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CORRECTION OF THE MECHANICAL SPEED FOR THE DFIG WIND TURBINE

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ABSTRACT

A wind's turbine role is to convert the kinetic energy of wind into energy electric. Its components are designed to maximize the conversion. Different control structures have been developed according to the characteristic power speed. In our case, we propose the control strategy of the wind turbine to maximize power with control of the speed. This control strategy consists in determining the speed of the turbine which provides the maximum generated power.

KEYWORDS: Wind, Turbine, DFIG, Control, PI

INTRODUCTION

During the last years, there was a strong penetration of the renewable resources of energy in the network of power supply. The wind power production played and will continue to play a very important role in this domain for years to come.

Wind turbines have base of the doubly fed induction machine (DFIG) undoubtedly appeared as one of the high technologies for the manufacturers of wind turbines, Demonstrating that it is about an actual cost, Effective and a reliable solution.

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

The second part, we present a mathematical model of the (DFIG) will simulate the model in generator mode.

The third is devoted to the study of the technique of indirect control power and compare the simulation results by PI Controller with Anticipation and PI Controller with Phase Advance.

MODEL OF THE TURBINE

The model is based on the characteristics of steady state power of the turbine (Lubosny. 2003).

$$P_m = \frac{P_m}{P_{mt}} P_{mt} = C_p . P_{mt} = \frac{1}{2} C_p(\lambda) \rho \pi R^2 V_1^3 \quad (1)$$

$$\text{With } \lambda = \frac{\Omega_1 R}{V_1} \quad (2)$$

Ω_1: Rotation speed before multiplier.

R :rotor radius *35.25 m*

ρ: air density, $1.225\ kg.m^{-3}$

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

with : $\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}$ et $C_1 = 0.5176$; $C_2 = 116$; $C_3 = 0.4$;$C_4 = 5$;$C_5 = 21$; $C_6 = 0.0068$ [1].

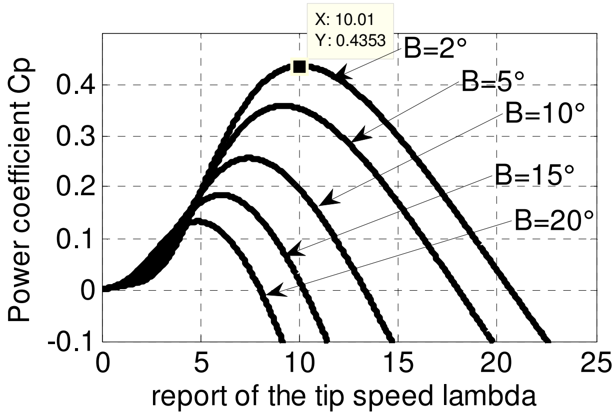

Figure 1: The Power Factor for Different Angles of Stalls

Characteristics of C_p in terms of λ for different values of the pitch angle are shown in figure 1. The maximum value of $C_p(C_{pmax} = 0.4353)$ is reached of β=*2°* and λ=*10.01.* This particular value of λ is defined as the nominal value λ_{nom} (Lubosny. 2003; EL Aimani. 2004).

DYNAMIC MODEL OF THE DOUBLY FED INDUCTION MACHINE

A commonly used model for the doubly fed induction generator (DFIG) is the Park model. The electrical equations of the DFIG in the Park reference frame are given as follows (EL Aimani. 2004; Poitiers. 2003):

$$\begin{cases} v_{sd} = R_s i_{sd} + \frac{d\varphi_{sd}}{dt} - \omega_s \varphi_{sq} \\ v_{sq} = R_s i_{sq} + \frac{d\varphi_{sq}}{dt} + \omega_s \varphi_{sd} \end{cases} \quad (4)$$

$$\begin{cases} v_{rd} = R_r i_{rd} + \frac{d\varphi_{rd}}{dt} - \omega_r \varphi_{rq} \\ v_{rq} = R_s i_{rq} + \frac{d\varphi_{rq}}{dt} + \omega_r \varphi_{rd} \end{cases} \quad (5)$$

