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Comparative Study between Direct and Indirect Vector Control Applied to a wind Turbine Equipped with a Double-fed Asynchronous Machine Article

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Abstract- This paper presents the study and the use of induction generator in wind energy production. To do this, a model of the wind turbine was established, and then presents the mathematical model of the double-fed induction generator (DFIG) variable speed and the control variables used when integrated with a wind system. Modeling in a reference related to the two-phase stator field and a strategy for vector control stator in active and reactive powers are provided with a summary of the controller proportional-integral (PI), as well as simulation results.

Keywords- Turbine, Wind, Generator Asynchronous, vector control, control direct power.

1. Introduction

This paper is to study the direct and indirect control power machine double-fed asynchronous generator operating Therefore, our work is organized as follows:

The first part is dedicated to the description and modeling of wind turbines based on physical equations responding operation.

The second section, we presented a mathematical model of the DFIG, the model will simulate mode generator.

The third is devoted to the study of the technical control direct and indirect power of the double-fed asynchronous machines.

2. Channel Conversion of Wind Energy

A wind turbine, commonly called wind is a device that converts a portion of the kinetic energy of wind into mechanical energy available to a drive shaft and then into electrical energy via a generator which in this case is a machine double-fed asynchronous.

3. Modeling of the Wind Turbine

The maximum power that can be collected by the blades:

$$P_{\max} = \frac{1}{2}\rho\pi R^2 V_{vent}^3 \quad (1)$$

ρ : Air density, about 1225 (Kg/m^3).

V_{vent} : wind speed (m / s).

S: surface swept by the propeller (m^3).

P_{max}: maximum power in (watts),

R: Radius of the turbine in (m).

The mechanical power is given by: [2]

$$P_{\max} = \frac{1}{2} C_p(\lambda) \rho \pi R^2 V_{vent}^3 \qquad (2)$$

C_p: The aerodynamic coefficient of power, with: $\lambda = \frac{\Omega_1 R}{V_1}$ specific speed.

C_p is given by the following equation: [3]

$$C_p = f(\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3 \beta - C_4 \right) e^{\left(\frac{C_5}{\lambda_i} \right)} + C_6 \lambda \qquad (3)$$

$$\text{with: } \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \qquad (4)$$

C_1=0.5176, C_2=116, C_3=0.4, C_4=5, C_5=21, C_6=0.0068.

$$C_{turbine} = \frac{P_m}{\Omega_1} = \frac{1}{2\Omega_1} C_p(\lambda) \rho \pi R^2 V_1^3 \qquad (5)$$

C_{em} : The turbine torque (Nm).

$$P_{mg} = C_p P_{mt} = \frac{1}{2} C_p \left(\frac{R\Omega_2}{KV_1} \right) \rho \pi R^2 V_1^3 \qquad (6)$$

P_{mg} : Mechanical Power (watts).

Ω_2 : Rotational speed after multiplier (rad / sec).

3.1. Multiplier Model

$$C_{mec} = \frac{C_{turbine}}{G} \qquad (7)$$

C_{mec} : Mechanical torque on the axis of the generator

(Nm): G : Value of the multiplier,

$$\Omega_{mec} = G\Omega_{turbine} \qquad (8)$$

Ω_{mec} : Mechanical angular speed of the generator (rad/s).

3.2. Tree Model

The fundamental equation of dynamics can be written:

$$J \frac{d\Omega_{mec}}{dt} = C_{turbine} - f\Omega_{mec} \qquad (9)$$

f : Viscous friction coefficient N.m.s / rad.

$C_{turbine} = C_{mec} + C_{em}$: Total torque of the wind turbine.

C_{em} : Torque electromagnetic generator.

J : Inertia (kgm2)

3.3. Simulation Results

We will perform using MATLAB / SIMULINK simulation of turbine system where the parameters are given as follows:

P_n=7.5kw, number de pale=2, R=3.5m, G=5.4, J=0.0017kg/m^2.

