Pitch Angle control of the variable speed wind turbine

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Abstract— Pitch control is look as the more profitable and famous way to control the power.

The control of Pitch angle is so important for regulating the wind's turbine aerodynamic torque when the wind speed is higher than the nominal speed also many values may be chosen, such as wind speed, generator speed and generator power.

Many methods of pitch angle control are found and approved with simulation results under Matlab\Simulink.

***Keywords*—variable-speed; wind turbine; Maximum Power Point Tracking; pitch angle control; Permanent magnetic synchronous generator.**

I. INTRODUCTION

Resources of energy will break off in the following years so it's very necessary to satisfy these needs and try to find a solution to this problem. Actually, it is so easy to exploit this renewable energy resources were a simple way to do [1-3].

This article is about the energy of wind which is an incessant energy in the earth.

Pitch angle regulation has an important role, when the nominal wind speed is high, while the rotational speed is conserved a fixed value. So this prospect of a pitch angle control can be expressed in this way [4-5]:

1) Modulation of the turbine and optimization the wind turbine power output
2) Admitting the maximum of wind turbine power output by the Maximum Power Point Tracking
3) Using pitch angle control to Regulate the aerodynamic power when rated wind speed is high

II. WIND TURBINE MODELING

The simulation of the wind turbine propriety, it's obligatory to have the torque which is applied on its shaft.

The equation of mechanical power obtained from the wind turbine is indicated with [6-7]:

$$P_t = C_p \cdot P_v \tag{1}$$

$$P_v = \frac{1}{2} \cdot S \cdot \rho \cdot V^3 \tag{2}$$

$$S = \pi \cdot R^2 \tag{3}$$

C_p depends on the tip speed ratio λ which has this expression [8]:

$$\lambda = \frac{\Omega_t \cdot R}{V} \tag{4}$$

This is the equation of the power coefficient:

$$C_p(\beta,\lambda) = 0{,}5176.\left(116.\frac{1}{\lambda_i} - 0{,}4.\beta - 5\right).e^{\frac{-21}{\lambda_i}} + 0{,}0068\lambda \tag{5}$$

Where:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0{,}008\beta} - \frac{0{,}035}{\beta^3 + 1} \tag{6}$$

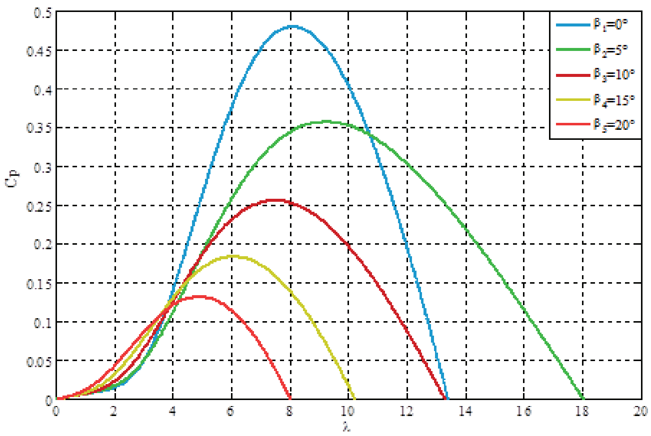


Fig.1.Power coefficient $Cp(\lambda, \beta)$

Fig.1. figured the variation of the power coefficient Cp when the tip speed ratio λ (TSR) changes for different value of β. When β_{opt} =0° we obtained the maximum.

In this study, changing PMSG speed for variety wind speed result this characteristic of the mechanical power extracted from wind energy which illustrated in this figure.

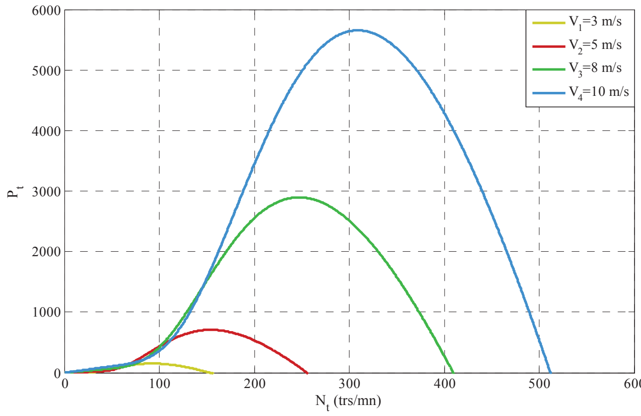


Fig.2.The mechanical power

The mechanical speed of turbine is obtained from the fundamental equation of the dynamics as:

$$T_{mec} = T_g - T_{em} - T_f \tag{7}$$

Where:

$$T_f = f \cdot \Omega \tag{8}$$

$$J \cdot \frac{d\Omega}{dt} = T_{mec} \tag{9}$$

Extraction of maximal power from the wind can be with controlling the wind turbine speed. In line with the Betz theory, the wind turbine can give us maximal power 59.3% the total wind power, so the power coefficient is 0.593 [9].

In this study for the wind turbine modeled, when $\beta = 0$ it shows an optimal value of the tip speed ratio ($\lambda_{opt} = 8.1$)which correspond to a maximum power coefficient (C_{pmax}=0.48) and fig.1 represent this result :

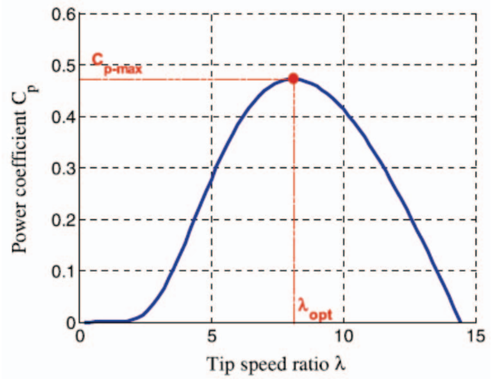


Fig.3. Cp versus λ curve

III. PERMANENT –MAGNETIC SYNCHRONOUS GENERATOR

Permanent magnetic synchronous generator has many advantages and it's very important.

The Park model of PMSG is used, so only the fundamental harmonic of the flux circulation in the air-gap of the machine is treated but we don't use the homopolar component, so dynamic equations of the stator obtained from the theory of the space vector:

$$\begin{cases} V_{sd} = -R_s i_{sd} - L_s \dfrac{di_{sd}}{dt} + L_s \Omega i_{sq} \\ V_{sq} = -R_s i_{sq} - L_s \dfrac{di_{sq}}{dt} - L_s \Omega i_{sd} + K_a . \Omega \\ C_{em} = p.\phi.i_{sq} \end{cases} \tag{10}$$

With:

R_s : The stator resistance (Ω)
L_s : The stator inductance (H)
ϕ : The flux of the permanent magnetic (Wb)
V_{sd}, V_{sq}: The stator voltages.
i_{sq}, i_{sd}: The stator currents.
p:the number of pairs of poles
K_a: voltage coefficient of the f.e.m

For many variable-speed wind turbines, the most power is a cubic function of rotational speed. The evolution of the generator torque is situated on q-axis current component of the stator; however the regulation of direct current is obtained from a freedom degree. In spite of decreasing current for a specific torque, and so, minimizing resistive losses the d-axis current component can be took at zero [10]. So, the control of the generator torque depends precisely on the d-q current component.

The control loops of the PMSG-face converter can be exemplified with the graphic design which figured on Figure4 .It is very important to control the d-axis current component and the q-axis component. In spite of improving the dynamic answer, compensation terms are combined.

The regulation needs the measure of the stator currents, dc voltage, and the position of the rotor.

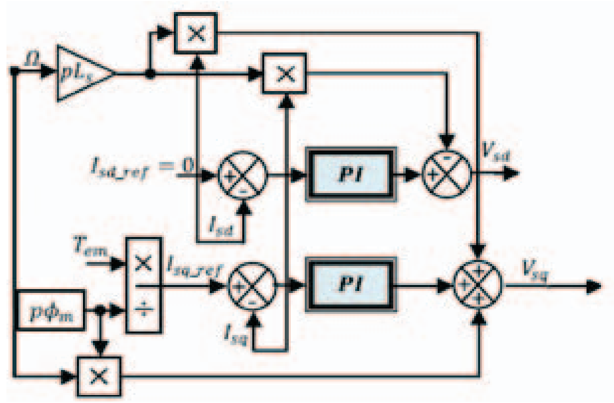


Fig.4. PMSG control

IV. CONTROL OF THE WIND GENERATOR

The power control of the generator is realized by the supervision of the Permanent magnetic synchronous generator electromagnetic torque T_{em}. The action of the system to control pitch angle needs to border the rotational speed of the shaft .In addition, the reference value of the electromagnetic torque T_{em-ref}, can be advanced bellow [11]:

The approach of an operating at maximum power, designs for expanding the aerodynamic output of the turbine, wishing to obtain a maximal power of the wind.

