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Power Control of DFIG-generators for Wind Turbines Variable-speed

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ABSTRACT

In this paper, we focus on the modeling and control of a wind power system based on a double-fed induction generator DFIG. We proposed a technique of active and reactive power control to improve the performance and dynamics of variable speed wind system. The objective of the modeling is to apply the direct and indirect vector control stator flux orientation to control independently, the active and reactive power generated doubly-fed induction generator (DFIG). The simulation results are tested and compared in order to evaluate the performance of the proposed system.

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1. INTRODUCTION

By reason of the fight against the green house effect and CO2 emissions into the atmosphere, renewables have experienced strong growth in recent years. Among these sources of energy are found " wind generators " that occupy a particular place [1],[2].

The wind power system using doubly fed induction generator composed by stator circuit connected directly to the network. A second rotor circuit is also connected to the network but via power converters [1],[3]. Since the rotor power transited is lower, the cost of the converters is reduced in comparison with a variable speed wind with a stator circuit connected to the network by power converters.This is the main reason why we find this generator for the production of high power. A second reason is the ability to adjust the voltage at the connection point of this generator [2]-[5].

The first part of this article will be devoted to modeling various parts of the wind power system based on the DFIG. The second part of the field oriented control specifically the stator field oriented control. In the third part with the use of MATLAB / Simulink we will present and analyze the simulation results to validate our theoretical study.

2. MODELING THE WIND CONVERSION CHAIN

A wind turbine is a device that converts a portion of the kinetic energy of wind into mechanical energy and then into electrical energy via a generator through a speed gain multiplier G [6], as the Figure 1 shows below [2]:

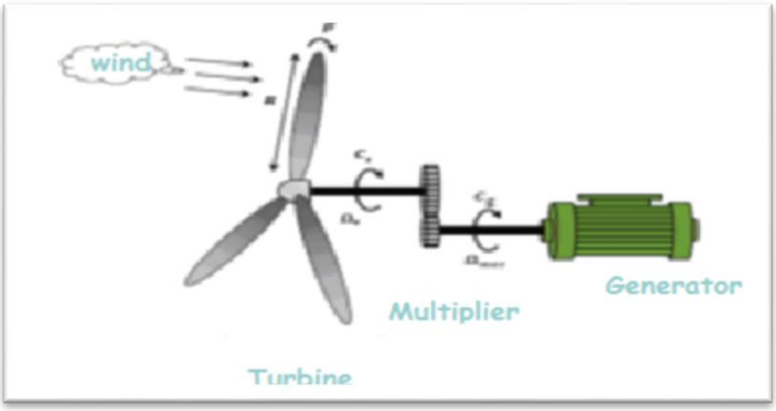

Figure 1. Wind turbine system

2.1. Wind Turbine Model

The wind power is given by [7]:

$$Pv = \frac{\rho.s.v^3}{2} \tag{1}$$

ρ: density of the area which equal to 1,225 Kg \ m3
s: the swept surface area of the turbine (π .R²)
v: wind speed

The wind turbine can only convert a percentage of the power of wind [6],[8].The latter is represented by C p (λ, β) which is a function of speed ratio λ and the angle of the blade orientation β. The aerodynamic power of the turbine [6],[8],[9] is given by:

$$Paero = \frac{cp(\lambda,\beta).\pi.R^2.\rho.v^3}{2} \tag{2}$$

The power coefficient Cp represents the aerodynamic efficiency of the wind turbine [6]. It depends on the characteristic of the turbine [6],[8]. It can be described as follows:

$$Cp(\lambda,\beta) = C1\left(\frac{C2}{A} - C3.\beta - C4\right) * \exp\left(-\frac{C5}{A}\right) + C6 * \lambda \tag{3}$$

With : $\frac{1}{A} = \frac{1}{(\lambda+0.08*\beta)} - \frac{0.035}{\beta^3+1}$ and C_1=0.5179 ; C_2=116 ; C_3=0.4 ; C_4=5 ; C_5=21 ; C_6=0.0068. The speed ratio λ, which is defined as the ratio between the linear speed of the turbine Ωt and the wind speed v [6],[8]:

$$\lambda = R.\frac{\Omega t}{v} \tag{4}$$

Knowing the speed of the turbine the aerodynamic torque is given by:

$$Caero = \frac{cp(\lambda,\beta).\rho.\pi.R^2.v^3}{2.\Omega t} \tag{5}$$

2.2. Multiplier Model

The speed multiplier [10]-[13] represents the connection between the turbine and the generator. It aims at adapting the slow speed of the turbine Ωt with the Ωmec high speed of the generator .

