International Conference on Automation, Control Engineering and Computer Science (ACECS)
Proceedings of Engineering and Technology – PET
Vol.20 pp.59 - 64

New MPPT Optimizer for Wind Turbine Energy Sources

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***Abstract*—This paper deals with the problem of the MPPT (maximum power point tracking) forDFIG (doubly fed induction generator) wind turbine.The control objective is to maximize the energy extracted from wind energy. Firstly, a mathematical modeling of the wind turbine is presented. Then, a control strategy is elaborated to get the maximum of power of the incidental wind energy. The performances of the proposed strategy are validated by simulations which show a high level of tracking in presence of changes of wind speed and blades pitch angle.**

***Keywords*—**Wind turbine, DFIG, MPPT.

NOMENCLATURE:

λ	Tip speed ratio
β	blades pitch angle
C_p	Turbine power coefficient
Ω_m	DFIG rotor speed (rad/s)
G	Gearbox ratio
Cp	Coefficient of performance
P	Number of poles pairs of the DFIG
Ω_m	DFIG rotor speed (rad/s)
Ω_t	Wind Turbine speed (rad/s)
ρ	Air density (Kg/m^3)
J	Total inertia constant (DFIG and Turbine)
f	Viscous friction coefficient (N.m/s)
T_{ae}	Aerodynamic torque (N.m)
$T_{m:}$	Mechanical torque (N.m)
P_a	Aerodynamic power captured (W)
P_e	Output electrical power (W)
S	The surface swept by the blades of the turbine (m^2)
DFIG	Doubly Fed Induction Generator
RSC	Rotor Side Converter
MPPT	Maximum Power Point Tracking

I. INTRODUCTION

The electrical energy is an essential factor for the development and the evolution of the nations. It became an essential form of energy by its flexibility of use and by the multiplicity of the fields of activity where it's called to play an important role, [1].

Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land.The growth of wind energy requires the development of methods and effective production tools, [2].

The installed wind turbines can be classified in two categories: wind turbines with fixed speed and with variable speed. In the past, the majority of the installed wind turbines were in fixed speed, [3]. Nevertheless, these wind turbines present some drawbacks: low energy efficiency, as far as they are optimized only for a set point and a short duration of life because of the important efforts undergone by their structure. Besides, these turbines generate fluctuations in voltage and power of the grid in presence of wind speed variations.

With the increase in the size of turbine, the inherent problems of the constant speed systems become more and more pronounced, especially in areas with relatively weakgrids. To overcome these problems, the trend in modern generator technology is toward variable-speed concepts.

A variable-speed system keeps the generator torque constant and it is the generator speed which changes. Variations in the incoming power are absorbed by rotor speed changes.The variable-speed system therefore incorporates a generator control system that can operate with variable speed. In this arrangement the variable-voltage variable frequency power generated by the machine is converter to fixed-frequency fixed voltage power by the use of back to back power converters. The arrangement can have either induction generator or synchronous generator as the electric machine.

The annual production of energy of a wind turbine with variable speed is increased from 5 to 10 % compared with a wind turbine with fixed speed. Besides, it was shown that the

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This work was supported by the Moroccan Ministry of Higher Education (MESRSFC) and the CNRST under grant number PPR/2015/36.

ISSN 2356-5608

control strategies could have a major effect on wind turbine loads and on the electrical system; and whatever is the wind turbine kind, the main factor remains the used control method, [4]-[8].

In this paper, a new MPPT optimizer for DFIG wind turbine is presented and discussed. Specifically, the power optimizer is expected to compute on-line the optimal rotor speed Ω_{opt} which ensures the maximal power extraction from the wind turbine. Presently, the power optimizer design is based on the $C_p(\lambda, \beta)$ characteristic of the considered turbine. This characteristic is highly nonlinear which makes the MPPT task a highly complex problem. Most existing works have proposed heuristic search algorithms, e.g. perturb-and-observe, incremental conductance, etc. The drawback of these solutions is a slow convergence rate and reduced accuracy. Our solution enjoys a rapid accurate convergence to the MPP. This achievement is made possible because our approach involves a reference speed optimization technique designed using a rigorous modeling of the dependence of the optimal couples (Ω_{opt}, C_{popt}) on λ and β. One key idea in the power optimizer design is to notice that the optimal reference speed is related to β by a well defined nonlinear function.