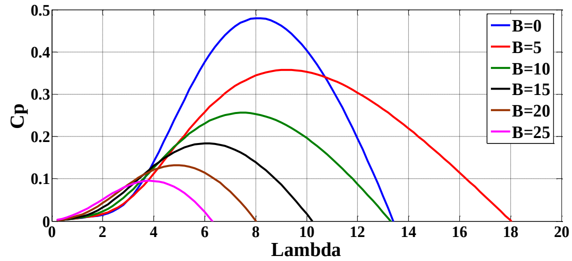


Fig. 1. Coefficient curves.

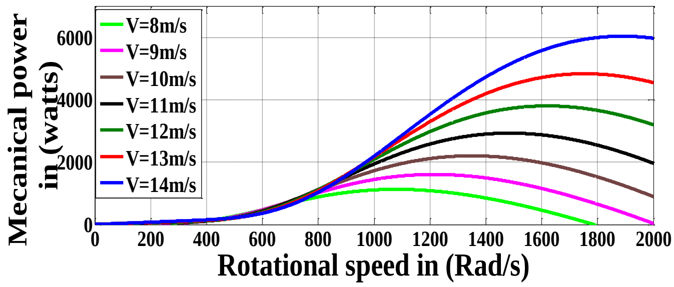


Fig. 2. Curves of mechanical power.

Fig. 1 shows the curves for several values of Cp. This curve is characterized by the optimum point ($\lambda_{opt} = 8.1, C_{p\max} = 0.48, \beta = 0^0$), this value is called the Betz limit, which is the point corresponding to the maximum power coefficient Cp and therefore the most of the mechanical power recovered.

Power curves as a function of wind speed and mechanical speed there are points that correspond to maximum power at different speeds, it is easy to see, then, that the wind turbine to operate in these operating points maximizes the power extracted from the wind during the variation of the latter.

4. Modeling of Asynchronous Generator Double-fed

The model of the DFIG model is equivalent to the cage induction machine. However, the rotor of the DFIG is not short-circuited.

4.1. Equations Voltages [4], [5]

$$[V_{sabc}] = [R_{sabc}][I_{sabc}] + \frac{d}{dt}[\varphi_{sabc}] \qquad (10)$$

$$[V_{rabc}] = [R_{rabc}][I_{rabc}] + \frac{d}{dt}[\varphi_{rabc}] \qquad (11)$$

4.2. Flow Equations

$$[\varphi_{sabc}]=[l_{ss}][I_{sabc}]+[M_{sr}][I_{rabc}] \quad (12)$$

$$[\varphi_{rabc}]=[l_{rr}][I_{rabc}]+[M_{rs}][I_{sabc}] \quad (13)$$

4.3. Mechanical Equation

$$\frac{d\Omega}{dt}=\frac{1}{J}(C_{em}-C_r-f_r\Omega) \quad (14)$$

$$C_{em}=P[I_s]^T\frac{d}{d\theta}([M_{sr}][i_r]) \quad (15)$$

4.4. Park Transformation

Double fed generator is modeled in the benchmark Park, following [6]

$$\begin{cases} V_{sd}=R_s i_{sd}+\dfrac{d\varphi_{sd}}{dt}-\dot{\theta}_s\varphi_{sq} \\ V_{sq}=R_s i_{sq}+\dfrac{d\varphi_{sq}}{dt}+\dot{\theta}_s\varphi_{sd} \end{cases} \quad (16)$$

$$\begin{cases} V_{rd}=R_r i_{rd}+\dfrac{d\varphi_{rd}}{dt}-\dot{\theta}_s\varphi_{rq} \\ V_{sq}=R_r i_{rq}+\dfrac{d\varphi_{rq}}{dt}+\dot{\theta}_r\varphi_{rd} \end{cases} \quad (17)$$

