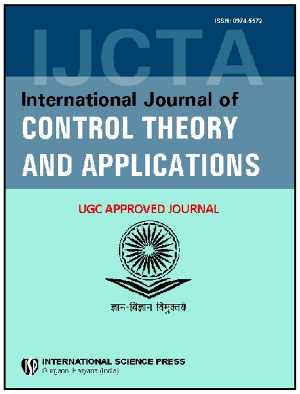

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 34 • 2017

Study of wind Turbine System based Onpmsg with Fuzzy-PI Controller

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Abstract: Nowadays, the use of electrical energy in the agricultural sector is of a remarkable importance essentially in the pumping of water. The use of this type of energy increases the cost of the use of the pumping station is therefore the invoice of electrical energy. To reduce energy costs, wind power is a solution to produce electrical energy from clean and sustainable way. In this work, we proposed a wind water pumping system consisting of a wind turbine with a synchronous permanent magnet generator coupled to a water pump. We have in the first part of the modelling of the wind conversion system. In the second part, an intelligent control for the DC bus voltage output from the rectifier based on the fuzzy logic and compared with a conventional regulator PI. The results obtained analyzed and validated by the Matlab simulation show that the fuzzy is more robust and of superior dynamic performances.

Keywords: Wind, PMSG, Power Maximisation Strategy, Vector Control, PI Controller, Fuzzy Logic Controller.

1. INTRODUCTION

There are different types of generator used wind turbines to convert electrical energy from wind power, such as the double-fed generator (MADA) and permanent magnet synchronous generator (PMSG) [1]. PMSG shows good performance, due to the absence of gearbox and most require no excitation current, for this, this type of wind turbine can avoid the problem of wear gear, it can help wind to operate more reliably and reduce risks [1]-[2]. This paper focuses on dynamic modeling of the wind system, modeling of the power turbine based on a synchronous machine with permanent magnets power controlled by a hysteresis rectifier for pumping 150V load.

2. MODELLING WIND GENERATOR

The wind generator, consisting of a variable speed turbine coupled directly a synchronous permanent magnet generator via a rectifier converter hysteresis by regulating the current to a DC bus connected to the forward load is shown in figure 2.

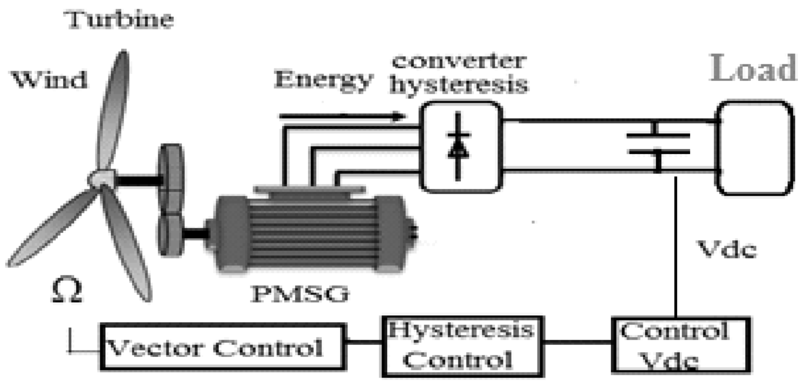

Figure 1: General Schematic Control Wind Turbine System

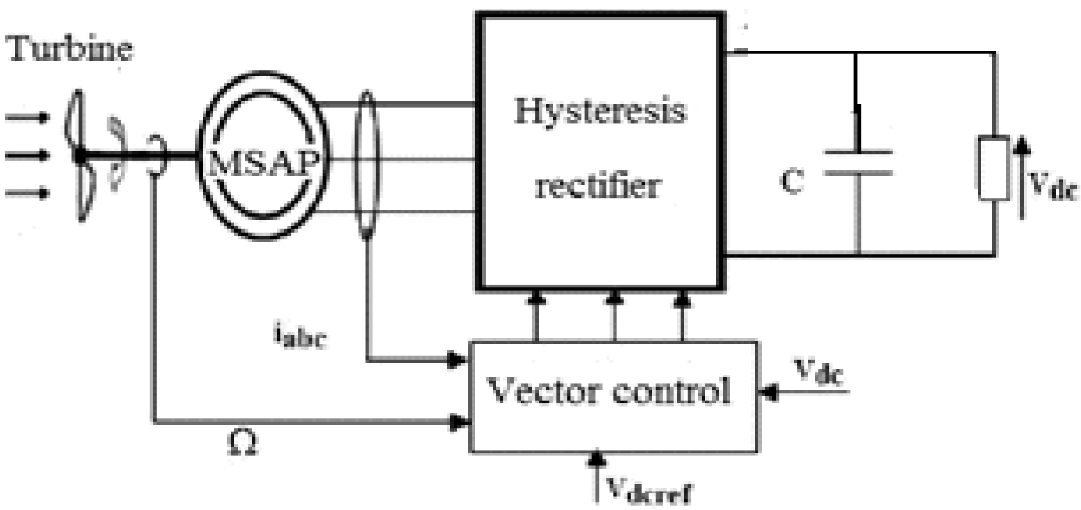

Figure 2: General Structure of Wind Generator

2.1. Wind Turbine Model

The wind turbine converts the kinetic energy of wind into mechanical energy. From the kinetic energy of the air mass of moving particles passing through the section of the active surface S of the wing, the power of the mass of air that passes through the area equivalent to the surface area S, wind is given by[10, 14]:

$$P_w = \frac{1}{2}.\rho.S.v^3.C_p(\lambda, \beta) \tag{1}$$

Where, $C_p(\lambda, \beta)$ is the power coefficient, λ is the speed ratio, b is the pitch angle, r is the air density, V is the wind speed and $S = \pi.R^2$ is the blades swept of the turbine.

