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Adaptive Fuzzy Logic Control of Wind Turbine Emulator

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ABSTRACT

In this paper, a Wind Turbine Emulator (WTE) based on a separately excited direct current (DC) motor is studied. The wind turbine was emulated by controlling the torque of the DC motor. The WTE is used as a prime mover for Permanent Magnet Synchronous Machine (PMSM). In order to extract maximum power from the wind, PI and Fuzzy controllers were tested. Simulation results are given to show performance of proposed fuzzy control system in maximum power points tracking in a wind energy conversion system under various wind conditions. The strategy control was implemented in simulation using MATLAB/Simulink.

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1. INTRODUCTION

Wind energy is one of the fastest growing major sources of new electricity around the world. Wind turbine development is currently a very dynamic industry [1]. However, access, testing and monitoring installed turbines is difficult. Simulation is an appropriate tool to evaluate the effect of modifications and offers a solution to this problem.

In research applications, the Wind Turbine Emulator is an important device for developing Wind Energy Conversion Systems. The WTE can be used to drive an electrical generator in similar way as a Wind Turbine. The motivation for this study is to create an emulation system that as closely as possible replicates the behavior of a wind turbine.

In the wind turbine emulator, the wind turbine was substituted by the output torque calculated from the wind turbine torque model.

The main objective of the WTE is reproducing the wind turbine output torque corresponding to any wind speed input. The reference current is calculated as function of the wind turbine speed and wind speed to produce the aerodynamic torque of the wind turbine [2].

The wind turbine emulator gives the opportunity that any desired wind speed profile can be tested and used to study the behavior of the system.

The Paper is organized as follows: Section 2 discusses on the system topology and modeling of the Permanent Magnet Synchronous Generator and wind turbine. Section 3 describes the Control strategy of the Emulator and the Fuzzy Logic Controller. Simulations run with MATLAB /Simulink showing the performance of proposed emulator are presented in Section 4. Section 5 concludes the paper with analysis of the results and discusses the validity of the proposed model.

2. SYSTEM CONFIGURATION AND MODELING

The power conversion system consists of a Permanent Magnet Synchronous Generator (PMSG), a rectifier and an inverter connected to the load or to the grid.

The system topology used in this work is shown in Figure1.

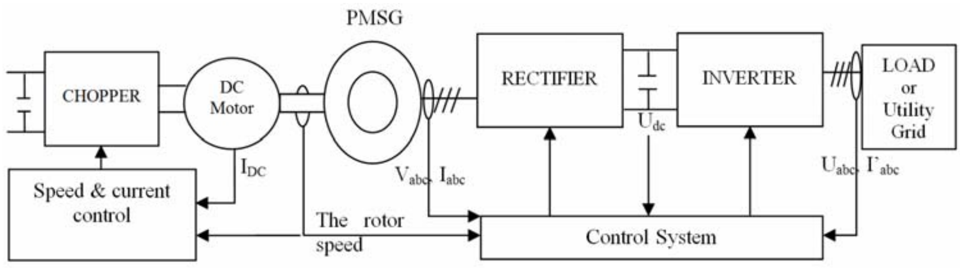

Figure 1. Control system

2.1. Permanent Magnet Synchronous Generator model

The rotor excitation of the Permanent Magnet Synchronous Generator (PMSG) is assumed to be constant, so its electrical model in the synchronous reference frame is given by [3], [4]:

$$\begin{cases} \dfrac{di_d}{dt} = -R_s i_d + V_d + \omega i_q L_q \\ \dfrac{di_q}{dt} = -R_s i_q + V_q - \omega i_d L_d + \omega \Phi_f \end{cases} \quad (1)$$

Where subscripts d and q refer to the physical quantities that have been transformed into the (d, q) synchronous rotating reference frame, the electrical rotating speed ω_e is given by:

$$\omega_e = n_p \omega_T \quad (2)$$

The power equations are given by:

$$P = \frac{3}{2}(v_d.i_d - v_q.i_q)$$
$$Q = \frac{3}{2}(v_q.i_d - v_d.i_q) \quad (3)$$

