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International Journal Of Modern Engineering Research (IJMER)

Tracking of Maximum Power from Wind Using Fuzzy Logic Controller Based On PMSG

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Abstract: *Wind energy has gained a growing worldwide interest due to the nonstop rise in fuel cost. The main aim of the wind-energy system is to extract the maximum power present in the wind stream. In order to extract the highest power, the maximum power point tracking (MPPT) algorithm is used. This paper proposes the fuzzy logic MPPT controller to track the maximum power from the wind generation system. The maximum power is achieved based on the rotor speed of the wind system which consists of wind turbine and PMSG. The error and change in error is given as input to the fuzzy logic and its output is connected to the boost converter. The voltage from the dc link is controlled by the Voltage Source Inverter (VSI), and it is placed in grid side converter control. The proposed system is designed and evaluated in MATLAB/SIMULINK. Simulation results show the good dynamic performance of the proposed system.*

Index Terms*: Wind turbine, Permanent Magnet Synchronous Generator (PMSG), Maximum power point tracking (MPPT) and Fuzzy control.*

I. Introduction

Wind power is used to produce electricity or mechanical power and supplies it to homes, business, schools, etc. Wind turbine converts kinetic energy into mechanical energy and then the generator in the wind turbine converts this mechanical energy into electrical power. Wind turbine consists of rotor, generator, tower that supports rotor, gear box, electrical cables, etc. It is classified into two major types; Horizontal Axis wind turbine and Vertical Axis wind turbine. A Permanent Magnet Synchronous Generator (PMSG) is a generator contains the permanent magnet in the excitation field instead of coil. It is used to convert the mechanical power into electrical power and supply it to the grid. It consists of stator and rotor where stator is the armature and rotor contains the magnet.

Maximum Power Point Tracking (MPPT) is a technique which is used to track the maximum power from various devices especially photovoltaic systems. The capacity and higher value of current and voltage in the solar panel can make higher power. MPPT contains different algorithms such as Perturb and Observe, Incremental Conductance and Current Sweep Method. In wind turbine, the rotor speed continuously changes with changing the wind speed to get Maximum power. Therefore, the Maximum Power Point Tracking controller is presented in the wind energy conversion system to extract the maximum possible wind power [1-5].

MPPT is achieved by controlling the duty cycle of the dc-dc boost converter. When the boost converter is controlled, the rotor speed is also controlled to get the maximum power. Maximum power can also be tracked by maintaining the tip speed ratio (TSR) as optimal value [6]. Most of the authors [7-9] have proposed a various types of Fuzzy logic MPPT Controller for tracking maximum power from the wind turbine system. Two fuzzy logic controllers were used in the control scheme of wind energy conversion system [10]. In these papers, there is an impact of difference and uncertainty in the wind speed and the performance of the wind energy system is poor. In this paper, tracking of Maximum Power from the wind generation system by using the fuzzy logic MPPT controller is presented. An uncontrolled rectifier is employed to convert the ac power into dc power. The error between the actual rotor speed and the estimated speed is an input to the fuzzy logic controller. The change in error is another input to the fuzzy logic controller. The output of the fuzzy controller is given to the duty cycle of the boost converter. The maximum power is achieved by adjusting the duty cycle of the DC-DC boost converter. By adjusting the duty cycle, the rotor speed is controlled to get the maximum power from the wind. The boost converter increases the voltage and supply to the Voltage Source Inverter (VSI) which acts as an interface between the DC-DC boost converter and the grid.

The concept of this paper is organized as follows: In Section 2, the Literature review related to the proposed work is discussed. Section 3 provides the detailed explanation of the proposed work. In Section 4, the various results for the proposed work obtained in the simulation are evaluated. Conclusions are summed up in Section 5.

II. Literature Review

T. Shanthi and A.S. Vanmukhil [8] have proposed the fuzzy logic controller to extract maximum power from the hybrid renewable energy system model. The proposed system includes both the photovoltaic (PV) and wind energy conversion system (WECS). Fuzzy logic controller was used to adjust the duty cycle of the switch converter to extract the maximum power from the PV array. The Voltage Source Inverter (VSI) was employed to control the voltage from the dc link and the output voltage of VSI was regulated by PI controller.

Huynh Quang Minh et.al [10] has proposed the control scheme of a wind energy conversion system using fuzzy logic. They have proposed two fuzzy controllers in the wind energy conversion system. The first fuzzy controller was used to track the maximum power from the wind turbine. The output of the fuzzy controller was given to the dc-dc converter to adjust the duty cycle. When adjusting the duty cycle, the rotor speed of PMSG was controlled to get the maximum power. The second one was used to maintain both the production and the storage of energy in respecting load demand for better performance of the system.

