

AERO DYNAMIC POWER CONTROL OF PERMANENT MAGNET SYNCHRONOUS GENERATOR USING FUZZY LOGIC PITCH ANGLE CONTROLLER

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Abstract: With an increase in renewable energy resources plays an important role now-a-days to maintain power quality and increase in electrical power generation to the end user. In this project various control techniques are used to control the aerodynamic power of wind generator using pitch angle control. In conventional methods pitch angle control uses PI and PID controller. In proposed technique hybrid fuzzy logic controller is modelled to control pitch angle of wind generator, here in fuzzy logic method of control turbine output power error and wind turbine speed taken as inputs, FLC produces pitch angle references will remunerates the non-linear sensitivity of wind turbine,. The proposed system is simulated on a 2MW Permanent Magnet Synchronous Generator(PMSG) at wind speed of 12m/sec and 14m/sec simulation can be done in MATLAB or in SIMULINK form. At the end results shows the effectiveness of wind generator which increases efficiency with controlled frequency and voltage magnitude using hybrid fuzzy logic controller.

Index Terms: Hybrid Fuzzy Logic controller, Pitch angle, Permanent Magnet Synchronous Generator, Wind Turbine.

Introduction:

In the past years variable speed wind turbines are pitch adjusting. These turbines consists of two controllers which are cross-coupled each other. At the time of low speed power output will be maximum by adjusting rotor speed using speed controller. Wind speed at above rated value the power output will be constant using pitch angle control. To control the aerodynamic power of wind turbine several methods are used like Proportional-integral (PI), Proportional Integral Derivative (PID) used to regulate the output power. Drawback of these methods is that the performance has been reduced when operating points are changed. Since the controller design is based on turbine model. On the other, gain scheduling control can be used to control the system non-linearity, here controller gains are adjusted when operating points are changed which provides faster response. The drawback of this method is that controller gains are designed based on turbine model and also it's difficult to design scheduled functions updating gains at different points.

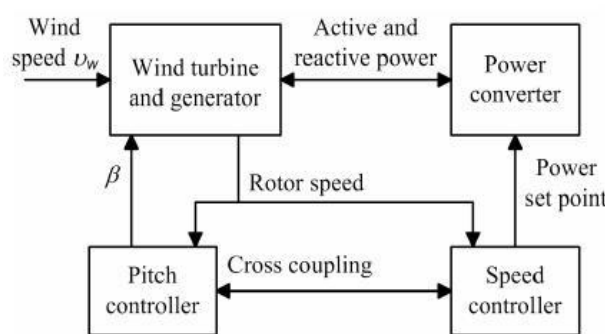


Figure.1. Block diagram of variable-speed wind turbine

In this proposed model fuzzy logic pitch angle control is used to regulate turbine output power and generator speed at full-load region. Generator output power and rotor speed are taken as inputs instead of wind speed which reduces the cost of anemometer. In addition this control variables power output, generator speed, wind turbine are well maintained to control speed and power output without ripples in output.

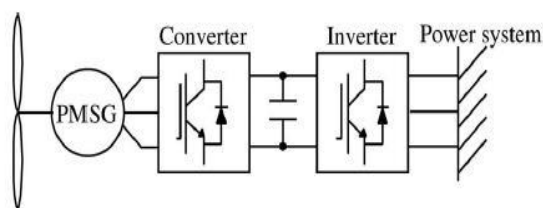


Figure.2. Gearless WECS using PMSG.

II.METHODS AND MATERIAL

A. SYSTEM CONFIGURATION

The gearless WECS system arrangement as shown in fig.2. Wind energy output is sent to PMSG through mechanical interconnection. The PMSG rotor speed is adjusted using pulse width modulation (PWM) control to attain maximum power. Utilising side by side generator-rectifier and grid-inverter the output power can be sent to grid.

