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Modelling and Plotting of Characteristics using Fuzzy Controllers for a Wind Turbine Connected Through a Doubly Fed Induction Generator to a Microgrid

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Abstract: This paper comprises of characteristics of a wind turbine connected through a dfig which is connected to microgrid. Discrete proportional-integral controllers and fuzzy controllers which are applied individually in the vector control controls the active power of wind turbine. Vector control is applied on the rotor side converter for this purpose. By making the rotor voltages in decoupled axis the active power is controlled. The reference frame employed for the induction generator employed in this modeling is synchronous reference frame. For applying the pulses a 3-phase pulse generator is used on the rotor side which is operated as an inverter. Maximum power is obtained by using discrete PI controllers and fuzzy logic controllers. The overshoot in the active power due to discrete PI controllers is reduced by replacing discrete PI controllers with fuzzy logic controllers. Four discrete PI controllers are employed in the vector control scheme, which were auto tuned. By formulating appropriate fuzzy rules the overshoot of active power is reduced. Finally, the active power, rotor pulses and grid voltages are plotted. The entire model is simulated on mat lab/simulink software.

Keywords: Active Power, Grid, dfig, wind turbine, discrete pi controller, fuzzy logic control, vector control.

1. INTRODUCTION

In the past, the usage of renewable energy sources is not so popular. They commonly used non-conventional energy sources which are limited. This resulted in global warming [1]. This lead to the use of unlimited sources which are called conventional energy sources. The examples of such are solar energy and wind energy respectively. Among number of available renewable energy sources wind energy proved to be more efficient and abundant .there are fixed speed wind turbines as well as variable speed wind turbines. The operation of fixed speed wind turbine is that the turbine runs at constant speed without following wind variations. But, variable speed wind turbine runs at speed varying according to wind speed variation [2]. There are two types of generators used commonly. One is squirrel cage induction generator and the other one is doubly fed induction generator. Fixed speed turbines results in low efficiency, which is a serious drawback [3]. This drawback is overcome by using a variable speed turbine which run according to the wind speed variation. The variable speed turbines also have advantage of extracting maximum active power [4]. This paper shows the characteristics of active power, grid voltages and currents, rotor pulses and electromagnetic torque obtained using fuzzy controllers and discrete pi controller. This paper is organized into six parts: first part gives the introduction, second part gives wind turbine and dfig, third part gives vector control, fourth part gives discrete pi control, fifth part gives fuzzy logic control and sixth part gives the results.

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2. WIND TURBINE AND DFIG

Figure 1 shows the block diagram of wind turbine with vector control block. The mechanical power equation of wind turbine is given by following relation [6]:

$$\text{Pm} = \frac{p\pi R^2 v^3 Cp(\lambda)}{2} \tag{1}$$

Torque developed is given by the following relation:

$$\text{Tm} = \frac{\text{Pm}}{\Omega} = \frac{1}{2\lambda} p\pi R^3 v^2 Cp(\lambda) \tag{2}$$

Where the tip-speed ratio λ is

$$\lambda = \frac{\Omega \times R}{V} \tag{3}$$

The power coefficient Cp depends on λ and angle of the blade. It varies from one turbine to other. It can't be calculated by mathematical equations. It is provided by the manufacturer. Ω is angular speed and v is wind speed.