$$\begin{cases} \Omega t = \frac{\Omega mec}{G} \\ Cg = \frac{Caero}{G} \end{cases} \tag{6}$$

2.3. Mechanical Shaft Model

The fundamental equation of dynamics permits the determination of the evolution of the mechanical speed from the mechanical torque (Cem) applied to the rotor [14]:

$$Cmec = J\ \frac{d\ \Omega mec}{dt} \tag{7}$$

With: J: the total inertia that appears on the generator rotor

This mechanical torque takes into account; the electromagnetic torque Cem produced by the generator, the torque of the viscous friction torque Cf and that of multiplier Cg.

$$Cmec = Cg - Cem - Cf$$

With: $Cf = f\ .\Omega m$. When replacing the mechanical torque and torque friction by their expressions, we obtain the following relation [5],[2]:

$$Cg - Cem = j\ \frac{d\ \Omega m}{dt} + Cf \tag{8}$$

The wind speed is given as a sum of several harmonics:

$$Vvent = V0 + \sum_{i=1}^{n} Vi\ .\ sin(\omega i\ .\ t) \tag{9}$$

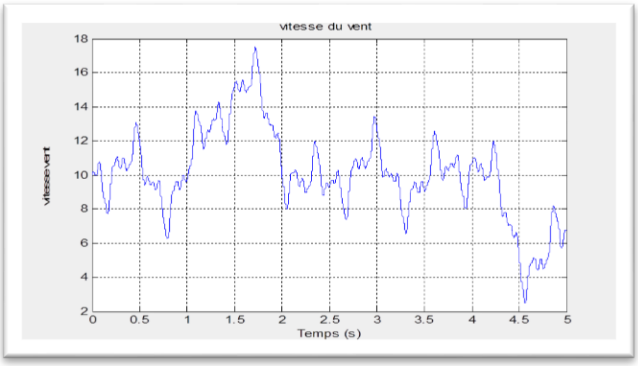

Figure 2. Wind speed reference

2.4. DFIG-Generator Model

Before doing the modeling of an asynchronous machine, it is necessary to represent a two-phase model (d, q) given by Park transformation [15].

The equations for the stator voltages Vs (d, q) and the rotor Vr (d, q) of the dynamic model of the DFIG are expressed by [16]:

$$\begin{cases} \mathrm{Vsd} = \mathrm{Rs}\ .\ \mathrm{Isd} + \frac{\mathrm{d}\phi\mathrm{sd}}{\mathrm{dt}} - \omega\mathrm{s}\ .\ \phi\mathrm{sq} \\ \mathrm{Vsq} = \mathrm{Rs}.\ \mathrm{Isq} + \frac{\mathrm{d}\phi\mathrm{sq}}{\mathrm{dt}} + \omega\mathrm{s}.\ \phi\mathrm{sd} \\ \mathrm{Vrd} = \mathrm{Rr}\ .\ \mathrm{Ird} + \frac{\mathrm{d}\phi\mathrm{rd}}{\mathrm{dt}} - \omega\mathrm{r}\ .\ \phi\mathrm{rq} \\ \mathrm{Vrq} = \mathrm{Rr}.\ \mathrm{Irq} + \frac{\mathrm{d}\phi\mathrm{rq}}{\mathrm{dt}} + \omega\mathrm{r}\ .\ \phi\mathrm{rd} \end{cases} \tag{10}$$

The field equations are given by [16],[2]:

$$\begin{cases} \Phi\mathrm{sd} = \mathrm{Ls}\ .\ \mathrm{Isd} + \mathrm{M}\ .\ \mathrm{Ird} \\ \Phi\mathrm{sq} = \mathrm{Ls}.\ \mathrm{Isq} + \mathrm{M}\ .\ \mathrm{Irq} \\ \Phi\mathrm{rd} = \mathrm{Lr}.\ \mathrm{Ird} + \mathrm{M}.\ \mathrm{Isd} \\ \Phi\mathrm{rq} = \mathrm{Lr}.\ \mathrm{Irq} + \mathrm{M}\ .\ \mathrm{Isq} \end{cases} \tag{11}$$