B.WIND TURBINE MODEL

Wind turbine outputs power T_p and wind turbine torque T_w are distinguished by following equations

$$P_w = 0.5 C_p(\lambda, \beta) \rho \pi R^2 V_w^3 \quad \dots (1)$$

$$T_w = 0.5 C_p(\lambda, \beta) \rho \pi R^3 V_w^2 / \lambda \quad \dots (2)$$

Where V_w is the wind speed, ρ is the air density, R is the radius of the wind turbine, C_p is the wind turbine power coefficient, $\lambda = \omega_r R / V_w$ is the tip-speed ratio, ω_r is the angular rotor speed of the wind turbine and, β is the pitch angle. C_p is described by the following equations:

$$C_p = 0.22 \left(\frac{116}{\lambda} - 0.4\beta - 5 \right) \exp \left(\frac{-12.5}{\lambda} \right) \quad \dots (3)$$

$$\Gamma = \frac{1}{(1/(\lambda + 0.08\beta)) - (0.035/(\beta^3 + 1))} \quad \dots (4)$$

C.PMSG MODEL

Essentially, the mass model of PMSG is same as permanent magnet synchronous machine (PMSS). The voltage and torque equations in d-q frame is shown below.

$$v_d = R_a i_d + L_d \frac{di_d}{dt} - \omega_e L_q i_q \quad \dots (5)$$

$$v_q = \omega_e L_d i_d + R_a i_q + L_q \frac{di_q}{dt} - \omega_e K \quad \dots (6)$$

$$T_e = p \{ K i_q + (L_d - L_q) i_d i_q \} \quad \dots (7)$$

where V_d and V_q are the dq -axis voltages, and are the dq -axis currents, R_a is the stator resistance, L_d and L_q are the dq -axis inductances, ω_e is the generator rotational speed, K is the permanent magnetic flux, and p is the number of pole pairs. Electromagnetic torque T_e should be negative to start generating operation.

2. EXISTING PITCH ANGLE CONTROLLERS:

At high speeds, wind turbine performance can be controlled by pitch angle of the blades. Again these pitch angle blades are kept into normal position by pitch servos which are hydraulic or electrical systems. The pitch angle reference β_{ref} is controlled by input values, generator power. The error is sent to PI controller to regulate the power by pitch angle.

A.PI/PID CONTROLLERS

These conventional methods are used to regulate rotor speed and turbine output power. For partial loads β_{ref} is set to zero and maximum power point tracking (MPPT) method is utilised. So that energy conversion coefficient is maximised at partial loads. Whereas in full-load region, the pitch controller is activated to regulate the generator output power. For designing PI/PID controllers

non-linear dynamics of wind turbine is linearized at particular operating point at which generator and turbine torques were same. In this method when operating points are changed PI gains should be adjusted to maintain the system dynamic response and stability.

B.PI CONTROLLER WITH GAIN SCHEDULING

This method is used to control nonlinearity in PI controller. This gain scheduling is used to remunerate for the changes in sensitivity of aerodynamic torque to pitch angle.

C.FUZZY LOGIC CONTROL

In this the controller can be designed based on human experience through a set of rules has been used to control pitch angle. The wind speed and generator output power taken as control inputs of FLC. The advantage of this method is that the parameter of wind turbine system doesn't need to be known accurately. Nevertheless this method requires wind speed information.

3. Proposed Hybrid Fuzzy Logic Pitch Angle Controller

The proposed pitch angle control block diagram shown below fig.3. At partial load the power reference P_{ref} of wind turbine can be determined by MPPT control strategy.

$$P_{ref} = K_{opt} * \omega_r^3 \quad \dots (8)$$

$$K_{opt} = 0.5 * \rho \pi C_p \max \frac{R^5}{\lambda_{opt}^3} \quad \dots (9)$$

Where

and the maximum power coefficient $C_p \max$ corresponds to the optimal tip-speed ratio λ_{opt} , with a zero-pitch angle. In the high-wind-speed region, P_{ref} the selected as the rated power of wind turbines. To find pitch angle reference FLC takes inputs and execute fuzzy rules and convert into output value is called defuzzification.