The electromagnetic torque Te can be derived from:

$$T_e = \frac{3}{2} n_p \Phi_f i_{sq} \quad (4)$$

2.2. Wind Turbine Modeling

The mathematical relation for the mechanical power extraction from the wind can be expressed as follows [5]:

$$P_m = C_P(\lambda,\beta).P_w = C_p(\lambda,\beta).\frac{\rho.A.V_w^3}{2} \quad (5)$$

The tip speed ratio, λ, is given by [6],

$$\lambda = \frac{R \times \omega_m}{V_w} \qquad (6)$$

The power coefficient Cp can be expressed as [7], [8],

$$C_P(\lambda, \beta) = C_1 \times (C_2 \times \frac{1}{\lambda_i} - C_3 \times \beta - C_4) \times \exp(-C_5 \times \frac{1}{\lambda_i}) + C_6 \times \lambda \qquad (7)$$

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

C_1=0.5176, C_2=116, C_3=0.4, C_4=5, C_5=21 and C_6=0.0068.
The torque of the wind turbine would be expressed as:

$$T = C_p(\lambda, \beta).\frac{\rho.A.V_w^3}{2.\lambda} \qquad (8)$$

3. CONTROL STRATEGY OF THE WIND TURBINE EMULATOR

In this section, the fuzzy control method applied to the wind turbine emulator is presented.

3.1. The Emulation of Wind Turbine

According to [9]-[12], the characteristics of Wind turbine have a great similarity to the characteristics of DC motor, so it can be simulated by a DC motor.

Figure 2 present the control block diagram of the wind turbine Emulator system.

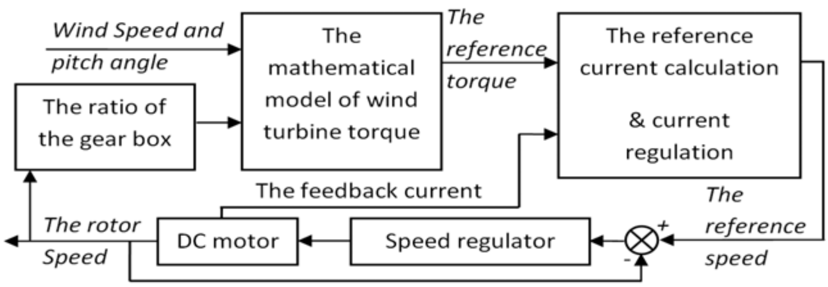

Figure 2. Control block diagram of the wind turbine Emulator system

In this diagram, the wind rotor speed is expressed as the measured DC motor speed divided by the ratio of the gearbox. The reference torque of the DC motor which is the Wind Turbine Aerodynamic torque is calculated by the Wind Turbine model according to the dynamic wind speed and the blade pitch angle and the wind rotor speed. The reference current of the DC motor is obtained by the reference torque of the DC motor.

In this work, PI and FLC controllers are used in speed regulation.

3.2. Fuzzy Logic Control

Fuzzy logic is able to use human reasons not in terms of discrete symbols and numbers, but in terms of fuzzy sets. These terms are quite flexible with respect to the definition and values. The big advantages of fuzzy logic control when applied to a wind turbine are that the turbine system neither needs to be accurately described nor does it need to be linear [13].

Rule based fuzzy logic controllers are useful when the system dynamics are not well known or when they contain significant nonlinearities, such as the un-stationary wind contains large turbulence.

In Figure 3, structure of fuzzy control is shown. A fuzzy controller usually contains four main components: Fuzzifier, fuzzy rule base, inference engine and Defuzzifier. The Fuzzifier changes the input (crisp signals) into fuzzy values. The fuzzy rule base consists of basic data and linguistic rules. The engine is the brain of a fuzzy controller which ability to simulate the human decision based on finally, the second transformation converts values into the real values [14].

