International Conference on Automation, Control Engineering and Computer Science (ACECS)
Proceedings of Engineering and Technology – PET
Vol.20 pp.97-101

Emulation of a Wind Turbine with a DC Motor controlled by Fuzzy Logic controller

L. BENAAOUINATE[1, 2], M. KHAFALLAH[1], A. MESBAHI[1], A. MARTINEZ[2], T. BOURAGBA[2]

[1] *Laboratory of Energy & Electrical Systems (LESE),*
Hassan II University of Casablanca ENSEM, Casablanca-Morocco
l.benaaouinate@ieee.org
Mohamed.khafallah@uh2c.com
abdelouahed.mesbahi@gmail.com

[2]*Laboratoire Energie Renouvelable Propre & Alternative (LERPA)*
EIGSI Casablanca, Maroc
Andre.martinez@eigsi.fr

***Abstract*— A Wind Turbine Emulator (WTE) is developed for testing Wind Energy Conversion Systems (WECS) control strategies. The configuration of the WTE consists of a permanent magnet DC motor controlled by Fuzzy Logic Controller (FLC). DC motor is used to generate speed and torque required by the generator (PMSG) for producing electrical power. The control of the DC motor is elaborated using Matlab/Simulink platform. Finally Results confirm that the WTE can perform satisfactorily under steady state wind speed profiles and it can provide all necessary parameters for the wind turbine system.**

***Keywords*— Wind Turbine Emulator (WTE); DC motor; Real Time Control; Fuzzy Logic Controller; Pitch Angle Control.**

I. INTRODUCTION

Due to the increased integration of renewable energy sources in the world, a great deal of researches has been focused on better ways to exploit and generate that kind of energy for making wind turbine more efficient.

Wind speed is not promising or reliable all the time, therefore it is difficult to use a real wind turbine in laboratory environment. So there is the need to build a WTE to simulate the steady-state and dynamic characteristics of the system in a controlled environment. WTE can produce the torque required by the electrical generator in a similar way as a real wind turbine. Moreover, it is an excellent tool for academic purposes such control, operation and characterization of a wind turbine.

The literature review has a lot of studies done on wind turbine emulator either based on induction motor [18][19], permanent magnet synchronous machine (PMSM) [17] or DC motor [3][20].

The aim of this paper is to develop a useful WTE based on permanent magnet DC motor controlled by Fuzzy Logic Controller (FLC) to obtain the characteristics and the performances for applying wind power conversion researches.

The FLC is chosen in this work for their high accuracy, fast dynamic response, stability, solving non-linear systems because it does not require a well-known system, ease of its modelling and its implementation.

The FLC is used in the structure of the WTE for comparing the armature current, generating Pulse-Width Modulated (PWM) to the transistor of DC-DC converter and controlling the pitch angle. It is presented as an alternative for Proportional-Integral (PI) controllers currently used in wind turbine Pitch Angle Control.

II. SUBSYSTEM MODELS

A. Wind Speed Model

The wind speed is modelled as the sum of several harmonics:

$$V_v(t) = A + \sum_{n=1}^{i} (a_n \sin(b_n \omega_v t)) \quad (1)$$

The wind profile of the emulator will be represented by the following scalar function:

$$V_v(t) = 9 + 0.2\ \sin 0.1047t + 2\ \sin 0.2665t + \sin 1.2930t + 0.2\ \sin 3.6645t \quad (2)$$

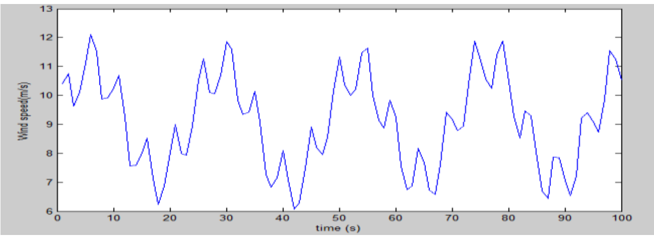

Fig. 1 Wind speed Profile

B. Wind Turbine Model

The rotor aerodynamics are presented by the well-known mechanical power, it is expressed as:

ISSN 2356-5608

$$P_w = \frac{1}{2}\pi \rho R^2 V_t^3 C_p(\lambda, \beta) \quad (3)$$

Where, ρ is the air density (kg/m^3), R is the turbine radius (m), V_t is the wind speed (m/s) and C_p is the power coefficient which is a function of both blade pitch angle β and tip speed ratio λ.