The error in the generator power ΔP , the variation of the power error $\delta(\Delta P)$, and the rotational speed are considered as the controller inputs.

$$\Delta P(k) = P_g(k) - P_{ref}(k) \quad \dots (10)$$

$$\delta(\Delta P) = \Delta P(k) - \Delta P(k - 1) \quad \dots (11)$$

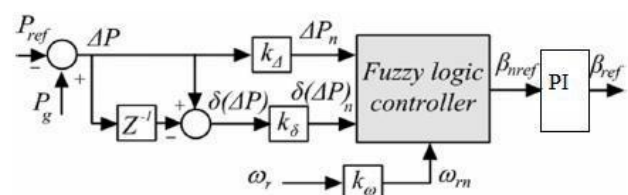


Figure.3. Block diagram of pitch control system using Hybrid FLC

The pitch angle reference is considered as a controller output. To design the fuzzy sets of the inputs and output, the triangular membership functions with the overlap are used, which are illustrated in Fig. 5. The linguistic variables are represented by Negative Big (NB), Negative Medium Big (NMB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Medium Big (PMB), and Positive Big (PB). The control rules are derived from the experience and knowledge on the control system. The fuzzy mapping of the input variables to the output is expressed by the following rules:

R_i : IF $w_r(k)$ is A_i and $\Delta P(k)$ is B_i and $\Delta P(k - 1)$ is C_i
 THEN β_{ref} is D_i .

The sugeno model of inference is applied to this system. Each rule is weighted by the weighting factor of the rule, which is obtained from the minimum operation as

$$W_i = \min\{\mu_{\Delta P}(\Delta P), \mu_{\delta\Delta P}(\delta(\Delta P)), \mu_w(w_r)\} \dots (12)$$

Where $\mu_{\Delta P}(\Delta P)$, $\mu_{\delta\Delta P}(\delta(\Delta P))$, and $\mu_w(w_r)$ are the triangular membership functions of the ΔP , $\delta(\Delta P)$.

The output of weighted average is the variation of pitch angle reference shown below

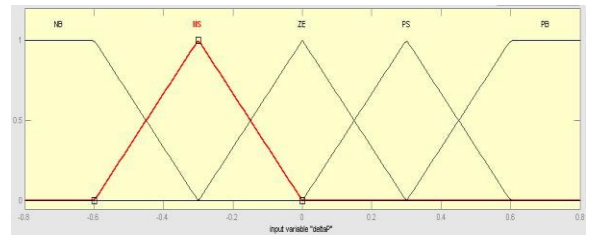
$$\beta_{nref} = \frac{\sum_{i=1}^N W_i D_i}{\sum_{i=1}^N W_i} \dots (13)$$

Rated Power	2 MW
Blade Radius	38.3 m
Air density	1.225 kg/m ³
Max. power coefficient	0.411
Cut in speed	3 m/s
Cut out speed	25 m/s
Rated wind speed	12 m/s
Blade Inertia	6.3*10 ⁶ kg.m ²

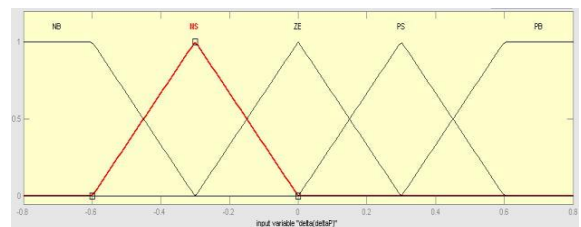
Table 1. Wind Turbine parameters for simulation

Rated Power	2 MW
Grid Voltage	690 v
Stator voltage/frequency	690v/16.6HZ
Stator resistance	0.008556Ω
Stator inductance	0.00359H
Generator inertia	48000 kg.m ²

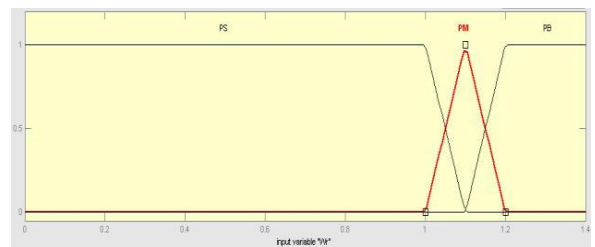
Table 2. PMSG parameters for simulation



(a)



(b)



(c)

Fig.4. Membership Functions of FLC. (a) Error of output generator power, (b) Variation of power error, (c) Rotational Speed, (d) Pitch angle reference

