r	Stator and rotor phase resistances
L_s, L_r	Stator and rotor phase inductances
M	Cyclic mutual inductance
p	Number of poles pair of the machine
C_r	The load torque
f	Friction constant
J	Moment of inertia
Ω	Mechanical rotor speed
ω	Rotor angular frequency
ω_s	Grid electrical angular frequency
ω_r	Rotor electrical angular frequency
C_q, C_d	Compensation terms
P_s, Q_s	Active and reactive power
$P_s{*}, Q_s{*}$	Active and reactive power reference
P_m	Mechanical power
$Vr_{a\_b}{*}$	Rotor voltages reference
V_{sa}, V_{sb}	Measured stator voltages
I_{ra}, I_{rb}	Measured rotor currents
e_p	Active power error
e_q	Reactive power error
E_p	Hysteresis output of active power
E_q	Hysteresis output of reactive power
$x_e{*}$	Input reference variable, Ps^* *or* Qs^*
x_s	Output variable, *Ps* or *Qs*

Acronyms

THD%	Total Harmonic Distortion rate

II. Introduction

The squirrel cage induction machine is extensively used for its weak cost and its simplicity of construction and maintenance, but when it is connected to a fixed frequency network, the totality of the power is not extracted because of its low sliding (restricted speed interval), on the contrary the wound-rotor induction machine can be used to remedy this drawback [1].

As wind turbines turn with a variable speed depending on the wind speed, the wound-rotor induction machine presents good performance

Received Date: 09.08.2008
Accepted Date: 01.07.2008

thanks to its large margin of speed variation. Besides, the power consumed by the rotor is very lower to the one provided to the stator [2] (| Pr | << | Ps | with Pr = g.Ps),

Running in generator mode, the wound-rotor induction machine provides the active power Ps to the network equal to the sum of the mechanical and rotor powers (Pm+Pr, with Pr>0 or Pr<0), when the different losses occurring during the electromagnetic conversion are neglected.

The advantage of the wound-rotor induction machine is based on the bi-directional transfer of the rotor power which depends on the rotor speed and the field speed. Indeed, to produce energy for the network, we have:

- To provide the energy for the rotor from the mechanical energy. The rotor speed should verify the following relationship $\omega > \omega_s$ (and $P_r < 0$) so $\omega_r = p\Omega - \omega_s$ [3].

- Or to provide the energy for the rotor from the network energy. In this case, we have $\omega < \omega_s$ (and $P_r > 0$) so $\omega_r = \omega_s - p\Omega$.

The inverter connected to the rotor of the DFIG must provide the necessary complement frequency in order to maintain constant the stator frequency despite the variation of the mechanical speed.

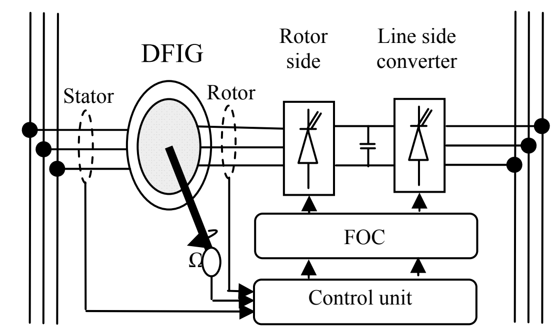


Fig.1. Synoptic of DFIG connected to the public network

The system studied in the present paper is constituted of a DFIG directly connected through the stator windings to the network, and supplied through the rotor by a static frequency converter as presented in Fig. 1.

The two approaches presented in this paper are the direct control of powers by using PI regulators, and the indirect control of the powers by DPC Control.

The energy exchange between public network and DFIG is obtained by controlling independently the active and reactive powers.

The connection of the DFIG is accomplished after having satisfied the following conditions.

1 - The regulation of the stator voltage amplitude and frequency is established.

2 – The voltage is stabilized to a value equal to the network one.

3- Dephasing between network phases and DFIG is equal to zero.

