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Wind Turbine Modelling and Pitch Angle Control Using PID, Fuzzy and Adaptive Fuzzy Control Techniques

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Abstract:- Wind energy plays vital role in present day power generation as wind turbine system actively participate in frequency and voltage stability .Maximum power is extracted from wind turbines if some of the considerations are taken in to account such as wind speed and pitch angle. Howeverwind speed is unpredictable and depends on the geographical conditions of the different areas, pitch angle plays a vital role in extracting maximum power from the wind energy .As energy extracted is limited according to Betz Law it is evident that with the help of pitch angle controllers it is possible to get desired output for certain conditions with in such limit. Hence it is necessary to design good pitch angle controller in order to obtain maximum performance. A system with wind turbine generator is modelled and different parameters of such system is observed for different conditions and an isolatedplant system is taken for study andconventional PID controller, Fuzzy logic controller, Adaptive Fuzzy logic controller are designed and compared plant without controller. Adaptive Fuzzy controller gives the desired output with good time response characteristics with step input.

I. INTRODUCTION

Wind energy contribution increases day by day in the power sector. As wind energy is emerging as crucial source for power generation,it is necessary to get the maximum efficiency to meet our requirements.In order to do so it is desired to control some parameters regarding wind power generation scheme. Pitch angle control plays a vital role in performance analysis of wind turbine generator scheme. This paper deals with pitch control of wind turbine using different techniques such as PID,Fuzzy,Adaptive Fuzzy control. Study of pitch system helps in understanding the mechanisms associated with the wind turbine and helps in determining the best performance accordingly. However some limitations may associated with pitch system and all such limitations are taken in to consideration for pitch system of wind turbine and controllers are designed according to the desired output range.

II. MATHEMATICAL MODEL OF WIND TURBINE

kinetic energy associated with air is given as
$E = 0.5mv^2$ (1)
Where m=mass of air,v=velocity of air.

Kinetic energy associated with wind turbine is
$E = 0.5\rho V v^2$ (2)
Where ρ=air density ,ϑ= volume of the air present at rotor.

Power associated is expressed as given
$P = 0.5\rho A v^3$(3)
Where A=crosectional area

Maximum power extraction associated with wind turbine is as follows
$P_R = 0.5\rho A C_p v^3$(4)

Where Cp= power coefficient

Power coefficient and tip speed ratio are interlinked and tip speed ratio is given as follows

Tip speed ratio $\lambda = \frac{w_t * R}{v}$

Wherev= wind velocity,$w_t * R$=linear velocity.Power Coefficient relation is $C_p = \frac{P_R}{\rho}$

(mechanical power of rotor blades/power of the wind)

Relation between power coefficient, tip speed ratio and pitch angle φ is described as [20]

$$C_p(\lambda, \Phi) = C_1[\frac{C_2}{\beta} - C_3\Phi - C_4\Phi^2 - C_5]\, e^{\frac{-C_6}{\beta}} \qquad (5)$$

c1-c6and x varies according to the manufacturer and is distinct for several wind turbines and β is defined by

$$\beta = \frac{1}{[\left(\frac{1}{\lambda+0.08\Phi}\right)-(\frac{0.035}{1+\Phi^3})]} \qquad (6)$$

where , $\lambda = \frac{R\omega_t}{v}$
R =length of blade,
ω =blade angular velocity.

Mathematical model of wind turbine helps in understanding the dynamic behaviour and helps to design the pitch angle controllers accordingly .Performance analysis is done with the help of mathematical model in order to obtain the desired output for different conditions

Wind Turbine System

Wind turbine system lock diagram is as follows in which drive train model and pitch actuator model are studied.