The mechanical equation is given by [17]:

$$Cem - Cg = j.\frac{d\Omega}{dt} + f.\Omega \quad (12)$$

The expression of electromagnetic torque based on stator field and currents is given, by:

$$Cem = p.(\Phi sd * Isq - \Phi sq * Isd) \quad (13)$$

With :
Φ_s (d, q), Φ_r (d, q): stator and rotor field in the reference of PARK.
I_s (d, q), I_r (d, q) stator and rotor currents in the reference of PARK.
R_s, R_r: stator and rotor resistances.
L_s, L_r: cyclical Inductors own stator and rotor.
M: mutual inductance cycle.
p: Number of pole pairs of the machine.
ω_s: Pulse of the stator electrical quantities.
ω_r: Pulse of the rotor electrical quantities.

3. FIELD ORIENTED CONTROL

3.1. PRINCIPLE OF CONTROL

The principle of control by stator field direction is to orient the stator field along the axis 'd' [18], that is to say : $\Phi sd = \Phi s$ and $\Phi sq = 0$. We know that for medium and large power equipment used in wind turbines, the stator resistance is negligible, and it is assumed that the grid is stable, the field is constant. The previous equations becomes as follows:

Expressions of the field [4]:

$$\begin{cases} \Phi sq = 0 = Ls.Iqs + M.Iqr \\ \Phi sd = Ls.Ids + M.Idr \end{cases} \quad (14)$$

We can obtain from the equation (14) the relation between the stator and rotor currents, we get the following equation [11]:

$$\begin{cases} Iqs = -\frac{M}{Ls}\, Iqr \\ Ids = \frac{1}{Ls}(\Phi s - M.Idr) \end{cases} \quad (15)$$

The expression of electromagnetic torque [11]:

$$Cem = p.\Phi s.Iqs = -p.\frac{M}{Ls}.\Phi s.Iqr \quad (16)$$

Based on the assumptions:

$$\begin{cases} Vds = 0 \\ Vqs = Vs = \omega s.\Phi s \end{cases} \; donc\; \Phi s = \frac{Vs}{\omega s} \quad (17)$$

The stator active and reactive powers are written according to following expressions [11]:

$$\begin{cases} Ps = Vsd\,.Isd + Vsq.Isq \\ Qs = Vsq.Isd - Vsd.Isq \end{cases} \quad (18)$$

By replacing the equation (18) by (14), (15) and (17), we get following expression of power [11]:

$$\begin{cases} Ps = Vs.Isq = -Vs.\frac{M}{Ls}.Irq \\ Qs = Vs.Isd = \frac{Vs^2}{\omega s.Ls} - Vs.\frac{M}{Ls}.Ird \end{cases} \quad (19)$$

The expression of the rotor field becomes:

$$\begin{cases} \Phi rd = \left(Lr - \frac{M^2}{Ls}\right).Ird + M.\frac{Vs}{Ls.\omega s} \\ \Phi rq = \left(Lr - \frac{M^2}{Ls}\right).Irq \end{cases} \tag{20}$$

From these equations we can deduce the relation between the rotor voltages (d, q) and the rotor currents (d, q):

$$\begin{cases} Vrd = \left(Rr + S.\left(Lr - \frac{M^2}{Ls}\right)\right).Ird - \omega s.g.\left(Lr - \frac{M^2}{Ls}\right).Irq \\ Vrq = \left(Rr + S.\left(Lr - \frac{M^2}{Ls}\right)\right).Irq + g.\omega s.\left(Lr - \frac{M^2}{Ls}\right).Ird + g.\frac{M}{Ls}.Vs \end{cases} \tag{21}$$

These equations allow establishing a block diagram of the electrical system that can be regulated given by the figure below:

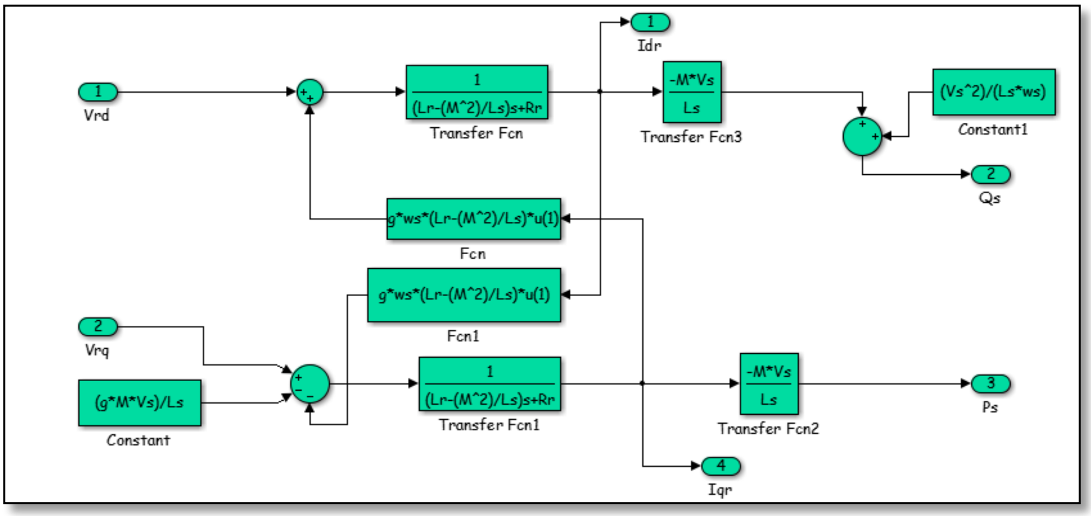

Figure 3. Block diagram of the DFIG

In this diagram we can notice that the powers and the voltages are linked by transfer functions with first order. Because the value of the slip ‘’ g ‘’ is low and the influences of the coupling is weak, the d and q axes can be controlled separately. This will allow us to easily establish vector control [3].

3.2. Field Oriented Control

There are two ways to perform the control power of this machine. The first is to ignore the terms of coupling and to establish an independent regulator in each axis to independently control the active and reactive power. This method is called Direct Method [2]-[4],[7],[8] because the power regulators directly control the rotor voltage of the machine as shown in the following Figure:

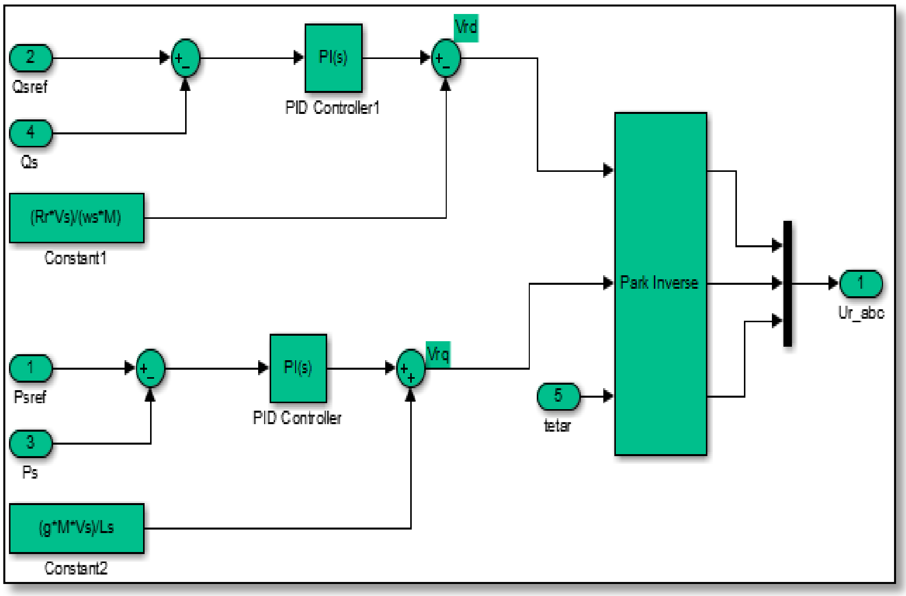

Figure 4. Direct vector control

The second method is to consider the coupling terms and compensate them performing a system with two loops to control the powers and rotor currents. This method which is called Indirect Method [3] is generated directly from equations (19) and (21).