III. Mathematical Model of the DFIG

In the rotating field reference frame, the model of the wound-rotor induction machine is given by the following equations:

Equations of stator voltage components:

$$V_{ds} = R_s.I_{ds} + \frac{d\Phi_{ds}}{dt} - w_s\Phi_{qs} \tag{1}$$

$$V_{qs} = R_s.I_{qs} + \frac{d\Phi_{qs}}{dt} + w_s\Phi_{ds} \tag{2}$$

Equations of rotor voltage components:

$$V_{dr} = R_r.I_{dr} + \frac{d\Phi_{dr}}{dt} - w_r\Phi_{qr} \tag{3}$$

$$V_{qr} = R_r.I_{qr} + \frac{d\Phi_{qr}}{dt} + w_r\Phi_{dr} \tag{4}$$

Equations of stator flux components:

$$\Phi_{ds} = L_s.I_{ds} + M.I_{dr} \tag{5}$$

$$\Phi_{qs} = L_s.I_{qs} + M.I_{qr} \tag{6}$$

Equations of rotor flux components:

$$\Phi_{dr} = L_r.I_{dr} + M.I_{ds} \tag{7}$$

$$\Phi_{qr} = L_r.I_{qr} + M.I_{qs} \tag{8}$$

Equations of electromagnetic torque:

$$C_{em} = p.\frac{M}{L_s}(\Phi_{ds}.I_{qr} - \Phi_{qs}.I_{dr}) \tag{9}$$

Mechanical equation:

$$C_{em} = C_r + J\frac{d\Omega}{dt} + f.\Omega \tag{10}$$

IV. Control with PI regulators:

The stator flux vector is orienting according to the d axis in the Park's reference frame (Fig.2).

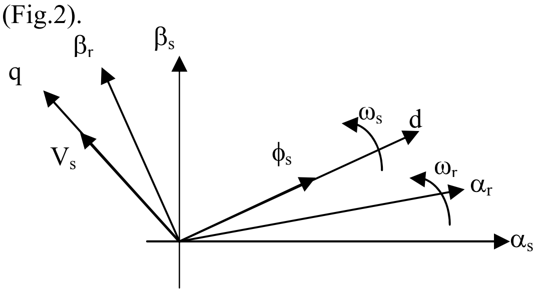


Fig.2 Stator flux vector oriented according the d axis in the Park's reference frame

If the voltage drops due to the stator resistance Rs which is neglected, we can write:

$$V_{dr} = R_r.I_{dr} + (L_r - \frac{M^2}{L_s})\frac{dI_{dr}}{dt} + \frac{M}{Ls}.\frac{d\Phi_s}{dt} - w_r(L_r - \frac{M^2}{L_s}).I_{qr} \qquad (11)$$

$$V_{qr} = R_r.I_{qr} + (L_r - \frac{M^2}{L_s})\frac{dI_{qr}}{dt} + w_r(L_r - \frac{M^2}{L_s}).I_{dr} + w_r.(\frac{M}{L_s}\Phi_s) \qquad (12)$$

We can notice in the equations of Vdr (11) (control variable of Ps) and Vqr (12) (control variable of Qs) that these two control variables are coupled. The decoupling is obtained by compensation in order to assure the control of Ps and Qs, independently of each other. So we get a first order system, and its control is simplified and realized by a PI controller.

The *Ps* and *Qs* expressions can be written as follow:

$$P_s = -V_s.\frac{M}{L_s}I_{qr} \qquad (13)$$

$$Q_s = V_s.\frac{\Phi_s}{L_s} - V_s.\frac{M}{L_s}.I_{dr} \qquad (14)$$

The system after compensation becomes:

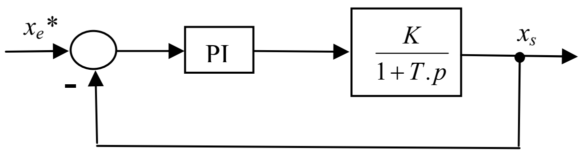


Fig.3 Scheme of the system with feed-back loop

The global scheme of the control through PI controller can be given as follows:

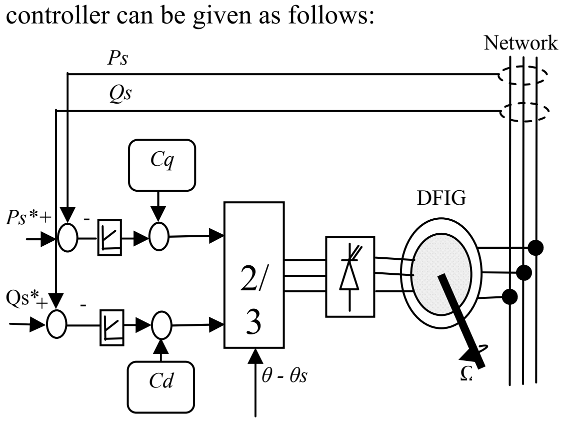


Fig.4. Global scheme of control through PI regulators

For decoupling the two axes, the terms shown in eq. 11 and 12 give the following compensation ones:

$$C_q = +w_r(L_r - \frac{M^2}{L_s}).I_{qr} \qquad (15)$$

$$C_d = -w_r(L_r - \frac{M^2}{L_s}).I_{dr} - w_r.(\frac{M}{L_s}\Phi_s) \qquad (16)$$