2.2. Permanant Magnet Synchronous Machine Model

In order to get a dynamical model for the electrical of the PMSG is the Park model that easily allows us to define the generator control system; the equations of the generator are projected on a reference coordinate system rotating synchronously with the magnet flux. The dynamic equations of the stator currents are given by: [4, 7].

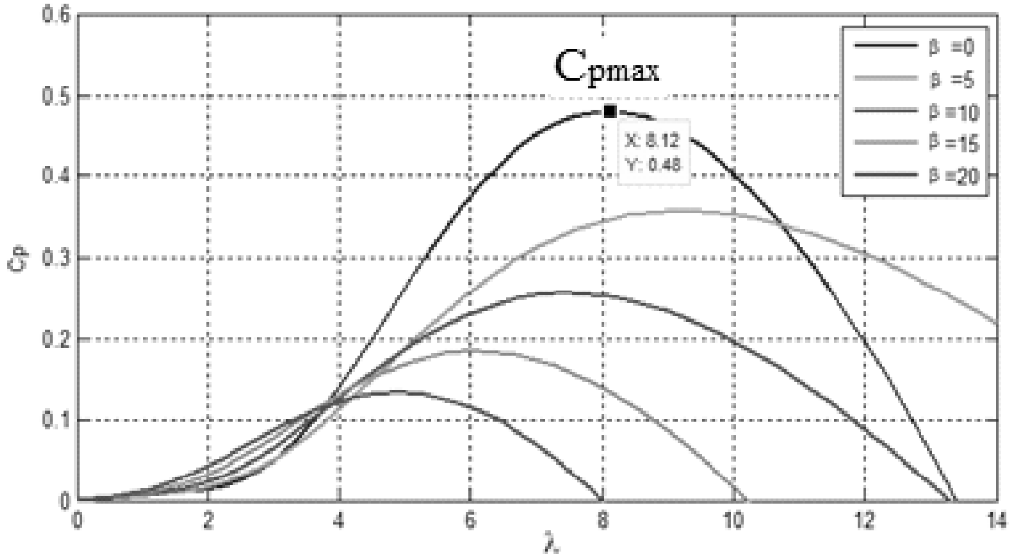

Figure 3: Cp (λ, β) Curve

$$\begin{cases} v_d = R\,.i_d + L_s.\dfrac{di_d}{dt} - p.\Omega.L_s.i_q \\ v_q = R.i_q + L_s.\dfrac{di_q}{dt} + p.\Omega.L_s.i_d + p.\Omega.\varphi_f \end{cases} \quad (2)$$

Where, V_d and V_q are the d-q components of the stator voltages respectively, id and iq are the d-q components of the stator currents respectively [14]. R is the phase resistance of the stator, Ls is the inductance cyclic of the stator, p is the number of pairs of poles and Φ_f is the permanent magnetic flux [4].

The electromagnetic torque equation of PMSG is:

$$T_{em} - T_r = J_m.\frac{d\Omega}{dt} + f.\Omega \quad (3)$$

Where the electromagnetic torque is:

$$T_{em} = 1,5.\frac{P}{2}.\varphi_f.i_q = k_e.i_q \quad (4)$$

2.3. Rectifier Model

We model the rectifier by a set of ideals switches: that is to say zero resistance in the on state, infinite resistance in the off state, instantaneous response to control signals.For the dynamic model of the system, we will divide the study of the converter into three parts: the AC side, the broken part composed by the switches and continuous side. In this context, the function of switches is to establish a connection between the alternating current side and the DC bus.

$$X = \begin{cases} +1, \overline{X} = -I \\ -1, \overline{X} = +I \end{cases} \text{Pour } X{=}1,\, 2,\, 3$$

The input phase voltages and the output current can be written by the equation:

$$ixa + ixb + ixc = 0 \tag{5}$$

The input voltages between phases of the rectifier can be written:

$$\begin{aligned} U_{Xab} &= (X_a - X_b) \cdot U_{dc} \\ U_{Xbc} &= (X_b - X_c) \cdot U_{dc} \\ U_{Xca} &= (X_c - X_a) \cdot U_{dc} \end{aligned} \tag{6}$$

The equations of tension for the balanced three-phase system without connection neutral can be written as follows:

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = R \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L \frac{d}{dt} \begin{bmatrix} e_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} U_{xa} \\ U_{xb} \\ U_{xc} \end{bmatrix} \tag{7}$$

Where:

$$\begin{aligned} U_{Xa} &= \frac{2X_a - X_b - X_c}{3} \cdot U_{dc} \\ U_{Xb} &= \frac{2X_b - X_a - X_c}{3} \cdot U_{dc} \\ U_{Xc} &= \frac{2X_c - X_a - X_b}{3} \cdot U_{dc} \end{aligned} \tag{8}$$

Finally, the equation of coupling between alternate and continuous sides is:

$$C \frac{dU_{dc}}{dt} = X_a i_{xa} + X_b i_{xb} + X_c i_{xc} - i_L \tag{9}$$

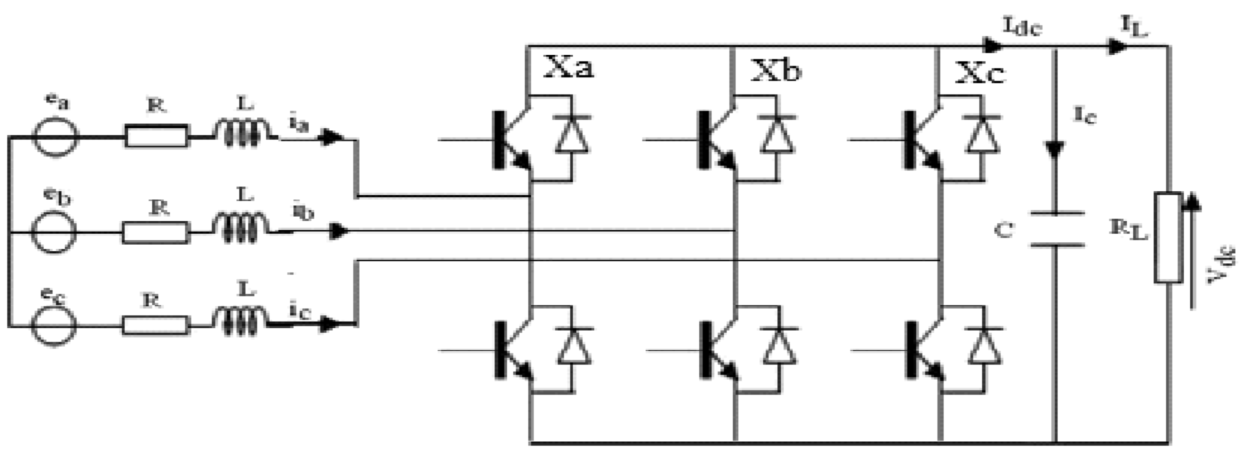

Figure 4: Association of MSAP – Rectifier

3. CONTROL WIND GENERATOR

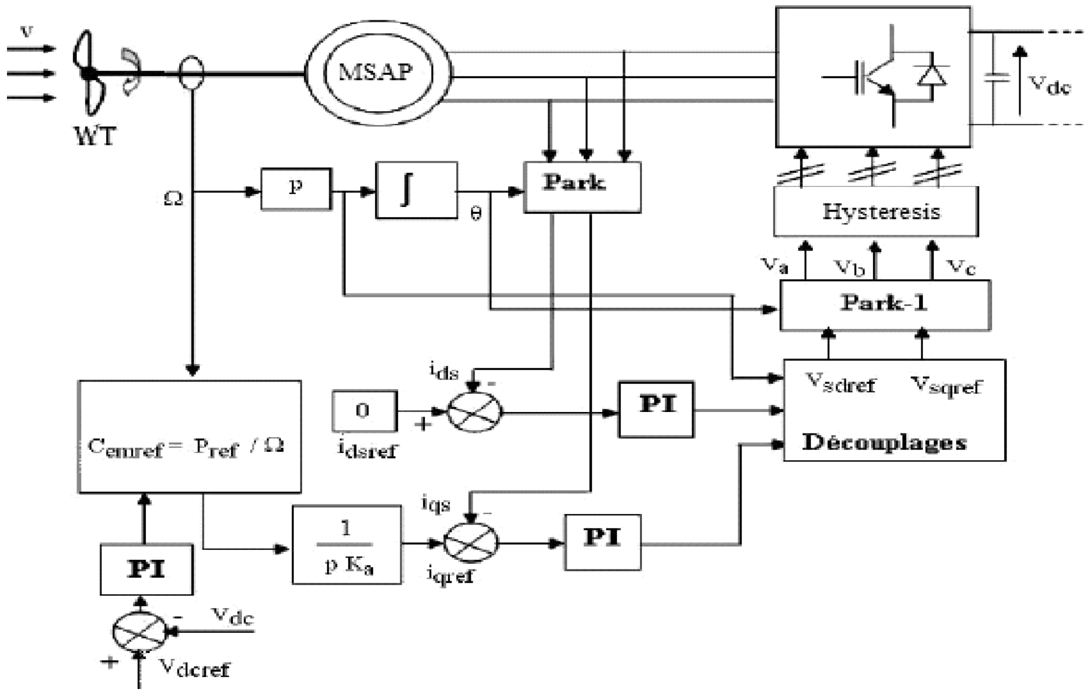

Figure 5: Block diagram of the Control of the Rectifier and of the Synchronous Machine[18]

3.1. Powermaximisation Strategy

The equations of the electric power and the mechanical power of the steady-state system allow the formulation of the new objective. To reduce the degree of freedom of the system, the wind speed, the only uncontrollable variable in the system, was obtained by mathematical formulation by the use of an optimal form [18] - [21].

Using the power coefficient Cp (λ), wind power is calculatedso:

$$P_{eol} = 0.5.C_P(\lambda) \times \rho \times S \times V_v^2 \tag{10}$$

Where the velocity ratio λ is maintained at its optimal value λ_{opt}, the coefficient of power is at its maximum value $C_{PM} = C_P\left(\lambda^{opt}\right)$, as well as the power of the wind turbine:

$$P_{eol}^{opt} = 0.5.C_{PM}(\lambda) \times \rho \times S \times V_v^2 \tag{11}$$

On the other hand, if the equation of the ratio of velocities maintained to the optimum value is isolated, the wind velocity (12) is isolated and replaced in the equation of maximum mechanical power (11), equation (13) is obtained as:

$$\lambda^{opt} = \frac{\Omega \cdot R}{V_v} \quad V_v = \frac{R}{\lambda^{opt}} \times \Omega \tag{12}$$

$$P_{eol}^{opt} = 0.5.C_{PM}(\lambda) \times \rho \times S \times \left(\frac{R}{\lambda^{opt}}\right)^3 \cdot \Omega^3 \tag{13}$$

An analytical form of the maximum mechanical power of the wind turbine is thus obtained as a function of its speed of rotation Ω only. From on figure 6, shows a network of characteristics of the wind power as a function of the speed Ω where the yellow curve represents the location of the optimum powers:

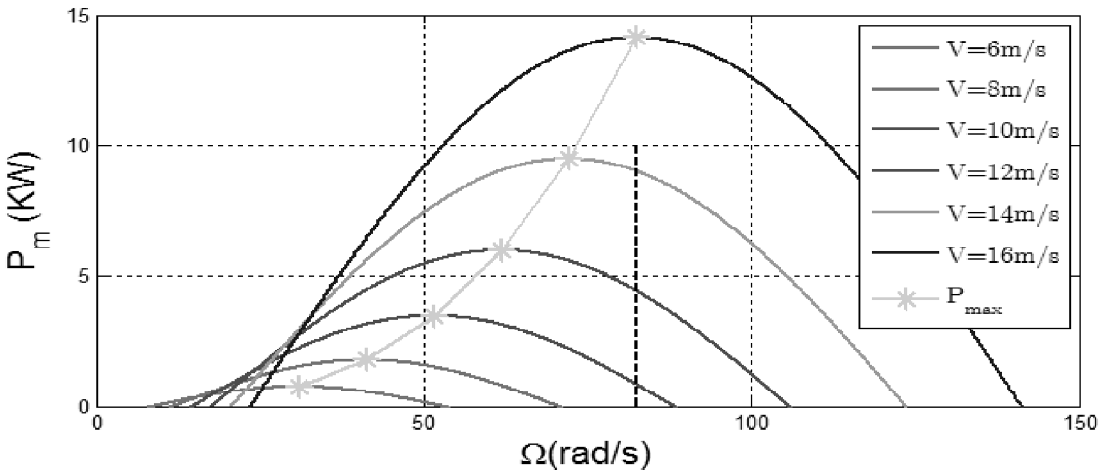

Figure 6: Characteristics of Wind Power as a Function of the Speed of Rotation

3.2. Control Generator

The technique of vector control is used to establish a linear model and transform the synchronous machine with magnets in a structure equivalent to the current machine continuously separate excitation of the torque point of view, to permit decoupling of torque and flux. If the current Id is set to zero, as the constant flow, the torque is directly proportional to Iq [18].

$$T_{em} = k_t . i_q \tag{14}$$

Where

$$k_t = p \cdot k_a \tag{15}$$

3.3. Control Hysteresis

This strategy is an alternative to the control in the frame (a, b, c).It requires for current regulation Iq and Id to impose the reference voltages Vdref and Vqref from which the sinusoidal reference voltages Varef, Vbref and Vcref are derived for the control of the rectifier.

3.4. Currents Control

There are two PI controllers were used in two independent current loops for the q-axis component and the second for the d-axis component shown in Figure 7.

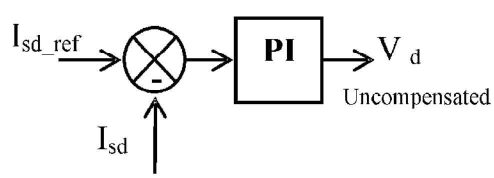

Figure 7: Currents control Isd, Isq loop with PI

3.5. DC Bus Control

The generator-side converter is controlled to catch the voltage load applied by the wind conversion. To size the voltage regulator, consider the following diagram, considering the performance of the hysteresis rectifier which uses voltage and loop current cascade, so here we will test the V_{DC} controller by two methods, regulation by the PI method and fuzzy logic method [14].

According to (10), in order to control the electromagnetic torque T_{em}, this study just controls the q-axis current i_q with the assumption that the d-axis current i_d is equal to zero. Furthermore, [8, 9], in order to catch maximum power, the optimum value of the rotation speed is adjusted. The tip speed ratio l is obtained by the equation:

$$\Omega_{ref} = \frac{\lambda_{opt}.V}{R} \tag{16}$$

Where, λ_{opt} is the tip speed ratio optimum and W_{ref} is the blade angular velocity reference.

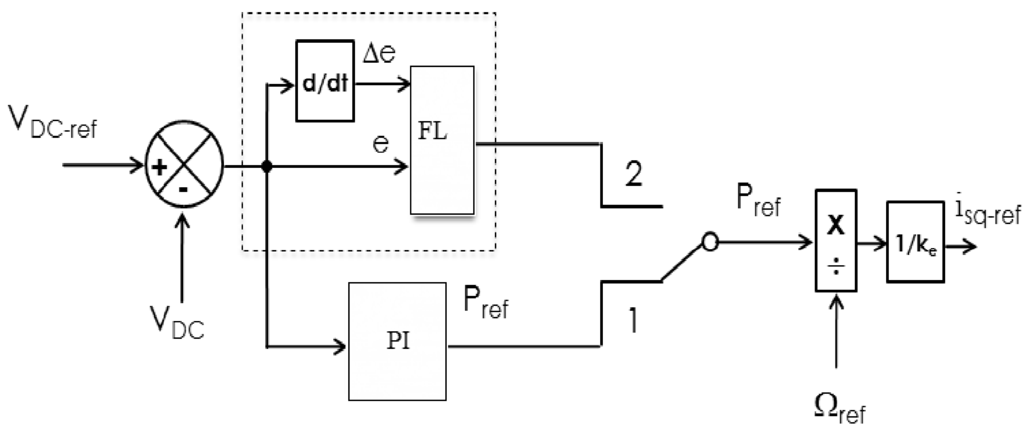

Figure 8: Fuzzy Logic/PI Diagram of DC bus voltage control

3.5.1. PI Controller For Dc Bus

For the regulation of the voltage VDC, the control diagram of Figure 9 is adopted. It is assumed that the transfer function of the rectifier is equal to 1.

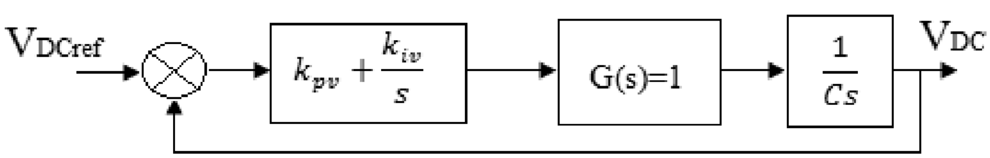

Figure 9: V_{DC} PI Controller

Theclosed loop transfer function is:

$$\frac{V_{DC}}{V_{DC}ref} = \frac{\frac{k_{pv}s + k_{iv}}{C}}{s^2 + \frac{k_{pv}}{C}s + \frac{k_{iv}}{C}} \tag{17}$$

This function is of a second order dynamics, whose characteristic equation is of the form:

$$s^2 + \frac{k_{pv}}{C}s + \frac{k_{iv}}{C} = 0 \tag{18}$$

By identifying the denominator with the canonical form, the parameters of the PI regulator given by:

$$\begin{cases} k_{pv} = 2.C.\xi.\omega_p \\ k_{iv} = C.\omega_p{}^2 \end{cases} \tag{19}$$

Where C=380μF: Capacitor Valueand ω_p = 60 rads^{-1}:The clean pulse.

