Study Contribution to Control Optimization of a Wind Turbine based on a DFIG

Authors Anis Tarfaya *[1] , Djalel Dib [2], and Mehdi Ouada

***Abstract*—**Through the work presented in this paper, we contribute with a study whose objective is to have a satisfactory result control optimization of a wind turbine based on a Doubly Fed Induction Generator (DFIG) , this chain contain1.5 MW wind turbine, gearbox , DC /AC converter numerical implementation of this model under *Matlab /Simulink* are reached using different toolbox, a direct vector control with direct field oriented control (FOC) applied for improving system performance under fast changing of wind speed conditions , the given simulation results quickly and correctly track change in power set point

***Keywords*---**WIND ENERGY ; DFIG; FOC; MODELING ; SIMULATION .

I. INTRODUCTION

In recent decades, the world has known a rapid development in various sectors which led to increase the demand on energy. That is why countries are concentrating on development of energy sources in order to ensure its energy security. Among these sources the renewal energies such as solar [17], wind, biomasses, waves and geothermal heat. Wind energy is a kind of clean energy. It is considered as one of the most challenge research areas. Wind energy system consists of wind turbine, drive train, and generator. Wind turbine converts the kinetic energy to the mechanical power which is coupled to the generator's shaft [1]. There are various kinds of generator applied in wind energy system such as Permanent Magnet Synchronous Generator (PMSG), induction generator and Doubly Fed Induction Generator (DFIG) [2,3]. DFIG is one of the most acceptable generators because of more flexible. Moreover, with the less rating of converter, it causes in lightweight mechanism structure and cost [4, 5]. Modeling and simulation of wind energy system play very important role to study wind turbine, drive train, DFIG and converter dynamic. It helps us to investigate the characteristic design and improve the converter controller before installation for maximum performance [6].

In this context, several control methods DFIG appeared, among them the Vector control, the principle of this technique has been developed by BLASCHKE in the early 70-ies. In order to achieve vector control to make this machine similar control perspective to a current machine separately excited DC. This command based on the classic controllers (Proportional control, integral and derivative) [7] - [8].

This work focuses preliminary study on for building optimal control of WTGs, with application of two vector control (direct and indirect) of the stator active and reactive power of DFIG, applied to the 1.5 MW wind system.

II. MODELING OF WIND TURBINE

The extracted power is given by [9]:

$$P_v = \frac{1}{2}.\rho.A.V_v^3 = \frac{1}{2}.\rho.\mathrm{R}^2.\pi.V_v^3 \tag{1}$$

Where ρ is the air density, A is the wind turbine blades swept area in the wind and V_v is the wind speed. In a wind energy system and due to various losses, the aerodynamic power P_{aer} available on the rotor of the turbine is less than the wind power P_v [10]. The aerodynamic power is expressed as follows:

$$P_{aer} = P_v.C_p(\lambda,\beta) \tag{2}$$

Considering equations (1) and (2), the expression of the aerodynamic power becomes:

$$P_{aer} = \frac{1}{2}.\rho.\mathrm{R}^2.\pi.V_v^3.C_p(\lambda,\beta) \tag{3}$$

Where C_p represents the wind turbine power conversion efficiency [11]. It is a function of the tip speed ratio λ and the blade pitch angle β in a pitch-controlled wind turbine [12]. The expression of λ is defined as:

$$\lambda = \frac{\Omega_{turb}.R}{V_v} \tag{4}$$

Where R is the blade radius and Ω_{turb} is the angular speed of the turbine.

In this work, the C_p equation is approximated using a non-linear function according to [13].