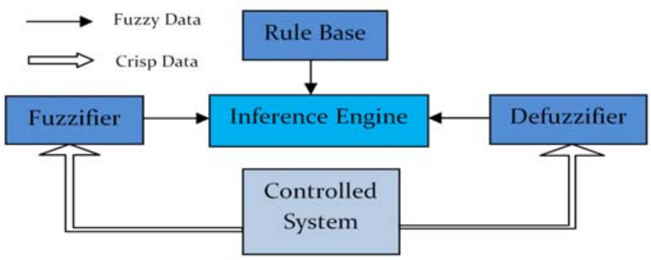

Figure 3. Fuzzy inference system

3.3. Design of the Fuzzy Logic Controller

The plant control u is inferred from the two state variables, error (e) and change in error Δe. The control rules are designed to assign a fuzzy set of the control input u for each combination of fuzzy sets of e and Δe. Table 1 shows the rules base. Each pair (e, Δe) determines the output level corresponding to u. Figure 4 shows the fuzzy logic controller.

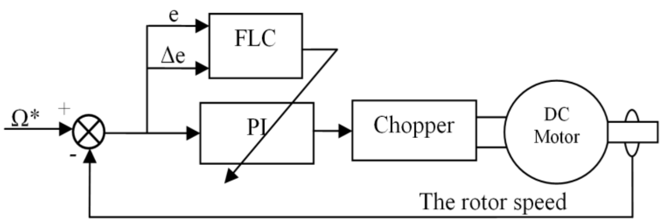

Figure 4. Fuzzy logic controller

Table 1. rule base

u		e						
		NB	NM	NS	ZR	PS	PM	PB
Δe	NB	B	B	B	B	B	B	B
	NM	S	B	B	B	B	B	S
	NS	S	S	B	B	B	S	S
	ZR	S	S	S	B	S	S	S
	PS	S	S	B	B	B	S	S
	PM	S	B	B	B	B	B	S
	PB	B	B	B	B	B	B	B

The abbreviations used in Table 1 are defined as follows: NB is Negative Big, NM is Negative Medium, NS is Negative Small, ZR is Zero, PS is Positive Small, PM is Positive Medium, PB is Positive Big, B is Big and S is small. Figures (5–7) represent, respectively, the membership functions of the input e, the membership functions of the input Δe and the membership functions of the output u.

In this paper, the triangular membership function, the max–min reasoning method, and the center of gravity defuzzification method are used, as those methods are most frequently used in many literatures [15-16].

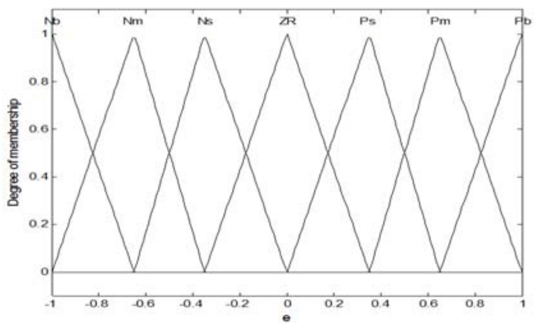

Figure 5. Membership function for input e

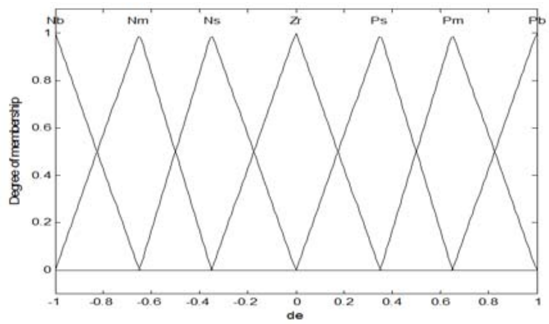

Figure 6. Membership functions for input Δe

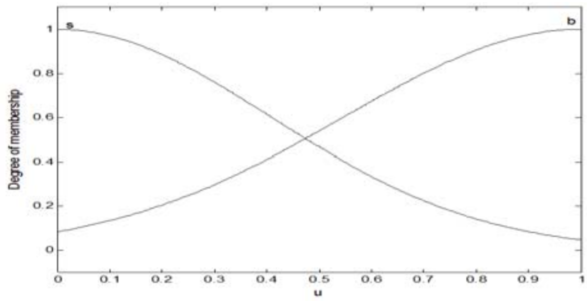

Figure 7. Membership function of output

4. SIMULATION RESULTS AND DISCUSSION

Simulations were carried out with a 3kW PMSG-based WECS which has the optimal power coefficient Cpmax=0.48 and the optimal tip-speed ratio λ=8.1.

