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Decoupled Control of Activeand Reactive Power for DFIG

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***Abstract*—this paper focuses on the decoupled control of activeand reactive power for doubly fed induction generator (DFIG).The system analysis is based on the mathematic model of doubly fed induction generator (DFIG) intwo-phase synchronous coordinate system, the decoupled control of active and reactive power using the method of stator field oriented vector control. An effective method of independentactive power and reactive power control is proposed. Detailed simulation on MATLAB/SIMULINK verifies the feasibility andvalidity of the proposed control strategy.**

***Keywords*— doubly-fedinduction generator(DFIG); active and reactive decoupled control, PI controller.**

I. INTRODUCTION

Double-fed induction generators (DFIG) are gaining more attention especially in the field of wind power generation due to rapid development in power electronics. Variable-speed wind-energy conversion system using DFIG, fed with variable frequency rotor voltage allows fixed-frequency electric power generation from the generator stator. One of the main advantages of these generators is that, if rotor current is governed applying stator-flux-oriented vector control—carried out using commercial double-sided PWM inverters [1][2], decoupled control of stator side active and reactive powers results [3][4]. Also, power converter is designed in partial scale, just about 30% of the generator rated power, which makes it attractive from economical point of view. The back to back AC-DC-AC voltage source converter has two main parts: grid side converter (GSC) that rectifies grid voltage and rotor side converter (RSC) which feeds rotor circuit. One of the most common control techniques is decouple [5].

So far, several different control method have been appliedto PWM rectifiers for improving their functionality and usefulness. A well-known method of indirect active andreactive power control is based on current vector orientation with respect to the line voltage vector and is known asvoltage-oriented control (VOC). VOC guarantees high dynamics and static performance via internal current controlloops. However, the final configuration and performance of the VOC system largely depends on the quality of the appliedcurrent control strategy. Another less known method is based on instantaneous direct active and reactive power control, and is called direct power control (DPC) [6].

In thispaper, the principles of the DFIG as well as its mathematic model have been presented. In the model areintroduced the transformations which are later used for the construction of the machine control. This paper introduces thetraditional stator flux-oriented vector control and improves the traditional PI controllerof active and reactive power to improve the dynamic behavior of (DFIG) through tuning of PI parameters.The simulation on the MATLAB/SIMULINK plat was performed,and the validity of this control was verified by the result of simulation[7].

II. MODELING AND VECTOR CONTROL OF (DFIG)

The electrical equations of DFIG in the repository can be written d-q Park [8-9] [10]:

$$\begin{aligned} v_{ds} &= R_s \cdot I_{ds} + \frac{d\varphi_{ds}}{dt} - \omega_s \cdot \varphi_{qs} \\ v_{qs} &= R_s \cdot I_{qs} + \frac{d\varphi_{qs}}{dt} + \omega_s \cdot \varphi_{ds} \\ v_{dr} &= R_r \cdot I_{dr} + \frac{d\varphi_{dr}}{dt} - (\omega_s - \omega_r) \cdot \varphi_{qr} \\ v_{qr} &= R_r \cdot I_{qr} + \frac{d\varphi_{qr}}{dt} + (\omega_s - \omega_r) \cdot \varphi_{dr} \end{aligned} \qquad (1)$$

Equation magnetic of flux:

$$\begin{cases} \varphi_{ds} = L_s \cdot I_{ds} + M \cdot I_{dr} \\ \varphi_{qs} = L_s \cdot I_{qs} + M \cdot I_{qr} \\ \varphi_{dr} = L_r \cdot I_{dr} + M \cdot I_{ds} \\ \varphi_{qr} = L_r \cdot I_{qr} + M \cdot I_{qs} \end{cases} (2)$$

Equation of the electromagnetic torqueC_{em}:

$$C_{em} = -\frac{3}{2} p \frac{M}{L_s} (\varphi_{ds} \cdot I_{qr} - \varphi_{qs} \cdot I_{dr}) (3)$$

The mechanical equation of motion is defined by:

$$J \cdot \frac{d\omega_r}{dt} = C_{em} - C_r - f \cdot \omega_r$$

The active and reactive power and stator rotor of **(DFIG)**are written as follows:

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$$\begin{cases} P_s = v_{ds} \cdot I_{ds} + v_{qs} \cdot I_{qs} \\ Q_s = v_{qs} \cdot I_{ds} - v_{ds} \cdot I_{qs} \\ P_r = v_{dr} \cdot I_{dr} + v_{qr} \cdot I_{qr} \\ Q_r = v_{qr} \cdot I_{dr} - v_{dr} \cdot I_{qr} \end{cases} \quad (4)$$

III. CONTROLLED FLOW GUIDANCE STATOR

To simplify the control of the **(DFIG)**, we approximate the model to that of the DC machine, the latter having the advantage of having a natural coupling between flows and currents. For this, we choose a benchmark two-phase d-q related rotating field and apply the order by orientation of the stator flux. [11] The stator flux φ_s is oriented along the axis, and thus we can write:

$$\varphi_{ds} = \varphi_s \,;\, \varphi_{qs} = 0 \quad (5)$$

Figure1 shows the principle of control Vector by orientation of the stator flux

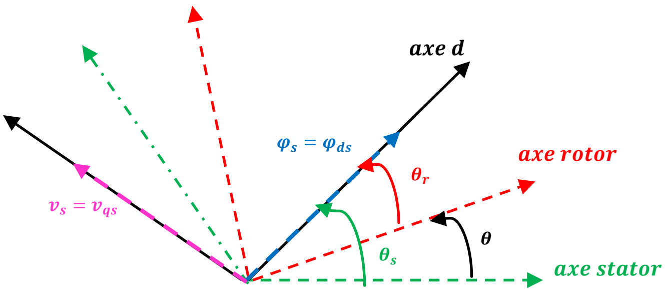


Fig. 1 Principle of the vector control.

The expression of the electromagnetic torque becomes then:

$$C_{em} = -\frac{3}{2} p \frac{M}{L_s} \varphi_{ds} \cdot I_{qr} \quad (6)$$

The expressions of the stator currents may be given as follows:

$$\begin{aligned} I_{qs} &= -\frac{M}{L_s} \cdot I_{qr} \\ I_{ds} &= \frac{\varphi_s}{L_s} - \frac{M}{L_s} \cdot I_{dr} \end{aligned} \quad (7)$$

Generally in the field of production of wind power, they are average and high power machinery. Thus one can neglect the stator resistance [8]. This gives us a constant stator flux:

$$\begin{aligned} v_{qs} &= v_s = \varphi_s \cdot \omega_s \\ v_{ds} &= 0 \end{aligned} \quad (8)$$

When the orientation of the stator flux aligned on the direct axis, tension is aligned with the quadrature axis. The active and reactive power of the stator will be reduced to:

$$\begin{aligned} P_s &= v_{qs} \cdot I_{qs} \\ Q_s &= v_{qs} \cdot I_{ds} \end{aligned} \quad (9)$$

Replace the expression (7) into (8):

$$\begin{aligned} P_s &= -v_s \cdot \frac{M}{L_s} \cdot I_{qr} \\ Q_s &= -v_s \cdot \frac{M}{L_s} \cdot I_{dr} + \frac{v_s{}^2}{\omega_s \cdot L_s} \end{aligned} \quad (10)$$

The terms rotor voltage based on rotor currents are given as follows:

$$\begin{aligned} v_{dr} &= R_r \cdot I_{dr} + L_r \cdot \sigma \cdot \frac{dI_{dr}}{dt} - L_r \cdot \omega_r \cdot \sigma \cdot I_{qr} \\ v_{qr} &= R_r \cdot I_{qr} + L_r \cdot \sigma \cdot \frac{dI_{qr}}{dt} + L_r \cdot \omega_r \cdot \sigma \cdot I_{dr} + g \cdot \frac{M \cdot v_s}{L_s} \end{aligned} \quad (11)$$

With:$\sigma = 1 - \frac{M^2}{L_s \cdot L_r}, g = \frac{\omega_s}{\omega_r}$

This model for the control of powersas presented by the block diagram figure 2 [12, 13].