The flow equations are expressed by:

$$\begin{cases} \varphi_{ds}=L_S i_{ds}+MI_{dr} \\ \varphi_{qs}=L_s i_{qs}+MI_{qr} \end{cases} \quad (18)$$

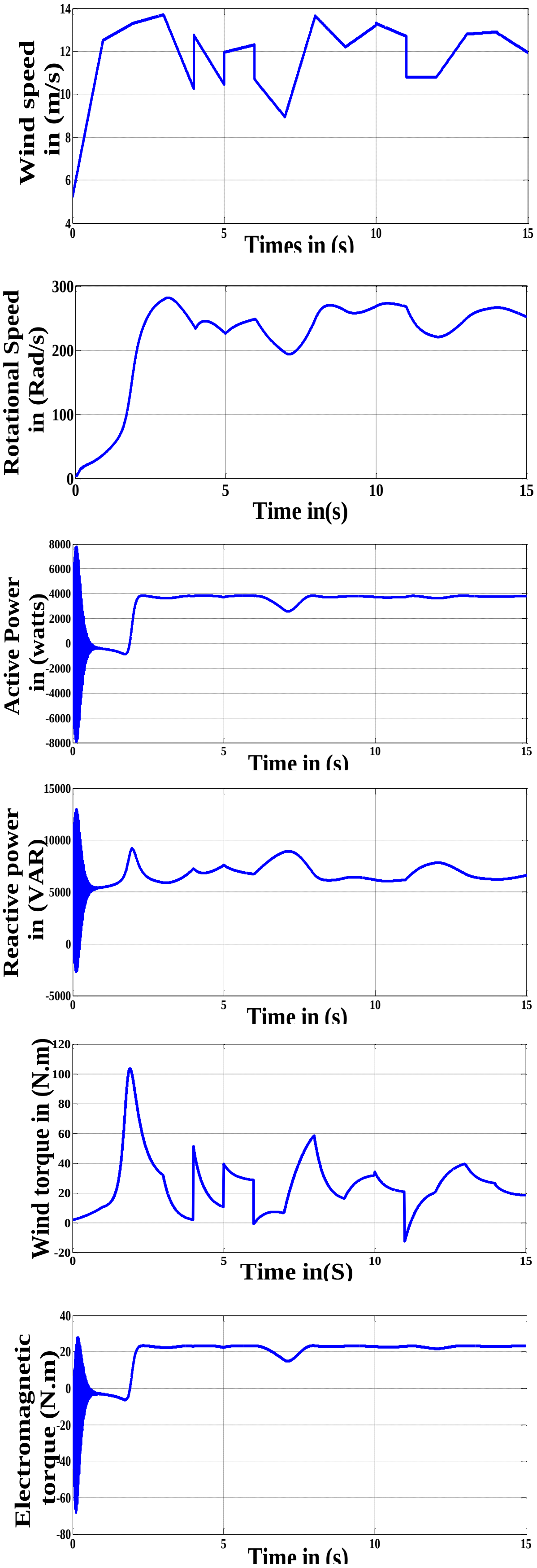
$$\begin{cases} \varphi_{dr}=L_r i_{dr}+MI_{ds} \\ \varphi_{qr}=L_s i_{qr}+MI_{qs} \end{cases} \quad (19)$$

The expression of electromagnetic torque becomes:

$$C_{em}=p\frac{M}{L_s}(\varphi_{ds}i_{qr}-\varphi_{qs}i_{dr}) \quad (20)$$

4.5. Simulation Results

In Fig. 3 shows the performance of the conduct of the DFIG driven by a three-phase 220/380V, 50Hz, the model developed in MATLAB / Simulink. According to the simulation results, we find that all variables have the DFIG transient oscillating electrical rotor speed follow the evolution of the wind speed varies between 193rd / s and 281.6 rad / s corresponds to the variation of the wind between 9 m / s and 14m / s, respectively, we also note that the stator and rotor currents present peaks reached 15A and presents considerable oscillations, then decreases to its variation around 10A, the torque variation wind leads to a variation of the electromagnetic torque at the end to compensate the torque wind.