The paper is organized as follows: in Section 2, the DFIG wind turbine is presented; Section 3 is devoted the wind turbine modelling; in Section 4 the MPPT optimizer is presented; in Section V the performances of the proposed MPPT strategy are illustrated by simulations. A conclusion and a reference list end the paper.

II. SYSTEM PRESENTATION

In this paper a wind turbine with the doubly fed induction generator is used. Fig.1 illustrates the configuration of the studied system.

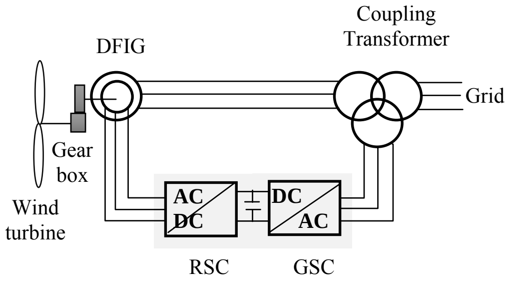


Fig. 1: Doubly fed induction generator wind turbine configuration

In this figure the back-to-back converter is a bi-directional frequency converter and, therefore, it should be able to operate with power flowing in both directions. It consists of two conventional voltage source converters (rotor side converter RSC and grid side converter GSC) and a common dc-bus, [5].

The objective of the rotor side converter (RSC) is to control independently the active power of the generator and the reactive power produced or absorbed from the grid.The objective of the grid side converter (GRC) is to keep the dc-link voltage constant regardless of the magnitude and the direction of the rotor power and to guarantee a converter operation with unity power factor (zero reactive power). This means that the grid side converter exchanges only active power with the grid, and therefore the transmission of reactive power from DFIG to the grid is done only through the stator, [6].

III. WIND TURBINE MODELING

A. *Wind Turbine Aerodynamic Modeling*

The incident wind power (the theoretical power) on the surface of the blades of the wind turbine is given by the following equation

$$P_i = \frac{1}{2}\rho S v^3 \qquad (1)$$

Where S is the surface swept by the blades of the turbine [m^2], ρ is the density of air (ρ =1.225kg / m3) and v is the wind speed [m / s].

Because of the various losses, the extracted power available on the rotor of the turbine is lower than the incidental power. The power captured by the turbine can be expressed asfollows, [7]-[8]

$$P_t = \frac{1}{2}\rho S C_p(\lambda, \beta) v^3 \qquad (2)$$

Where $C_p(\lambda,\beta)$ is the wind-turbine power coefficient (dimensionless), β isthe pitch angle (in degree), and λ isthe ratio of the turbine speed to the wind speed

$$\lambda = \frac{R\Omega_t}{v} \qquad (3)$$

The turbine power coefficient, $C_p(\lambda, \beta)$, describes the power extraction efficiency of the wind turbine. It is defined as the ratio between the mechanical power available at the turbine shaft and the power available in wind. In this study the following approximation, valid for a wide range of commercial turbine (Wind power in power systems [1]), is considered

$$C_p(\lambda, \beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right) e^{\left(\frac{-c_5}{\lambda_i}\right)} + c_6\lambda \qquad (4)$$

with

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1+\beta^3}$$

The parameters $c_1 = 0.5109$, $c_2 = 116$, $c_3 = 0.4$, $c_4 = 5$, $c_5 = 21$ and $c_6 = 0.0068$, are chosen so that the maximum of C_p corresponds to β=0°.

ISSN 2356-5608

It is worth noting that the maximum of the power coefficient $C_p(\lambda, \beta)$ was determined by Albert Betz (1920) as follows [9]

$$C_p^{max}(\lambda, \beta) = \frac{16}{27} \simeq 0.59 \qquad (5)$$

In practice, the frictions and the drag force reduce this value in approximately 0.5 for the large-sized wind turbines.

Using Matlab-Simulink, equation (4) is simulated using the diagram illustrated in Fig. 2.