From equations (13) and (14) we can write:

$$I_{qr} = \frac{-.L_s}{M.V_s}P_s \qquad (15)$$

$$I_{dr} = \frac{L_s}{M.V_s}Q_s - \frac{\Phi_s}{M} \qquad (16)$$

By replacing Idr and Iqr in (11) and (12), neglecting the terms cancelled by compensation (eq. 15 and 16) and taking Φ_s constant we obtain:

$$V_{dr} = \frac{R_r.L_s}{M.V_s}.Q_s + (L_r - \frac{M^2}{L_s})\frac{L_s}{M.V_s}.\frac{dQ_s}{dt} - \frac{R_r.\Phi_s}{M} \qquad (17)$$

$$V_{qr} = \frac{-R_r.L_s}{M.V_s}.P_s + (L_r - \frac{M^2}{L_s})\frac{-L_s}{M.V_s}.\frac{dP_s}{dt} \qquad (18)$$

We can write:

$$V_{dr} = -A.Q_s - B.\frac{dQ_s}{dt} - C \qquad (19)$$

$$V_{qr} = AP_s + B.\frac{dP_s}{dt} \qquad (20)$$

Where:

$$A = \frac{-R_r.L_s}{M.V_s}\ ,\ B = (L_r - \frac{M^2}{L_s})\frac{-L_s}{M.V_s}$$

$$(21)\quad C = \frac{R_r.\Phi_s}{M} \qquad (22)$$

Therefore:

$$\frac{P_s}{V_{qr}} = \frac{1}{A + B.s} = \frac{\frac{1}{B}}{s + \frac{A}{B}}. \qquad (23)$$

We can represent the fig.5 as follows:

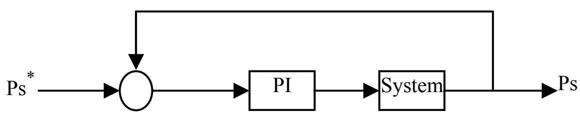


Fig.5. Scheme of the system with feed-back loop.

The gain of block PI is in the form:

$$G_{PI} = K_p + \frac{K_i}{s} = \frac{K_p}{s}.(s + \frac{K_i}{K_p}) \qquad (24)$$

Therefore the fig. 7 becomes:

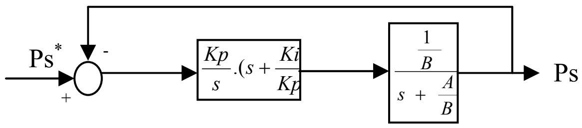


Fig.6. Scheme of the PI and system form with feed-back loop.

So, if we want to model the loop of regulation by a first order, we can compensate the zero introduced by PI with the pole in open loop of the system:

$$\frac{K_i}{K_p} = \frac{A}{B} \Rightarrow K_i = K_p.\frac{A}{B} \qquad (25)$$

$$\frac{P_s}{P_s*} = \frac{\frac{K_p}{B.s}}{1 + \frac{K_p}{B.s}} = \frac{K_p}{B.s + K_p} = \frac{1}{1 + \frac{B}{K_p}.s} = \frac{1}{1 + T.s} \qquad (26)$$

$$\frac{P_s}{P_s*} = G_{BF} = \frac{1}{1 + T.s} \qquad (27)$$

V. Direct Power Controller (DPC)

The strategy of the DTC (Direct torque control) is introduced by TAKAHASHI in the 80s. This strategy is based on the control of the electromagnetic torque and the stator flux of an induction machine in motoring mode, by two hysteresis controllers. The outputs of these last ones and along with the orientation of the stator flux in α,β plane, generate the switching table [1] which gives the orders of switching to apply to the voltage inverter in order to feed the wound rotor.

To control a DFIG in generating mode, variables to be controlled become the active and reactive powers. The rotor wound can be fed by a two levels inverter.

Since I_{qr} and I_{dr} are the images respectively of Ps and Qs (with $Vds = 0$ *and* $\Phi qs = 0$) (eq. 13 & 14), instead of measuring the two powers on the line, we capture the rotor currents, and estimate Ps and Qs. This approach gives an anticipated control of the powers in the stator windings, and consequently the response to the reference variations will be faster.

The studied system can be shown on Fig.7.