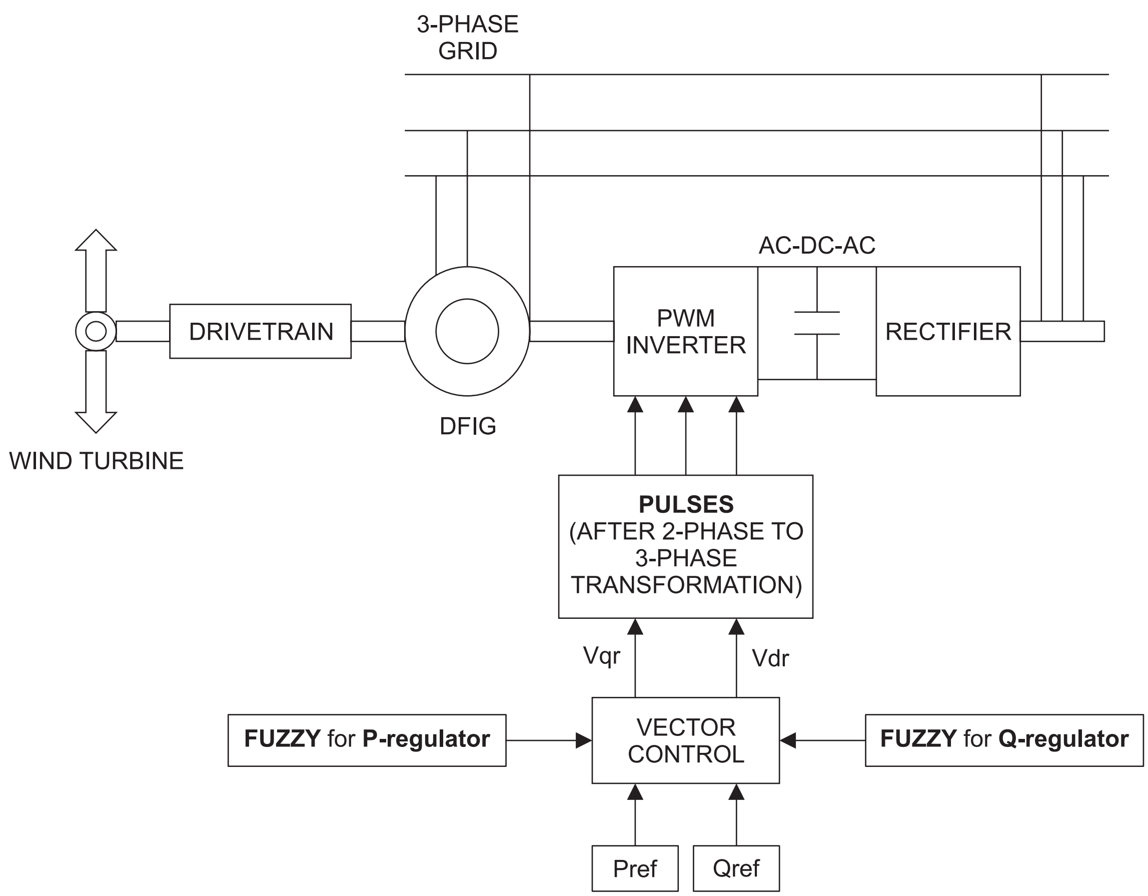

Figure 1: Block Diagram of Vector Controlled dfig Based Wind Turbine

The rotor side is pwm inverter and grid side is rectifier. The wind energy extracted from wind using wind turbine is converted to electrical energy by using doubly fed induction generator. The extraction of maximum power is done by doubly fed induction generator. An AC-DC-AC converter is employed for this type. It is operated in synchronous reference frame. The stator and rotor voltage equations of d-axis and q-axis are given by [5]:

$$V_{ds} = R_s \times I_{ds} + \frac{d\varnothing_{ds}}{dt} - W_s \times \varnothing_{qr} \tag{4}$$

$$V_{qs} = R_s \times I_{qs} + \frac{d\varnothing_{qs}}{dt} + W_s \times \varnothing_{ds} \tag{5}$$

$$V_{dr} = (R_r \times I_{dr}) - (W_s - W_r) \times \varnothing_{qr} + \left(\frac{d(\varnothing_{dr})}{dt}\right) \tag{6}$$

$$V_{qr} = (R_r \times I_{qr}) - (W_s - W_r) \times \varnothing_{dr} + \left(\frac{d(\varnothing_{qr})}{dt}\right) \tag{7}$$

For making dc-link voltage constant a dc link capacitor is employed.

3. VECTOR CONTROL

Vector control is a process where making the rotor voltages in decoupled axis [6]. Rotor field orientation control is employed for controlling the power generated by the generator. The equations of rotor voltages in decoupled axis are shown below:

$$V_{dr} = R_r \times I_{dr} + \sigma L_r \frac{dI_{dr}}{dt} - g \times w_s \times \sigma \times L_r \times I_{qr} \tag{8}$$

$$V_{qr} = R_r \times I_{qr} + \sigma L_r \frac{di_{qr}}{dt} + g \times w_s \times \sigma \times L_r \times I_{dr} + \frac{g \times M \times V_s}{L_s} \tag{9}$$

Where: $\sigma = 1 - \frac{M^2}{L_r L_s}, \; g = 1 - \frac{w_r}{w_s}$

The stator flux is oriented on *d*-axis, therefore:

$$\varnothing_{qs} = 0, \varnothing_{ds} = \varnothing_s, V_{qs} = V_s, V_{ds} = 0$$

Therefore, the $Power_{Active}$ and $Q_{Reactive}$ are given by equations (10)-(11)

$$P_{active} = -V_s \frac{M}{L_s} I_{qr} \tag{10}$$

$$Q_{reac} = -V_s \frac{M}{L_s} I_{dr} + \frac{V_s \times \varnothing_s}{L_s} \tag{11}$$

Figure 2 shows the simulink views of vector controlled generator. The pulses to the inverter side are given by a three phase pulse generator. The vector control is applied on the rotor side converter .The inputs to the vector control block are $P_{measured}$ and $Q_{measured}$. These are measured using grid data. Equations (10) and (11) show the control of active and reactive powers by the rotor currents of *q*-axis and *d*-axis.

4. DISCRETE PI CONTROLLER

The discrete pi controllers are used in the vector control block to control the active power. In the active power regulator two discrete pi controllers are employed. One is for controlling Vqr and the other one is for controlling active power. The pi controllers are auto tuned, the values of discrete pi controllers after auto tuning were shown in Table 1.