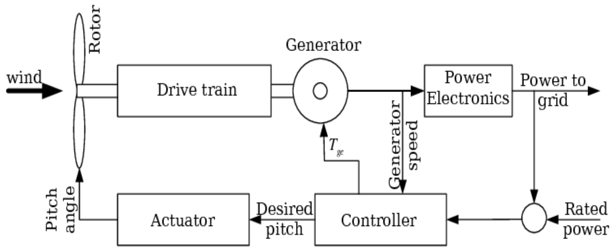


Figure1: Feedback Control of wind turbine

III. PITCH ACTUATOR MODEL

Blades are turned along longitudinal axis by pitch actuator according to the requirement. Pitch control dynamics are studied through this model

$$\frac{d\beta}{dt} = \frac{(\beta_d - \beta)}{T_\beta} \qquad (7)$$

$$T_\beta \frac{d\beta}{dt} = (\beta_d - \beta) \qquad (8)$$

$$T_\beta \frac{d\beta}{dt} + \beta = \beta_d \qquad (9)$$

Applying Laplace transform,

$$T_\beta S\beta + \beta = \beta_d \quad (10)$$

$$\beta(T_\beta S + 1) = \beta_d \quad (11)$$

$$\frac{\beta}{\beta_d} = \frac{1}{(T_\beta S + 1)} \qquad (12)$$

Transfer Function is obtained and time constant is derived from the wind turbine parameters

$$\mathrm{T}_\beta = \frac{(\beta_d - \beta)}{\frac{d\beta}{dt}} = \frac{0.3}{0..6} = 0.5$$

$$\frac{\beta}{\beta_d} = \frac{1}{(0.5S+1)} \qquad (13)$$

Parameters	Values
Generator power (rated)	1000kw
Generated speed(rated)	1500rpm
Turning speed of rotor(rated)	20rpm
Blade radius of wind turbine	35meters
pitch blade reference	0 -90 Degrees
pitch angle rate change	0.6degree/sec
Pitch angle control accuracy	0.3degrees
Coefficient of damping	2N.m/rad/sec
Inertia of drive train	0.75N.m2

Parameter	Description	Parameter	description
J_t	Inertia of wind turbine[kg-m2]	W_t	shaft speed of wind turbine[rad/sec]
J_g	Inertia of generator[kg-m2]	W_g	Shaft speed of generator[rad/sec]
K_a	Coefficient of stiffness[N.m/rad]	θ_t	shaft angle of wind turbine[rad]
B	Coefficient of damping[N.m/rad/sec]	θ_g	shaft angle of generator[rad]
T_t	Torque of wind turbine[N.m]	$1{:}n_{gear}$	Ratio of gear system
T_g	Electro mechanical torque of generator[N.m]		

Table1:Wind turbine parameters

IV. DRIVE TRAIN MODEL

Drive train model is as follows

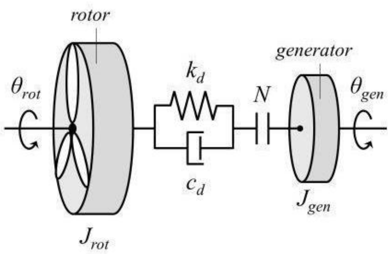


Figure 2:Drive train mechanical model

Dynamics of drive-train are described as :

$$J_T \frac{d(\omega_T)}{dt} = T_T - (K_S \delta\theta_T + B\delta\omega) \qquad (14)$$

$$\frac{d(\delta\theta)}{dt} = \delta\omega \qquad (15)$$

From Newton's second law,

$$J \frac{d(\omega)}{dt} = T - (B\omega) \qquad (16)$$

Applying Laplace transform ,

$$JS\omega = T - (B\omega)(17)$$

$$JS\omega + (B\omega) = T$$

$$(JS+B)\omega = T$$

$$\frac{\omega}{T} = \frac{1}{(JS+B)} \qquad (18)$$

Drive train transfer function is obtained as

$$\frac{\omega}{T} = \frac{\frac{1}{B}}{(\frac{J}{B}S+1)}$$

$$\frac{\omega}{T} = \frac{\frac{1}{2}}{(\frac{0.75}{2}S+1)} \qquad (19)$$

$$\frac{\omega}{T} = \frac{0.5}{(0.375S+1)} (20)$$

V. IMPLEMENTATION OF PID CONTROL

PID tuning is done for the plant and control parameters are obtained by varying values in which near to the optimal desired output is obtained. Simulation model for PID controller is as follows.