4.SIMULATION DIAGRAM

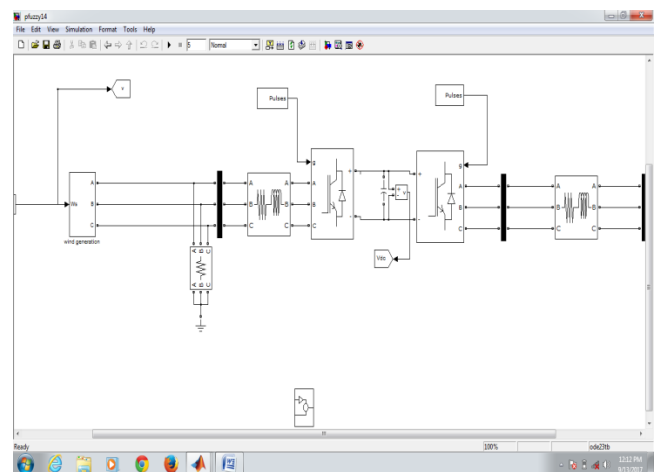


Fig.5.Simulation Diagram

5. RESULTS

Simulation Results

For proposed model, the simulation had done on a 2MW PMSG wind turbine system shown in fig.5. To

investigate the performance of the PI controllers and the Hybrid FLC at the different operating point, the rated wind speed which classifies the partial and full-load regions is set as 14 m/s, differently from the previous case of 12 m/s. Fig. 6 shows the results of the pitch control for the PI controller and the proposed fuzzy controller, at the rated wind speed of 14 m/s. The gain parameters for both the PI/PID controllers and the membership function of the fuzzy logic control are the same as those of the prior case. All of the pitch angle control methods can limit the generator power and rotor speed to their rated values. However, the pitch angle control employing the proposed hybrid fuzzy control method gives better performance than those of the PI control. The results of generator output power, rotor speed, and mechanical torque, respectively, where with the same controller. Below results shows fuzzy logic controller at 14m/sec wind speed.