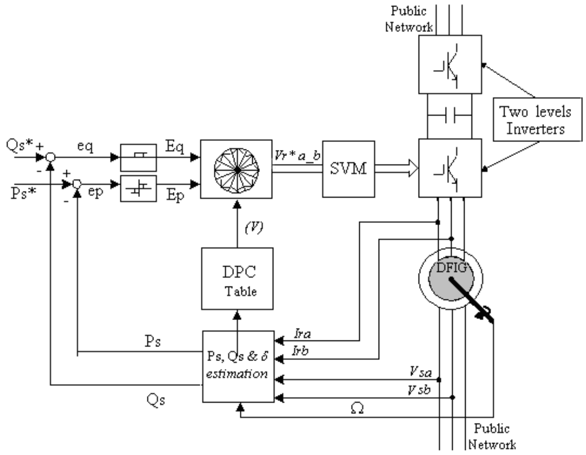


Fig.7. Control system through DPC Controller

In this approach, we present the direct control of active and reactive powers by using space vector modulation provided to two levels inverter which supplies the rotor windings.

By using the previous equations (eq. (1) to (9)), we can create the relations of Ps and Qs according to both components of the rotor flux:

$$P_s = -V_s.\frac{M}{L_s.L_r - M^2}.\Phi_{qr} \qquad (17)$$

$$Qs = \frac{V_s.L_r}{L_s.L_r - M^2}.\Phi_s - \frac{V_s.M}{L_s.L_r - M^2}.\Phi_{dr} \qquad (18)$$

We see although that so as to control Ps, the imaginary component of the rotor fluxes (ϕqr) must be controlled, whereas we can control Qs through the real component of the rotor flux (Φ_{dr}) [4].

I. Relation between space vectors and active and reactive powers

While we apply the various vectors to the rotor windings, we notice that:

Assuming ϕr is in the kth sector ($1 \le k \le 6$), in generating mode and motoring mode, the voltage vector in different direction of V_k vectors increases or decreases Ps and Qs, as shown in Fig. 8 and 9.

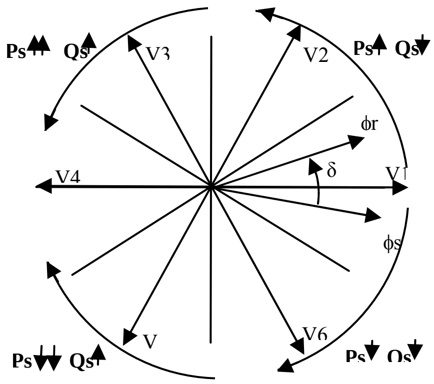


Fig.8. Effect of space vectors direction on active and reactive power in generating mode

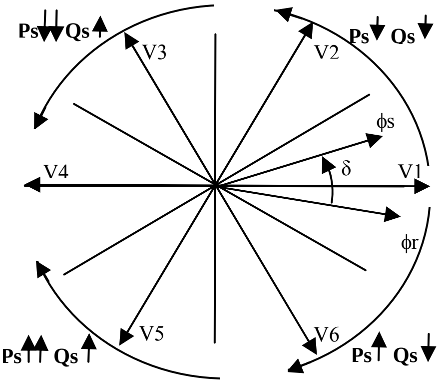


Fig.9. Effect of space vectors direction on active and reactive power in motoring mode

In this paper, we opt to provide at each instant a voltage vector which accelerates or decelerates ϕr in order to increase or reduce active and reactive power in the two running modes.

II. Switching table logic

We consider e_p as the error between the reference active power value and the estimated one, and e_q as the error between the reactive power reference value and the estimated one as follows:

$$if \quad e_p > 0 \Rightarrow \begin{cases} E_p = \ 1 \ if \ P_s^* > 0 \ (motoring \ mode) \\ E_p = -1 \ if \ P_s^* < 0 \ (generating \ mode) \end{cases}$$

$$if \quad e_p < 0 \quad \Rightarrow \quad E_p = 0$$

$$if \quad e_q > 0 \quad \Rightarrow \quad E_q = 1$$

$$if \quad e_q < 0 \quad \Rightarrow \quad E_q = 0$$

From the relations given above, we deduce the following switching table:

TABLE I
Two levels inverter switching table for generating mode

Ep	Eq	Sector 1 to 6
0	0	δ+2π/3
	1	δ+π/3
-1	0	δ−2π/3
	1	δ−π/3

TABLE II
Two levels inverter switching table for motoring mode

Ep	Eq	Sector 1 to 6
0	0	δ−2π/3
	1	δ−π/3
1	0	δ+2π/3
	1	δ+π/3

VI. Simulation results

The both control strategies are simulated by using the MATLAB/SIMULINK software. So as to really evaluate the performances of the two strategies of regulation, we test and compare the responses of the two last ones in three cases:

a) In the first case, we apply an active power step from 0 to -5 kW at the instant t=1.5s, (Qs*=0 VAR).

b) In the second case, we apply a rotation speed step varying from 3120 r/min to 3540 r/min at the instant t=2s.

c) In the third case, we increase Rr and Rs of 100% (case of warming-up of the stator and rotor windings) and decrease all inductances of 100% (case of inductances saturation).