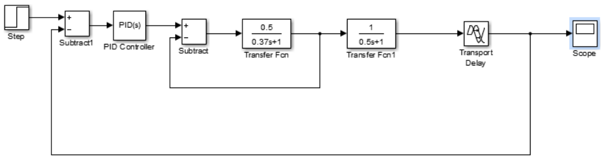
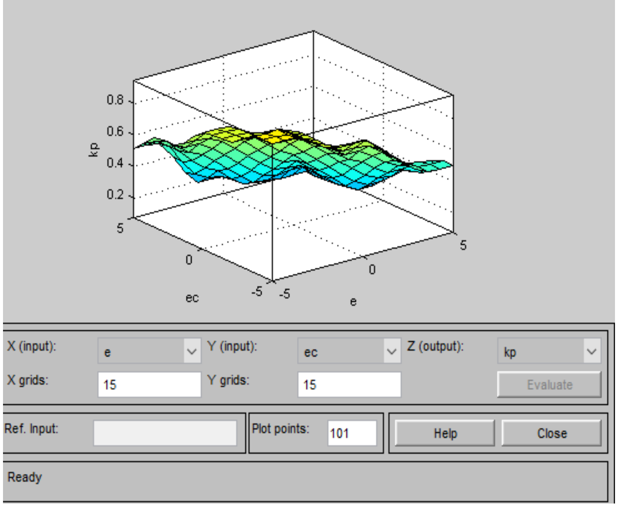


Figure 3: PID controller simulation diagram

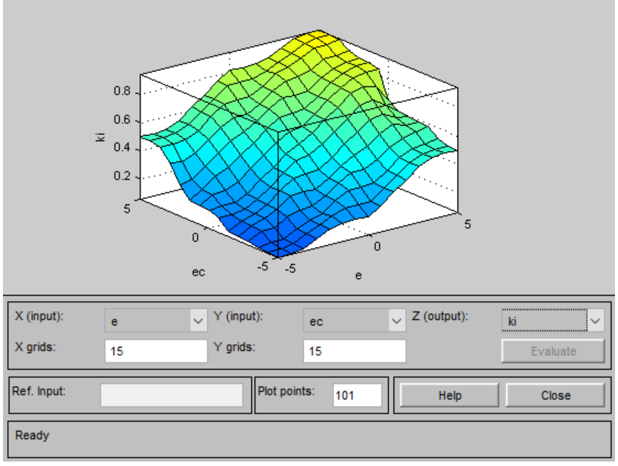
VI. IMPLEMENTATION OF FUZZY LOGIC CONTROL

Kp, Ki, Kd parameters corresponding surface rules are shown in the figures 4, 5 and 6.Rules associated with them are shown in the figure7.Here rules are selected according to the output performance of the controller to get the better results.



X (input): e
Y (input): ec
Z (output): kp
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Figure 4: Kp surface rule