Control performances of both PI and FUZZY Controllers are compared in parallel. The stochastic wind profile is shown in Figure 8.

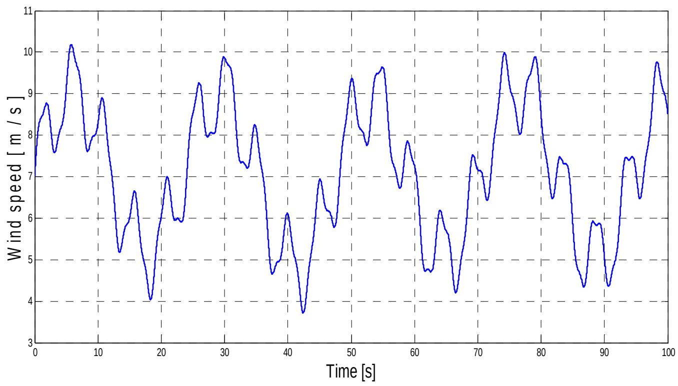

Figure 8. Wind velocity

Figure 9 shows the output tracking performances.

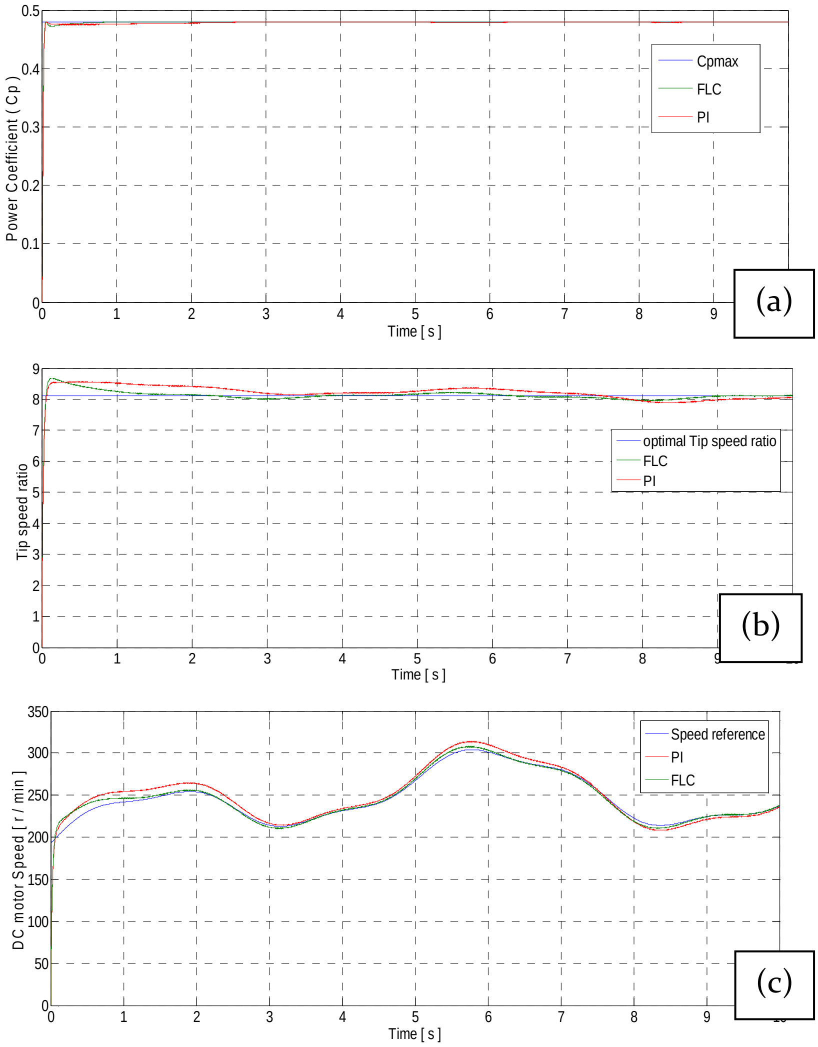

Figure 9. (a) Power coefficient (b) Tip-speed ratio (c) Speed

In Figure 10, it's indicated the tracking errors.

Both of the two methods track the output reference adequately. The FLC provides better tracking than the PI controller.