The tip speed ratio λ is expressed as:

$$\lambda = \frac{\omega . R}{V_t} \quad (4)$$

Where, ω is the angular speed of the turbine rotor (rad/s), and R is the radius of turbine blades.

$$T_w = \frac{1}{2} \frac{\pi \rho R^3 V_t^2 C_p(\lambda, \beta)}{\lambda} \quad (5)$$

The power coefficient is different for each turbine and is relative to the tip speed ratio λ and pitch angle β. A generic equation is used to model Cp (β, λ). This equation, based on the modelling turbine characteristics [12]:

$$C_p(\lambda, \beta) = C_1(C_2.\lambda_i - C_3.\beta - C_4)e^{C_5\lambda_i} + C_6.\lambda \quad (6)$$

$$\lambda_i = \frac{1}{\lambda + 0.08\beta} - \frac{0.0035}{\beta^3 + 1} \quad (7)$$

The table 1 shows the parameters of the performance coefficient.

TABLE 1. PARAMETERS OF THE PERFORMANCE COEFFICIENT

C1	C2	C3	C4	C5	C6
0.5109	116	0.4	5	21	0.0068

III. WIND TURBINE EMULATOR

A. Structure of the Wind Turbine Emulator

Figure 2 represents the structure of the wind turbine emulator using DC motor controlled by Fuzzy Logic Controller.

The wind speed, the pitch angle, and the angular speed of DC motor are the three inputs of mathematical model of wind turbine and its output is a torque depending practically on the wind velocity.

For emulating the real behavior of the wind turbine, it is necessary to compare the torque characteristics of the mathematical model of the wind turbine and the DC motor. The reference torque derived from the mathematical model is multiplied with torque constant and gear ratio to obtain the reference current, which is compared with the DC motor armature current. The current error is tuned by a Fuzzy Logic Controller (FLC). The output of this controller is then used to generate PWM gate pulses to drive the transistor of DC buck converter that regulate the DC motor armature voltage. A variation in armature voltage generates a speed variation for DC motor, which allows to obtain a mechanical torque depends on the wind velocity. It varies over the time in similar way as the torque of the wind turbine.

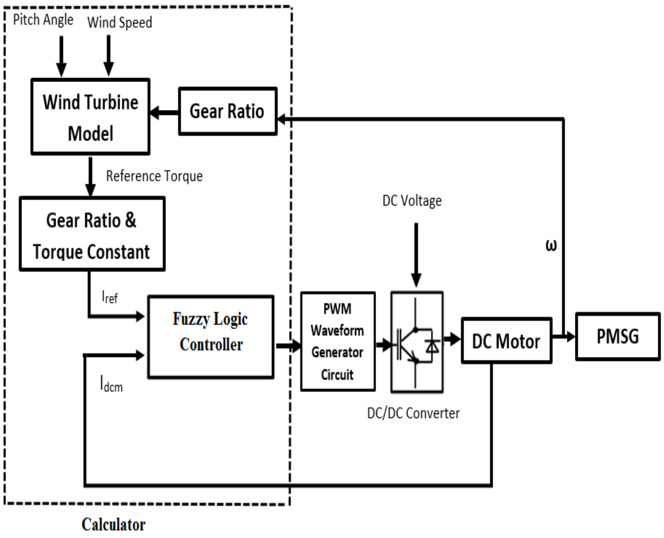

Fig. 2 Structure of wind turbine emulator

B. Structure of the (FLC)

In this work, the FLC is used in order to decide the duty cycle according to the inputs; error (e) and derivative from error (Δe). The error is the difference of the DC motor armature current (I_{dcm}) and the reference current obtained from the wind turbine model (I_{ref}). The output of FLC is used to generate PWM gate pulses to drive the DC buck converter that regulate the DC motor armature voltage to obtain a mechanical torque depends on the wind speed velocities.