---

[1].Electromechanical Dept. Electromechanical engineering laboratory Badji Mokhtar University Annaba , Algeria, Phone :+21338871168

[2].Department of Electrical Engineering, University of Tebessa, Tebessa, Algeria tarfayaanis@gmail.com, dibdjalel@ gmail.com

[3]. Mehdi Ouada,Electromechanical Dept, University Annaba, Algeria ouadamehdi@gmail.com

http://dx.doi.org/10.15242/IAE.IAE0615202

$$c_p(\lambda,\beta)=0.5176\left(\frac{116}{\lambda_i}-0.4\beta-5\right)e^{\frac{-21}{\lambda_i}}+0.0068\lambda \quad (5)$$

Which

$$\frac{1}{\lambda_i}=\frac{1}{\lambda+0.8\beta}-\frac{0.035}{\beta^3+1} \quad (6)$$

The c_p characteristics depending on λ for different values of the pitch angle β are represented in (fig.1)

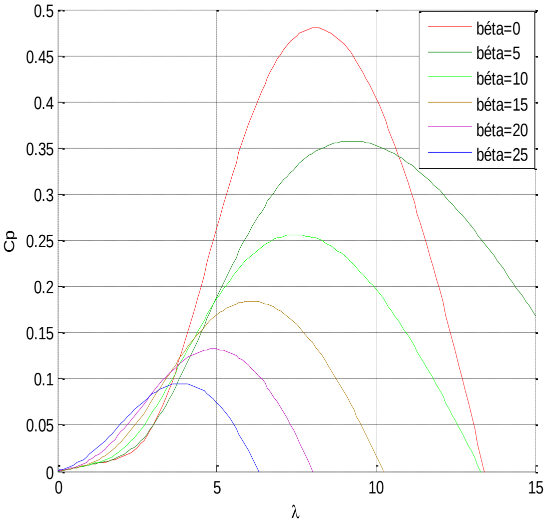

Fig 1. Aerodynamic power coefficient Cp depending on tip speed ratio λ and pitch angle β.

According to Fig.1, which corresponds to the characteristic of the coefficient of power depending on parameters λ and β, the coordinates of the optimal point is the maximum power coefficient Cp are (λopt=8.1, Cpmax=0.48, β=0°). The increase of β allows the decreasing of mechanical power recovered from the axis of the wind turbine.

From the Fig. 2 shows the power-speed characteristics curves of a typical wind turbine for various wind velocities.

From Fig.2 we can observe, for each wind speed we have once optimal speed operation of the wind turbine and the optimal speed increase with increase of wind speed.

The gear box adapts the slow speed of the turbine to the generator speed.

This gear box is mathematically modeled by where C_m is the driving torque of the generator and Ω_m is the generator shaft speed.

JT : is the total inertia of the shaft which equal to the sum of the inertia of generator and turbine.

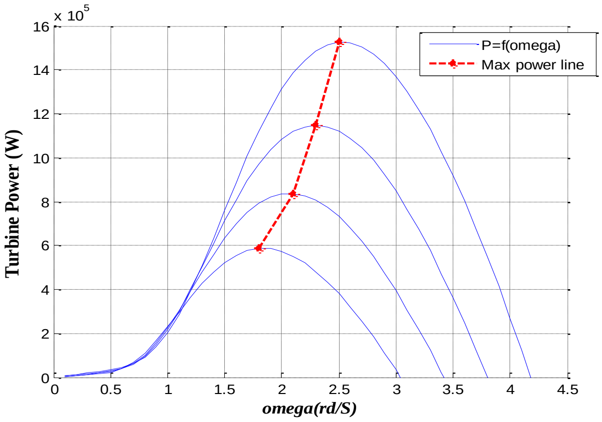

Fig 2 Characteristics P=f(Ω_{turb}) of wind turbine .

The following equations:

$$\begin{cases} C_m=\dfrac{C_{turb}}{G} \\ \Omega_{turb}=\dfrac{\Omega_m}{G} \\ J_T=\dfrac{J_{turb}}{G^2}+J_g \end{cases} \quad (7)$$

$$C_{turb}=\frac{P_{turb}}{\Omega_{turb}} \quad (8)$$

The generator shaft is modeled by the following equation:

$$J_T.\frac{d\Omega_{mec}}{dt}=C_{mec}=C_m-C_{em}-C_f.\Omega_{mec} \quad (9)$$

Or J_T = total inertia that appears on the shaft of the generator, the electromagnetic torque C_{em} produced by the generator, the torque C_m from the multiplier, f the viscous friction coefficient.