3.5.2. Fuzzy Logic Controller for DC Bus

The fuzzy control system is a control system based on fuzzy logic, is one of the most powerful control methods that analyzes the analog input values in terms of logical variables that take continuous values between 0 and 1.Contrary to the classical logic, expressed in terms that human operators can understand. The fuzzy logic algorithm is suitable for controlling wind turbines with nonlinear models without knowing the characteristic of the wind turbine. This facilitates the mechanization of tasks already performed successfully [14, 19].

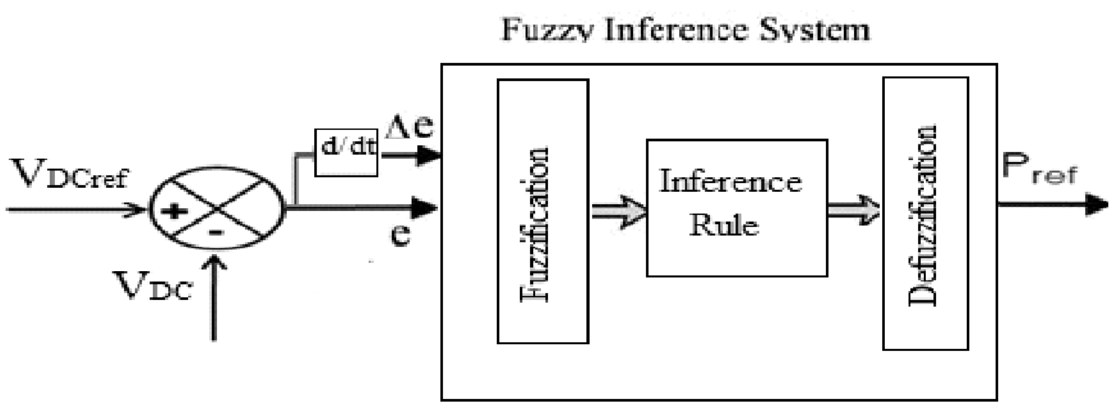

Figure 10: V_{DC}Fuzzy Logic Controller

The fuzzy logic controller consists on three parts:

- Fuzzification :consists in transforming the variables that have a physical reality at the input of the fuzzy regulator into fuzzy variables.
- Inference rules where fuzzy variables are used in an inference mechanism that creates and determines fuzzy output variables using operations on membership functions.
- Defuzzification, which consists in extracting an actual output value from the belonging function of the output fuzzy sub-set established by the inference mechanism.

The DC bus fuzzy logic controller has three parameters. The first input is the error of DC voltage, the second input is the rate of change of error and the output is the power controlling calculated at every sampling instant say k [14].

$$e(k) = V_{DCréf}(k) - V_{DC}(k)$$
$$\Delta e = \frac{e(k) - e(k-1)}{T_s} \tag{20}$$

Where: $V_{DCref}(k)$: the reference voltage at instant k, $V_{DC}(k)$: the measured voltage at instant k and $T_{s:}$ Sampling period.The functions of triangular and trapezoidal belonging are chosen to cover the reference sets of linguistic variables;Mamdani is method is used to perform fuzzy inference and The center of gravity method is selected to de-fuzzify the fuzzy output, The standard triangular membership functions were used for the inputs and outputs of the fuzzy sets of fuzzy controllers. The fuzzy schemes for e(k) and De(k) are shown in Figure 10. The fuzzy schematic rules used are given in Table 1.The fuzzy sets have been determined as: NB (Negative Big), NM (Negative Medium), NS (Negative Small), NVS (Negative Small), EZ(Equivalent Zero), PS (Positive Small), PM(Positive Medium), PB(Positive Big)[14].

Table 1
Fuzzy Rules Table

e / *Δe*	*NB*	*NM*	*NS*	*EZ*	*PS*	*PM*	*PB*
NB	NB	NB	NB	NB	NS	NP	EZ
NM	NB	NB	NB	NS	NP	EZ	PS
NS	NB	NB	NS	NP	EZ	PS	PM
EZ	NB	NS	NP	EZ	PS	PM	PB
PS	NS	NP	EZ	PS	PM	PB	PB
PM	NP	EZ	PS	PM	PB	PB	PB
PB	EZ	PS	PM	PB	PB	PB	PB

4. EXPERIMENTAL RESULTS

The operation of the complete system was simulated in MATLAB-Simulink environment. Using the electrical parameters of the machine (below). The reference voltage at the rectifier output being taken as 150 V.