Wei Qiao et.al [11] have proposed the sensor less maximum wind power tracking controller based on the wind speed estimation. A Control algorithm was presented to control the wind turbine equipped with doubly fed induction generator (DFIG). The wind speed was estimated from the measured generator output power and the dynamics of the wind generator based on nonlinear mapping which was provided by a Gaussian radial basis function network (GRBFN). The estimated wind speed was used to find the optimal DFIG rotor speed for extraction of maximum wind power. The speed controller of DFIG was designed to damp low-frequency torsion oscillations.

M. Sarvi, Sh. and Abdi, S. Ahmadi [12] have proposed the maximum power point tracking control scheme based on particle swarm optimization _ fuzzy logic for wind turbine PMSG system. The maximum wind power was captured by adjusting the rotor speed of the PMSG. The rotor speed varies according to the wind speed and the wind turbine generator was operated by adjusting the duty cycle of the boost converter and increases the efficiency of wind energy conversion system.

Jogendra Singh Thongam and Mohand Ouhrouche [13] have proposed MPPT controllers to extract maximum power from the wind using various types of generators such as Permanent Magnet Synchronous Generator (PMSG), Squirrel Cage Induction Generator (SCIG) and Doubly Fed Induction Generator (DFIG). They have used three main control methods to track the maximum power namely tip speed ratio (TSR) control, Power signal feedback (PSF) control and hill-climb search control (HCS).

E. Koutroulis and K. Kalaitzakis [14] have proposed the Maximum power tracking system for wind energy conversion applications. The output voltage and current of the wind generator was determined to monitor the output power of wind generator. Based on the result of comparison between successive wind power values, the dc-dc boost converter was adjusted directly.

Y. Izumi et.al [15] has proposed a control method for tracking maximum power in a wind energy conversion system using online parameter identification. The wind turbine was connected with PMSG and transmits the power into AC grid through the converter. The generator side converter controls the torque of PMSG and the grid side inverter controls the voltage in the dc link and the grid for steady operation. The online parameter identification was used to determine the optimum torque of the PMSG and it varies due to wind turbulence, parameter error and other unexpected conditions. The parameter identification was achieved by the use of weighted least square method and it was appropriate for practical systems.

III. Proposed Work

System Description

Figure 1 shows the block diagram for the proposed wind generation system with fuzzy logic controller. The wind generation unit consists of PMSG and it is connected to uncontrolled rectifier which is used to convert the ac output voltage from the wind generation unit into dc voltage. The dc-dc boost converter is used to catch the maximum power from the wind, where a fuzzy logic MPPT controller is employed. In fuzzy logic controller two inputs are given, one is the error between the actual rotor speed and the estimated speed, another one is the derivative of this error. The output of the fuzzy controller is connected to the boost converter. The Voltage Source Inverter (VSI) is placed at the grid side converter control to control the dc link voltage. The proposed system is designed and simulated in the MATLAB/SIMULINK.