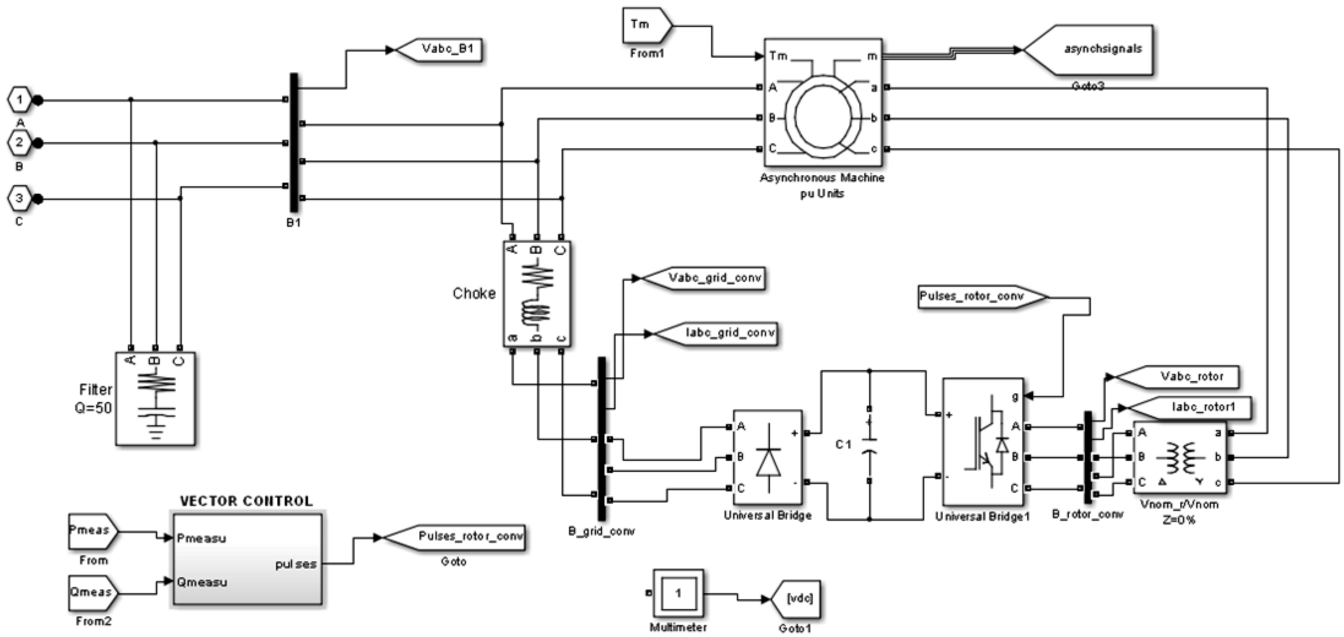

Figure 2. Simulink Diagram of Vector Control of Grid Connected dfig Based Wind Turbine

Table 1
PI controller values for P-regulator

For P-regulator:	P = 0.134588141992715	I = 0.269176283985431
For V_{qr}:	P = 0.134588141992715	I = 0.269176283985431

Similarly, two discrete pi controllers are used in the Q-regulator. One is for controlling V_{dr} and the other one is for controlling reactive power. The pi controllers are autotuned.the values of discrete pi controllers after auto tuning were shown in Table 2.

Table 2
PI controller values for Q-regulator

For Q-regulator:	P = 0.141012944732399	I = 0.282025889464799
For Vdr:	P = 0.12846268093414	I = 0.25692536186828

The disadvantage of using discrete pi controller in this paper is it results in overshoot in the active power characteristics which are reduced using fuzzy controllers.

5. FUZZY CONTROLLERS

The main advantage of using fuzzy logic control is that, we can control a system without mathematical equations [7].The fuzzification process and defuzzification processes are shown in Figure 4.

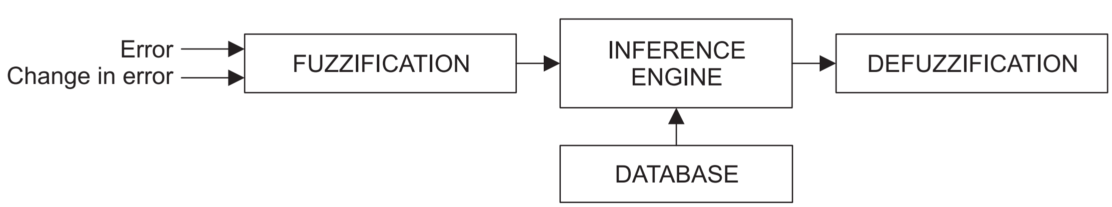

Figure 3: Fuzzy Logic Control System

The input to the fuzzy controller are error (e) and changes in error (de). These inputs are fuzzified by fuzzification process. The inference system used is Mamdani model. The membership functions shapes used were triangular membership functions. After that the fuzzy variables are defuzzified by using centroid method which is a defuzzication technique. Figure 4.toFigure 6 shows the windows for error (e), change in error (de) and output of fuzzy membership functions.