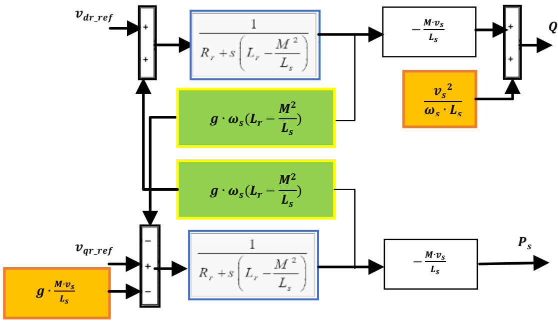


Fig.2: Model of MADA for control of powers

IV. INDEPENDENT CONTROL OF ACTIVE AND REACTIVE POWER

After developing the model for independent control of the powers of MADA, simply now to reverse his blocks to derive the reference voltages of the inverter from the active and reactive power references [12, 14].

A. Direct Control

If we observe the equations (10), we see that the rotor currents are related to the active and reactive power by the term. Moreover, the terms involving derivatives of the rotor currents in the two-phase system (11), go steady. We can write[15]:

$$\begin{aligned} v_{dr} &= R_r \cdot I_{dr} - g \cdot \omega_s(L_r - \frac{M^2}{L_s}) \cdot I_{qr} \\ v_{qr} &= R_r \cdot I_{qr} + g \cdot \omega_s(L_r - \frac{M^2}{L_s}) \cdot I_{qr} \cdot I_{dr} + g \cdot \frac{M \cdot v_s}{L_s} \end{aligned} \quad (12)$$

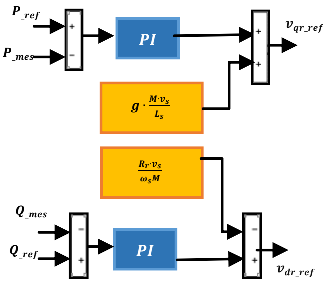


Fig.3:Block diagram of the direct control

B. indirect control

1) Open loop control

Open loop control is essentially based on the assumption of a stable network voltage and frequency, it is to subjugate either the powers but rather indirectly by the rotor currents do not like using the measured power back on Compare but the rotor currents to d and q axis.

From the expressions of the stator active and reactive power of the system is deduced references rotor currents and direct quadrature according to the relations [15].

$$
\begin{aligned}
I_{qr\_ref} &= \frac{L_S}{M \cdot v_S} \cdot P_{s\_ref} \\
I_{dr\_ref} &= -\frac{L_S}{M \cdot v_S} \cdot Q_{s\_ref} + \frac{v_S}{M \cdot ws}
\end{aligned}
\qquad (13)
$$

These currents are used as references in place of references to the active and reactive power, it then leads to the block diagram of Figure 4[15].

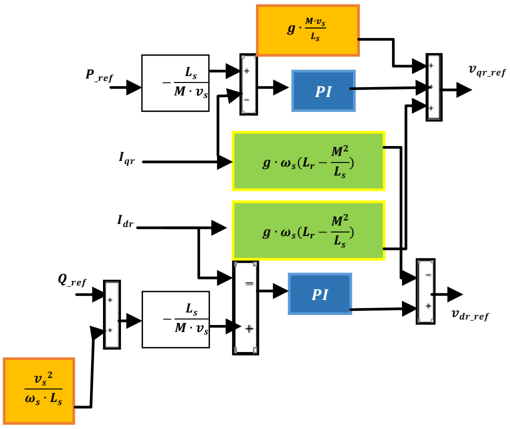


Fig.4:Block diagram of indirect control open loop.

This configuration remains as the reliable electrical network remains stable voltage and frequency. Grid instability will therefore cause an error on the follow instructions for active and reactive power.

2) Control closed loop

Powers to regulate optimally, we will set up two control loops on each axis with proportional integral controller for each, a loop on the power and the other on the current corresponding while compensating the terms of disturbance and couplings appearing on the block diagram modelMADA. We obtain the control structure shown in Figure 5[15].