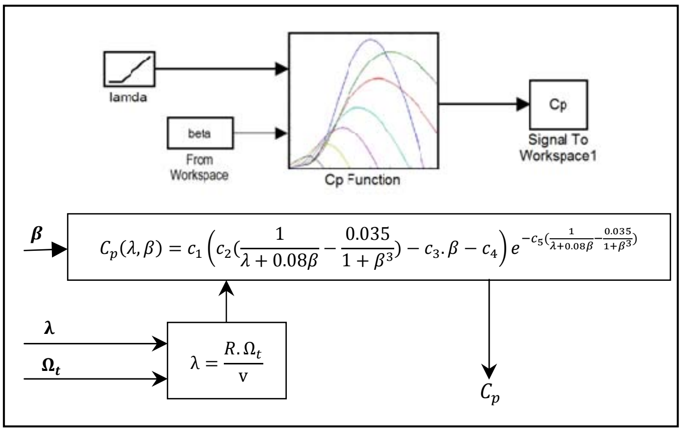


Fig.2: Simulated model of the considered wind turbine

Accordingly, the characteristics $C_p(\lambda, \beta)$ are shown in Fig.3.

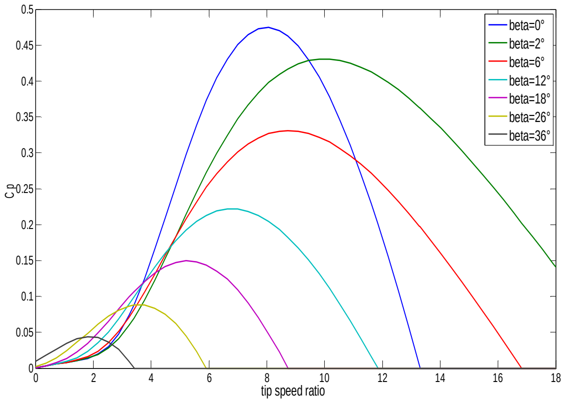


Fig.3: The power coefficient as a function of tip speed ratio for various values of ß

B. Mechanical Model of the Wind Turbine

In this paper medium-power variable-speed variable-pitch wind turbine, with collective blade pitch actuation (according to pitch-to-feather strategy), are considered [14]. According to drive train scheme of Fig. 4, the rotational dynamics of the system can be modeled as follows

$$J\frac{d\Omega_m}{dt} = T_m - T_{ae} - f\Omega_m \qquad (8)$$

Where J is the total rotational inertia, collecting the blades, drive train shaft, and electric generator rotor contributions which is given as follows

$$J = \frac{J_{turbine}}{G^2} + J_g \qquad (9)$$

Where $J_{turbine}$ is the inertia of the turbine, J_g is the inertia of the generator and G is the gearbox ratio.
The function T_{ae} is the aerodynamic torque which, assuming a perfect alignment with wind direction, can be expressed as follows [12]

$$T_{ae} = \frac{P_t}{\Omega_t} = \frac{1}{2}\rho\pi R^3\frac{C_p(\lambda,\beta)}{\lambda}v^2 \qquad (10)$$

where Ω_t is the turbine speed.

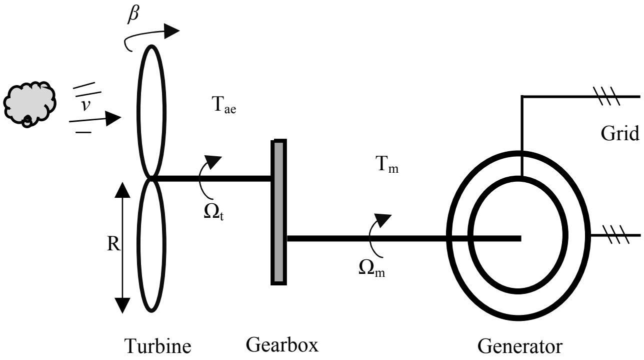


Fig.4: Drive train scheme

Using the previous equations, the system consisting of the wind turbine associated with the DFIG can be represented by the block diagram shown in Fig.5. This representation is used to simulate the whole system in Matlab-Simulink environment.