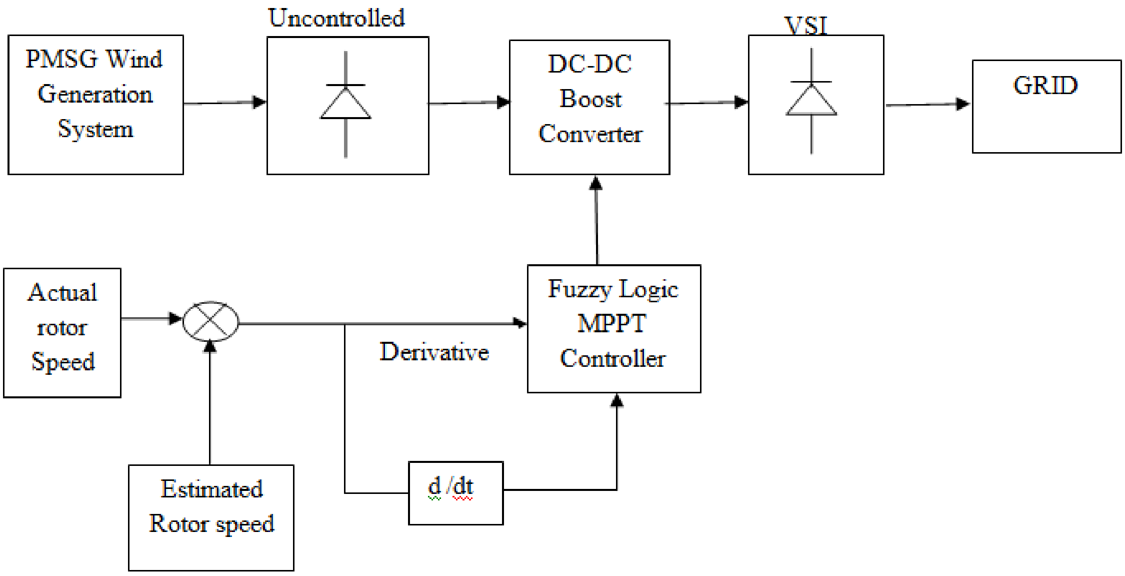


Figure 1: Block diagram of the proposed Wind generation system

Wind Energy Conversion System

The output mechanical power of the wind generation system is given by the following equation.

$$P_m = \frac{1}{2} C_p(\lambda, \beta)\rho A V_{wind}^3 \qquad (1)$$

where C_p is the power coefficient of the wind, ρ is the air density (kg/m^3), A is the swept area of the turbine (m^2), V_{wind} is the wind speed (m/s), λ is the tip speed ratio and β is the blade pitch angle (deg.).

Tip speed ratio (TSR) depends on the number of rotor blades of the wind turbine. If the number of rotor blade is less than the wind turbine rotates fast to get the maximum power from the wind. The equation of the TSR (λ) can be explained as follows,

$$\lambda = \frac{\omega_m R}{V_{wind}} \qquad (2)$$

Whereω_m, the rotor speed and R is the radius of the blade. The optimum value of TSR will be 8.1. The rotor speed can be estimated using the formula,

$$\omega_m = \frac{V_d + 2R_s I_d}{\frac{3\sqrt{3}}{\pi}K_m - \frac{P}{20}L_s I_d} \qquad (3)$$

Where V_d and I_d are the dc voltage and current respectively. The parameters of the wind generation system used in this paper are given in table 1.

Table 1: Parameters of the proposed system

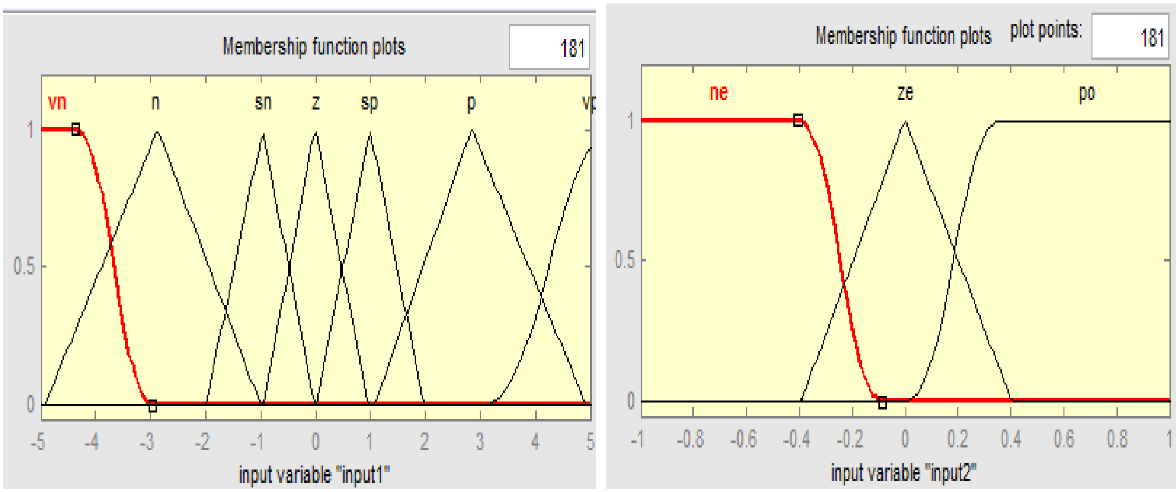
Parameter Name	**Value**
Air density, ρ	1.225 kg/m^3
Rated Wind Speed	12 m/s
Pitch angle, β	0 deg.
Power coefficient, C_p	0.48
Stator Leakage Inductance, L_s	4.48 mH
Peak line-neutral back emf constant	1.4 V/rpm
Stator winding resistance, R_s	0.1764 ohm

Fuzzy logic MPPT controller

In this paper, the fuzzy logic controller is present to track the maximum power from the wind by using the rotor speed of the wind. Fuzzy logic is the best controller to track the maximum power point. The inputs of the fuzzy controller are the error between the actual rotor speed and the estimated rotor speed and change in this error. Output of the fuzzy controller is the duty cycle of the boost converter. By adjusting the duty cycle of the boost converter the maximum power will be achieved. The rotor speed is found out using the equation (3). At first, the various terms are selected to form the fuzzy rules. Based on these terms, the different rules are formed. The linguistic terms used here are:

1. Error (Very Negative, Negative, Small Negative, Zero, Small Positive, Positive, Very Positive)
2. Derivative of error (Negative, Zero, Positive)

The seven various terms of error and three terms of change in error are shown in figure 2 (a) and (b) respectively. The output of fuzzy rule is shown in figure 3.