Eq.11 donate the equation of the most power extracted using the strategy of MPPT which modify naturally the ratio speed to its optimal rate, in spite of having the maximum power coefficient C_{pmax}, to express the relation between the power of turbine and the speed of the turbine at the maximal power we have the expression bellow. Regulating the system under the specification of the best power, it's important to regard that the turbine power cannot be higher than the nominal power. When we attain the nominal power, it is important to limit the output one.

$$P_{MPPT} = K_{opt}.\Omega^3 \tag{11}$$

Where:

$$K_{opt} = \frac{1}{2}\frac{R^3 \rho\pi C_{p\max}}{\lambda_{opt}^3} \tag{12}$$

On condition when the wind is high, it's important to limit the rotational speed in order to do not have a destruction of the turbine. This limit was got with the pitch angle control.

V. CONTROL OF PITCH ANGLE

The strategy of the pitch control is an important design to check the rotational speed of the turbine.

We can control the reference of the pitch angle with the input measures, it can be as bellow:

- Wind speed, reference of the pitch angle can be exposed from the curve of the pitch angle versus wind speed, the regulation is easy with measuring directly the wind speed; despite this isn't a pertinent procedure, by cause of the difficulty to measure the wind speed correctly. Absolutely, the pitch angle is decreased at time of exceeding the maximal speed by the rotor of the turbine by the rotor speed
- The generator rotor speed, as pictured in Figure 5. a. A comparison between the rotor speed control with its value of reference. After that, the signal of error will be given to the PI controller and β_{ref} will be also given.
- Generator power, as figure 5.b pictured. The signal of the error power generator is posted to the regulator PI. The PI regulator gives β_{ref}.

In the variation of the turbine speed, a mechanical actuator is ordinarily use in order to regulate the pitch angle of blade to minimize C_p also keep the power at the nominal power. The linearization of the model to order 1 [12- 13] so the torque has been considered proportional to the rotational speed of the turbine. So this is the regulation strategy:

$$\begin{cases} \beta_{ref} = \beta_0 = 0 & for\ 0 \leq \Omega_t \leq \Omega_{tn} \\ \beta_{ref} = \frac{\Delta\beta}{\Delta\Omega}(\Omega_t - \Omega_{tn}) & for\ \Omega_t > \Omega_{tn} \end{cases} \tag{13}$$

With:

β_0 (°): the initial pitch angle

Ω_{tn}(rad/s):the rated mechanical turbine speed

A. *PI control*

A transfer function of the first order is proposed in spite of regulating the location of blades conforming to the reference value.