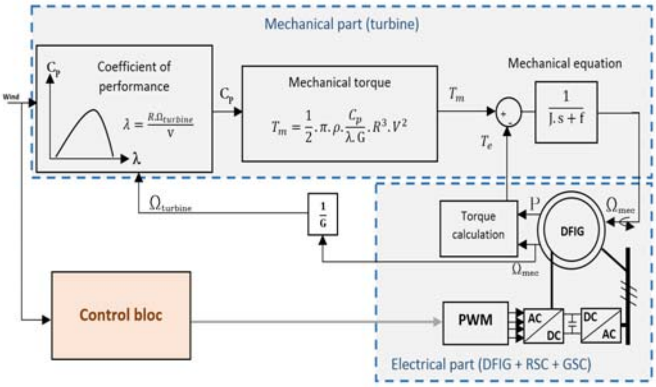


Fig. 5: Wind energy conversion system model

All the involved notations and variables are described in the nomenclature at the beginning of the paper.

IV. PROPOSED MAXIMUM POWEREXTRACTION

A. Determination of the optimal tip speed ratio

From the expression of aerodynamic power (2) and Fig.3 it can be seen that the energy captured from the wind can be varied shaping the power coefficient by means of the tip speed ratio and the pitch angle; the maximum power coefficient corresponds to the optimal values λ_{opt} , β_{opt} . While λ_{opt} slightly depends on the system specific aerodynamic characteristic, the corresponding pitch angle which maximize the power coefficient, for all kind of wind turbine, regardless power curve uncertainties, is $\beta_{opt} = 0°$ .Hence, in order to achieve maximum power extraction at below rated wind speed, the pitch angle can be held constant to zero, while the angular speed is varied to reach the optimal tip speed ratio. From (3), the optimal angular speed Ω_{opt} is related to the optimal tip speed ratio by the following equation

$$\Omega_{opt} = \frac{\lambda_{opt} v}{R} \tag{11}$$

In this work, a new MPPT optimizer for DFIG wind turbine is proposed. Specifically, the power optimizer is expected to compute on-line the optimal rotor speed Ω_{opt} which ensures the maximal power extraction from the wind turbine. Presently, the power optimizer design is based on the $C_p(\lambda, \beta)$ characteristic of the considered turbine. Our solution enjoys a rapid accurate convergence to the MPP. This achievement is made possible because our approach involves a reference speed optimization technique designed using a rigorous modeling of the dependence of the optimal couples (Ω_{opt} , C_{popt}) on λ and β.

The optimizer we are seeking is expected to compute on-line the optimal tip speed ratio λ_{opt} so that, if the tip speed ratio λ is made equal to λ_{opt} then, maximal power is extracted from the wind turbine. Presently, the design of the optimal tip speed reference optimizer is performed on the basis of the power coefficient $C_p(\lambda, \beta)$ characteristics shown in Fig. 3. The summits of these curves correspond to the maximum extractable power P_m and so represent the optimal points. Each one of these points is characterized, for a given pitch angle β , by the optimal tip speed ratio λ_{opt} . A set of optimal couples (β , λ_{opt}), is thus collected and plotted in Fig. 6.

The next step is now to find a mathematical function that fit the curve plotted in Fig.6.

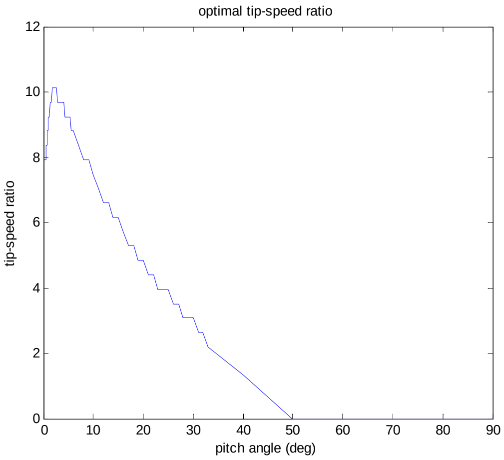


Fig.6: Optimal tip-speed ratio vspitch angle

B. Determination of the fit function

The toolbox *cftool* of Matlabhas been invoked in order to determine an interpolation function that perfectly fit the optimal speed ratio curve shown in Fig. 6. This curve fitting application enables to fit a variety of curves and surfaces to data through an interactive interface. Since each curve fitting problem is different, the application allows to efficiently exploring a variety of algorithms in order to find a solution to data fitting problem. In our case we trying different type of fit, like polynomial, exponential, Gaussian, etc., using the so called "try-error" method. We also trying for each type of fit a variety of algorithms, like Trust-Region, Levenberg-Marquardt and Gauss-Newton. However, the obtained results with the predefined functions are not satisfactory. We, then, tried using a "Custom Equations" and we have, after several attempts, succeeded to the following function obtained after use of "Levenberg-Marquardt" algorithm.