Wind Turbine Parameters

Parameter Name Parameter Value		
Power Turbine	P_T	3500 W
Ray	R	2.04m
Lambda Optimum	λ_{opt}	8.1
Power Coefficient	C_p	0.49

Parameters Generator

Parameter Name Parameter Value		
Power Generator	P_g	3800 W
Stator resistor	R_s	0.94W
Inductance	L_d , L_q	8.3mh
Flux of permanent magnet	Φ_f	0.12 Wb
Poles pairs	p	2
DC voltage	V_{DC}	150V

We selected a random wind signal;

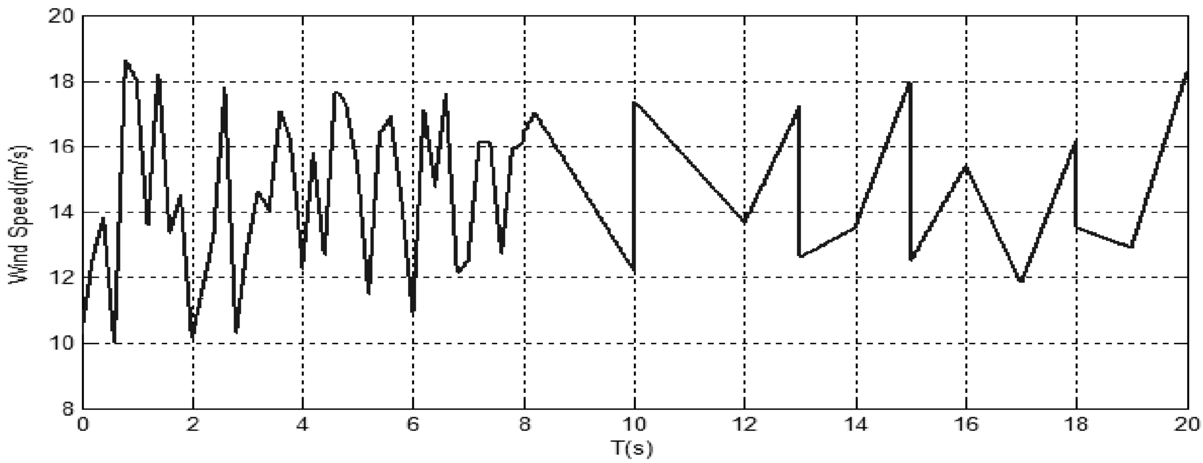

Figure 11: Wind Speed (m/s)