(a) (b)

Figure 2: (a) Variable terms of error, (b) Terms for change in error

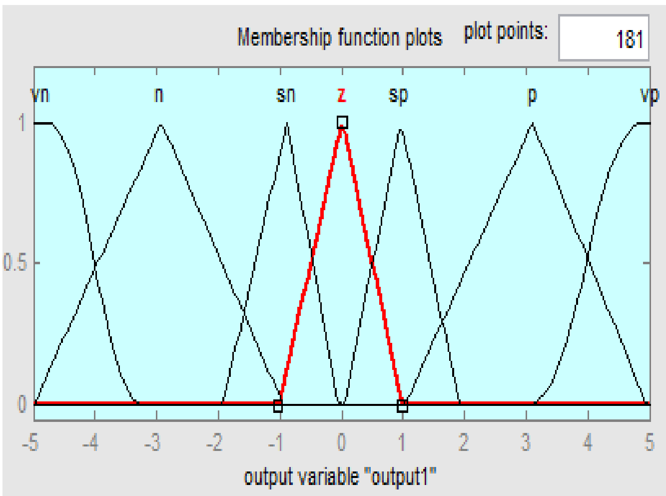


Figure 3: Output of fuzzy rules

Table 2: Various fuzzy rules for MPPT

D (%)		Derivative of error		
		Negative	**Zero**	**Positive**
Error	**VN**	VP	VP	VP
	N	SN	SN	VN
	SN	N	SN	VN
	Z	Z	Z	Z
	SP	SP	SP	P
	P	P	VP	VP
	VP	VP	VP	VP

In the proposed fuzzy controller, totally 21 rules are formed and it shown in table 2. For example, if the error is positive and change in error is negative then the duty cycle will be positive. The rules formed process is called as fuzzification. After the fuzzification process, the defuzzification is performed which converts the fuzzified value into defuzzified value. It gives the final output value. The defuzzification is shown in figure 4.

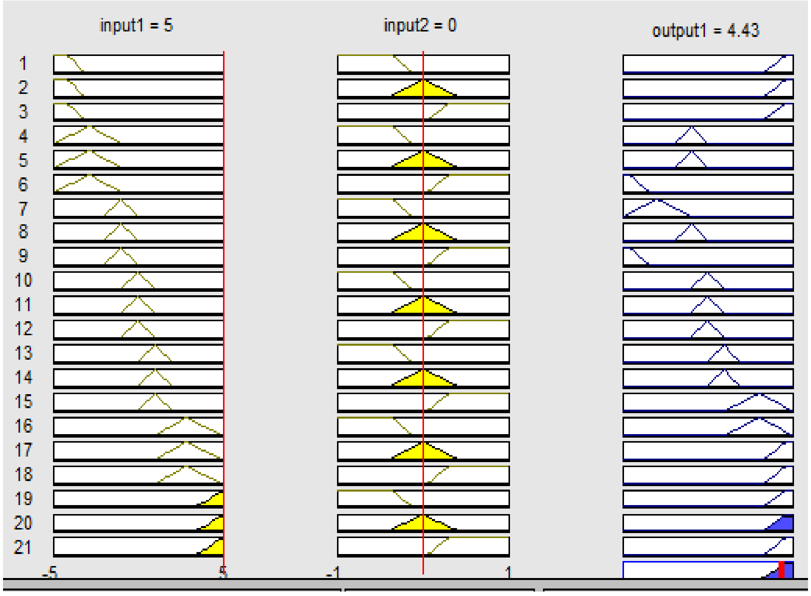


Figure 4: Defuzzification

IV. Simulation Results

The proposed work is implemented in MATLAB/SIMULINK and its simulation diagram is shown in figure 5. For tracking the maximum power from the wind, the fuzzy logic controller is presented. Fuzzy controller tracks the maximum power with respect to the speed of the wind generation system. The simulation diagram for the main wind generation system with PMSG is shown in figure 6. The diagram for the estimation of rotor speed is shown in figure 7.