$$\lambda_{opt} = \sum_{i=1}^{8} a_i \sin(b_i \beta + c_i) \tag{12}$$

where the coefficients a_i(i $= 1 \dots 8$)$, b_i$(i $= 1 \dots 8$)and c_i(i $= 1 \dots 8$) are listed in Table I which prove to be convenient. Fig.7 illustrates the result of the curve fitting process. One can clearly show that the proposed mathematical function (12) approximate accurately the behavior of the optimal tip-speed ratio obtained in Fig. 6.

TABLE I: The coefficients a_i, b_i an d $c_i$used in (12)

$a_1 = 8.34$	$a_2 = 4.43$	$a_3 = 1.5$	$a_4 = 1.71$	$a_5 = 1.66$	$a_6 = 1.37$	$a_7 = 0.7$	$a_8 = 0.19$
$b_1 = 0.07$	$b_2 = 0.13$	$b_3 = 0.3$	$b_4 = 0.38$	$b_5 = 0.48$	$b_6 = 0.56$	$b_7 = 0.64$	$b_8 = 0.7$
$c_1 = 0.1$	$c_2 = 1.4$	$c_3 = -0.38$	$c_4 = 0.25$	$c_5 = 0.59$	$c_6 = 1.65$	$c_7 = 2.64$	$c_8 = 4.05$

ISSN 2356-5608

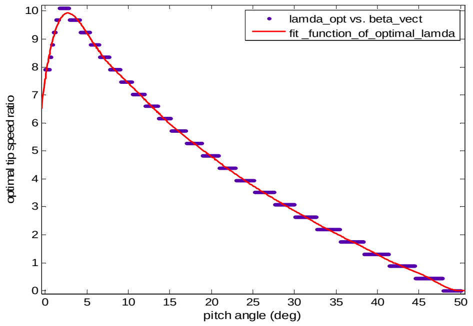


Fig. 7: Curve fitting process

V. SIMULATION RESULTS

In order to check the performances of our proposed MPPT optimizer a simulation bench is developed using Matlab/Simulink® environment according to the scheme shown in Fig.8. Using a PI controller, we guarantee that the actual value of the rotational speed converges toward its optimal value and the maximum power is then extracted from the wind turbine.