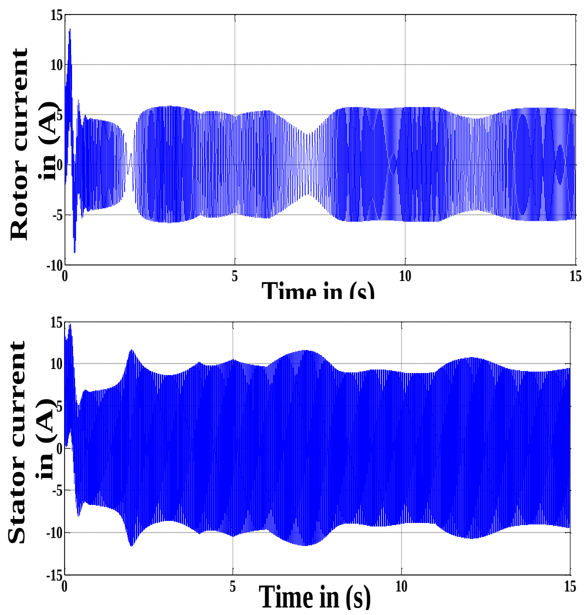


Fig. 3. Results of simulation of the DFIG (stator and rotor powered by a three-phase system).

5. Vector Control by Directing the Flow Stator

The principle is to orient the stator flux along the axis of the rotating frame

$\varphi_{qs} = 0, \varphi_{ds} = \varphi_s$ [7]

Machines for medium and high power used in wind turbines, we can neglect the stator resistance.

Under these assumptions, the equations (16), (17), (18) and (19) become:

$$\begin{cases} \varphi_{ds} = \varphi_s = L_s i_{ds} + M i_{dr} \\ \varphi_{qs} = 0 = L_s i_{qs} + M i_{qr} \end{cases} \quad (21)$$

Equation (21) allows us to write:

$$\begin{cases} i_{ds} = \dfrac{\varphi_s}{L_s} - \dfrac{M}{L_s} i_{dr} \\ i_{qs} = -\dfrac{M}{L_s} i_{qr} \end{cases} \quad (22)$$

$$\begin{cases} V_{ds} = 0, R_s = 0 \\ V_{qs} = V_s = \omega_s \varphi_{ds} \end{cases} \quad (23)$$

$$\begin{cases} \varphi_{dr} = (L_r - \dfrac{M^2}{L_s} i_{dr}) + M \dfrac{V_s}{L_s \omega_s} \\ \varphi_{qr} = (L_r - \dfrac{M^2}{L_s}) i_{qr} \end{cases} \quad (24)$$

The equations of active and reactive power become:

$$\begin{cases} P = V_{ds} i_{ds} + V_{qs} i_{qs} \\ Q = V_{qs} i_{ds} - V_{ds} i_{qs} \end{cases} \quad (25)$$

$$\begin{cases} P = -V_s \dfrac{M}{L_S} I_{qr} \\ Q = \dfrac{V_s^2}{L_s} V_s \dfrac{M}{L_s} i_{dr} \end{cases} \quad (26)$$

Replaces equations (24) into (17) we obtain:

$$\begin{cases} V_{dr} = R_r i_{dr} + (L_r - \dfrac{M^2}{L_s}) p i_{dr} - g\omega_s (L_r - \dfrac{M^2}{L_s}) i_{qr} \\ V_{qr} = R_r i_{qr} + (L_r - \dfrac{M^2}{L_s}) p i_{qr} + g\omega_s (L_r - \dfrac{M^2}{L_s}) i_{dr} + g \dfrac{MV_s}{L_s} \end{cases} \quad (27)$$