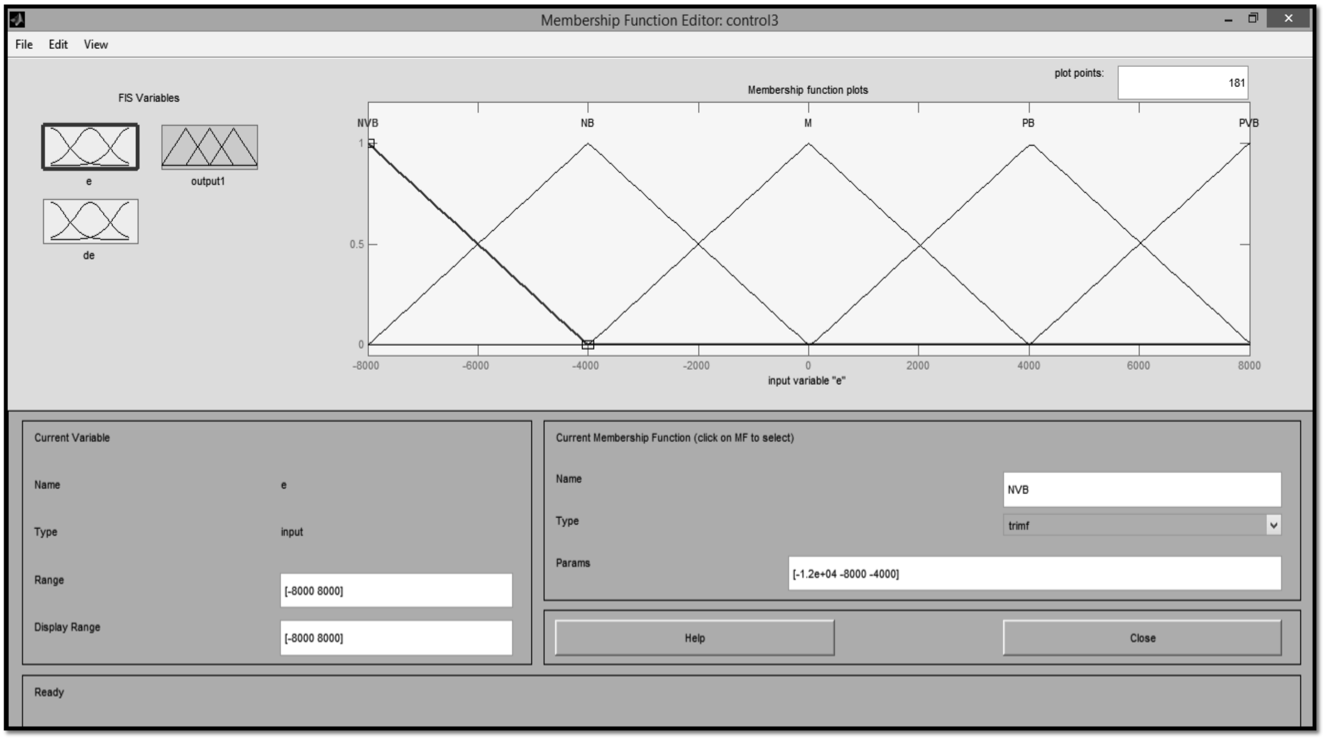

Figure 4. Error (e)

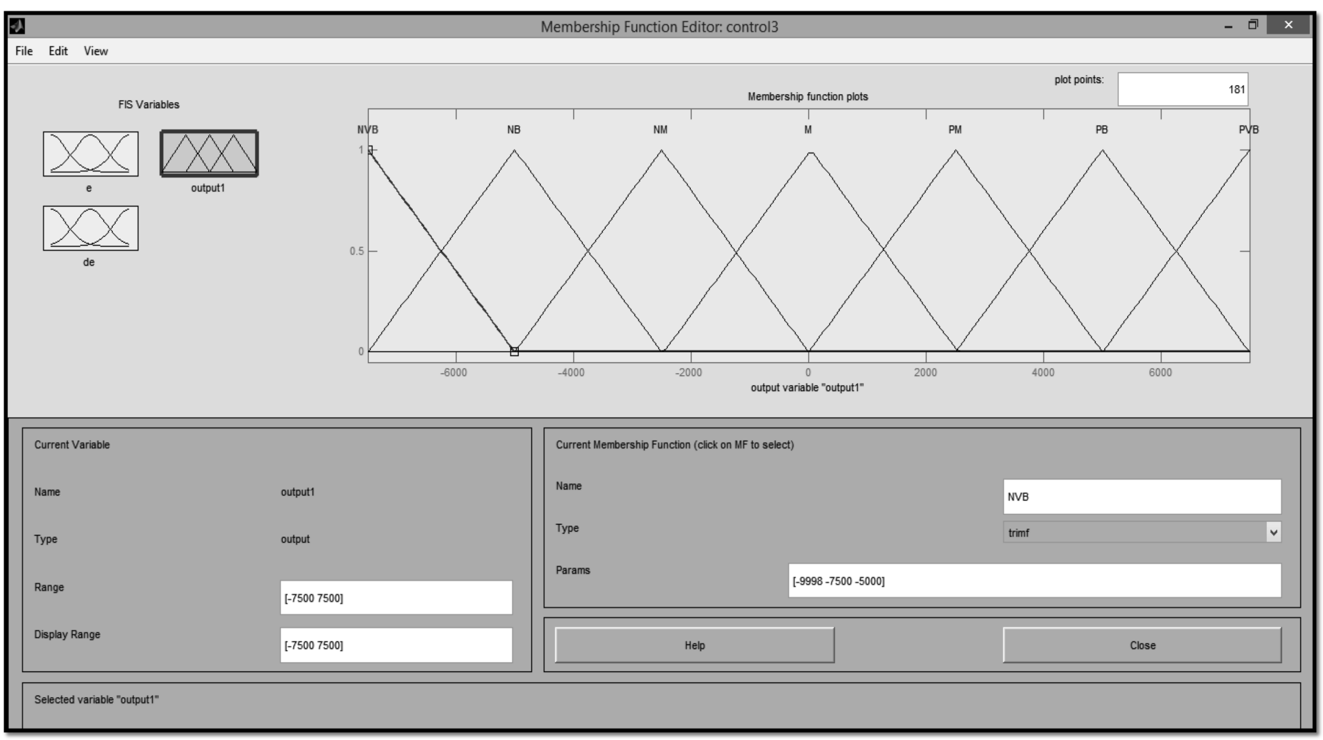

Figure 5. Change in Error (de)