The stator and rotor flux are given as:

$$\begin{cases} \varphi_{sd} = L_s i_{sd} + L_m i_{rd} \\ \varphi_{sq} = L_s i_{sq} + L_m i_{rq} \end{cases} \quad (6)$$

$$\begin{cases} \varphi_{rd} = L_r i_{rd} + L_m i_{sd} \\ \varphi_{rq} = L_r i_{rq} + L_m i_{sq} \end{cases} \quad (7)$$

In these equations,R_s, R_r, L_s and $L_r$are respectively the resistances and the inductances of the stator and the rotor windings,$L_m$is the mutual inductance.

v_{sd}, v_{sq}, v_{rd} , v_{rq}, i_{sd}, i_{sq}, i_{rd} , i_{rq}, φ_{sd}, φ_{sq}, φ_{rd} , φ_{rq} are the d and q components of the stator and rotor voltages, currents and flux, whereas $\omega_r$is the rotor speed in electrical degree.

The electromagnetic torque is expressed as:

$$C_{em} = p(\varphi_{sd}.i_{sq} - \varphi_{sq}.i_{sd}) \tag{8}$$

Stator and rotor variables are both referred to the stator reference Park frame. With the following orientation, the d component of the stator flux is equal to the total flux whereas the q component of the stator flux is null figure. 2.

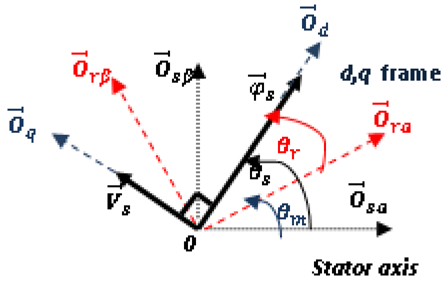

Figure 2: Determination of the Electrical Angles in Park Reference Frame

$$\varphi_{sd} = \varphi_s, \varphi_{sq} = 0 \tag{9}$$

By replacing (9) in (6) and (8), the electromagnetic torque can be given as follows:

$$C_{em} = -p\frac{L_m}{L_s} i_{rq}\varphi_{sd} \tag{10}$$

Assuming that the resistance of the stator winding $\mathbf{R_s}$ is neglected, and referring to the chosen reference frame, the voltage equations and the flux equations of the stator winding can be simplified in steady state as follows:

$$\begin{cases} v_{sd} = 0 \\ v_{sq} = v_s = \omega_s\varphi_s \end{cases} \tag{11}$$

$$\begin{cases} \varphi_{sd} = L_s i_{sd} + L_m i_{rd} \\ 0 = L_s i_{sq} + L_m i_{rq} \end{cases} \tag{12}$$

From (12), the equations linking the stator currents to the rotor currents are deduced below:

$$\begin{cases} i_{sd} = \frac{\varphi_s}{L_s} - \frac{L_m}{L_s} i_{rd} \\ i_{sq} = -\frac{L_m}{L_s} i_{rq} \end{cases} \tag{13}$$

The active and reactive powers at the stator side are defined as:

$$\begin{cases} P_s = v_{sd} i_{sd} + v_{sq} i_{sq} \\ Q_s = v_{sq} i_{sd} + v_{sd} i_{rq} \end{cases} \tag{14}$$

Taking into consideration the chosen reference frame, the above power equations can be written as follows:

$$\begin{cases} P_s = v_s i_{sq} \\ Q_s = v_s i_{sd} \end{cases} \tag{15}$$

Replacing the stator currents by their expressions given in (15), the equations below are obtained:

$$\begin{cases} P_s = -v_s \frac{L_m}{L_s} i_{rq} \\ Q_s = \frac{v_s\varphi_s}{L_s} - \frac{v_s L_m}{L_s} i_{rd} \end{cases} \tag{16}$$

The block diagram of the DFIG model in Park reference frame is depicted in figure 3, assuming a constant stator voltage (*vs*).