In steady state, we can write:

$$\begin{cases} V_{dr} = R_r i_{dr} - g\omega_s (L_r - \dfrac{M^2}{L_s}) i_{qr} \\ V_{qr} = R_r i_{qr} + g\omega_s (L_r - \dfrac{M^2}{L_s}) i_{dr} + g \dfrac{MV_s}{L_s} \end{cases} \quad (28)$$

$$\begin{cases} i_{dr} = \dfrac{1}{R_r + (L_r - \dfrac{M^2}{L_s}) p} \left(V_{dr} + g\omega_s (L_r - \dfrac{M^2}{L_s}) i_{qr} \right) \\ i_{qr} = \dfrac{1}{R_r + (L_r - \dfrac{M^2}{L_s}) p} \left(V_{qr} - g\omega_s (L_r - \dfrac{M^2}{L_s}) i_{dr} - g \dfrac{V_s M}{L_s} \right) \end{cases} \quad (29)$$

$V_{dr} et V_{qr}$: Rotor voltages to impose on the machine to get the desired rotor currents.

$\left(L_r - \dfrac{M^2}{L_s} \right)$: Coupling term between the two axes.

The couple has the expression:

$$C_{em} = p \frac{M}{L_s} (\varphi_{ds} i_{qr} - \varphi_{qs} i_{dr}),$$

$$C_{em} = p \frac{M}{L_s} \varphi_{ds} i_{qr} \quad (30)$$

Therefore, the above equations to establish a block diagram of the electrical system to regulate:

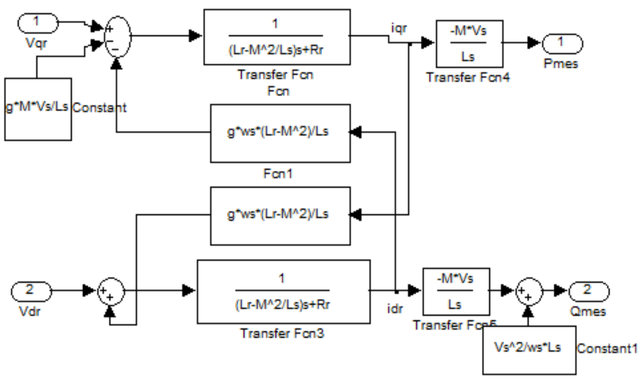


Fig. 4. Driving performance of the DFIG during direct control powers.

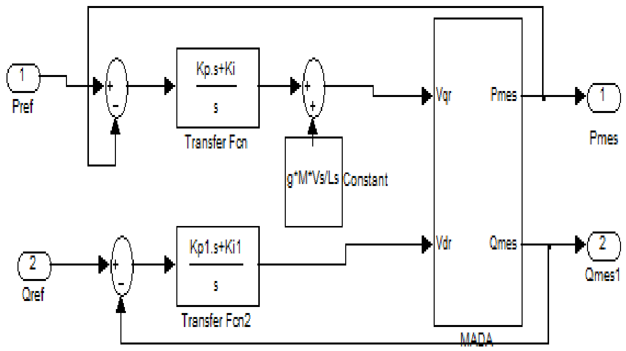


Fig. 5. Block diagrams of the directly power control.

The direct control consists in neglecting the coupling terms and implement a PI controller independent of each axis independently control the active and reactive power.

5.1. Results of Direct Vector Control

The simulation is performed by imposing the active and reactive power reference (ref, Qref), while the machine is driven at variable speed, Pref range between 0 and -7500 2000watts, Qref and range between 0 and 2000 -6500 VAR.