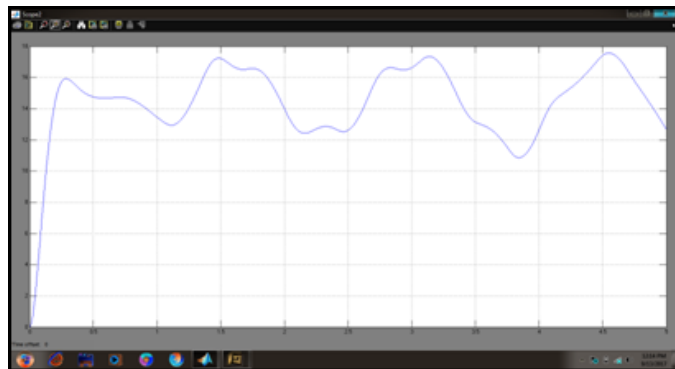


Fig.6 Wind Speed at 14m/sec

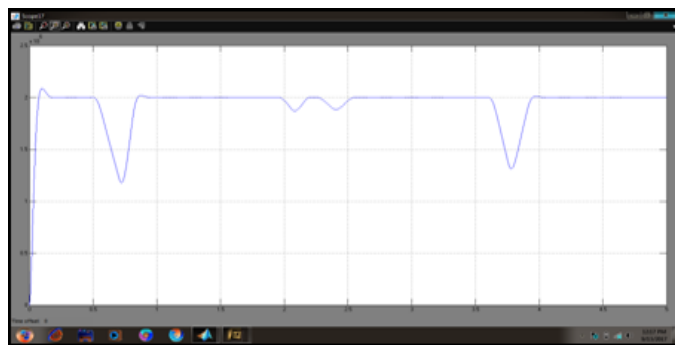


Fig.7. Generator Powers



Fig.8. Rotor speed

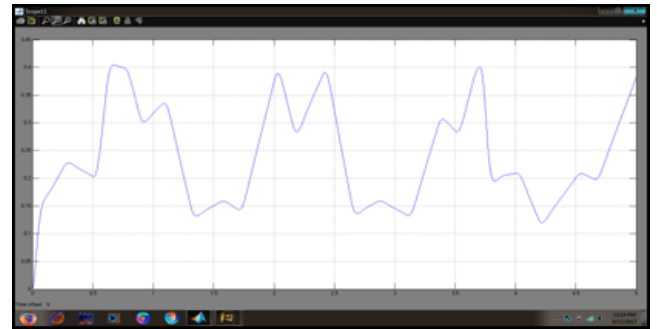


Fig.9. Power Conversion Coefficient

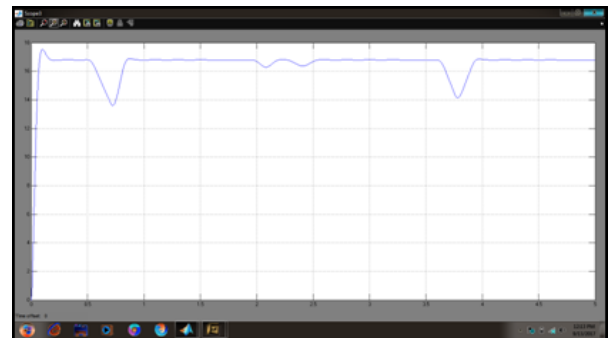


Fig.10. Mechanical Torque

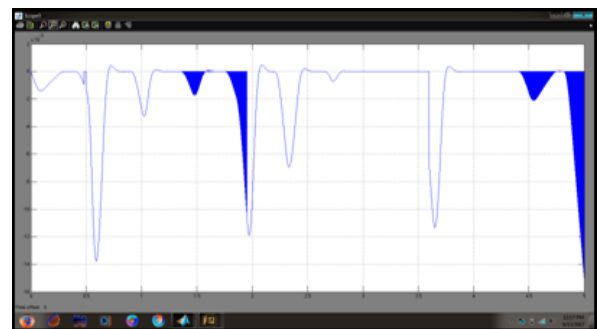


Fig.11. Pitch angle reference

Fuzzy Logic Controller at 12m/sec wind speed

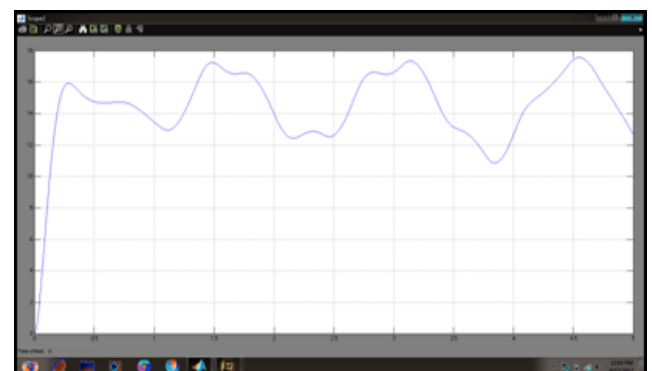


Fig.12. Wind Speed at 12m/sec

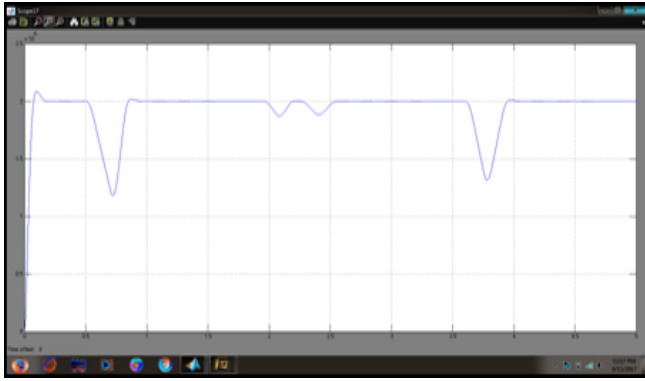


Fig.13.Generator Powers

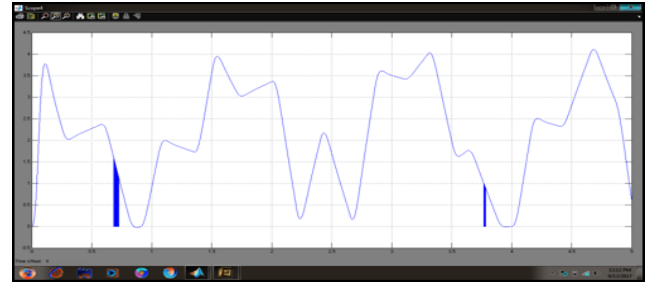


Fig.17.Pitch angle reference

SIMULATION RESULTS WITH PI CONTROLLER

Wind Speed at 12m/sec



Fig.14.Rotor speed