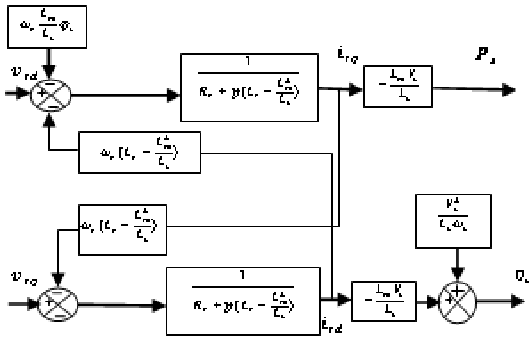

Figure 3: Block Diagram of the DFIG Model

REGULATION WITH BUCKLE OF POWER

To improve the control system the DFIG, we will introduce an additional loop control of active and reactive power in the block diagram of the control loop without power so that each axis controller contains two PI control, one to control the power and the other rotor current (figure 4) (Mehdary. 2009).

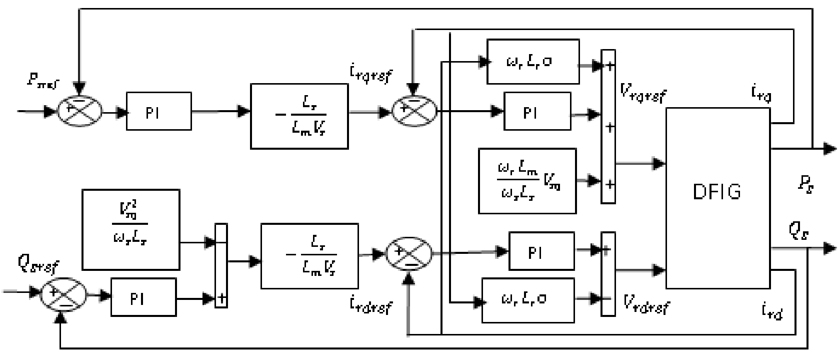

Figure 4: Schema Block Indirect Regulation with Loop Power

SYNTHESIS OF THE REGULATOR PI FOR THE CONTROL OF THE POWER

It is a simple and easy to implement controller. Figure 5 shows a closed loop system corrects by a PI controller. In our case, the transfer function is in the form $k_p + \frac{k_i}{p}$ as shown in Figure 5

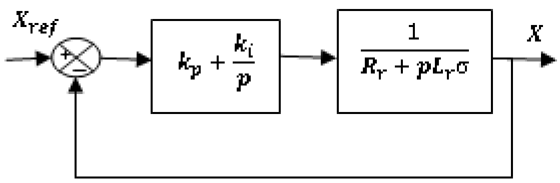

Figure 5: Diagram of the Control System by PI

The transfer function of the open loop (FTBO) with regulators is written as follows (EL Aimani. 2004; Moriarty, Butterfield. 2009; Multon, Obin, Gergaud, Ben Ahmed. 2003):

$$F_{BO} = \frac{p+\frac{k_i}{k_p}}{\frac{p}{k_p}} \cdot \frac{\frac{1}{L_r\sigma}}{\frac{R_r}{L_r\sigma}+p} \tag{17}$$

Applying the method of compensation pole transfer function 1, we obtain the following equality:

$$\frac{k_i}{k_p} = \frac{R_r}{L_r\sigma} \tag{18}$$

After compensation, the following are obtained FBO:

$$F_{BO} = \frac{k_p}{L_r\sigma p} \tag{19}$$

This gives us the transfer function following closed loop:

$$F_{BF} = \frac{1}{1+\tau p} \tag{20}$$

With: $\tau = \frac{L_r\sigma}{k_p}$ and $\sigma = \left(1 - \frac{L_m^2}{L_s L_r}\right)$

τ: is the response time of the system that we fix the order of 10ms. In this case, the gains of the PI controllers are expressed in terms of machine parameters and response time as follows:

$$\begin{cases} k_p = \frac{L_r\sigma}{\tau} \\ k_i = \frac{R_r}{\tau} \end{cases} \tag{21}$$

We used the method of compensation poles for its speed; it is clear that n 'not the only valid method for the synthesis of PI controller.