The various results obtained from the simulation diagram are shown in figure 8. Figure 8(a) shows the output of wind speed, rotor speed, pitch angle and torque in the wind turbine model. The output from the PMSG is represented as generator terminal and generator terminal 2 and it is shown in figure 8(b) and 8(c) respectively. In figure 8(d), the overall output of the wind generation system is shown. Figure 8(e) shows the output voltage of uncontrolled rectifier and the voltage source inverter. The maximum power tracked from the wind using fuzzy controller is shown in figure 8(f). The maximum output power from the wind is 4.438 KW is evaluated using fuzzy logic controller.

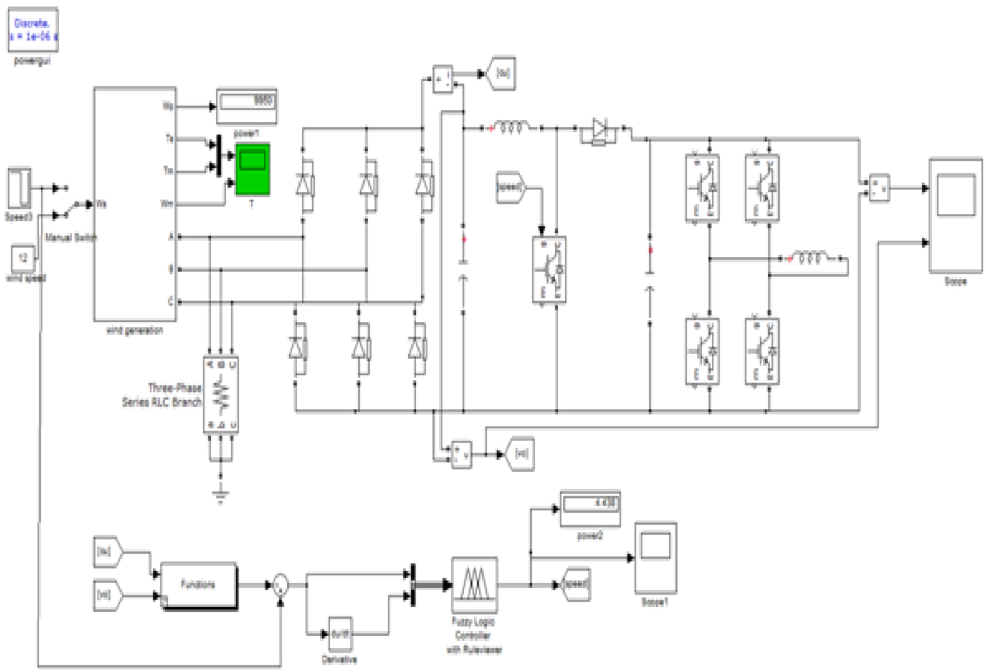


Figure 5: Simulation diagram for the proposed work

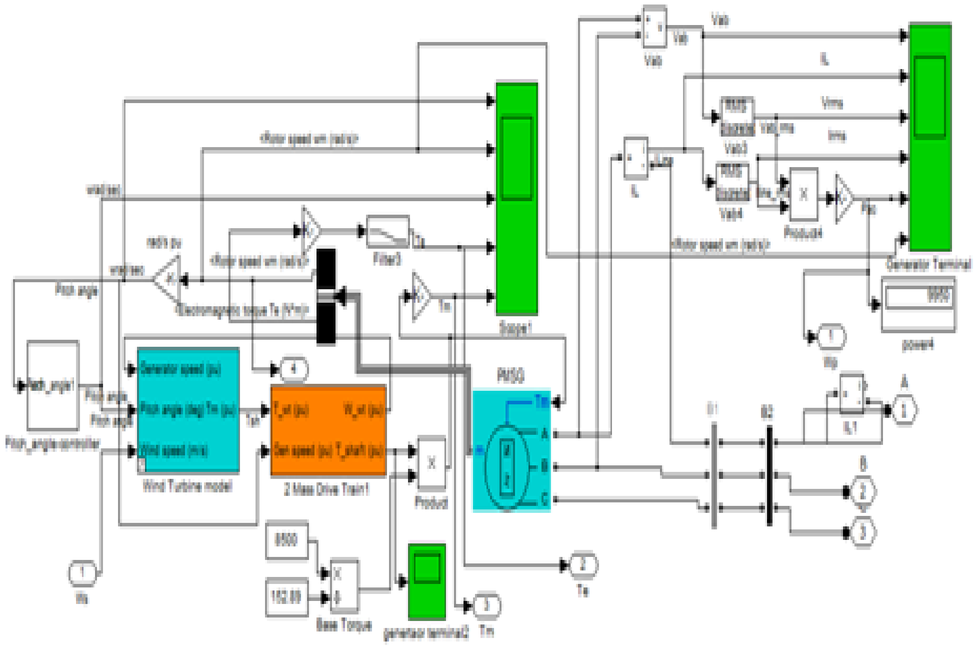


Figure 6: Simulation diagram for the wind generation system

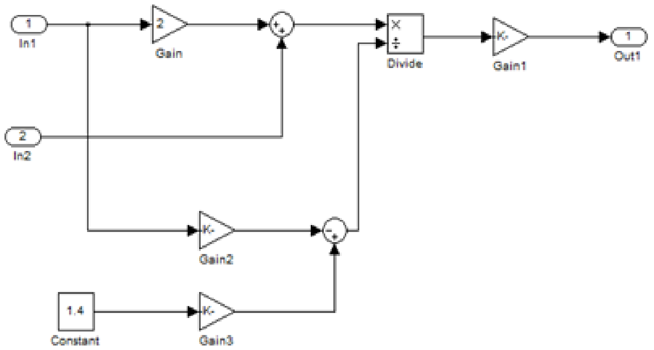
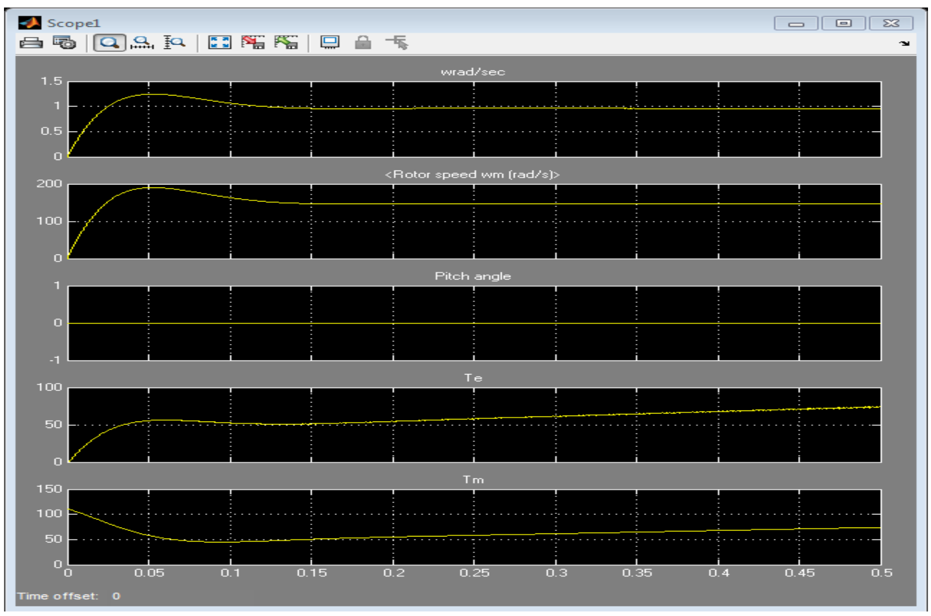
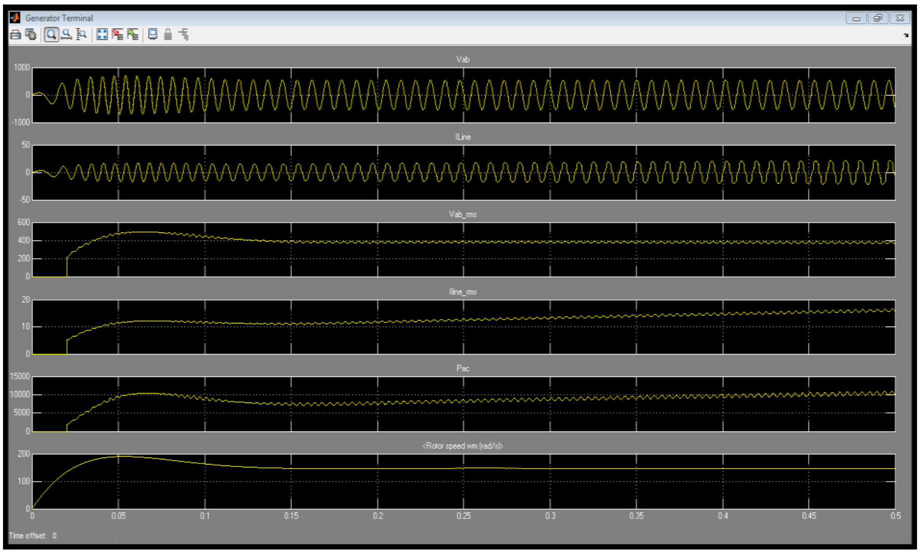