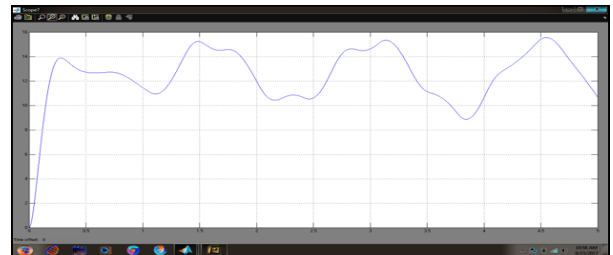


Fig.18.Wind speed at 12m/sec



Fig.15.Mechanical Torque

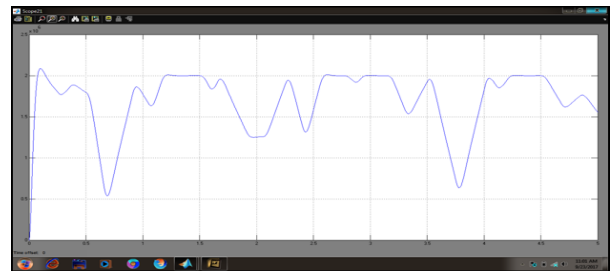


Fig.19.Generator Power

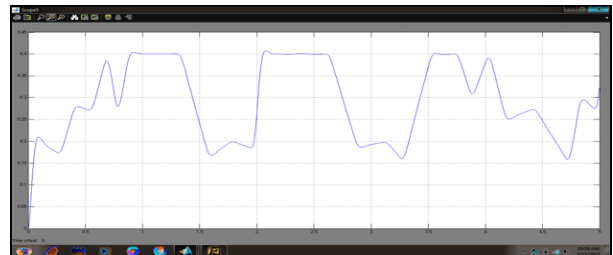


Fig.20.Mechanical torques

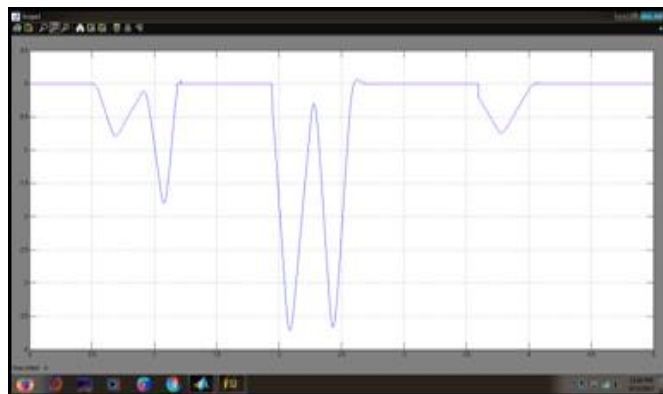


Fig.16.Power Conversion Coefficient

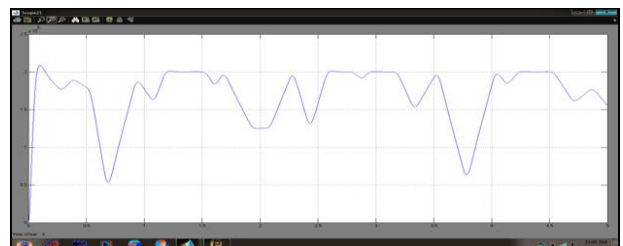


Fig.21.Power conversion coefficients

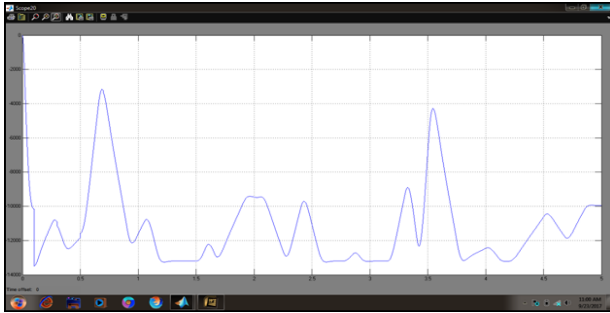


Fig.22.Pitch angle

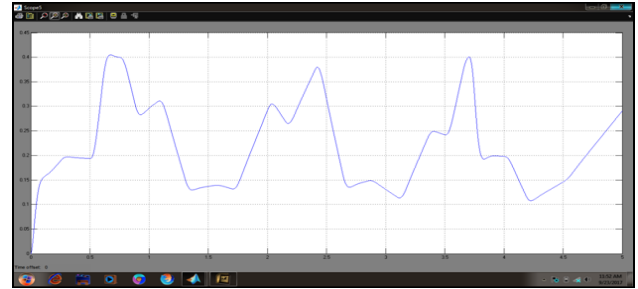


Fig.26.Power conversion coefficients

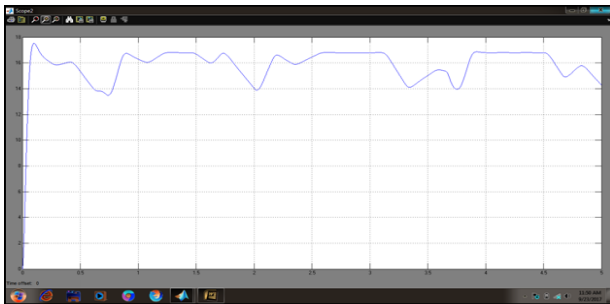


Fig.23.rotor speed

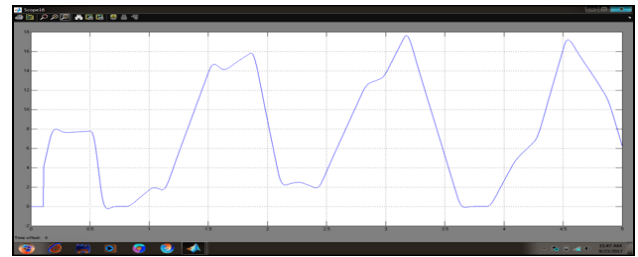


Fig.27.Pitch angle

Wind speed at 14m/sec

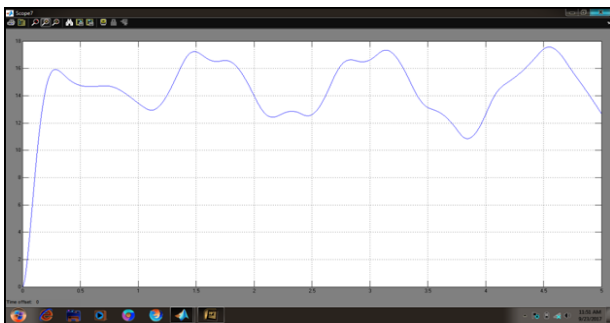