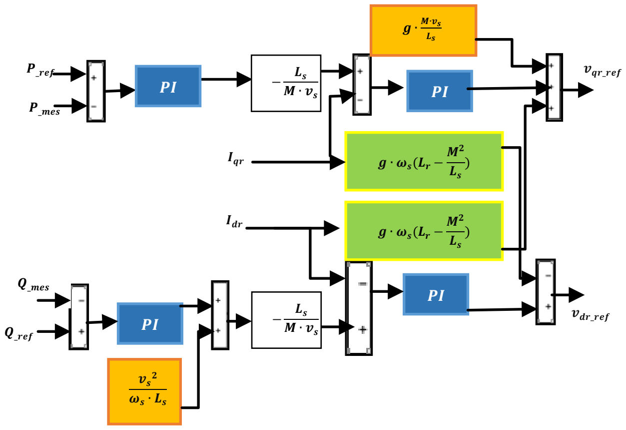


Fig.5:Block diagram of indirect control closed loop.

V. SIMULATION AND RESULTS

Simulation results show the figure below, allows us to present performance driving the DFIG powered by a two-level inverter controlled by the strategy triangulo-sinusoidal, with a vacuum and then start with the application of active power P = -3000W between t = 1 s and t = 3s, and reactive power between t = t = 2s and 4s for two carrier frequency $f_p = 1000\ Hz$.

Fig (9) and (10) the three-phase voltage applied to the stator and that applied to the rotor of the DFIG [15].

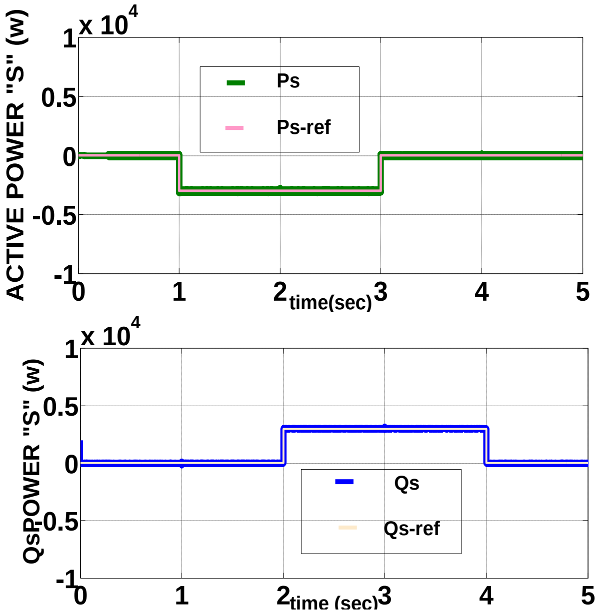
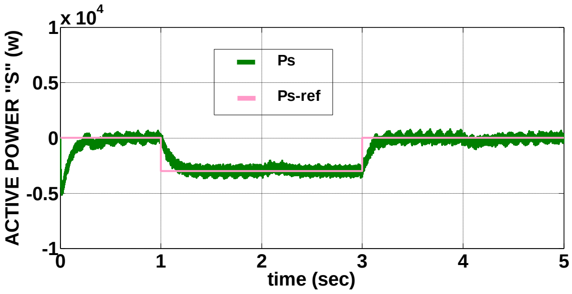