III. MODELING OF DFIG

In this section we are describing dynamic modeling DFIG in alpha beta frame in order to build numerical simulation in Matlab/ Simulink environment to apply this model was based on simplifying assumption [14]

- Winding is assumed distributed so as to give a sinusoidal emf if powered by sinusoidal currents.
- The hysteresis, eddy currents and the skin effect is neglected and operation is not in the saturated regime.
- In the end the zero sequence system is zero because the neutral is not connected

With application of Faraday's low in the stator of machine we can give voltage in born of stator:

$$\begin{cases} V_{sd} = R_s.i_{sd} + \dfrac{d\varphi_{sd}}{dt} - \omega_s.\varphi_{sq} \\ V_{sq} = R_s.i_{sq} + \dfrac{d\varphi_{sq}}{dt} + \omega_s.\varphi_{sd} \end{cases} \qquad (10)$$

And rotoric voltage:

$$\begin{cases} V_{rd} = R_r.i_{rd} + \dfrac{d\varphi_{rd}}{dt} - (\omega_s - \omega_r).\varphi_{rq} \\ V_{rq} = R_r.i_{rq} + \dfrac{d\varphi_{rq}}{dt} - (\omega_s - \omega_r).\varphi_{rd} \end{cases} \qquad (11)$$

Note that the super scripts “s” and “ r ” indicate that space vectors are referred to stator and rotor reference frames, respectively. On the other hand, the correlation between the fluxes and the currents, in space vector notation, is given by

$$\begin{cases} \varphi_{sd} = L_s.i_{sd} + M.i_{rd} \\ \varphi_{sq} = L_s.i_{sq} + M.i_{rq} \end{cases} \qquad (12)$$

$$\begin{cases} \varphi_{rd} = L_r.i_{rd} + M.i_{sd} \\ \varphi_{rq} = L_r.i_{rq} + M.i_{sq} \end{cases} \qquad (13)$$

The mechanical equations:

$$C_{em} = p.\frac{M}{L_s}(\varphi_{sd}.i_{rq} - \varphi_{sq}.i_{rd}) \qquad (14)$$

IV. MODELING OF DC/AC CONVERTER

To facilitate the modeling and reduce the simulation time is modeled by the UPS switches a set of ideals: that is to say zero resistance state, infinite resistance in the off state, instant response to signals command [16] .

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{DC}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \times \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix}$$

V. THE PRINCIPLE FOC

In order to easily control the production of electricity from wind, we will realize independent control of active and reactive power by orientation of the stator flux.

In this section, the DFIM model can be described by the following state equations in the synchronous reference frame whose axis d is aligned with the stator flux vector, ($\Phi_{sd} = \Phi_s$ and $\Phi_{sq}=0$).

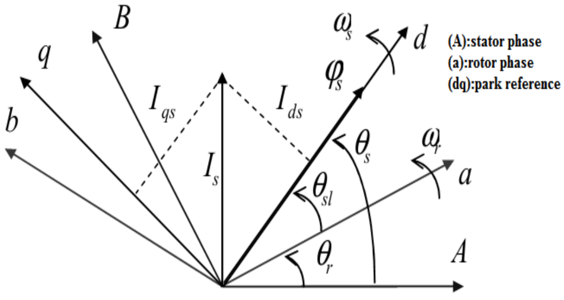

Fig 3. Orientation of the stator flux on the axis d.

Simplified expression of the electromagnetic torque is obtained:

$$C_{em} = p.\frac{M}{L_s}(\varphi_{sd}.i_{rq}) \qquad (15)$$

The control of the DFIG must allow a control independent of the active and reactive powers by the rotor voltages generated by an inverter.