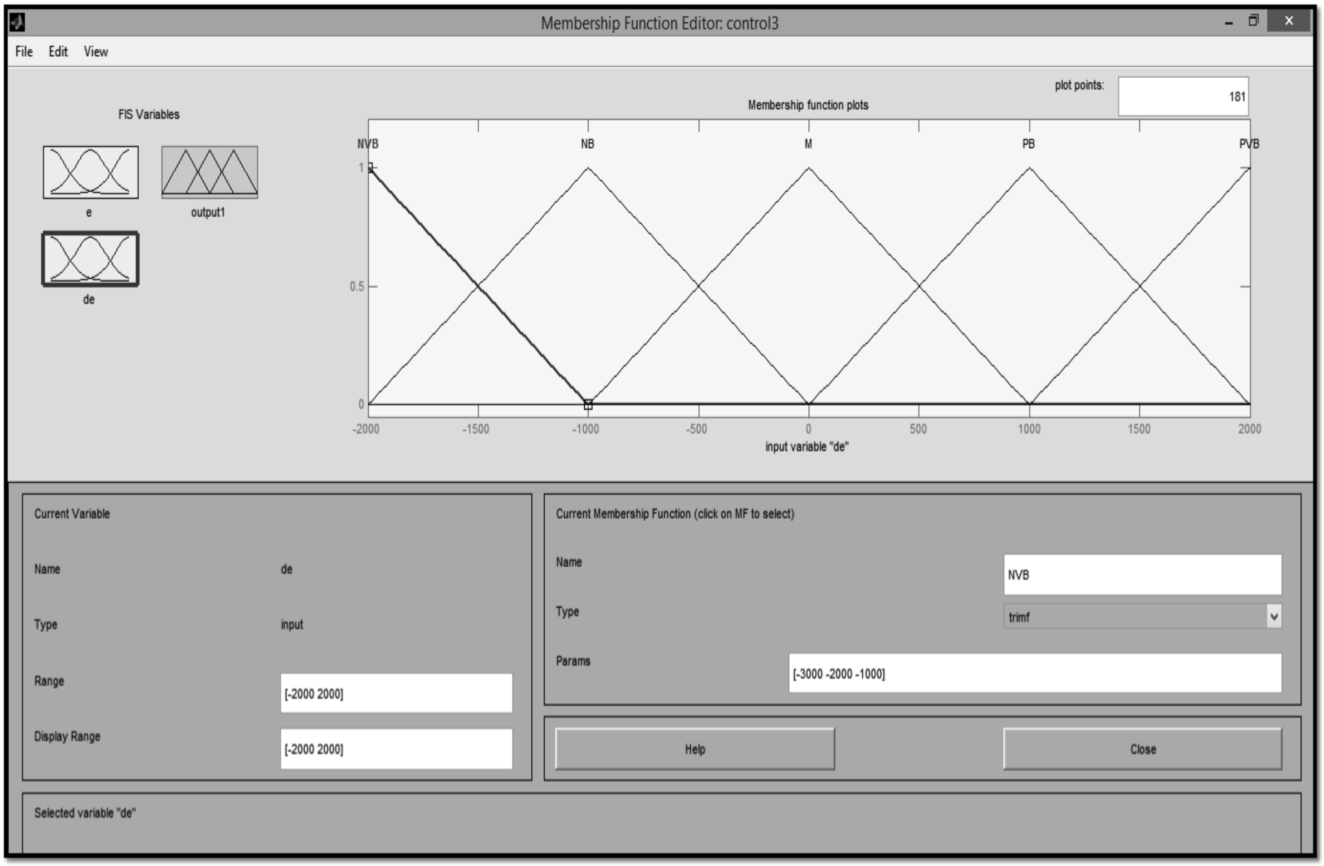

Figure 6. Output

The rule table used in applying if-then rules in this work used is shown inTable.3.there are 5 input membership functions each for inputs *e* and de, they are negative very big (NVB), negative big (NB), medium (M), positive big (PB) and positive very big (PVB), as there are 5 membership functions for input *e* and 5 membership functions for input de, a total of 25 rules are established. The output fuzzy variable is having 7 membership functions. They are negative very big (NVB), negative big (NB), negative medium (NM), medium (M), positive medium (PM), positive big (PB), positive very big (PVB), these rules were formed based on associative memory concept.

Table 3
Rule Base Table

		e				
	Output	NVB	NB	M	PB	PVB
de	NVB	NVB	NVB	NB	PB	M
	NB	NVB	NB	NM	M	PM
	M	NB	NM	M	PM	PB
	PB	NM	M	PVB	PB	PVB
	PVB	M	PM	PB	PVB	PVB

6. Results

The results of different outputs due to discrete pi controllers and fuzzy controllers are shown below.