$$\beta = \frac{1}{1+\tau_b.s}\beta_{ref} \tag{14}$$

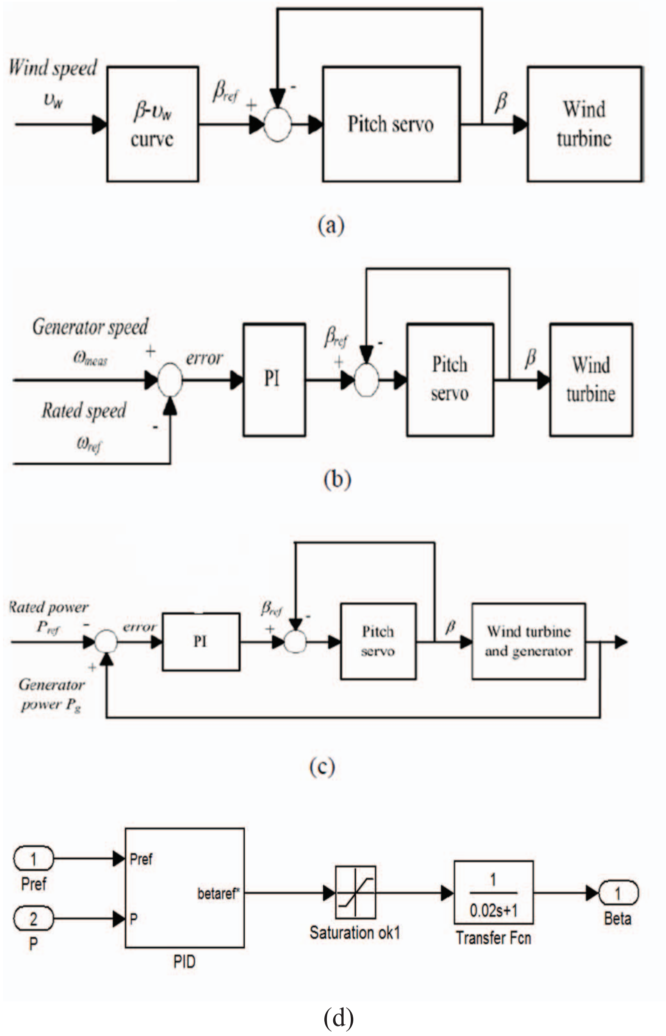


Fig.5. strategy of Pitch control (a), (b) regulation of speed; (c, d) power regulation

Simulation results and discussion

To simulate the control system of the pitch angle we need a program to check the regulation strategy also criticize the work of the system so we use MATLAB/SIMULINK tool.

During 100s, we tested the model of the wind turbine with many profile wind of between 5 and 13 m/s with a value of 10 m/s. This result is pictured .Fig.6.