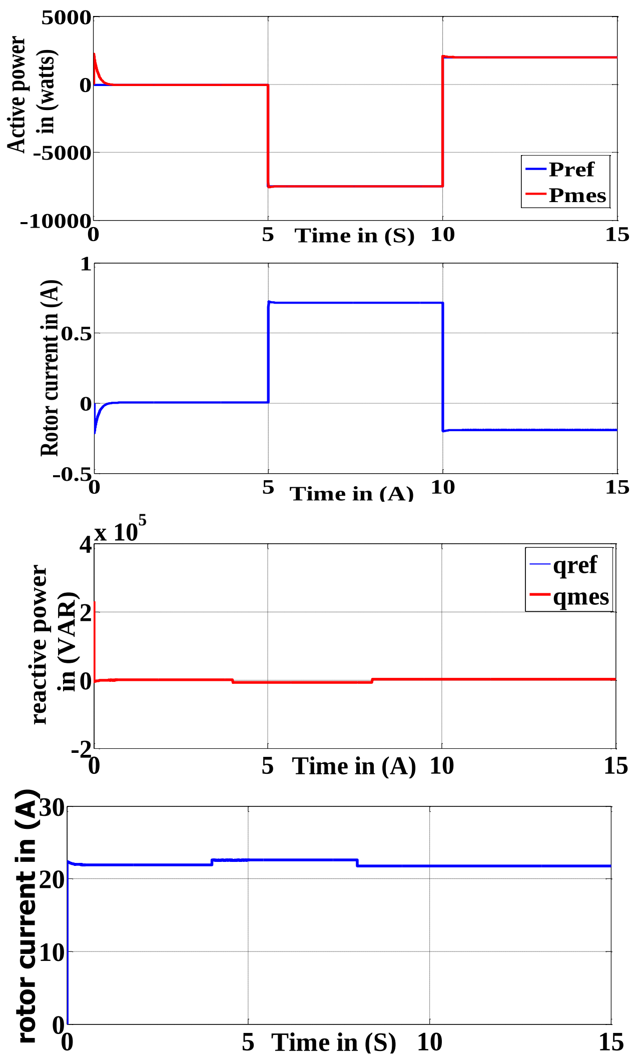


Fig. 6 Driving performance of the DFIG during direct control powers.

5.2. Indirect Vector Control

Keeping the same assumptions. Combining the various equations above, we can express the tensions based powers. and include:

$$
\begin{cases}
V_{dr} = g\omega_s \dfrac{\left(L_r - \dfrac{M^2}{L_s}\right)}{\dfrac{MV_s}{L_s}} p - \left(\dfrac{R_r + \left(L_r - \dfrac{M^2}{L_s}\right)p}{\dfrac{MV_s}{L_s}}\right) Q + \left(\dfrac{R_r V_s}{\omega_s M} + \left(L_r - \dfrac{M^2}{L_s}\right)\dfrac{V_s}{\omega_s M} p\right) \\
V_{qr} = -\left(\dfrac{R_r + \left(L_r - \dfrac{M^2}{L_s}\right)p}{\dfrac{MV_s}{L_s}}\right) p - g\omega_s \dfrac{\left(L_r - \dfrac{M^2}{L_s}\right)}{\dfrac{MV_s}{L_s}} Q + g\omega_s \left(L_r - \dfrac{M^2}{L_s}\right)\dfrac{V_s}{\omega_s M}
\end{cases}
$$