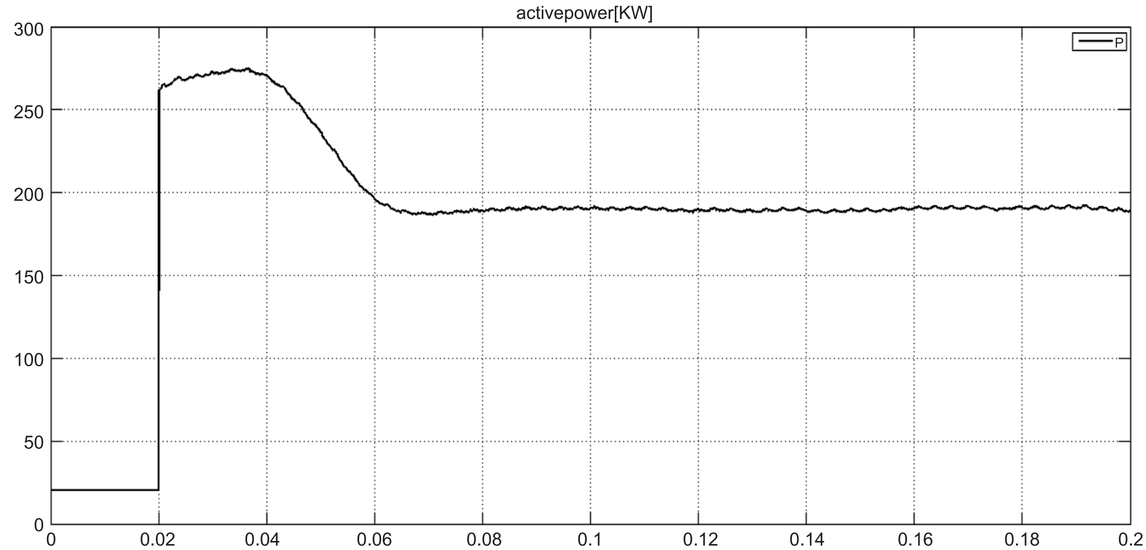

Figure 8: Characteristics of P_{active} of Wind Turbine using Discrete P_i Controllers