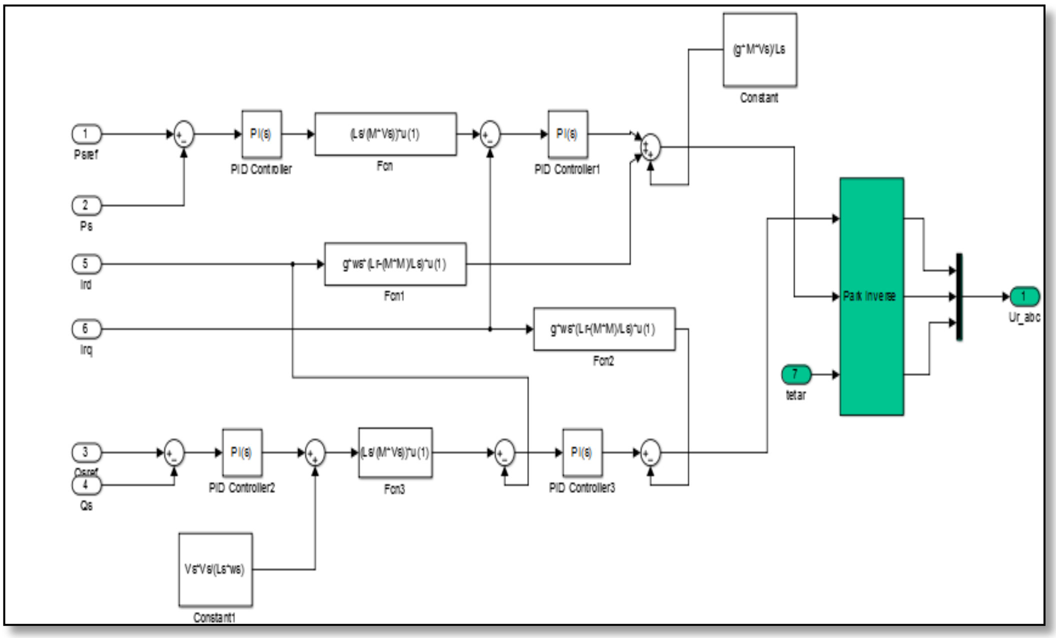

Figure 5. Indirect Field Oriented Control

4. SIMULATIONS RESULTS

We subjected the wind system to a speed of variable wind. We chose a reference active power Psref and reference reactive power Qsref in the form of steps. The following figures represent the overall pattern of the wind system in the MATLAB / SIMULINK. The simulation results are summarized in Figure 6:

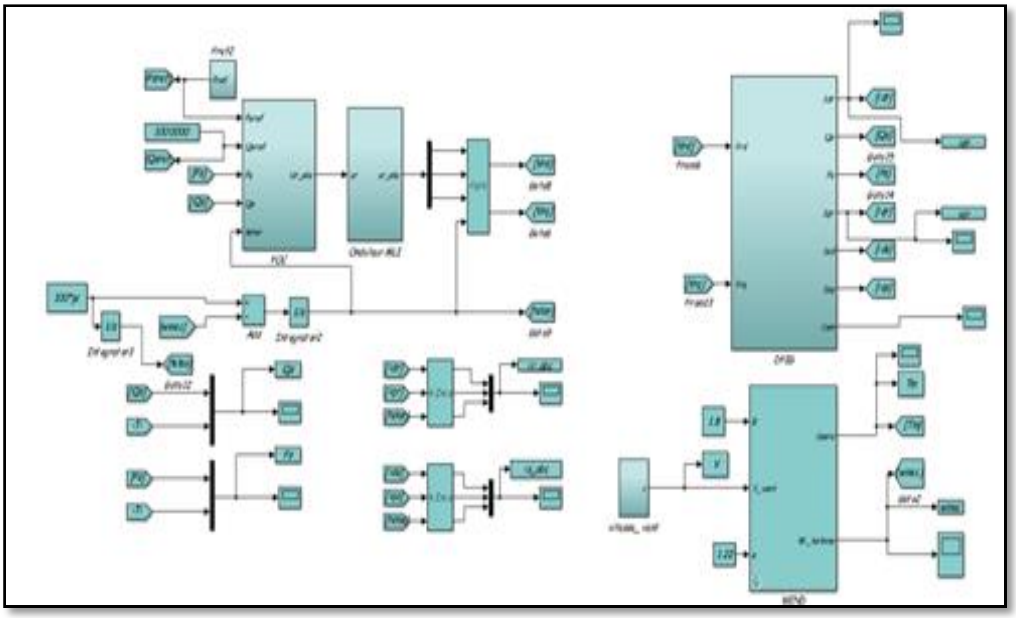

Figure 6. Wind System and direct field oriented control with MATLAB /SIMULINK

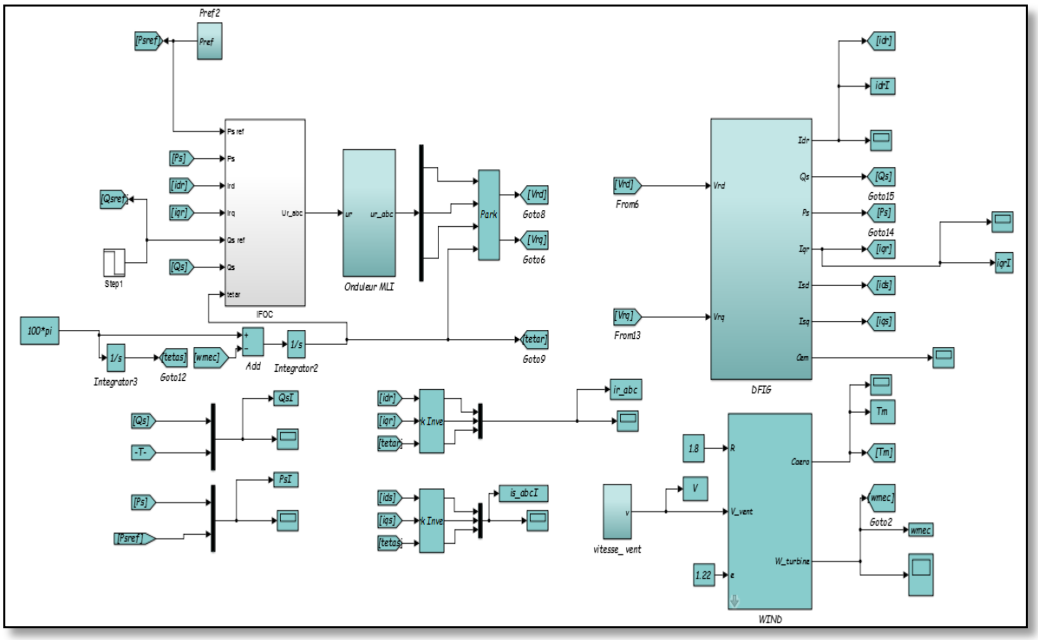

Figure 7. Wind System and indirect field oriented control with MATLAB /SIMULINK

According to (Figure 8), we see that the power steps are followed by the generator both for the active and reactive powers. We also see that the stator active power Ps depends on the quadrature rotor current Iqr and the stator reactive power Qs depends on the direct rotor current Idr and there the effect of coupling is also observed between the two control axes d and q. The active and reactive powers of the stator side are adjustable depending on network requirements. In our case it is negative, which means that the network is a receiver of the energy supplied by the DFIG.

The (Figure 9) shows that our system has satisfactory dynamics which react rapidly, without overtaking and the static error is almost zero for both the active or reactive powers. The coupling between the two powers is very low and barely perceptible.