We finally study the rate of harmonics in stator currents in each strategy.

I. Variation of the reference

While imposing a step of Ps=-5kw at the instant t=1.5s, we get the responses respectively for the PI and DPC controller.

The responses of the two regulators pursue the reference with a very fast time response. For the DPC controller, the time response is equal to 1ms (Fig.8) and a slower time response is obtained for the PI regulator equal to 15ms. We also notice on the Fig.8 to 14 that the variation of the active power has a slight influence with the PI regulator on the reactive power and a quasi negligible effect for with DPC controller.

The Fig.12 and 13 show the transient response of the stator current from 0A to 12.5A respectively for the PI regulator and the DPC controller. With the last one controller, the currents present a less fluctuations.

II. Gear-change

In the Fig. 16 and 18, the variation of the rotation speed at the instant t=2s affects the two powers with a transient regime which lasts 0.2s, and the same case for the stator current (Fig.20) obtained with the PI regulator. No influence appears in the case of the DPC controller as we can see on Fig. 17, 19 and 21.

III. Change of the machine parameters

In the Fig. 22 to 27, we have changed the value of the machine parameters at the instant t=0s, we decrease Rr and Rs of 100% and increase all inductances of 100%. The results show that the influence of the parameters variations has more effect on the DPC controller, because Ps and Qs are estimated using the rotor currents and machine parameters, it is the major inconvenient of this strategy. If the machine parameters variations are significant, it will be necessary to measure the Ps and Qs on the network line, as shown in responses of Fig. 23, 25 and 27.

For the PI regulator, it has the same inconvenient, the fluctuations on Ps, Qs and stator currents responses are also significant for the same reason Fig. 22, 24 and 26.

IV. Filtering

To reduce the harmonic distortion rate, we can add an inductance on each phase between the stator of the machine and the network. This process presents some drawbacks:

- We have the voltage drop due to the passage of the fundamental current in inductances
- The commutation angle increases and as well as the surface of the switching notches [6].

The inductance of the filter is generally dimensioned to a fraction of the impedance of the machine. Thus the voltage drop is reduced in the inductance of the filter. In this case we will choose: L = 0.1 Ls. The resistance corresponds to the internal resistance of the inductance and is thus proportional to the internal Joules losses of inductance [7]; if we consider that these losses are lower than 1% of the total power, therefore:

$$r = \frac{0.01.Ps}{3.Is} \tag{19}$$

V. Analysis of the harmonics rate in stator currents

The equations (5) and (6) give the following equations with $\Phi_{ds} = \Phi_s = c^{te}$ and $\Phi_{qs} = 0$:

$$I_{ds} = \frac{\Phi_s}{L_s} - \frac{M.I_{dr}}{L_s} \tag{20}$$

$$I_{qs} = -\frac{M.I_{qr}}{L_s} \tag{21}$$

These equations show the linear relation between the rotor and stator currents. And the harmonics of the rotor currents provided by the inverter generate the same harmonics in the stator currents.

The harmonics in the case of the DPC controller are less significant than those in the case of the PI controller, and it is due to the use of the PMW strategy in the first controller, which is the source of the harmonics in the inverters and SVM in the switching case which eliminates the most of the harmonics. Moreover the DPC controller gives a faster response since it reacts to the variations of the rotor currents and its SVM strategy which reduce fluctuations specially caused by this controller and get consequently a better outputs. So there are less disturbances and better stability of the rotor currents and less harmonics in the stator currents.

We can evaluate the importance of these harmonics by using Fast Fourier Transform (FFT) of the stator currents and the results obtained show the difference of the harmonics rate between the two strategies (Fig. 28 and 29)

In another manner, we can evaluate these distortions due to the harmonics using the THD where:

$$THD_{Is} = \frac{\sum I^2{}_{sh}}{I^2{}_{sf}} \tag{22}$$

I_{sf} represents the amplitude of the fundamental current, I_{sh} the harmonic current of the row h.