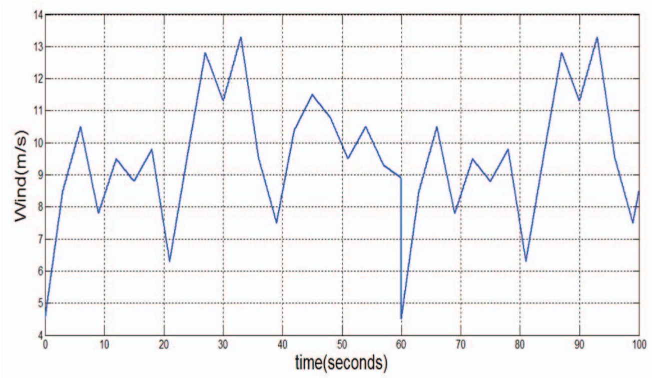


Fig.6. Wind speed

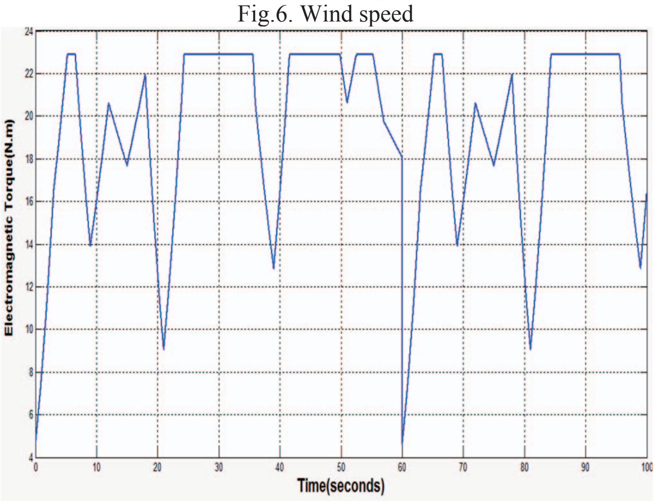


Fig.7. Electromagnetic torque

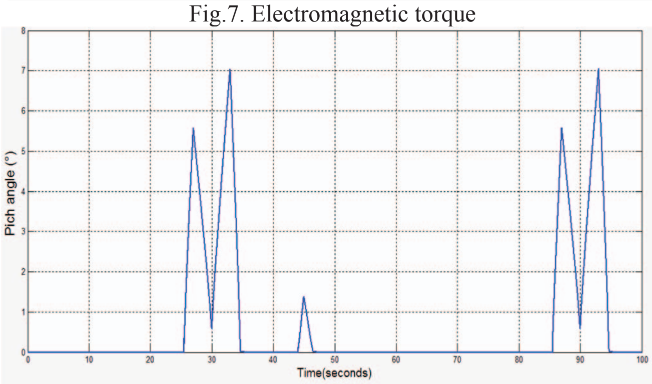


Fig.8.Pĭtch angle

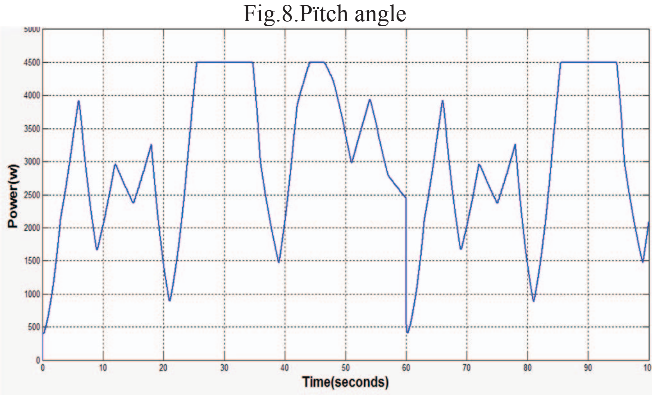


Fig.9.PMSG power

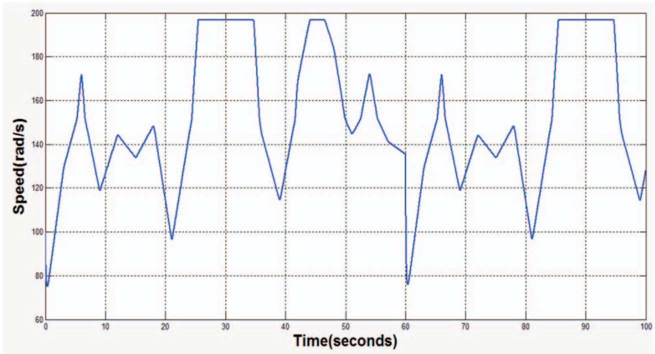


Fig.10. Mechanical speed

The modulation of the wind turbine is in order to give a rated power at a rated speed. Above this value of wind, it's so important to preserve the wind turbine facing mechanical failures; so, its speed must be bordered.

To have this limitation we use a regulation of pitch angle. The mechanical speed which pictured in Figure 10 is realized close the variation of the pitch angle which pictured in Figure8.

When a pitch angle rises, power coefficient reduces. The difference between many methods pictured in results obtained by the simulation, view that strategy of pitch angle regulation when we use the generator power as the regulating values has a fast answer of pitch angle to the variation of the wind speed and littlest ripples of power.

When the error of the regulating speed is equal of 0.80 so the fault of answer attained close the curve of wind equal to 0.96.These result obtained with the second strategy so it focus the power of this method of the regulator of the generator power.

B. *Fuzzy Logic control*

The regulation with Fuzzy logic considered one of the robust methods to control. Fuzzy set theory and associated techniques is the base of this control. Complex nonlinear models and parameters variation are important to suit the fuzzy logic algorithm control.

Also without knowing the propriety of the wind turbine it can know the optimal pitch angle with using the perturbation and observation.

Three important stages are important on the basic structure of the fuzzy logic controller:

- Fuzzification
- Decision Making Unit
- Defuzzification Unit

A selection as error the inputs of the Fuzzification and rate of change of error but the pitch angle reference is the output.

To calculate the input variables at each instant we use this expression [14].

$$e(k) = P_{réf}(k) - P_g(k)$$

$$\Delta e = \frac{e(k) - e(k-1)}{T_s} \qquad (15)$$

Where:

$P_{ref}(k)$: the reference power at instant n

P_g *(k)* generated power at instant n.

In Fuzzification stage the crisp variables e(k) and Δe(k) are changed into fuzzy variables which can be identified by member ship function.