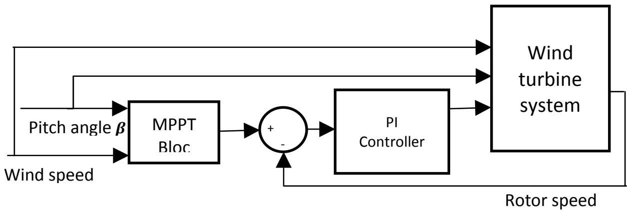


Fig. 8: Experimental bench of the controlled system

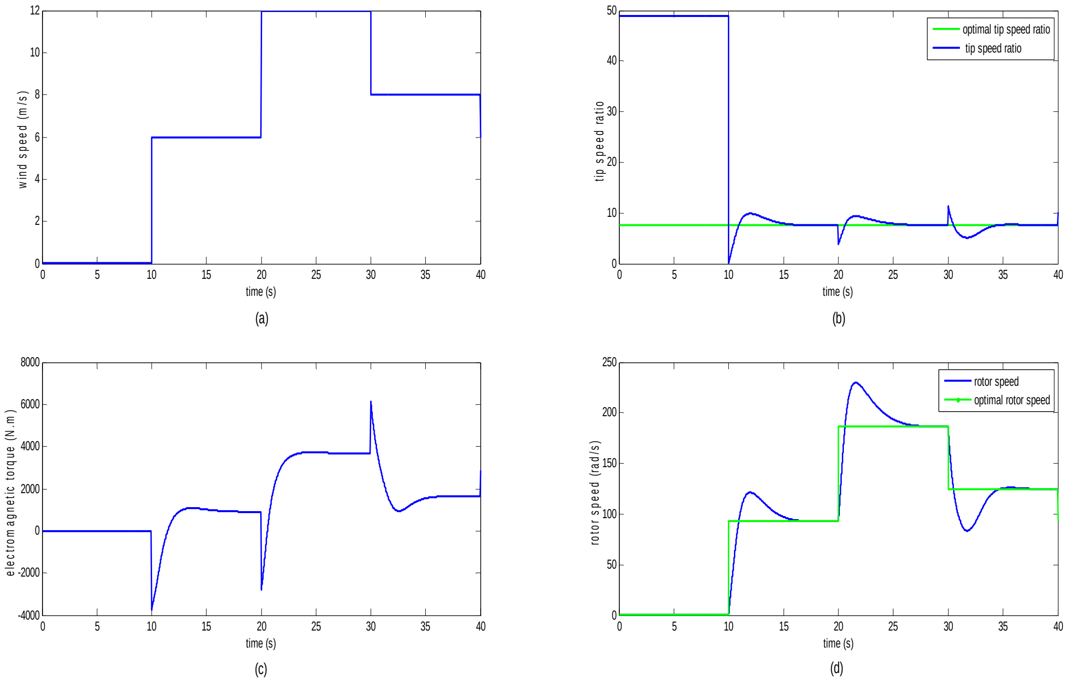
The turbine and controller parameters considered in this work are given in TABLE II.

TABLE II: Parameters of the studied system

Parameter	**Value**
Turbine radius R	21m
Gearbox ratio G	43
Specific air density ρ	1.22 kg/m^3
Turbine inertia J	30 kg/m^2
Viscous friction coefficient f	0.07N.m/s
Gain K of PI controller	- 40
Time constant T_i of PI controller	1.4 s

In order to validate our new MPPT strategy, two scenarios are used: the first one corresponds to fix the pitch angle and to vary the wind speed, the second one is to fix the wind speed and to vary the pitch angle.

For the first scenario, the value of the pitch angle is fixed to 0 degrees, in order to visualizing the behavior of our system in presence of step changes of the wind speed. The considered step changes are: 6m/s, 12m/s and 8 m/s at times 10s, 20s and 30s, respectively. The simulations of the first scenario are illustrated by Fig. 9. It can be seen clearly from Fig. 9, (b), that the tip speed ratio perfectly tracks the optimal tip speed ratio for various intervals of the wind speed corresponding to the maximum and optimal value of C_p as shown in Fig. 3. As a result of this MPPT optimizer, the speed of the wind turbine tracks its reference after as shown in Fig. 9, (d).



(a)

(b)

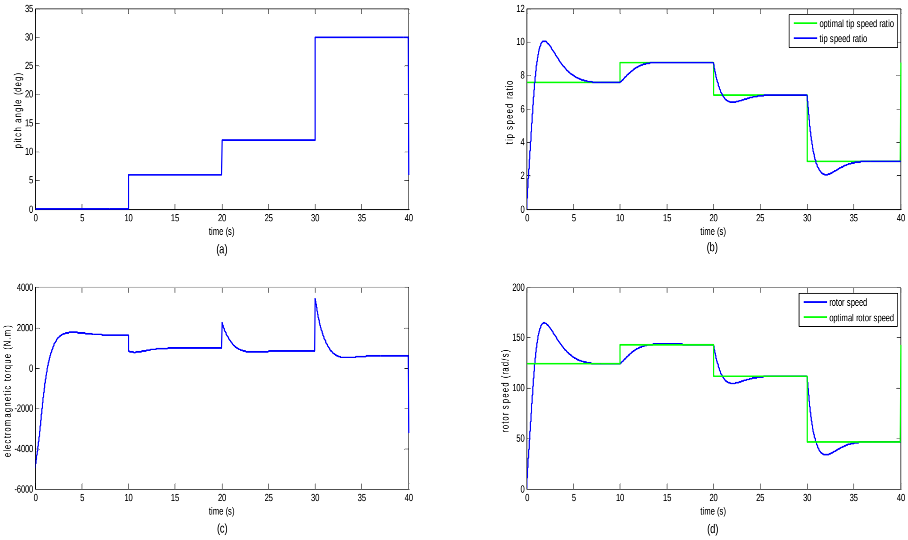
(c)

(d)

Fig. 9: Controller behavior in presence wind speed changes: (a) wind speed profile, (b) tip speed ratio and its optimal value, (c) electromagnetic torque, (d) rotor speed and its optimal value.