MODEL OF THE MULTIPLIER MECHANICAL PART

The mechanical party of the turbine includes three directional blades pitch and of length R. They are fixed to a drive shaft in a rotation speed Ω_t, a multiplier Connected of gain G. This multiplier causes the electric generator. We can model all the three blades as one and the same mechanical system characterized by the sum of all the mechanical characteristics. Due to the aerodynamic blade design, we believe that the coefficient of friction with respect to the air is very small and can be neglected. Also, the speed of the turbine being very low, Friction losses will be negligible compared to the friction losses on the side of the generator. On the basis of these hypotheses, is then obtained a mechanical model consisting of two masses as shown in figure 6, the validity, relative to the complete model of the turbine, has already been verified(Lubosny. 2003; Usaola, Ledesma, Rodriguez, Fernadez, Beato, Iturbe, Wihelmi).

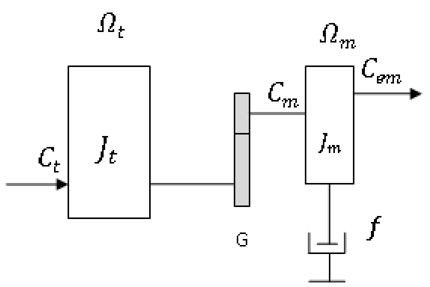

Figure 6: Mechanical Model of the Wind Turbine

With:

· $\mathbf{J_t}$ **:** Moment of inertia of the turbine to the equivalent inertia of the three blades of the turbine.

· $\mathbf{J_m}$ **:** the moment of inertia of the DFIG.

· ***f*** **:** The coefficient due to viscous friction of DFIG.

· $\mathbf{C_m}$ **:** mechanical torque on the shaft of the DFIG.

·$\mathbf{\Omega_m}$ **:** the rotational speed of the DFIG.

$\mathbf{C_{em}}$ **:** the electromagnetic torque of the DFIG.

By considering that the multiplier is ideal, That is to say, the mechanical losses are negligible, it is then modelled by the following two equations:

$$C_m = \frac{C_t}{G} \tag{22}$$

$$\Omega_m = G.\Omega_t \tag{23}$$

From Figure 6, we can write the fundamental equation of dynamics of the mechanical system of the mechanical shaft DFIG by:

$$\left(\frac{J_t}{G^2} + J_m\right)\frac{d\Omega_m}{dt} + f.\Omega_m = C_m - C_{em} \tag{24}$$

The total inertia J :

$$J = \left(\frac{J_t}{G^2} + J_m\right) \tag{25}$$

CONTROL STRATEGIES OF THE TURBINE

The control strategy is to adjust the torque appearing on the tree turbine speed so as to fix a reference. To achieve this, we will use a speed control (EL Aimani. 2004; Poitiers. 2003).

According to equation (24) and (25):

$$\frac{d\Omega_m}{dt} = \frac{1}{J}.(C_m - f.\Omega_m - C_{em}) \tag{26}$$

The electromagnetic torque is:

$$C_{em\_ref} = PI.(\Omega_{ref} - \Omega_{mec}) \tag{27}$$

$$\Omega_{ref} = G.\Omega_{turbine\_ref} \tag{28}$$

The reference speed of the turbine corresponds to the optimum value corresponding to the speed ratio λ_{pmax} (fixed on the blade angle β to 2°).

$$\Omega_{turbine\_ref} = \frac{\lambda_{C_{pmax}}.v}{R} \tag{29}$$

The couple thus determined by the controller is used as a reference torque of the turbine model as can be seen in figure 7.