X (input): e
Y (input): ec
Z (output): ki
X grids: 15
Y grids: 15
Ref. Input:
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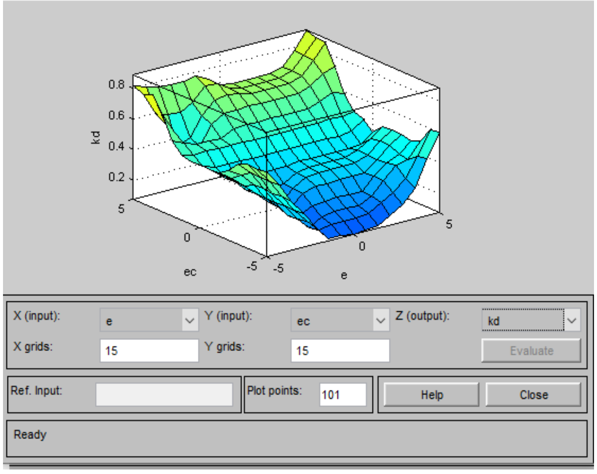
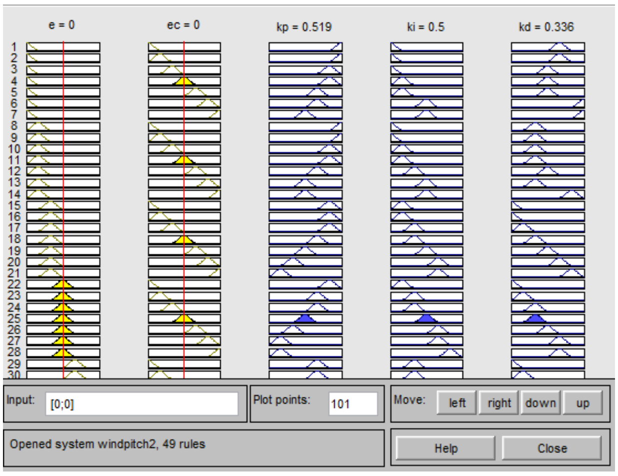
Figure 5.Ki surface rule



X (input): e
Y (input): ec
Z (output): kd
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Figure 6:Kd surface rule



e = 0
ec = 0
kp = 0.519
ki = 0.5
kd = 0.336
Input: [0;0]
Plot points: 101
Opened system windpitch2, 49 rules

Figure 7:Fuzzy Controller rule view

VII. IMPLEMENTATION OF FUZZY ADAPTIVE PID CONTROL

Optimum control gives the best performance analysis among the different control techniques as per the requirement. Fuzzy Adaptive control is one of such technique helps in doing so for a wide range of operating conditions. Relations associated with Adaptive fuzzy control technique is as follows;

$$Kp = (Kp\,(pid)) + (Kpf\,(fuzzy) * Kp(pid))$$

$$Ki = (Ki\,(pid)) + (Kif\,(fuzzy) * Ki(pid))$$

$$Kd = (Kd\,(pid)) + \{Kdf\,(fuzzy) * Kd(pid)\}$$

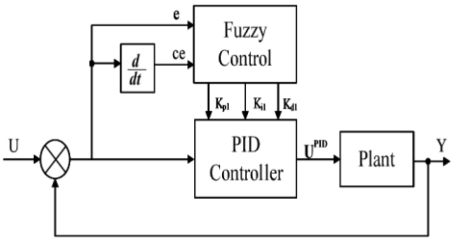


Figure 8:Control block of Adaptive Fuzzy

VIII. SIMULATION OF THE PLANT WITHOUT CONTROLLERS

Simulation of the plant without controllers is as shown and results are compared with plant using different types of controllers.