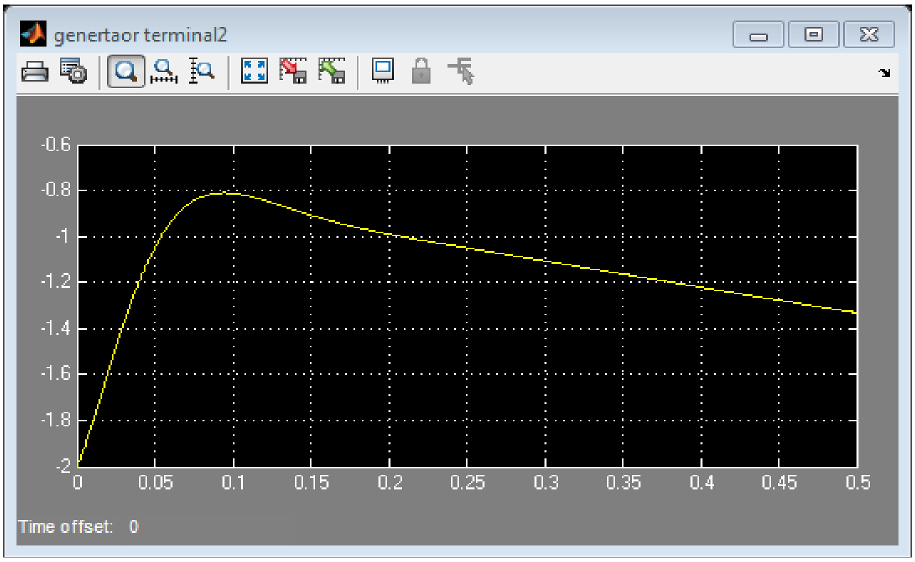
Figure 7: Estimated rotor speed



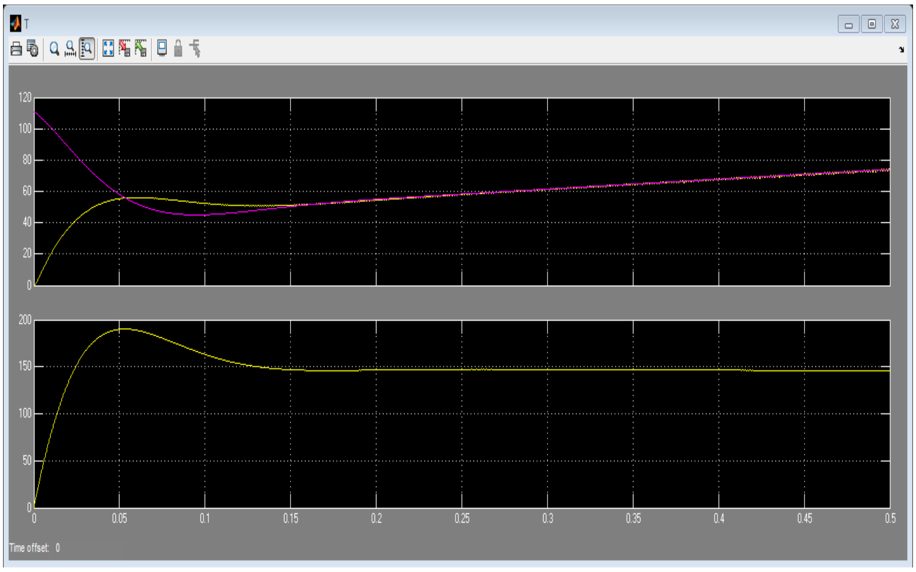
(a) Simulation results for wind speed, rotor speed, pitch angle and torque in wind turbine