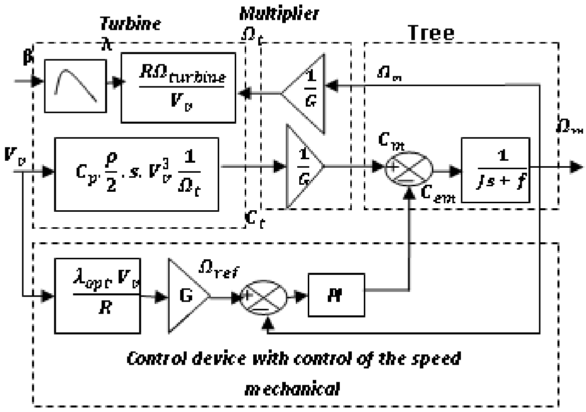

Figure 7: Block Diagram of the Controller with Mechanical Speed

CORRECTION OF THE SPEED OF THE TURBINE

Different technologies can be considered markers for control of the speed; in our case we describe two types of regulations:

A. PI Controller with Anticipation

We consider a correction proportional integral (PI):

$$C_{em\_ref} = \left(b_1 + \frac{b_0}{s}\right).\left(\Omega_{ref} - \Omega_{mec}\right) \tag{30}$$

b_1 : proportional gain and b_0: integral gain, correction parameters are determined. It is necessary to increase the parameter b_0 to reduce the action of C_g wind torque. The natural frequency and damping coefficient are given by:

$$\omega_n = \sqrt{\frac{b_0}{J}} \text{ and } \xi = \frac{f+J+b_1}{b_0}.\frac{\omega_n}{2} \tag{31}$$

Can impose a time response and damping factor given was:

$$b_0 = \omega_n^2.J \text{ and } b_1 = \frac{2.b_0.\xi}{\omega_n} - f - J \tag{32}$$

B. PI Controller with Phase Advance

We consider a correction proportional integral (PI):

$$C_{em\_ref} = \frac{a_1.s+a_0}{\tau.s+1}.\left(\Omega_{ref} - \Omega_{mec}\right) \tag{33}$$

a_1, a_0 et τ are the parameters to determine the corrector and s is the Laplace variable. It is necessary to increase the parameter a_0 to reduce the action of C_g wind torque. The natural frequency and damping coefficient are given by:

$$\omega_n = \sqrt{\frac{a_0+f}{J.\tau}} \text{ and } \xi = \frac{\tau+J+a_1}{a_0+f}.\frac{\omega_n}{2} \tag{34}$$

SIMULATION RESULTS

The simulation is done by imposing active and reactive power reference (P_{ref}, Q_{ref}), While the machine is entailed in variable speed

$P_{ref} = \eta . P_{m\_opt}, Q_{ref} = 0,$

with:

η: Performance DFIG;

P_{m_opt}: The optimal mechanical power

The simulation results are given by the following figures.