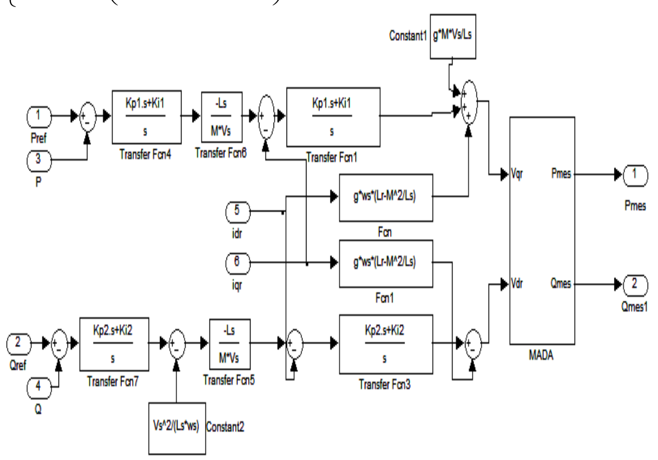
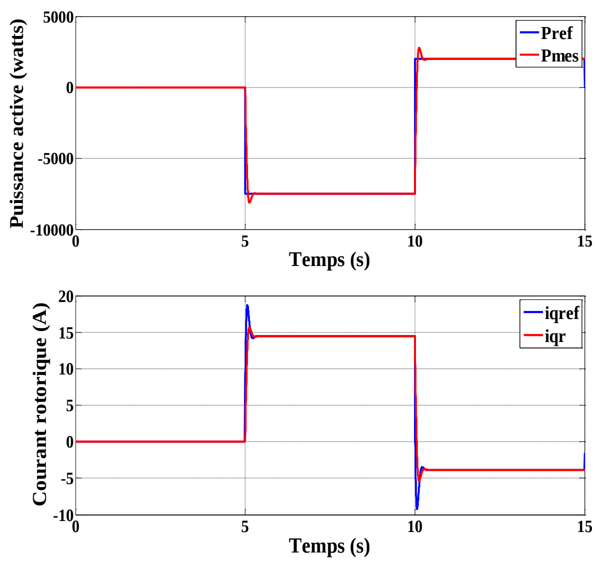


Fig. 7. Block diagram of the control loop with indirect power.

5.3. The Simulation Results of the Indirect Control



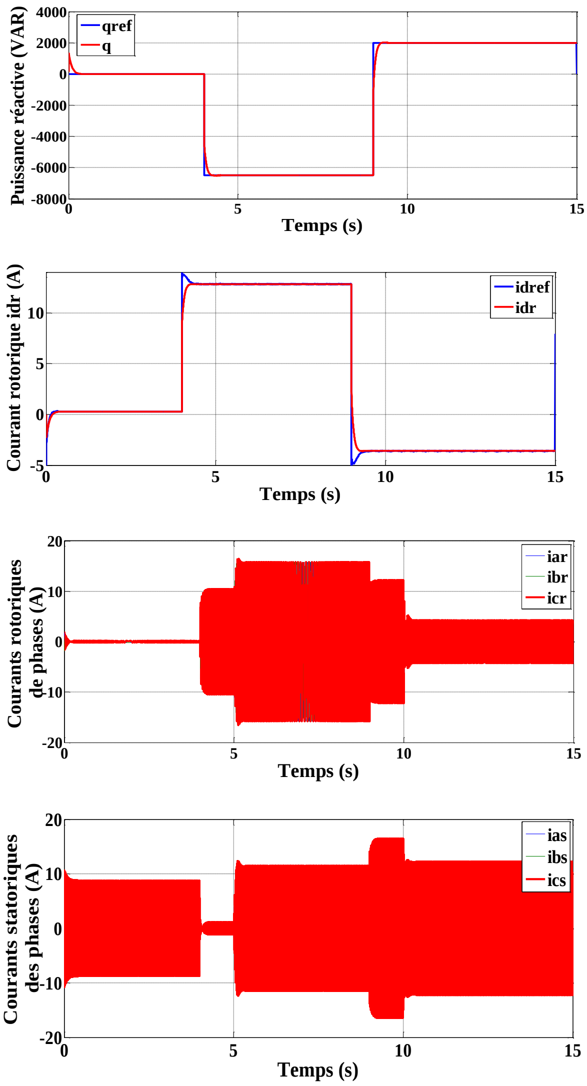


Fig. 8. Driving performance of the DFIG during indirect control powers.

6. Conclusion

In our work, we established the model of the machine using its power equations in the dq axis system related to timing. We have also developed two methods of vector control power of the machine ie the direct control and indirect control. Indeed, we have seen that direct control is the simplest, but not the most efficient. The indirect method allows us, in combination with the closure of powers, having a powerful and robust. It is more complex to implement, but will have an optimal system of power generation by minimizing any concerns related to changes in the parameters of the machine and the wind system.

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