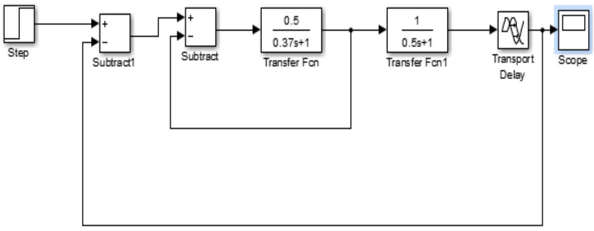


Figure9:Simulink Wind Turbine Model without Controllers

IX. SIMULATION RESULTS

Simulation results for constant speed and pitch angle ‘0’ degrees

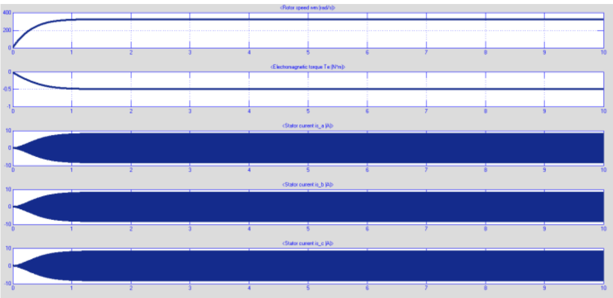


Fig 10:variations of Torque ,speed and stator currents

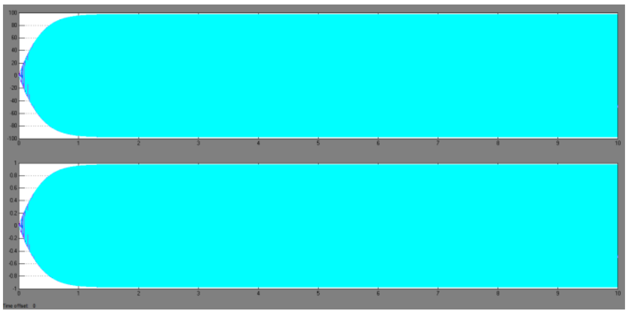


Fig 11: variation of phase Voltage and current of of generator

Simulation with constant speed and pitch angle ‘10’ degrees

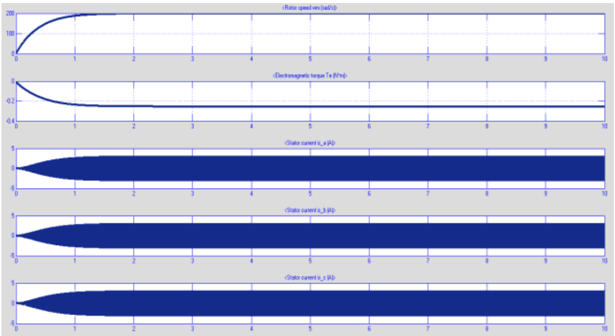


Fig12:variations of Torque ,speed and stator currents

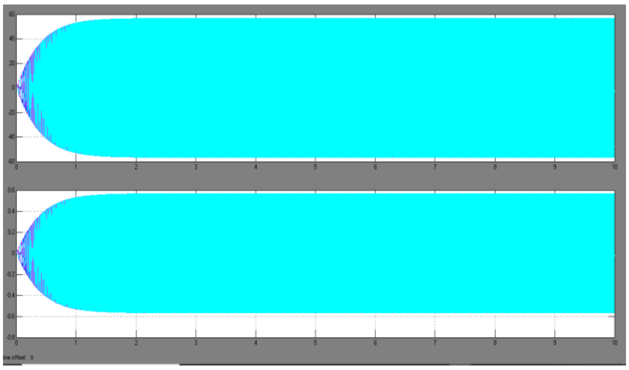


Fig13:variation of phase Voltage and current of of generator

Simulation with variable speeds and with pitch angle ‘ 0’ degrees