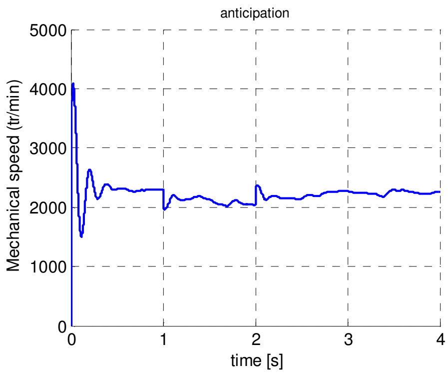

Figure 8: Mechanical Speed with Anticipation Control

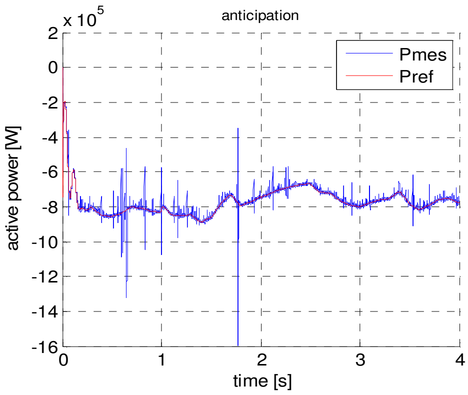

Figure 9: Electrical Active Power Produced with Anticipation Control

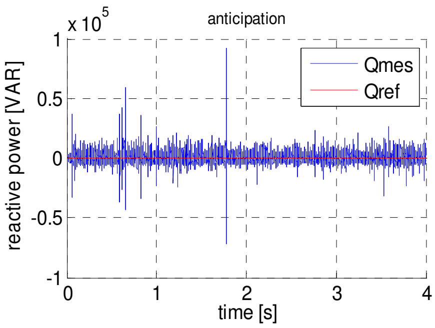

Figure 10: Electrical Reactive Power Produced with Anticipation Control

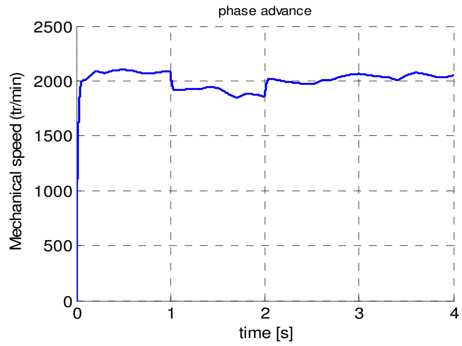

Figure 11: Mechanical Speed with Phase Advance Control

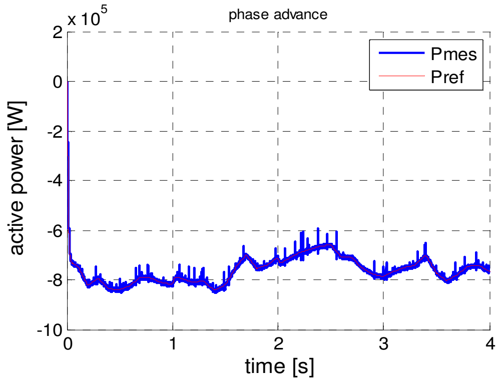

Figure 12: Electrical Active Power Produced with Phase Advance Control

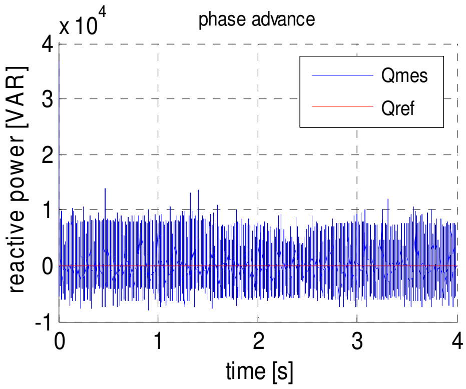

Figure 13: Electrical Reactive Power Produced with Phase Advance Control

CONCLUSIONS

In our work, we have established the model of the machine using its power equations in the dq axis system related to synchronization. We have also developed the method of vector control power of the machine to know the order.

The two methods of maximizing power were almost granny gives results (speed mechanical, power active and reactive) the only difference and the transient time in the case of PI with big anticipation and compared PI phase advance.

APPENDICES

- NOMINAL POWER =1.5(MW)

- Stator Per Phase Resistance =0.012 (Ω)
- Rotor Per Phase Resistance=0.021 (Ω)
- Stator Leakage Inductance= $2.0372.10^{-004}$ (H)
- Rotor Leakage Inductance= $1.7507.10^{-004}$ (H)
- Magnetizing Inductance= 0.0135 (H)
- Number Of Poles Pairs=2
- Moment Of Inertia= 1000 ($Kg.M^2$)
- Friction Coefficient =0.0024

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