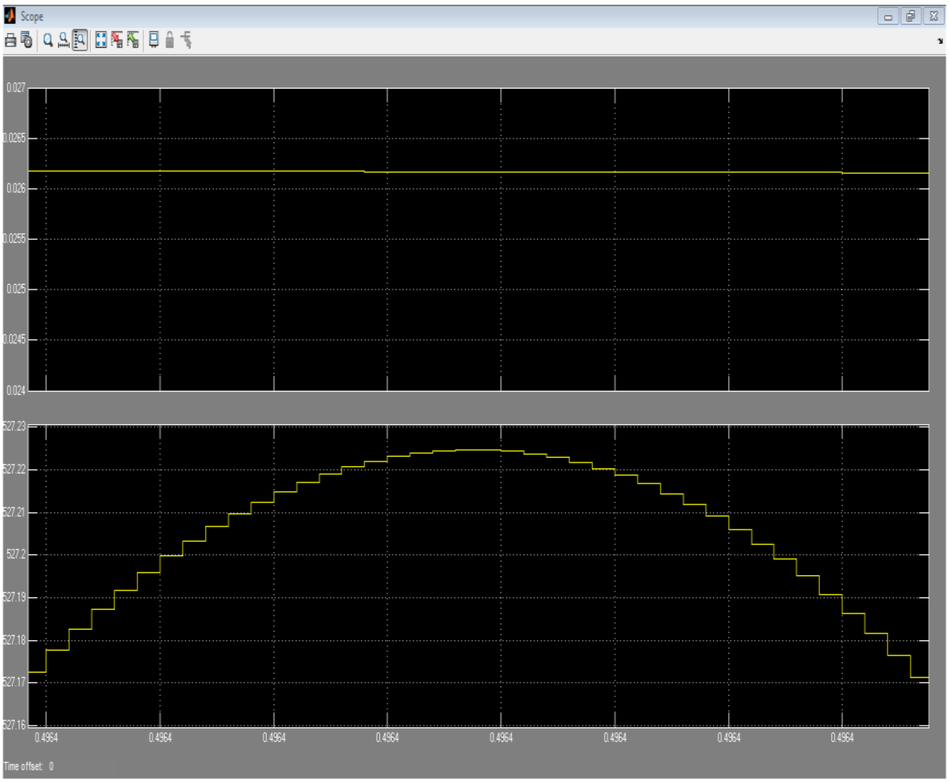
(b) Results for voltage, current, power and rotor speed in PMSG



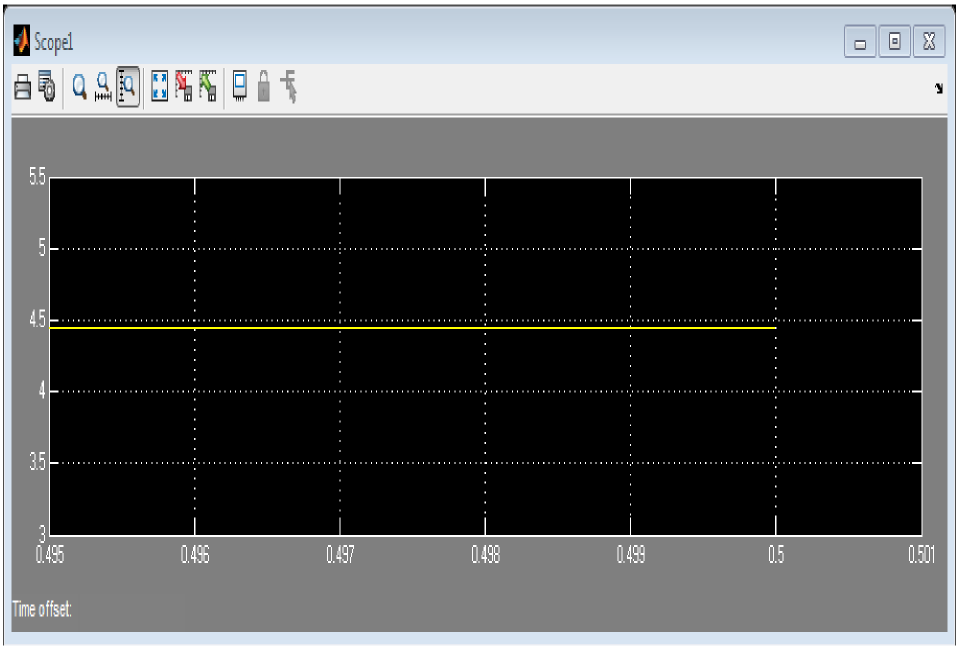
(c) Generator terminal 2



(d) Torque from wind generation system



(e) Voltage from rectifier VSI



(f) Maximum output power from wind

Figure 8: The various simulation results for the proposed system

V. Conclusion

In this paper, maximum power point is tracked from the wind using fuzzy logic MPPT controller is presented. The maximum power is tracked based on the rotor speed of the wind generation system. The output of the fuzzy controller is connected to the boost converter to adjust the duty cycle. The maximum power is achieved by controlling the duty cycle of the boost converter. The system evaluations are performed in the MATLAB/SIMULINK. The simulation results represent that the proposed system shows the dynamic and steady state performances. Some advantages of using fuzzy controller are quick response, limit insensitivity and universal control algorithm. The proposed wind generation system supplies maximum power to the grid with high efficiency and reliability.

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