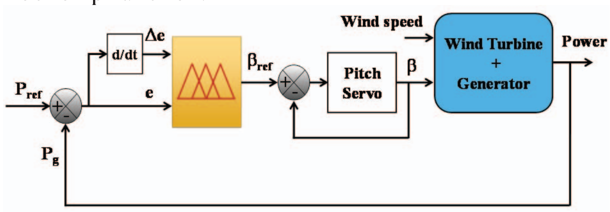


Fig. 11 strategy of Fuzzy logic control

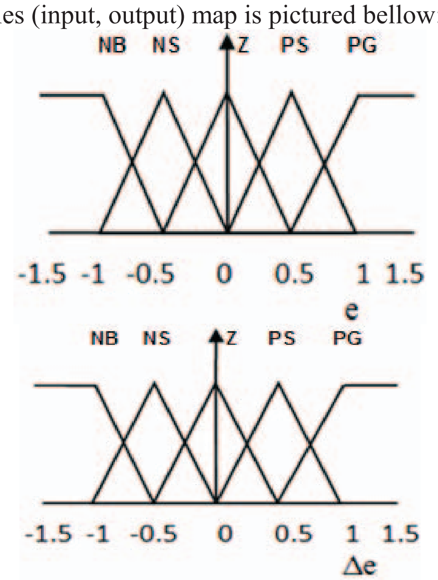
Those linguistic labels are proposed to use by the controller: NB (Negative Big), NS (Negative Small), Z(Zero), PM(Positive Small), PB(Positive Big).

Table1 present the Fuzzification :

TABLE 1 : RULES TABLE

e / Δe	NB	NS	Z	PS	PB
NB	NB	NB	NS	NS	Z
NS	NB	NS	NS	Z	PS
Z	NB	NS	Z	PS	PS
PS	NS	Z	PS	PS	PB
PB	Z	PS	PS	PB	PB

Variables (input, output) map is pictured bellow:



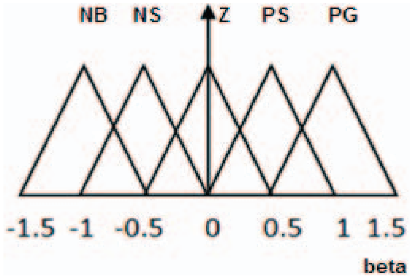


Fig. 12 Fuzzy Inference System

The definition of the error and the rate change of error which are inputs and the pitch angle which is an output we need the triangular of membership function

Simulation results and discussions

For checking the power of fuzzy logic regulator compared with the conventional PI controller at specific value of wind speed, so we use MATLAB/Simulink software to obtain results.

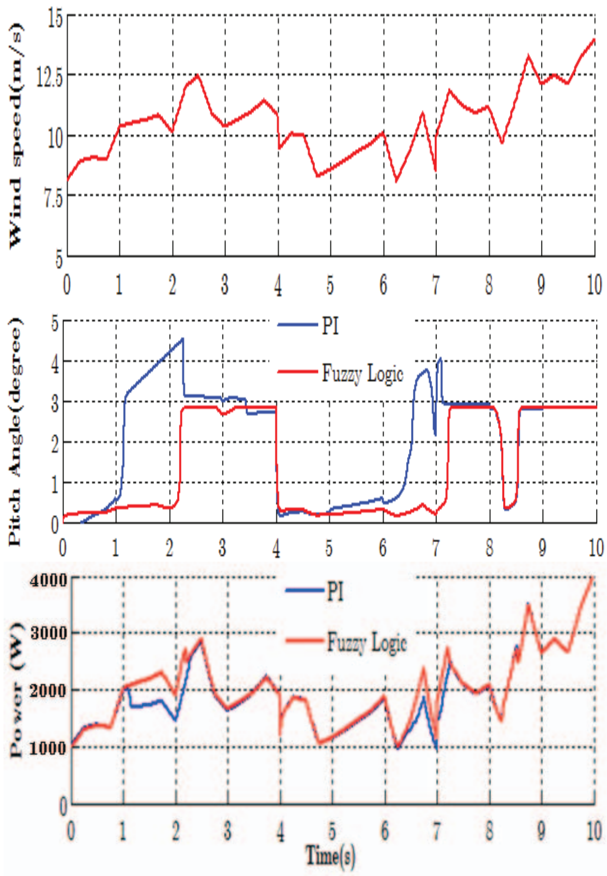


Fig. 13 difference between different pitch angle control strategies.

When we compare between different pitch angles controls strategies as shown on Figure.13 we obtain that the best strategy to control pitch angle is the fuzzy logic control strategies because it considered more robust and powerful.