Assuming that the resistance of the stator winding R_s is neglected, the voltage equations and the flux equations of the stator windings can be simplified in steady state as:

$$\begin{cases} V_{sd} = \dfrac{d\varphi_{sd}}{dt} \\ V_{sq} = \omega_s.\varphi_{sd} \end{cases} \qquad (16)$$

The stator phases the stator voltage will be expressed by:

$$\begin{cases} V_{sd} = 0 \\ V_{sq} = V_s \end{cases} \qquad (17)$$

$$\begin{cases} \varphi_{sd} = L_s.i_{sd} + M.i_{rd} \\ 0 = L_s.i_{sq} + M.i_{rq} \end{cases} \qquad (18)$$

Using equation (18), we can make the link between the stator and rotor currents:

$$\begin{cases} i_{sd} = -\dfrac{M}{L_s}.i_{rd} + \dfrac{\varphi_s}{L_s} \\ i_{sq} = -\dfrac{M}{L_s}.i_{qr} \end{cases} \qquad (19)$$

The active and reactive stator powers are written:

$$\begin{cases} P_s = V_{sd}.i_{sd} + V_{sq}.i_{sq} \\ Q_s = V_{sq}.i_{sd} - V_{sd}.i_{sq} \end{cases} \qquad (20)$$

Or, according to equation (17):

$$\begin{cases} P_s = V_s.i_{sq} \\ Q_s = V_s.i_{sd} \end{cases} \qquad (21)$$

To obtain the powers expression of according to the rotor currents, the currents in the above equation are replaced by the equation (19):

$$\begin{cases} P_s = -V_s.\dfrac{M}{L_s}.i_{qr} \\ Q_s = -V_s.\dfrac{M}{L_s}.i_{rd} + V_s.\dfrac{\varphi_s}{L_s} \end{cases} \qquad (22)$$

From the equations (16) and (17) we obtain, for the stator flux, the following expression:

$$\varphi_s = \frac{V_s}{\omega_s} \qquad (23)$$

The powers expression can therefore be simplified as follows:

$$\begin{cases} P_s = -V_s.\dfrac{M}{L_s}.i_{rq} \\ Q_s = -V_s.\dfrac{M}{L_s}.i_{rd} + \dfrac{V_s^2}{L_s.\omega_s} \end{cases} \tag{24}$$

By replacing the stator currents in equation (12) and (13) of the flux by the expression (19) we obtain:

$$\begin{cases} \varphi_{rd} = \left(L_s - \dfrac{M^2}{L_s}\right).i_{rd} + \dfrac{M.V_s}{L_s.\omega_s} \\ \varphi_{rq} = \left(Lr - \dfrac{M^2}{L_s}\right).i_{rq} \end{cases} \tag{25}$$

For the control of the generator, the expressions established show the relationship between current and rotor voltages that will be applied to it.

$$\begin{cases} V_{rd} = R_r.\mathrm{i}_{rd} + \left(Lr - \dfrac{M^2}{L_s}\right)\dfrac{d\,\mathrm{i}_{rd}}{dt} - g.\omega_s.\left(L_s - \dfrac{M^2}{L_s}\right).i_{rq} \\ V_{rq} = R_r.\mathrm{i}_{rq} + \left(Lr - \dfrac{M^2}{L_s}\right)\dfrac{d\,\mathrm{i}_{rq}}{dt} + g.\omega_s.\left(L_s - \dfrac{M^2}{L_s}\right).i_{rd} + g.\dfrac{M.V_s}{L_s} \end{cases}$$

(26)

The previous equations used to establish a block diagram of the electrical system to regulate given by (Fig.4).

We note that the powers and tensions are linked by a transfer function of first order. Moreover, due to the low value of the slip g, it is possible to ascertain easily a vector control since the coupling influences will remain low and the axes d and q, can be ordered separately with their own regulators.

Then, we applied the method which consists in neglecting the coupling terms and setting up an independent regulator on each axis for an easy control of active and reactive power. This method is called direct method since the power regulators control directly the rotor voltage of the machine (Fig. 5).