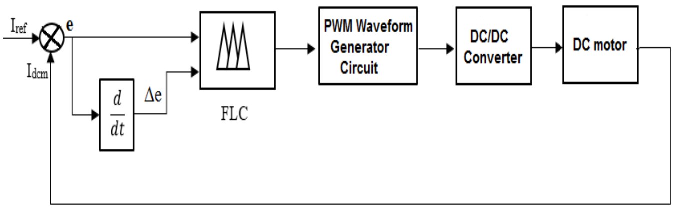

Fig. 3 Structure of FLC

Figures 4, 5, and 6 represent respectively Membership function plots of inputs and output of the FLC.

ISSN 2356-5608

International Conference on Automation, Control Engineering and Computer Science (ACECS)
Proceedings of Engineering and Technology – PET
Vol.20 pp.97-101

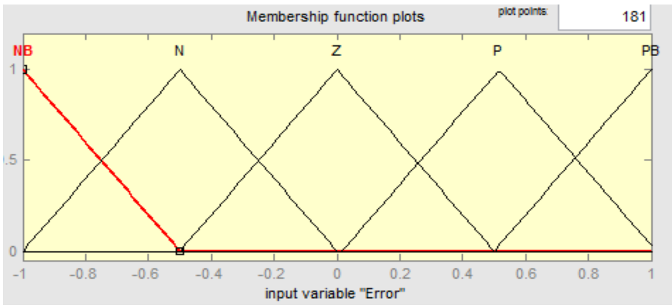

Fig. 4 Membership function of e

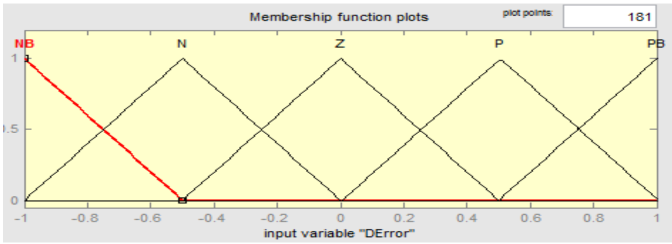

Fig. 5 Membership function Δe

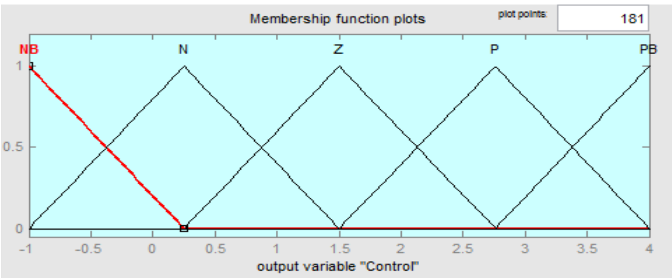

Fig. 6 Membership function Output

The table 2 gives the rule base modelled in this work for the FLC.

TABLE 2: RULE BASE FOR FLC

		e				
		NB	N	Z	P	PB
Δe	NB	NB	NB	NB	N	Z
	N	NB	N	N	Z	P
	Z	NB	N	Z	P	PB
	P	N	Z	P	PB	PB
	PB	Z	P	PB	PB	PB

The abbreviations used in the table are defined as follows:

- NB is negative big;
- N is negative;
- Z is zero;
- P is positive;
- PB is positive big.

In this FLC, the centre of gravity de-Fuzzification method is used.

IV. PITCH CONTROL

C. Pitch angle control using fuzzy control

Figure 7 shows the pitch angle control block diagram using fuzzy control.

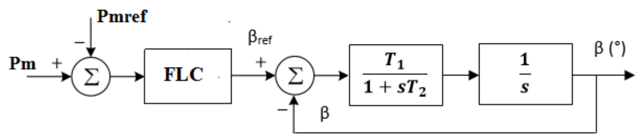

Fig 7: Pitch angle block diagram using Fuzzy Logic controller

Figures 8 and 9 represent respectively Membership function plots of input and output of the FLC.