The harmonic rate for the PI regulator is 0.14%. On the other hand the harmonic rate in the DPC Controller regulator is 0.03%.

a. Responses of PI Controller

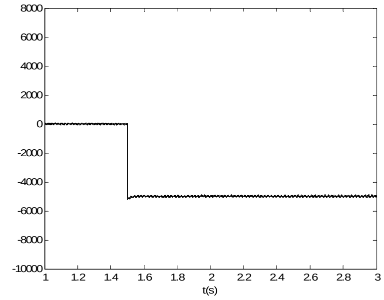


Fig. 10 Ps response for Ps* step

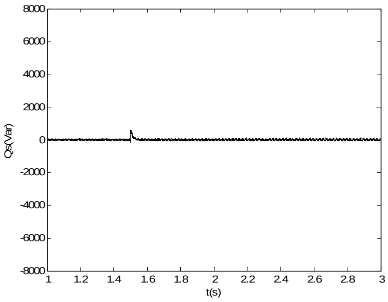


Fig.12 Qs response for Ps* step

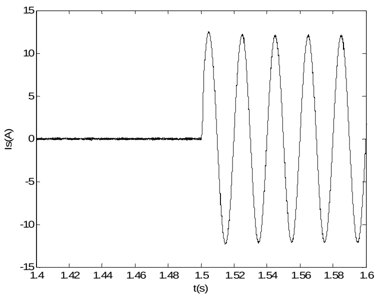


Fig.14 Isα response for Ps* step

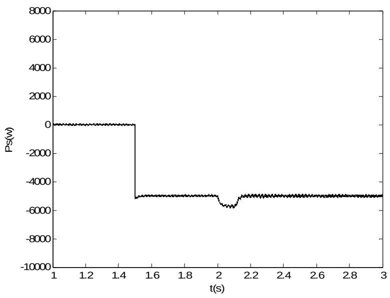


Fig.16 Ps response for Ps* step and Ω variation

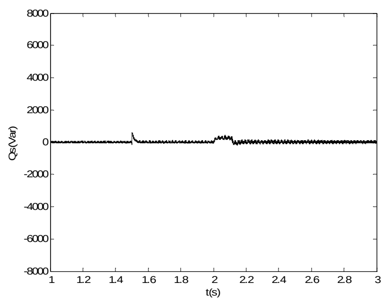


Fig. 18 Qs response for Ps* step and Ω variation

b. Responses of DPC Controller

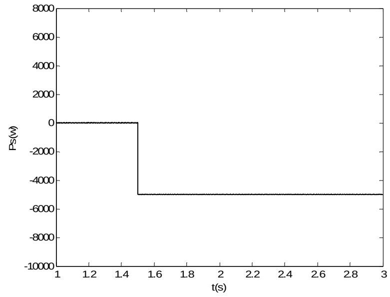


Fig.11 Ps response for Ps* step

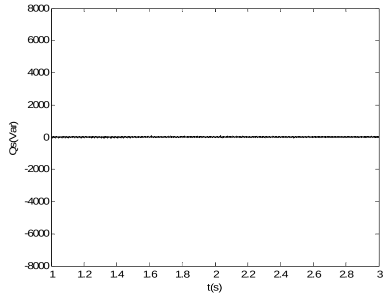


Fig.13 Qs response for Ps* step

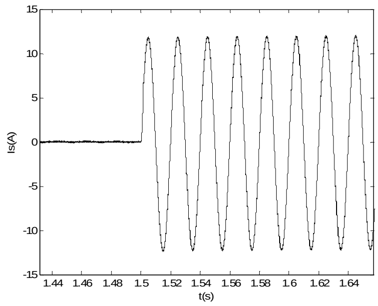


Fig.15 Isα response for Ps* step

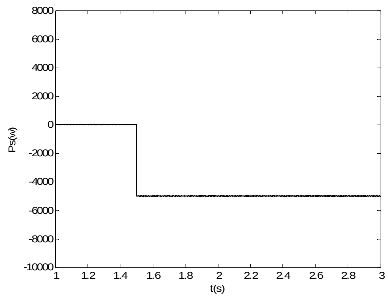


Fig. 17 Ps response for Ps* step and Ω variation

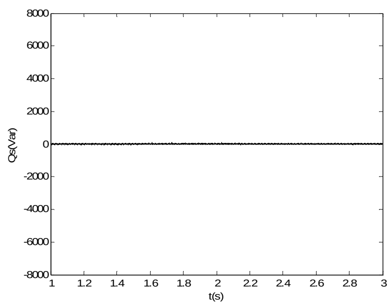


Fig. 19 Qs response for Ps* step and Ω variation

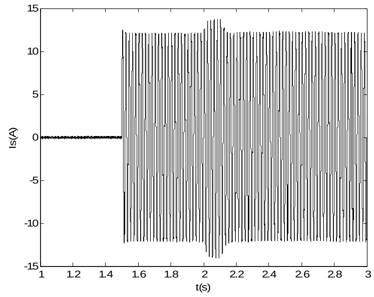


Fig. 20 Isα response for Ps* step and Ω variation

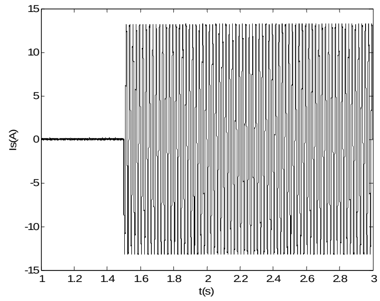


Fig. 21 Isα response for Ps* step and Ω variation