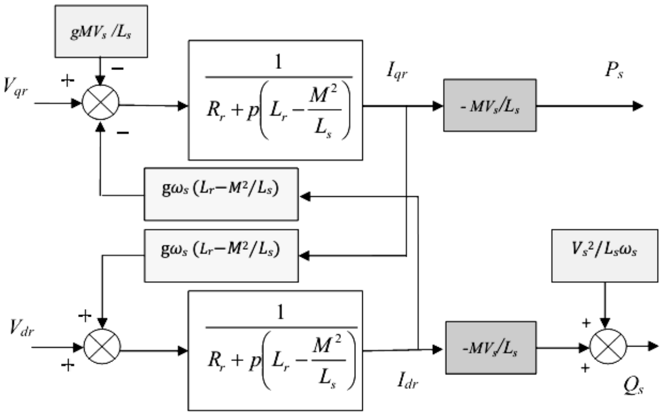

Fig 4 Block diagram of the DFIG

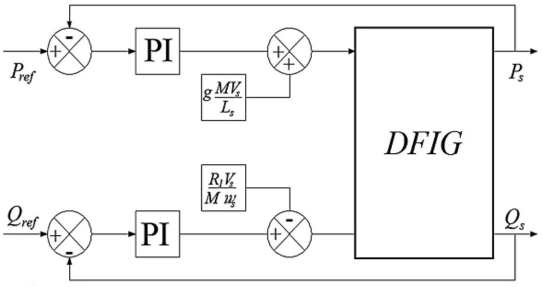

Fig 5 Direct control bloc diagram.

VI.SIMULATION RESULTS AND DISCUSSION

The simulation is performed using the Matlab /Simulink software. So we put this system for active and reactive power levels to observe the behavior of its regulation.

The figures (Fig.6.7.8) represent the simulation results of the direct vector command of the double fed asynchronous generator.

For (Fig.6.7.8.9), we can notice that the power levels arefollowed by the generator both for the active power and reactive power. We also notice that although the stator active power Ps depends on the rotor current quadrature Iqr and that the stator reactive power Qs depends on the direct rotor current Idr, the effect of coupling between the two control axes d and q is also observed.

The active power of the stator side is reactive and adjustable according to the needs of the negative network which means that the network in this case is a receiver of the energy supplied by the DFIG.

TABLE I.
PARAMETERS OF THE TURBINE[15]

denotation	Numerical value of parameter
Radius of the wind	35.25 m
G	90
Air density (p)	1.22 g/m3

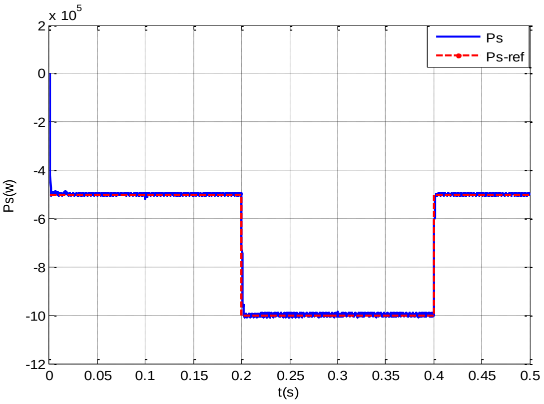

Fig 6 Active power direct control.

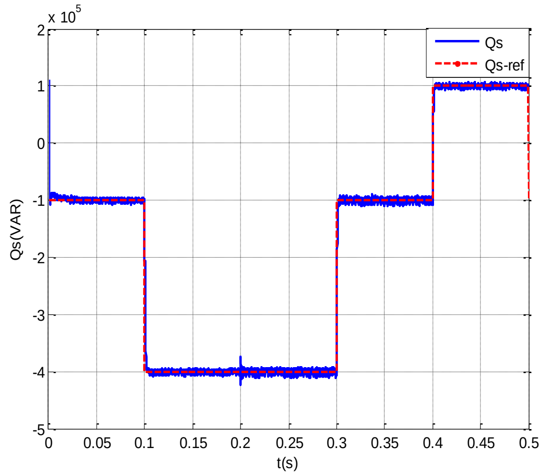

Fig 7 Reactive power direct control.