Fig.6:active and reactive stator powers online ordering



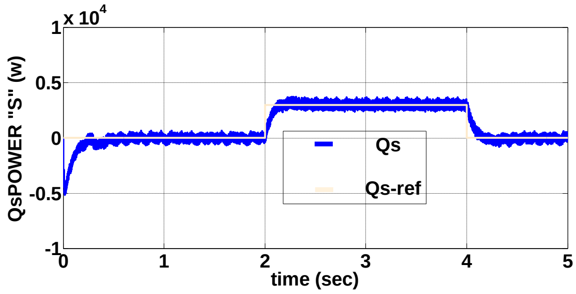


Fig.7:Powers and reactive stator indirect command without power loop

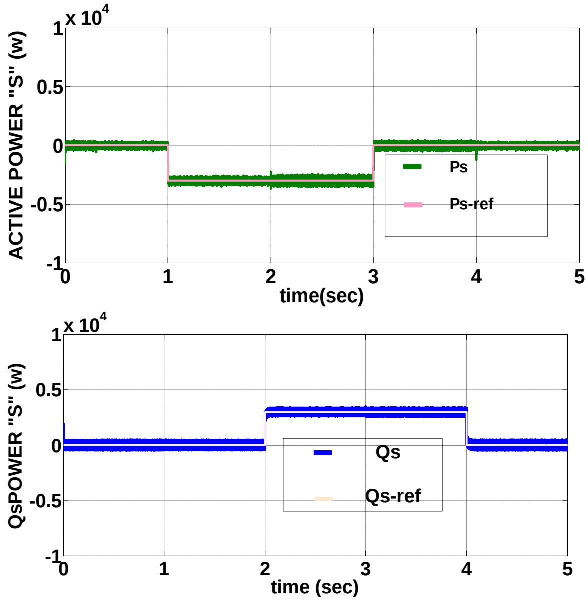


Fig.8:Powers and reactive stator indirect control withpower loop

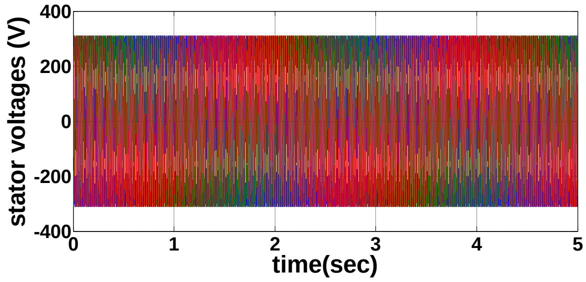


Fig.9:stator voltage (V).

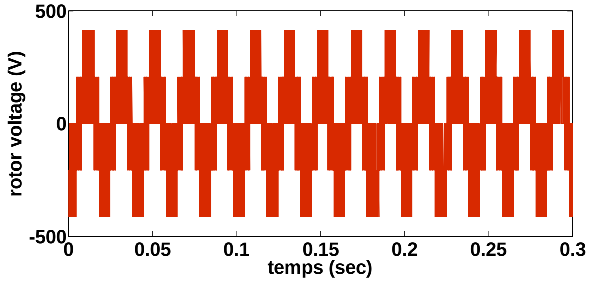


Fig. 10: rotor voltage (V).

The above simulation results show the effectiveness of the control in powers ofMADA for the three methods studied. Indeed, active power levels are monitored by the generator mostly indirect closed loop control (without overshoot or disturbance) (Figure 8), and active and reactive power following the reference (Figure (6) (7), (8)). However, we note the oscillations at the instants of application of power levels due to coupling between the two axes of the machine and power fluctuations for the open-loop method, particularly the active and reactive power (Figure 4) due in the absence of a control loop on the power to this method, these oscillations and these power fluctuations are compensated for in the closed loop methods (direct and indirect closed loop) (Figure 6, 8) [15].

VI. CONCLUSION

This paper has allowed us to establish the synthesis of vector control for active and reactive power of the stator doubly fed induction machine. Three control modes have been detailed using a proportional integral regulator. Direct control, based on the assumption of a perfect decoupling between the two axes and quadrature Direct and indirect control, with and without power loop, which hold account the coupling between the axes and uses terms for compensation correct.Although direct command we gave satisfactory results with a simplicity of implementation, indirect control closed loop on power, certainly more complex, allowed us to have a more efficient and robust system. The presence of a current loop in the indirect control offers an advantage, relative to direct control, allowing the limitation of the rotor currents to protect the machine and also the ability to overlay references of harmonic currents for the possible application of MADA into an active filter.

VII. APPENDIX

TABLE I
DATA OF DFIG

Rated Power	4 kW
Stator Voltage	311.127 V
Stator Frequency	50 Hz
Stator Resistance, Rs	1.2Ω
Rotor Resistance, Rr	1.8Ω
Stator Inductance, Ls	0.1554mH
Rotor Inductance, Lr	0.1568mH
Magnetizing Inductance, Lm	0.15mH
J	0.2
Number of Poles	2

NOMENCLATURE

v_s, v_r Stator, rotor voltage vectors.

I_s, I_r Stator, rotor current vectors.

ω_s, ω_r Stator, rotor angular frequency.

P_s, Q_s Stator active and reactive power.

M Mutual inductance.

L_s, L_r Stator, rotor self-inductance.

R_s, R_r Stator, rotor resistance.

p Machine pole pairs.

s, r Stator, rotor.

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