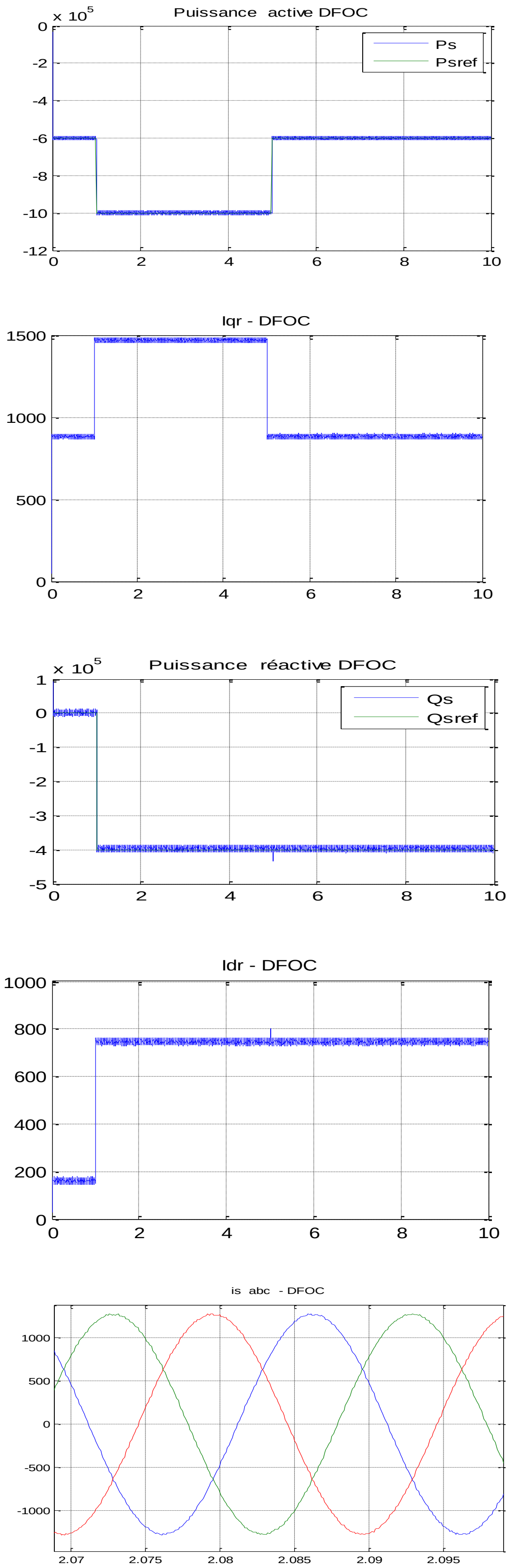

Figure 8. Direct Field Oriented Control

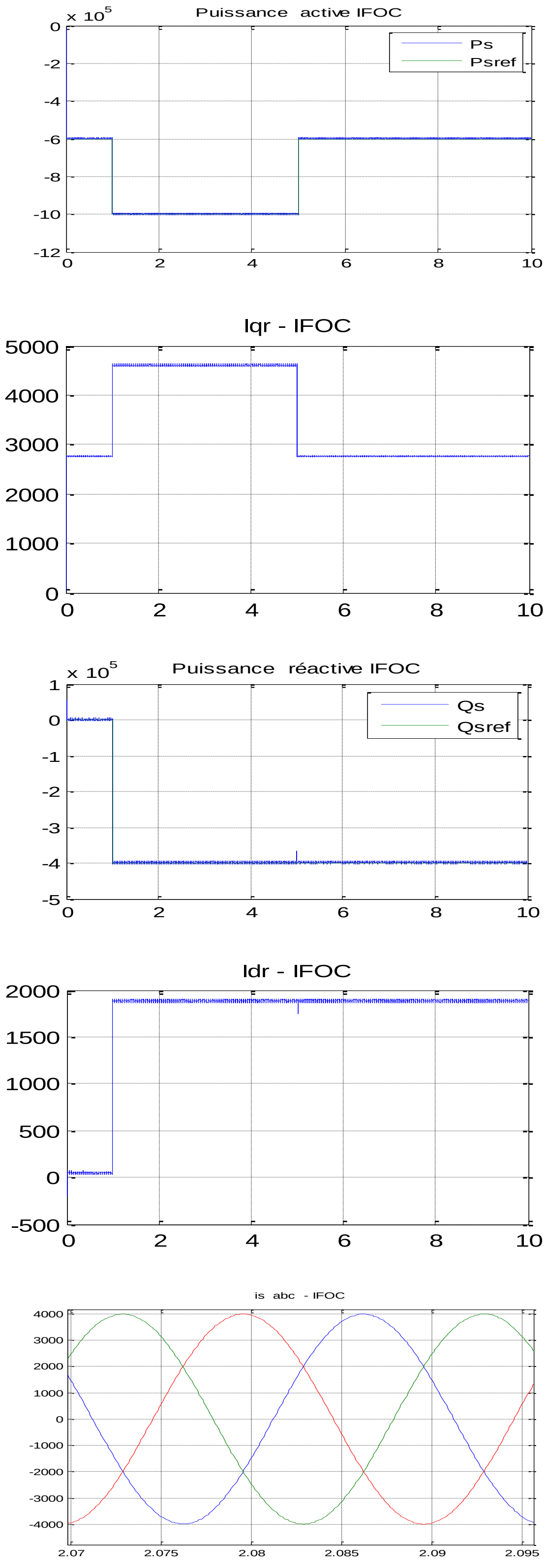

Figure 9. Indirect Field Oriented Control

5. CONCLUSION

This article presents a comparative study between the direct and indirect field oriented control of the Doubly Fed Induction Generator DFIG integrated in a wind system. First, we started by modeling both the turbine, then Doubly Fed Induction Generator DFIG in order to apply the flux orientation control (FOC).

According to this study, we found that direct control is the simplest to implement, but not the most efficient. However, the indirect method allows us, with the loop cascade, to have an inefficient system. It is certainly more complex to implement compared to direct control, but will have optimal operation of electrical generation system by minimizing potential problems related to parametric variations of the DFIG. As perspective, this work can be continued and completed by the implementation of this command in an FPGA.

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