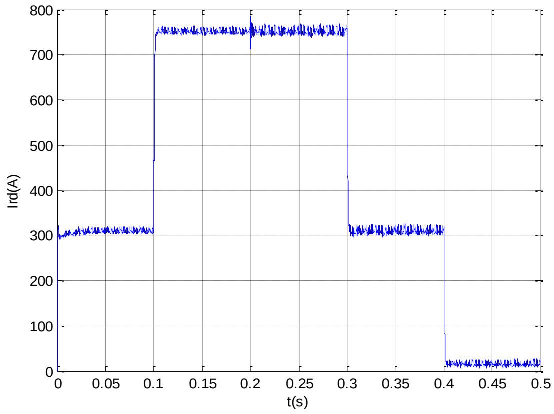

Fig 8 Simulation Results rotor current direct Idr

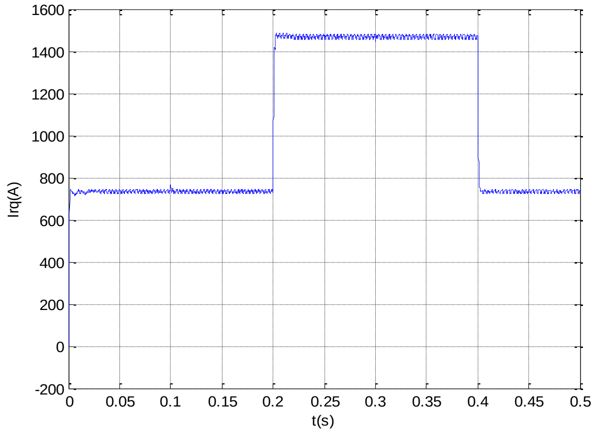

Fig 9 Simulation Results quadrature *Iqr*.

TABLE II.
DFIG PARAMETERS[15]

Denotation	Numerical value of parameter
power output	1.5MW
Voltage	690 V
speed (Ωs, fs)	1500 tr/mn ; 50Hz
Number of pole pairs (Np)	2
stator inductance (Ls)	0.0137 H
rotor inductance (Lr)	0.0137 H
mutual inductance (M)	0.0135 H
stator resistance (Rs)	0.012 Ω
rotor resistance (Rr)	0.021 Ω
Moment of inertia (J)	1000 kg.m2

VI. CONCLUSION

A study of modeling of wind energy production is the first ideain this work , began by modeling and numérical simulation of the wind turbine in Matlab / simulink envirenement suited by extraction of maximum power point operation of wind turbine , and corespondance speed , and the generator is constructed to apply the flux guidance technique (FOC).

Indeed we have seen that direct control is the most simple to realised .

A good dynamic of this system is also observed, and follows the change in imposed variation in wind speed.

The presented study makes a path for research and obtains optimal solution to eliminate major disadvantages of the studied system.

REFERENCES

[1] A. Luna, F. K. A. Lima, D. Santos, P. Rodriguez, E. H. Watanabe, and S. Arnaltes, “Simplified Modeling of a DFIG for Transient Studies in Wind Power Applications,” IEEE Trans. Industrial Electronics, vol. 58, no. 1, pp. 9-20, Jan. 2011. http://dx.doi.org/10.1109/TIE.2010.2044131

[2] A. Uehara, A. Pratap, T. Goya, T. Senjyu, A. Yona, N. Urasaki and T. Funabashi, “A Coordinated Control Method to Smooth Wind Power Fluctuations of a PMSG-Based WECS,” IEEE Trans. Energy Conversion, vol. 26, no. 2, pp. 550-558, Jun. 2011
http://dx.doi.org/10.1109/TEC.2011.2107912

[3] E. S. Abdin, W. Xu, “Control Design and Dynamic Performance Analysis of a Wind Turbine-Induction Generator Unit,” IEEE Trans. Energy Conversion, vol. 15, no. 1, pp. 91-96, Mar. 2000.
http://dx.doi.org/10.1109/60.849122

[4] X. Yan, G. Venkataramanan, P. S. Flannery, Y.Wang, Q. Dong, and B.Zhang, “Voltage-Sag Tolerance of DFIG Wind Turbine With a Series Grid Side Passive-Impedance Network,” IEEE Trans Energy Conversion, vol. 25, no. 4, pp.1048-1056, Dec. 2010.
http://dx.doi.org/10.1109/TEC.2010.2054097

[5] H. Xu, J. Hu, and Y. He, “Integrated Modeling and Enhanced Control of DFIG Under Unbalanced and Distorted Grid Voltage Conditions,” IEEE Trans. Energy Conversion, vol. 27, no. 3, pp.1485-1493, Sep. 2012.
http://dx.doi.org/10.1109/TEC.2012.2199495

[6] M. Ghofrani, A. Arabili, and M. Etezadi-Amoli, “Modeling and Simulation of a DFIG-Based Wind-Power System for Stability Analysis,” IEEE Power and Energy Society General Meeting, pp. 1-8, Jul. 2012.
http://dx.doi.org/10.1109/pesgm.2012.6345680

[7] Y. Djeriri : Commande Vectorielle d'une MADA Intégrée à un Système Eolien, Mémoire de Magister, Université de Sidi Bel-Abbes, Alger, 2009.