Fig.24.Wind speed at 14m/sec

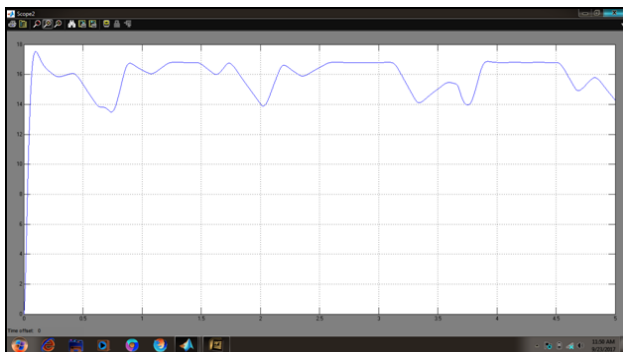


Fig.25.Rotor speed

6. CONCLUSION

At the end simulation done on PMSG wind generator using fuzzy logic controller. Here generator output power and wind speed are taken as fuzzy inputs. Fuzzy logic pitch angle controller can regulate the generator output power and wind speed at high speed regions. It is more accurate than conventional PI/PID controller. In this control scheme derived from small signal analysis. It improves the performance and efficiency of wind generator under high speed and reduces faults due to pitch angle variations.

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BIOGRAPHIES



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