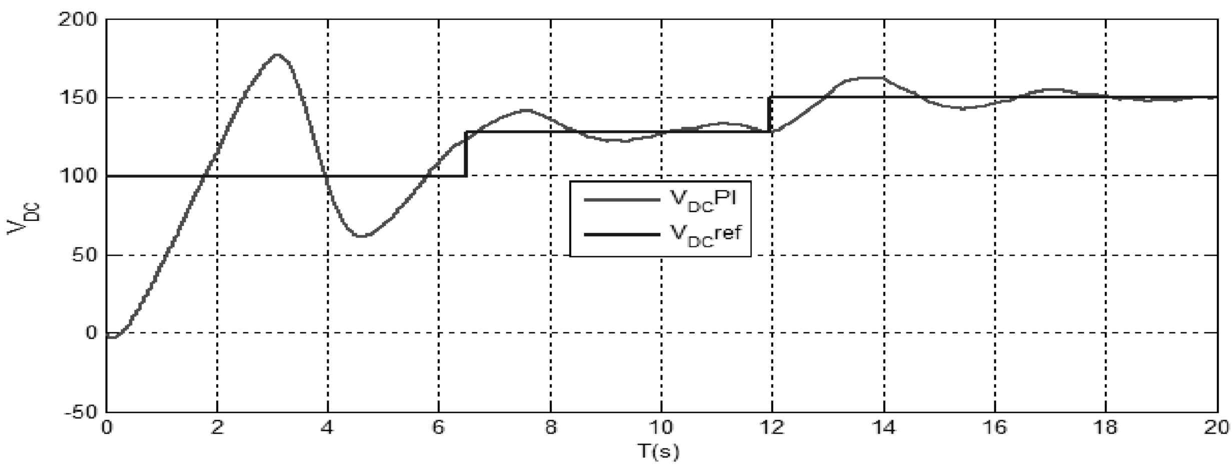

Figure 12: DC Voltage response with PI

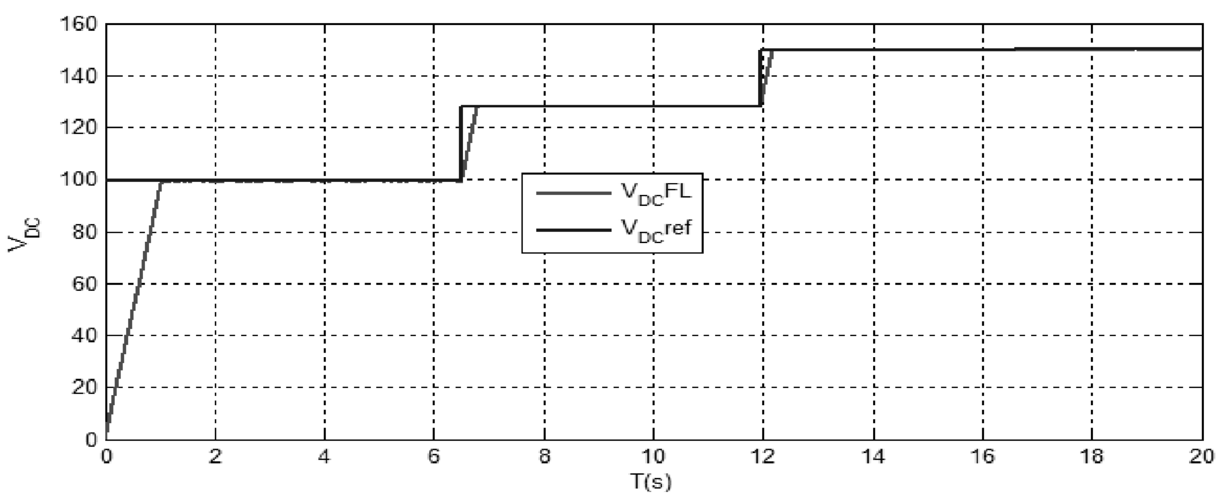

Figure 13: DC Voltage response with Fuzzy Logic

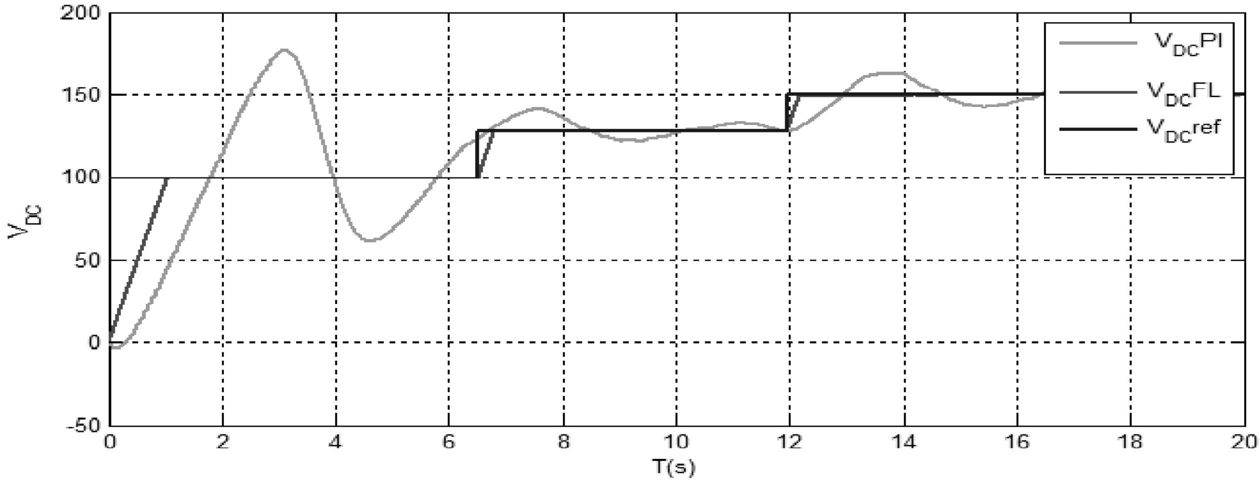

Figure 14:Comparison between the Different Controllers(PI-Fuzzy Logic)

We have simulated the rectified voltage by two methods: the PI regulator method is given in figure 12, and the fuzzy logic is shown in figure 13 by a model of variable Wind speed to ensure a smooth DC voltage and to optimize the converted power for the wind system.

From figure 14, showing the comparison of two responses, We note that the use of the control by fuzzy logic controller provides a response without exceeding, with a faster response time and in addition it is stable than control by the conventional PI regulator.

4. CONCLUSIONS

This paper presents the dynamic model of PSMG wind generation system in Matlab/Simulink. The proposed method is based on fuzzy logic and PI controller to control the generator side bus with DC variable speed. Fuzzy logic controller capacity is checked and it is found that it has a faster response than the conventional PI controller. The results show that the output will get the optimal power for load.

REFERENCES

[1] S.Yang and L.Zhang, "Modeling and control of the PMSG wind generation system with anovel controller", Third International Conference on Intelligent System Design and Engineering Applications, 2013.

[2] Chen, J. Wu, H.B.Sun, M.Jiang, W.N., Cai, L. and Guo, C.Y. (2012) Modeling and Simulation of Directly Driven Wind Turbine with Permanent Magnet Synchronous Generator. Proceedings of the 2012 IEEE Innovative Smart Grid Technologies, Asia, May 2012, 1-5.

[3] M.Ben Smida, A.Sakly," Fuzzy Pitch Angle Control for Grid ConnectedVariable-Speed Wind Turbine System", 978-1-4673-9768-IEEE.

[4] H.Kumar, A.Gupta, R.Kumar Pachauri, Y.K.Chauhan" PI/FL Based Blade Pitch Angle Control for Wind Turbine Used in Wind Energy Conversion System" International Conference on Recent Developments in Control, Automation and Power Engineering (RDCAPE), 2015.

[5] C. Krause. Analysis of electric machinery. 2nd Edition. United States of America: Willey, 2002.

[6] I. Boldea. Synchronous Generators. United States of America: Taylor and Francis, 2006

[7] M. Chinchilla, S. Arnaltes, and J. C. Burgos, "Control of permanent-magnet generators applied to variable-speed windenergy systems connected to the grid," IEEE Transactions on Energy Conversion, vol. 21, no. 1, pp. 130–135, 2006.

[8] S. Li, T. A. Haskew, and L. Xu, "Conventional and novel control designs for direct driven PMSG wind turbines," Electric Power Systems Research, vol. 80, no. 3, pp. 328–338, 2010.

[9] M. Chinchilla, S. Arnaltes, and J. C. Burgos, "Control of permanent-magnet generators applied to variable-speed windenergy systems connected to the grid," IEEE Transactions on Energy Conversion, vol. 21, no. 1, pp. 130–135, 2006.

[10] B. Multon, X. Roboam, B. Dakyo, C. Nichita, O. Gergaud et H. Ben Ahmed, 'Aérogénérateurs Electriques', Techniques de l'Ingénieur, Traités de Génie Electrique, D3960, Novembre 2004.

[11] F. Yassa, B. Batoun and R. Khaniche, 'Study of Wind Resources in Algeria Based upon Satellite Data', International Conference on Ecological Vehicles & Renewable Energies, EVER'08, Monaco, March 27-30, 2008.

[12] A. Mirecki, 'Etude Comparative de Chaînes de Conversion d'Energie Dédiées à une Eolienne de Petite Puissance', Thèse de Doctorat, Institut National Polytechnique, Toulouse, 2005.

[13] O. Gergaud, 'Modélisation Energétique et Optimisation Economique d'un Système de Production Eolien et Photovoltaïque Couplé au Réseau et Associé à un Accumulateur', Thèse de Doctorat, Eole Normale Supérieure de Cachan, Décembre 2002.

[14] S.Hafsi,M.Dhaoui,L.Sbita "Advanced Control of a PMSG Wind Turbine" International Journal of Modern Nonlinear Theory and Application, 2016, 5, 1-10.