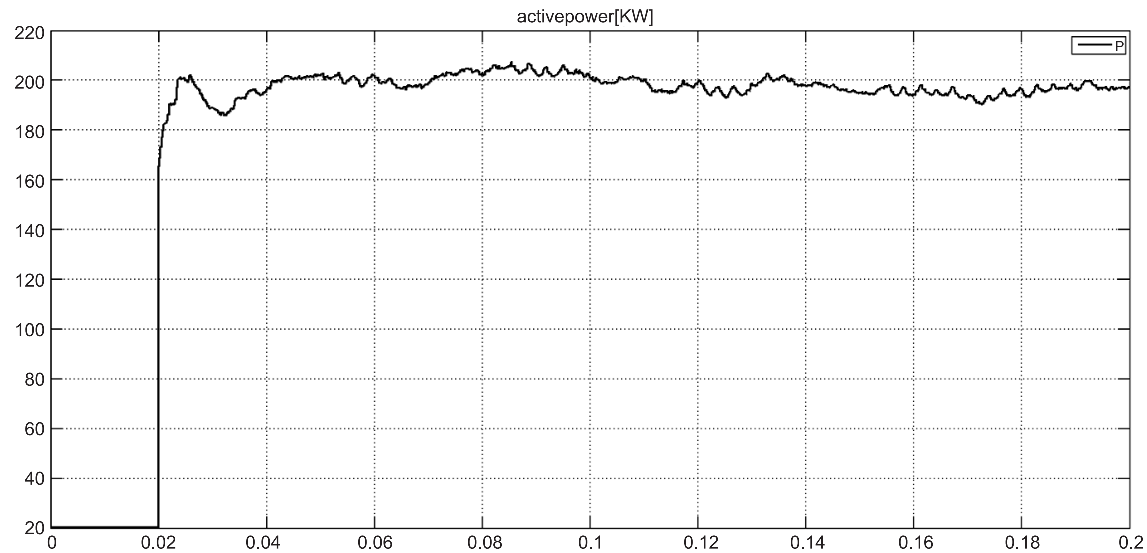

Figure 9: Characteristics of P_{active} of Wind Turbine using Fuzzy Controllers

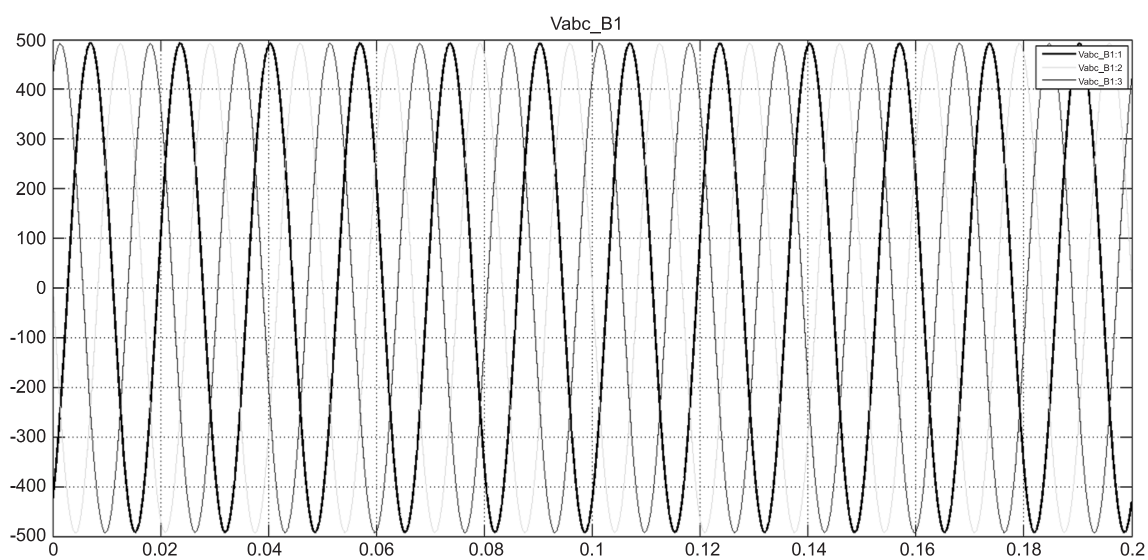

Figure 10: Grid Voltages

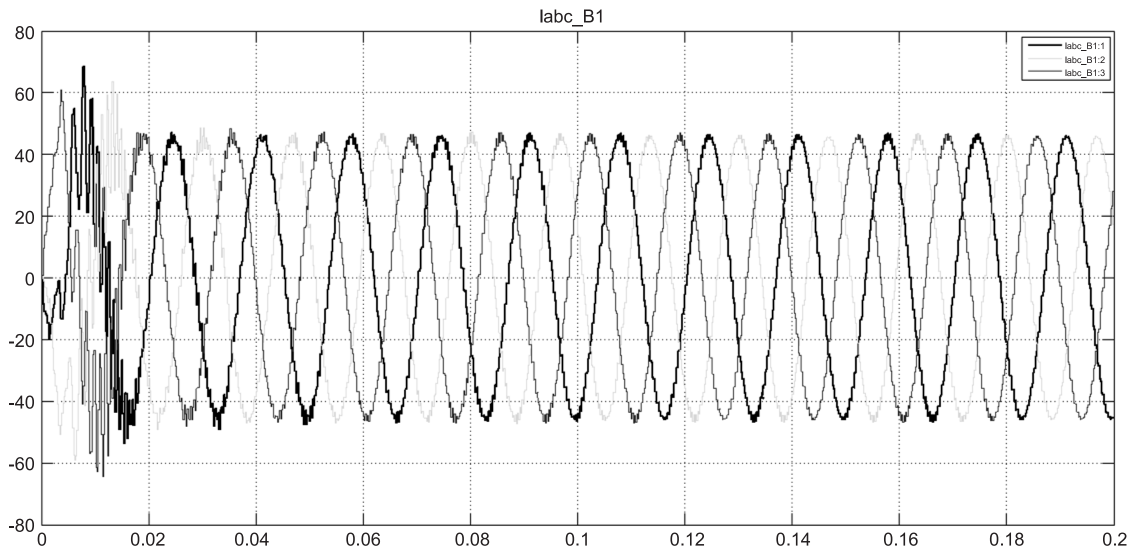

Figure 11: Grid Currents

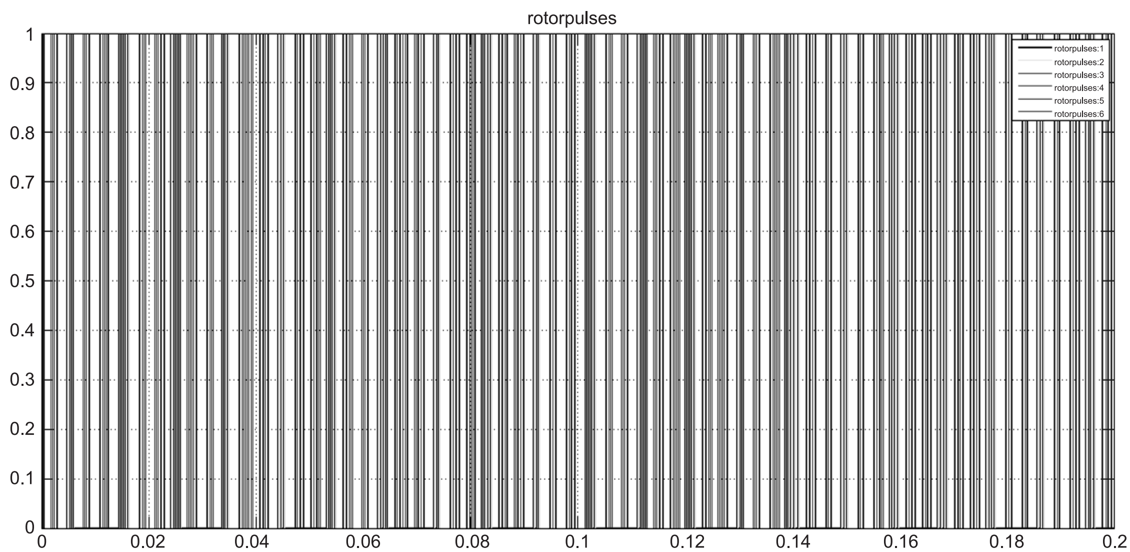

Figure 12: Rotor Pulses Due to Discrete P_i Controller

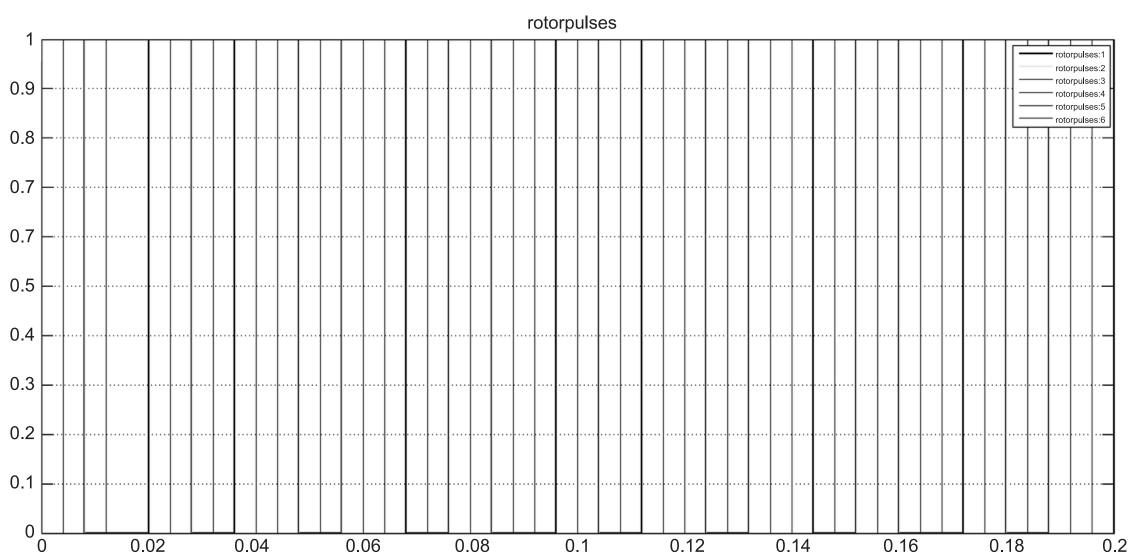

Figure 13: Rotor Pulses Due to Fuzzy Logic Controller

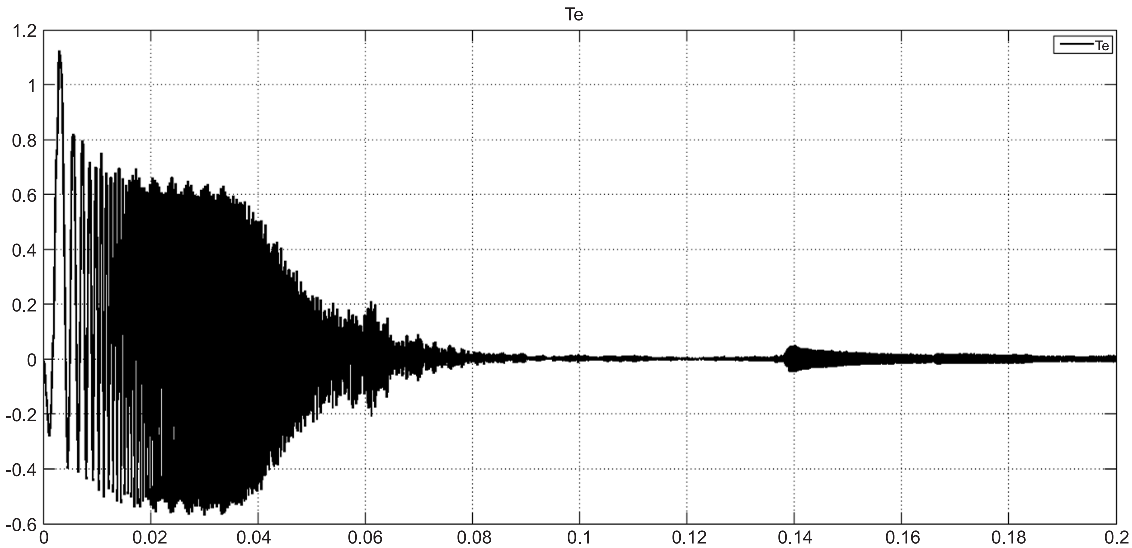

Figure 14: Electromagnetic Torque Due to Discrete P_i Controller

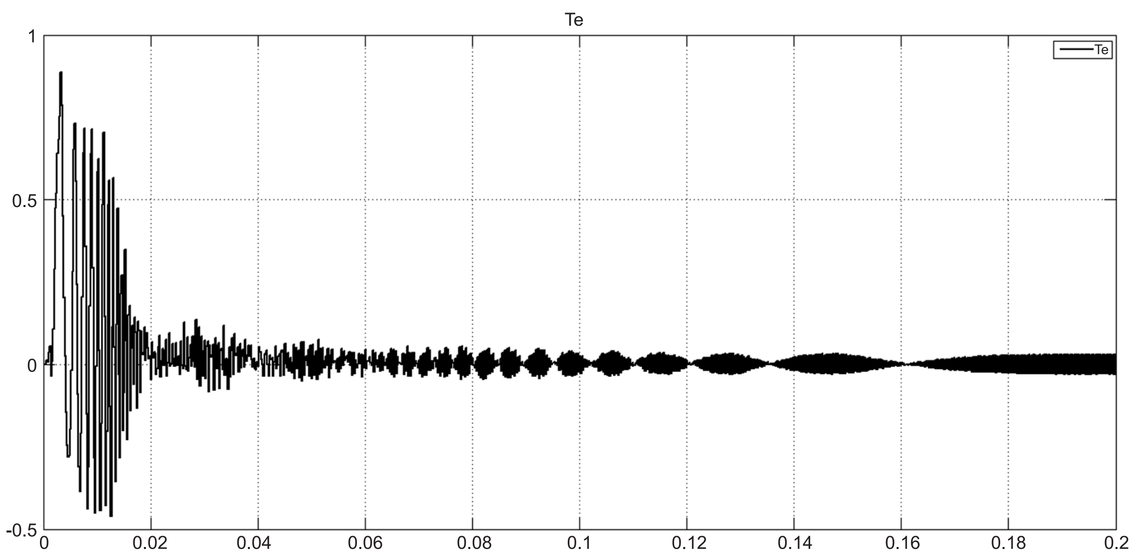

Figure 15: Electromagnetic Torque Due to Fuzzy Logic Controller

7. CONCLUSION

The characteristics of active power, grid voltages and current, electromagnetic torque using discrete pi and fuzzy controllers are plotted. A vector control is applied on rotor side. The overshoot in the active power which is due to discrete pi controller is reduced by using fuzzy controllers. The fuzzy controller plays a vital role in this work. The dfig values are given as follows: Line to line voltage = 692 V, Frequency = 50 Hz, R_s = 0.455 ohms, R_r = 0.62 ohms, L_s = 0.084 H, L_r = 0.081 H, M = 0.3125 kg m^2. The experiment is conducted on mat lab/simulink.

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