Two important factors show the efficiency of the power conversion: the power coefficient maintenance and the tip-speed ratio maintenance under wind speed fluctuations. The FLC shows better performances better than PI controller in optimizing the power conversion. The PI controller stays oscillating around optimal values. The FLC keeps the optimal power coefficient and tip-speed ratio values constant after transient time.

It is clear that the maximum power extraction control works very well where the value of power coefficient was kept at optimum value of power coefficient Cp_{opt} which equals 0.48 with varying wind speed.

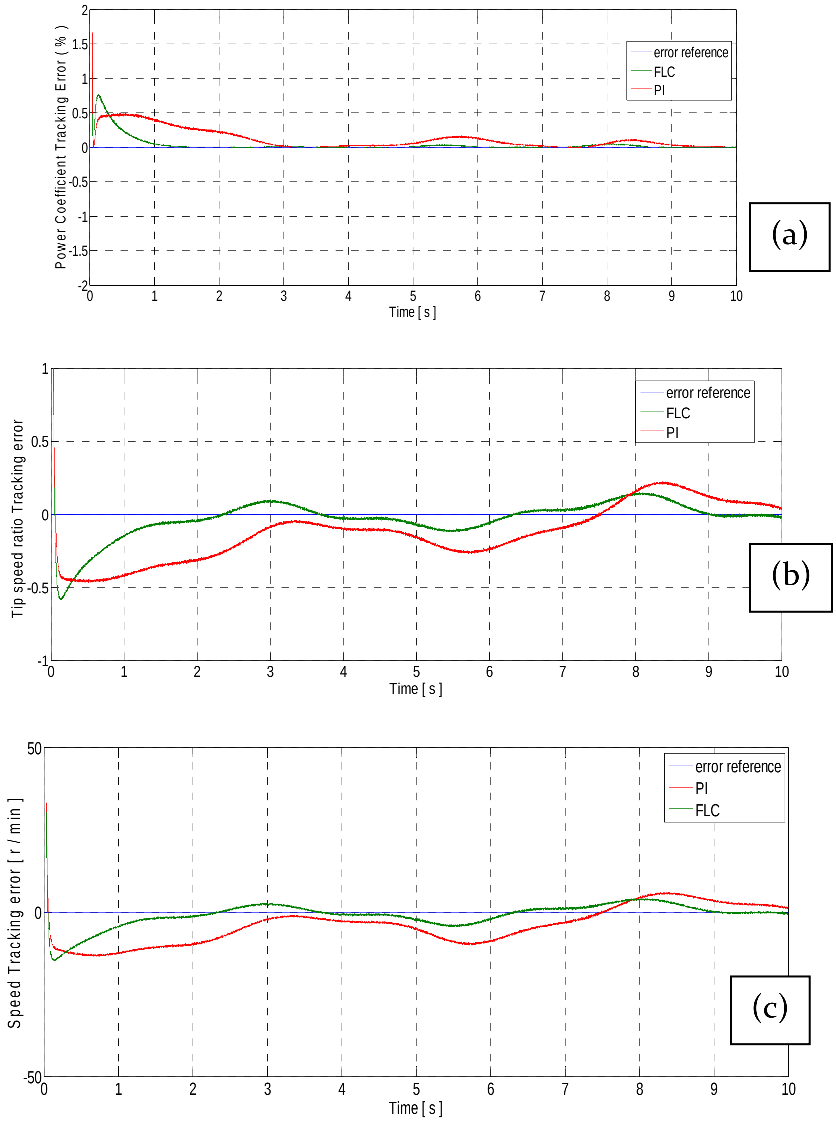

Figure 10. (a) Power coefficient tracking error (b) Tip-speed ratio tracking error (c) Speed tracking error

5. CONCLUSION

In this work, the model of the DC motor was incorporated within a larger simulation of a PMSG system with the DC motor acting as the prime mover.

One of the advantages of the WTE is that various wind profiles can be tested to verify the control algorithms.

The FLC method can quickly and accurately track the maximum power output for wind power system.

Simulation results presented in this paper prove that a good MPPT strategy can be implemented with a fuzzy logic controller.

Further work will be focused on induction machine to emulate the wind turbine.

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