[15] A. Rolan, A. Luna, G. Vazquez, D. Aguilar and G. Azevedo " Modeling of a Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator ", IEEE International Symposium on Industrial Electronics (ISlE 2009), pp. 734-739, Seoul, Korea, July 5-8, 2009.

[16] M. Yin, G. Li, M. Zhou, and C. Zhao, "Modeling of the Wind Turbine with a Permanent Magnet Synchronous Generator for Integration," IEEE, Power Engineering Society General Meeting, Print ISBN: 1-4244-1296-X, pp. 1-6, 2007.

[17] M.S. Aït Cheikh, C. Larbes, G.F. Tchoketch Kebir and A. Zerguerras,''Maximum power point tracking using a fuzzy logic control scheme, Revue des Energies Renouvelables Vol. 10 N°3 2007) 387 – 395.

[18] S. Belakehal, A. Bentounsi, M. Merzoug et H. Benalla " Modélisation et commande d'une génératrice Synchrone à aimants permanents dédiée à la conversion de l'énergie éolienne ", Revue des Energies Renouvelables Vol. 13 N°1 (2010) 149 – 161.

[19] W. M. Lin and C. M. Hong, "A new Elman neural network-based control algorithm for adjustable-pitch variable-speed wind-energy conversion systems," IEEE Trans. Power Electron., vol. 26, no. 2, pp. 473–481, Feb. 2011.

[20] A. Mirecki, X. Roboam and F. Richardeau, 'Architecture Complexity and EnergyEfficiency of Small Wind Turbines', IEEE Transaction on Industrial Electronics,Vol. 54, N°1, 2007.

[21] A.M. Knigh and G.E. Peters, 'Simple Wind Energy Controller for an Expanded Operating Range', IEEE Transaction on Energy Conversion, Vol. 20, N°2, pp. 459- 466, 2005.

[22] A.T. Azar and S. Vaidyanathan, Chaos Modeling and Control Systems Design, Springer, Berlin, Germany, 2015.

[23] A.T. Azar and S. Vaidyanathan, Advances in Chaos Theory and Intelligent Control, Springer, Berlin, Germany, 2016.

[24] S. Vaidyanathan and C. Volos, Advances and Applications in Nonlinear Control Systems, Springer, Berlin, Germany, 2016.

[25] S. Vaidyanathan and C. Volos, Advances and Applications in Chaotic Systems, Springer, Berlin, 2016.

[26] S. Vaidyanathan and C. Volos, Advances in Memristors, Memristive Devices and Systems, Springer, Berlin, 2017.

[27] S. Vaidyanathan and C.H. Lien, Applications of Sliding Mode Control in Science and Engineering, Springer, Berlin, 2017.

[28] S. Vaidyanathan, "A novel 3-D conservative chaotic system with sinusoidal nonlinearity and its adaptive control", International Journal of Control Theory and Applications, 9 (1), 115-132, 2016.

[29] S. Vaidyanathan and S. Pakiriswamy, "A five-term 3-D novel conservative chaotic system and its generalized projective synchronization via adaptive control method", International Journal of Control Theory and Applications, 9 (1), 61-78, 2016.

[30] V.T. Pham, S. Jafari, C. Volos, A. Giakoumis, S. Vaidyanathan and T. Kapitaniak, "A chaotic system with equilibria located on the rounded square loop and its circuit implementation," IEEE Transactions on Circuits and Systems-II: Express Briefs, 63 (9), 2016.

[31] S. Vaidyanathan and S. Sampath, "Anti-synchronisation of identical chaotic systems via novel sliding control and its application to a novel chaotic system," International Journal of Modelling, Identification and Control, 27 (1), 3-13, 2017.

[32] S. Vaidyanathan, K. Madhavan and B.A. Idowu, "Backstepping control design for the adaptive stabilization and synchronization of the Pandey jerk chaotic system with unknown parameters," International Journal of Control Theory and Applications, 9 (1), 299-319, 2016.

[33] R.K. Goyal, S. Kaushal and S. Vaidyanathan, "Fuzzy AHP for control of data transmission by network selection in heterogeneous wireless networks," International Journal of Control Theory and Applications, 9 (1), 133-140, 2016.

[34] C.K. Volos, D. Prousalis, I.M. Kyprianidis, I. Stouboulos, S. Vaidyanathan and V.T. Pham, "Synchronization and anti-synchronization of coupled Hindmarsh-Rose neuron models," International Journal of Control Theory and Applications, 9 (1), 101-114, 2016.

[35] S.M.B. Mansour and V. Sundarapandian, "Design and control with improved predictive algorithm for obstacles detection for two wheeled mobile robot navigation," International Journal of Control Theory and Applications, 9 (38), 37-54, 2016.

[36] A. Ouannas, A.T. Azar and S. Vaidyanathan, "A robust method for new fractional hybrid chaos synchronization," Mathematical Methods in the Applied Sciences, 40 (5), 1804-1812, 2017.

[37] S. Vaidyanathan and S. Sampath, "Anti-synchronisation of identical chaotic systems via novel sliding control and its application to a novel chaotic system," International Journal of Modelling, Identification and Control, 27 (1), 3-13, 2017.

[38] A. Ouannas, A.T. Azar and S. Vaidyanathan, "New hybrid synchronisation schemes based on coexistence of various types of synchronisation between master-slave hyperchaotic systems," International Journal of Computer Applications in Technology, 55 (2), 112-120, 2017.

[39] S. Vaidyanathan, "A conservative hyperchaotic hyperjerk system based on memristive device," Studies in Computational Intelligence, 701, 393-423, 2017.

[40] B. Raj and S. Vaidyanathan, "Analysis of dynamic linear memristor device models," Studies in Computational Intelligence, 701, 449-476, 2017.