[8] A. Chaiba : Commande de la Machine Asynchrone à Double Alimentation par des Techniques de l'intelligence artificielle, Thèse de Doctorat, Université de Batna, Alger, 2010.

[9] S. Nouali and A. Ouali, Sensorless Control Strategy for Wind Energy Conversion System Based on Cascaded Doubly Fed Induction Generator Using Artificial Neuronal Network, 2011 IEEE, pp. 42-48, 2011

[10] T. Luu and A. Nasiri. Power Smoothing of Doubly Fed Induction Generator for Wind Turbine Using Ultracapacitors, University of Wisconsin Milwaukee, 2008.

[11] X. Zheng, L. Li, D. Xu, J. Platts, Sliding mode MPPT control of variable speed wind power system, Power and Energy Engineering Conference, pp. 1-4, APPEEC 2009. http://dx.doi.org/10.1109/appeec.2009.4918770

[12] Y. Bekakra, D. Benattous . Active and Reactive Power Control of a DFIG with MPPT for Variable Speed Wind Energy Conversion using Sliding Mode Control, World Academy of Science, 2011.

[13] Ma Wen, Yu Junjie, Wu Guoxiang , Chen Guocheng. “Doubly-fed Wind Power Generation System Maximum Power Point Trac king Control Strategy,” Transactions of china electrotechnical society , vol. 24, no. 4,2008, pp. 202-208.

[14] N Akari , contribution a l’amelioration de la robustesse de la commande d’une machine asynchrone a double alimentation, Phd thesis , Batna university , Alegria.

[15] El Aimani, Salma. *Modélisation des différentes technologies d'éoliennes intégrées dans un réseau de moyenne tension*. Diss. Ecole Centrale de Lille, 2004.

[16] Faiz, Jawad, and Ghazanfar Shahgholian. "Modeling and simulation of a three-phase inverter with rectifier-type nonlinear loads." *Armenian Journal of Physics* 2.4 (2009): 307-316.

[17] M. Ouada, M. S. Meridjet, and N. Talbi, “Optimization photovoltaic pumping system based BLDC using fuzzy logic MPPT control,” *2013 Int. Renew. Sustain. Energy Conf.*, pp. 27–31, Mar. 2013. http://dx.doi.org/10.1109/IRSEC.2013.6529718

Anis Tarfaya -was born in Annaba, Algeria, on Nonvabre 27, 1986. He received a Master degree in electromechanical engineering (with first class honors) from Badji Mokhtar Annaba university in 2011, where he is currently working, PhD. Student degree in electromechanical engineering in same university and is he member in electromechanical engineering laboratory. His interests are in power system modeling and control design.

DIB Djalel is currently working as a research professor with the rank of senior lecturer in the department of Electrical Engineering at the University of Tebessa in Algeria. He was born in 1966 in Tebessa, Algeria, he received his Phd diploma in power systems in 2007 from university of Annaba in Algeria. He participated in several international conferences and has published several papers in various international journals. Currently he is a senior research in laboratory of Electrical Engineering in Tebessa LABGET and leading two projects approved and funded by the Algerian state, it is also designated as a reviewer in several journals. His research interests fields are: the electric power networks, the power quality and the renewable energy.

OUADA Mehdi -was born in Annaba, Algeria, on April 20, 1988. He received a Master degree in electromechanical engineering (with first class honors) from Badji Mokhtar Annaba university in 2011, where he is currently working, PhD. Student degree in electromechanical engineering in same university and is he member in electromechanical engineering laboratory. His interests are in power system modeling and control design.