The classic controller requires a thorough study of the system to adjust it is essential for the regulator to give adequate modeling with a transfer function or a state of the equation system. Therefore against fuzzy regulator requires operators experience to write the inference.

In this case, it is not necessary to have a system model to adjust but just one of its dynamic behavior description.

This regulation may be use for non-modeled system (highly nonlinear) .It replaces in this case the classic regulator.

VI. CONCLUSION

To control the aerodynamic power and the aerodynamic loads, so it used the pitch angle control in order to finish lower torque peak and lower fatigue loads. The results present that the low torque peak and a low power peak are obtained with the power controller.

In this study, we can track the optimal pitch angle with using fuzzy logic and PI controller. So the fuzzy logic controller is the best and it is obtained that this method has a fast answer more than the conventional PI controller.

APPENDIX

Wind turbine

Number of blades : 3

Rayon of pales : R=2.5 m

Viscous friction coefficient : $f= 10^{-3}$N.m.s.rad^{-1}

Total inertia of the mechanical transmission: J =99 x 10^{-4} kg.m^2

PMSG

Rated power: P_n= 4.5kW

Number of pole pairs: p=2

Rated speed: n_n=1500 rpm

Self-inductance: Ls= 21.3mH

Stator resistance: Rs= 0.89Ω

Permanent magnetic flux: Φ= 0.5 Wb

REFERENCES

[1] N.Lior, “Energy resources and use: the present situation and possible paths to the future”, Energy 2008;33(6), pp. 842-57.

[2] Lund PD,“Effects of energy policies on industry expansion in renewable energy”, Renew Energy 2009;34(1), pp. 53-64.

[3] Ostergaard PA, “Reviewing optimization criteria for energy systems analyses of renewable energy integration,” Energy 2009.

[4] Wen, J., Zheng, Y., Donghan, F. (2009) A Review On Reliability Assessment for Wind Power, Renew Sustain Energy Review, 13(9): pp. 2485-94.

[5] Chowdhury M.A, Hosseinzadeh N, Shen W.X. (2012) Smoothing Wind Power Fluctuations by Fuzzy Logic Pitch Angle Controller. Renewable Energy; 38: pp. 224-233.

[6] A. Mamadie Sylla,“ Modélisation d'un émulateur éolien à base de machine asynchrone à double alimentation,’’. Thèse de Doctorat présenté à l’université du Québec à trois rivières.

[7] F. MeibodyTabar,“Machines synchrones à aimants permanents alimentées par onduleurs de tension : modélisation, commande et segmentation de puissance,’’. Habilitation à Diriger des Recherches, Nancy, janvier 2000.

[8] I. Cruz, F. Avira, L. M. Arribas and R. P. Fiffe, “Assessment of different energy storage systems for wind energy integration,’’. European Wind Energy Conference 2001.

[9] M. Mohamed, “Contribution à l’intégration de la production décentralisée dans le réseau électrique,’’. Thèse de Doctorat en Génie Electrique,Ecole nationale d’ingénieurs de Monastir, Tunisie.

[10] C.Veeramani and G.Mohan, "A fuzzy basedpitch angle control for variable speed wind turbines" International of Engineering and Technology (IJET), Apr-May 2013.

[11] F. Kendouli, K. Nabti, K. Abed et H. Benalla,“Modélisation, simulation et contrôle d’une turbine éolienne à vitesse variable basée sur la génératrice asynchrone à double alimentation”, Revue des Energies Renouvelables Vol. 14 N°1 (2011), pp. 109 – 120.

[12] P.Wang and R.Billinton, “Reliability benefit analysis of adding WTG to a distribution system,”. IEEE Trans Energy Conversion 2001.

[13] L.Leclercq, “Apport du stockage inertiel associé à des éoliennes dans un réseau électrique en vue d’assurer des services systèmes,”. Thèse de Doctorat en Génie Electrique, Université des Sciences et Technologies de Lille, Villeneuve d’Asq, 2004, n°3563.

[14] M. Ben smida,“Different Conventional Strategies of Pitch Angle Control for Variable Speed Wind Turbines,”. *IEEE* Transl.15th international conference on Sciences and Techniques of Automatic control & computer engineering - STA'2014,Hammamet, Tunisia, December 21-23, 2014.