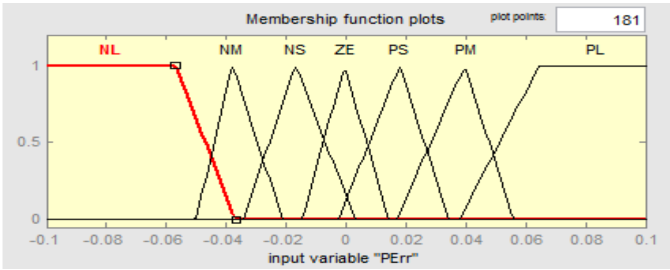

Fig. 8 Membership function ΔP

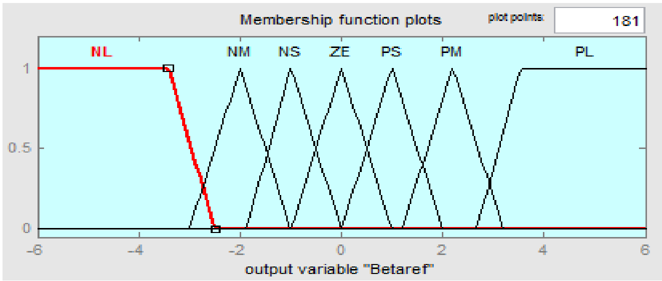

Fig. 9 Membership function Output

The table 3 gives the rule base modelled in this work for the FLC.

TABLE 3: RULES BASE FOR FLC

ΔP	NL	NM	NS	ZE	PS	PM	PL
βref	NL	NM	NS	ZE	PS	PM	PL

The abbreviations used in the table are defined as follows:

- NL is negative large;
- NM is negative medium;
- NS is negative small;
- ZE is Zero;
- PL is positive large;
- PM is positive medium;
- PL is positive large.

V. SIMULATION RESULTS

ISSN 2356-5608

International Conference on Automation, Control Engineering and Computer Science (ACECS)
Proceedings of Engineering and Technology – PET
Vol.20 pp.97-101

This section of paper presents the results of the proposed WTE, for the wind speed signal (Figure1), with Matlab/Simulink simulation.

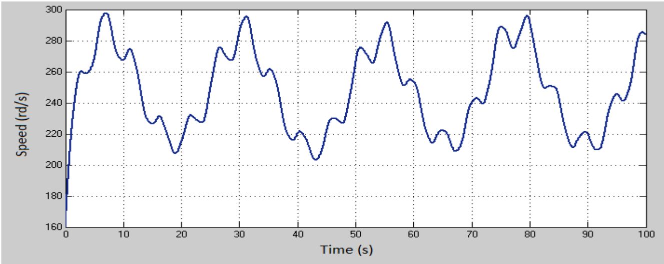

Fig. 10 Variation of rotational speed of the DC motor

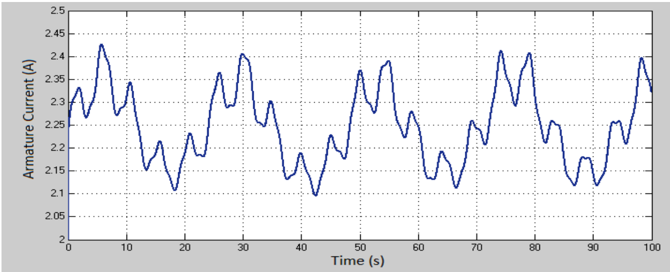

Fig. 11 Variation of armature current of DC motor

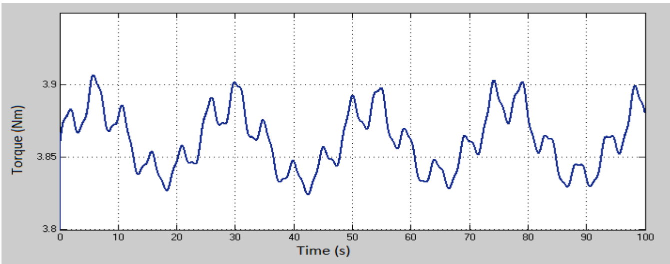

Fig. 12 Variation of torque of DC motor

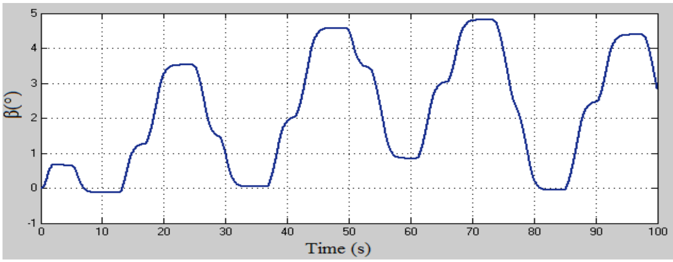

Fig. 13 Variation of pitch angle β

Figure 10 shows the dynamic behavior of the rotational speed of DC motor. As shown the DC motor's speed practically depends on the wind speed velocities. This means WTE can give a speed similar to the wind turbine speed.