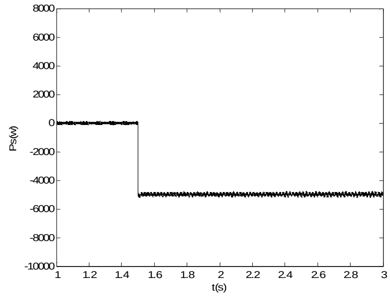


Fig. 22 Ps response for Ps* step and parameters change

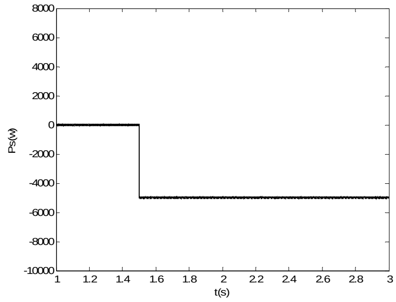


Fig. 23 Ps response for Ps* step and parameters change

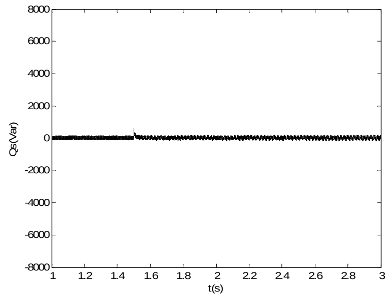


Fig. 24 Qs response for Ps* step and parameters change

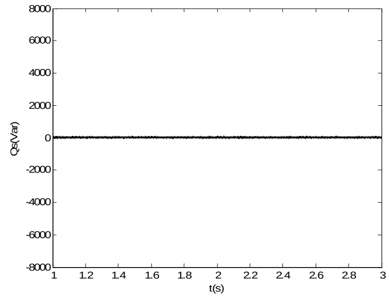


Fig. 25 Qs response for Ps* step and parameters change

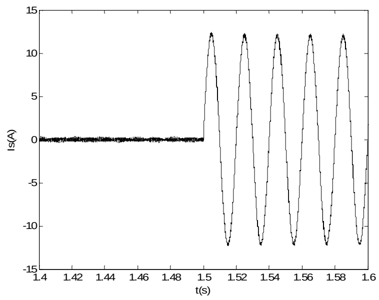


Fig. 26 Isα response for Ps* step and parameters change

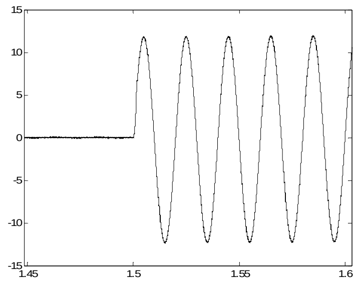


Fig. 27 Isα response for Ps* step and parameters change

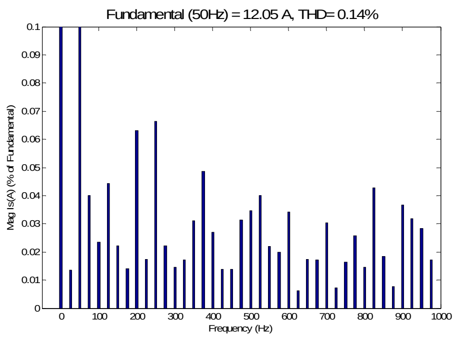


Fig. 28 FFT of stator current component Isα

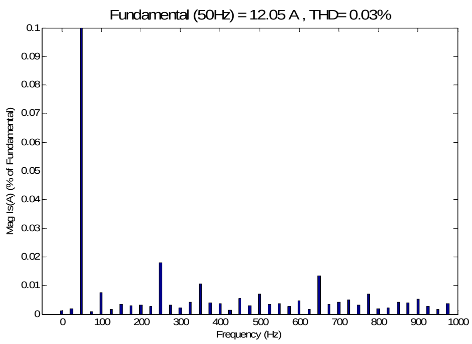


Fig. 29 FFT of stator current component Isα

VII. Conclusion

After introducing the mathematical model of the DFIG, we have presented two control strategies of active and reactive powers of the DFIG connected to the network: the first one is based on PI controller and the second one relies on DPC controller. So as to evaluate the performances of each strategy, we applied an active power step reference, a speed variation, and a variation of the machine parameters.