In the second scenario, the value of the wind speed is fixed to 8 m/s when pitch angle is step changing. The considered step changes are: 6°, 12° and 30° at times 10s, 20s and 30s, respectively.

The simulations of the second scenario are illustrated by Fig. 10.



(a) (b)

(c) (d)

Fig. 10: Controller behavior in presence pitch angle changes: (a) pitch angle profile, (b) tip speed ratio and its optimal value, (c) electromagnetic torque, (d) rotor speed and its optimal value.

Fig. 10 clearly shows that the rotor speed tracks its optimal value which guarantees that the maximum power is captured from the wind turbine.

VI. CONCLUSIONS

In this paper, a new solution for MPPT of variable speed wind turbine is developed. A novel combined MPPT-PI controller was proposed, in order to benefit the maximum power from the wind and exploit wide range of wind speed.

When the rated speed is exceeded, the rotor speed isoptimizedby generating the optimal tip-speed ratio corresponding to the operated pitch angle. The system is regulatedby a PI controller to enforce the rotor speed to track its reference value. The validity of the studied system has been verifiedby simulation results using Matlab/simulink. Furthermore, the applied control strategies can benefit of a high efficiency with good robustness and low cost.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of the Moroccan Ministry of Higher Education (MESRSFC) and the CNRST under grant number PPR/2015/36.

REFERENCES

[1] T. Ackermann *Wind power in power systems* Wiley & Sons,Ltd Baffins Lane, Chichester, West Sussex, England, 2005..

[2] Krishnama Raju S, Pillai GN. Design and real time implementation of type-2 fuzzy vector control for DFIG based wind generators. *Renew Energy* 2016;88:40e50.

[3] Y. Majdoub, A. Abbou and M. Akherraz, "Variable Speed Control of DFIG-Wind Turbine with Wind Estimation," *IEEE IRSEC conf., International Renewable and Sustainable Energy Conference*, October 2014, pp. 268–274.

[4] Dahbi, A., Nait-said, N., & Nait-said, M. (2016). ScienceDirect A novel combined MPPT-pitch angle control for wide range variable speed wind turbine based on neural network. *International Journal of Hydrogen Energy*, 1–16.

[5] B. Boukhezzar H. Siguerdidjane M. Hand "Nonlinear control of variable-speed wind turbines for generator torque limiting and power optimization" ASME J. Solar Energy vol. 128 pp. 516-530 Nov. 2006

[6] Hansen, A. D., Sørensen, P., Iov, F., & Blaabjerg, F. (2006). Centralised power control of wind farm with doubly fed induction generators, 31, 935–951.

[7] Hong Chih-Ming, Chen Chiung-Hsing, Chia-Sheng Tu. Maximum power point tracking-based control algorithm for PMSG wind generation system without mechanical sensors. *Energy Convers Manag* 2013:58e67

[8] Eltamaly, A. M., & Farh, H. M. (2013). Maximum power extraction from wind energy system based on fuzzy logic control. *Electric Power Systems Research*, 97, 144–150.

[9] M. Budinger, D. Leray, et Y. Deblezer, «Eoliennes et vitesse variable », *La revue 3EI*, vol. 21, pp. 79-84, (2000).

[10] K. Belmokhtar, M. L. Doumbia and K. Agbossou, "Modelling and fuzzy logic control of DFIG based Wind Energy Conversion Systems," 2012 *IEEE International Symposium on Industrial Electronics*, Hangzhou, 2012, pp. 1888-1893.

[11] Khalil, H. K., *Nonlinear Systems*, 3rd edition, Prentice Hall, New Jersey 07458 (2002).

[12] T. Burton, D. Sharpe, N. Jenkins, E. Bossanyi *Wind energy handbook* Wiley & Sons, 2000