Figure 11 shows the armature current of DC motor. As it can be depicted the actual armature current pursues the variation of the wind speed profile which proves the high accuracy, fast dynamic response and stability of the FLC.

Figure 12 shows the torque generated by the DC motor, it pursues the different variation of wind speed, which provide the main objective of WTE by reproducing the torque developed by a wind turbine for given wind velocities and driving an electrical generator in a similar way as a wind turbine.

Figure 13 shows the different values of pitch angle β for different wind velocities. Adjusting the pitch angle of the blades, provide an effective means of regulations or limiting turbine performance in strong wind speeds. The pitch angle β, increases and the angle of attack, decreases when the wind speed increases. The lift force decreases as well and this causes reduction of mechanical power of WTE.

As depicted is a right degree of agreement between the wind speed profiles applied to mathematical model of the wind turbine and characteristics of different responses of the WTE such as the torque, the speed and pitch angle. It proves the high accuracy of the Fuzzy Logic Controller used in the control of DC motor and the control of the pitch angle.

From results it can be verified that the WTE can efficiently reproduce the steady state and dynamic characteristics of a given wind turbine for different wind conditions.

VI. Conclusion

Our work proposes an accomplished model of Wind Turbine Emulator based on DC motor controlled by Fuzzy Logic Controller.

Wind Turbine Emulator WTE can efficiently reproduces the steady state and dynamic characteristics of a given wind turbine for different wind conditions. It creates a controlled test environment for research into Wind Energy Conversion Systems WECS.

The system can provide all necessary parameters of the wind turbine system such as wind speed, output torque, output power, torque efficient, power coefficient, and tip speed ratio.

The next step in our research is to design, develop and build a WTE based on asynchronous motor. A DC machine, although is ideal from the standpoint of control, is in general, bulky and expensive compare with an AC machine and it needs frequent maintenance due to its commutators and brushes. Integration of the effects of a pitch angle controller on power output when the wind speed is greater than the rated wind speed would provide more realistic conditions for the emulator

References

[1] A. V. A. Macêdo, W. S. Mota, and S. Member, "Wind Turbine Pitch Angle Control Using Fuzzy Logic," pp. 1–6, 2012.
[2] H. M. Kojabadi and L. Chang, "Wind Turbine Simulators," Wind Turbines, pp. 163–174, 2011.
[3] M. Arifujjaman, « Emulation of a small wind turbine system with a separately-excited Dc machine », IU-Journal of Electrical & Electronics Engineering, vol. 8, no. 1, 2012.

ISSN 2356-5608

[4] S. Kumsup, C. Tarasantisuk, « Real-time wind turbine emulator for testing wind energy conversion systems », in IEEE International Energy Conference and Exhibition, 2010, p. 7–9.

[5] W. Li, D. Xu, W. Zhang, H. Ma, « Research on wind turbine emulation based on DC motor », in 2nd IEEE Conference Industrial Electronics and Applications, 2007, p. 2589–2593.

[6] H. Wu, M. Ding, « Modeling and control of distribution system with wind turbine generators », in Third International Conference Electric Utility Deregulation and Restructuring and Power Technologies, 2008, p. 2498–2503.

[7] L. Guangchen, W. Shengtie, Z. Jike, « Design and Realization of DC Motor and Drives Based Simulator for Small Wind Turbine », in Asia-Pacific Power and Energy Engineering Conference ,2010, p. 1–4.

[8] H. Wu, M. Ding, « Modeling and control of distribution system with wind turbine generators », in Third International Conference Electric Utility Deregulation and Restructuring and Power Technologies, 2008, p. 2498–2503.

[9] M. G. Simões and I. S. Shaw, Controle e Modelagem Fuzzy. 2nd ed. São Paulo: Blucher, 186 p. 200*FLEXChip Signal Processor (MC68175/D)*, Motorola, 1996.

[10] V. Akhmatov, Variable-speed Wind Turbines with Doubly-fed Induction Generators – Part I: Modelling in Dynamic Simulation Tools. Wind Engineering, [S.l.], vol. 26, no. 2, p. 85-108, 2002

ISSN 2356-5608