Simulation results show that DPC controller:

- gives the best time response,
- is less sensitive to speed variation (which is better for the application to wind turbines),
- is more robust to parameters variation of the machine,
-and provides less harmonics in stator currents,

However the DPC controller presents the drawback to having a high frequency of switching which may lead to the warming-up of the silicon switchers.

Using the DPC controller, the Ps and Qs estimation respectively from the I_{rq} and I_{rd} currents, is better if the parameters variation is not significant.

References

[1] D. Forchetti, G. Garcia, M. I. Valla, Vector control strategy for a doubly-fed stand-alone induction generator, Industrial Electronics Society, IEEE 2002 28th Annual Conference of the IEEE journal, Vol. 2, pp. 0_1-VI, 2002.

[2] R. Datta, V. T. Ranganathan, A simple position-sensorless algorithm for rotor-side field-oriented control of wound-rotor induction machine, IEEE trans. Ind. Elect., vol 48, N°4, pp. 786-793, August 2001.

[3] Y. Tang, L. Xu, A flexible active and reactive power control strategy for variable speed constant freqency generating system, *IEEE Transactions on Power Electronics*, vol 10 N°4, pp. 472-478, July/Aug., 1995

[4] D. Forchetti, , G. Garcia, , M. I. Valla,., *Vector control strategy for a doubly-fed stand-alone induction generator*, 28th Annual Conference of the IEEE Industrial Electronics Society (IECON'02), Vol. 2, pp. 991 – 995, 2001.

[5] R. Datta, and V.T. Ranganathan, *Direct Power Control of grid-connected wound rotor Induction Machine without rotor position sensors*, IEEE Transactions on Power Electronics, Vol. 16 N° 3, pp. 390-399, 2001.

[6] J. Bonal, G. Seguier, Entrainements électriques à vitesse variable, Prométhée Schneider Electric, Vol.3, 2000.

[7] C. Khatounian, F. Khatounian, E. Monmasson, F. Berthereau, J.P. Louis, *Commande d'un système de génération électrique pour réseau de bord d'avion –Introduction de charges non linéaires et la mise en place d'un filtre LC*, Conférence Avion et électricité, 18-19 mars 2004, Cergy Pontoise, France.

Received Date: 09.08.2008
Accepted Date: 01.07.2008

Authors' information

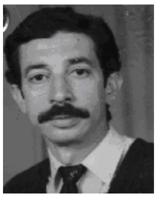
[1]*Laboratory of Automatic and Industrial Informatics (LAII), University of Poitiers, France (Corresponding author : cheikh.belfedal@ext.univ-poitiers.fr)*
[2]*Electrical Engineering Department, University of Tiaret,, Algeria*
[3]*Laboratory of Automatic, University of Oran, Algeria*

C. Belfedal received Magister degree in electrical engineering from Tiaret University, Algeria, in 1996. Currently he is with the Department of Electrical Engineering, Tiaret University. His fields of interest are control of electrical machines, power converters, modelling and control of wind turbines.

Sandrine MOREAU was born in France in 1972. She received the PhD degree from the University of Poitiers in automatic control in 1999. She is now Assistant Professor at the University of Poitiers (France). Her major research interests are modelling, identification, diagnosis and control of electrical machines associated with static converters.

Gérard Champenois was born in France in 1 1957. He receives the Ph.D. degree in 1984 and the "habilitation degree" in 1992 from the Institute National Polytechnique of Grenoble (France). Now, he is professor at the University of Poitiers (France). His major fields of interest in research are electrical machines associated with static converter; control, modelling and diagnosis by parameter identification techniques.

T. Allaoui was born in Algeria in 1973. He received Magister degree from the University of Science and Technology of Oran, Algeria in electrical engineering in 2002. Currently, he is with the Department of Electrical Engineering of Tiaret University, Algeria. His major research interest are modeling and control of electrical machines associated with static converters.



M. Denaï received the engineer degree in electrical engineering from Ecole Polytechnique of Algiers in 1982, the PhD in Control Engineering from the University of Sheffield, UK in 1988. Currently, he is a Professor in automatic control at the University of Science and technology of Oran, Algeria. His research interests are in system modelling and control using soft-computing techniques