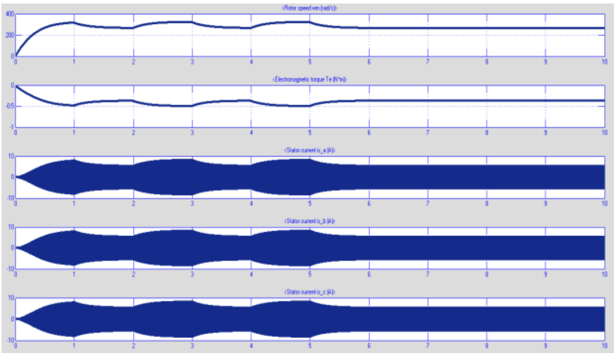


Fig14: variations of Torque ,speed and stator currents

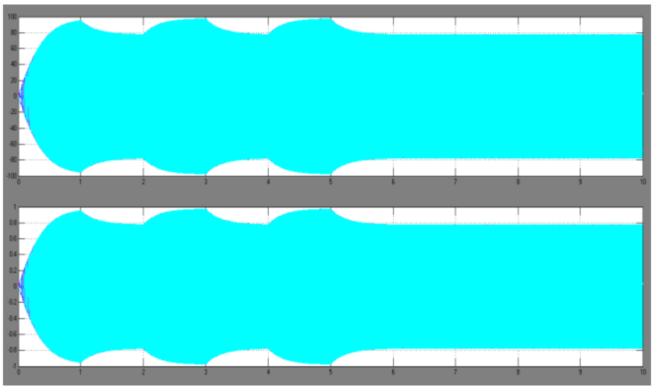


Fig15:variation of phase Voltage and current of of generator

Simulation with variable speeds and with pitch angle ‘10’ degrees

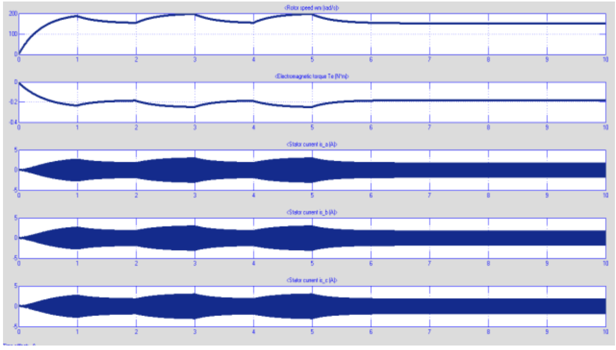


Fig16:variations of Torque ,speed and stator currents

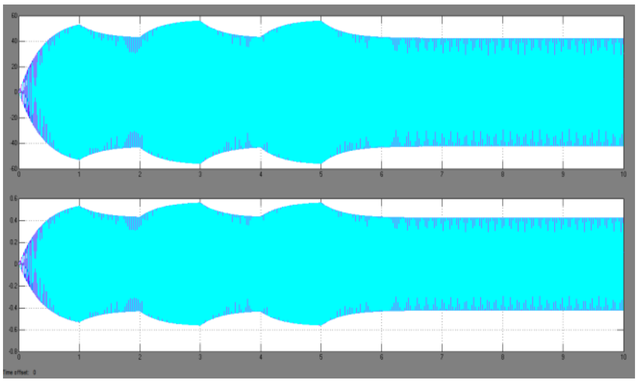


Fig17: variation of phase Voltage and current of of generator

Simulation of plant without Controller

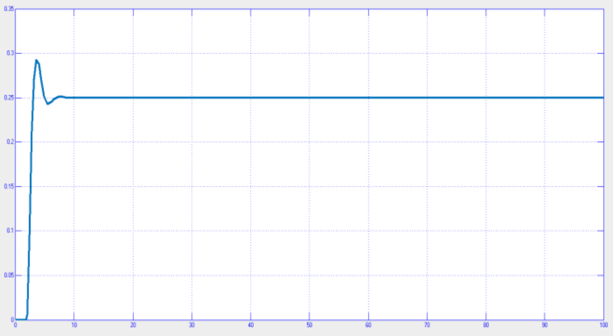


Figure18: step response of plant without control

Simulation of Plant with PID control

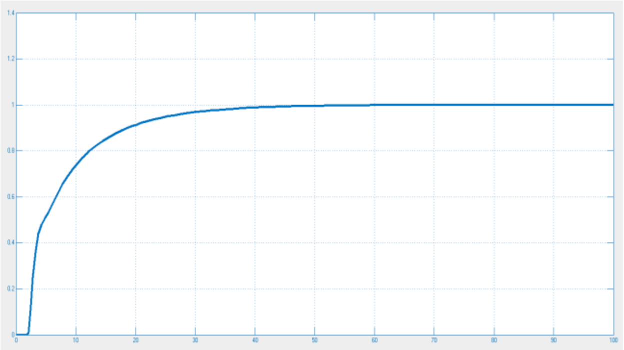


Figure 19:step response with PID

Simulation of the Plant with Fuzzy control

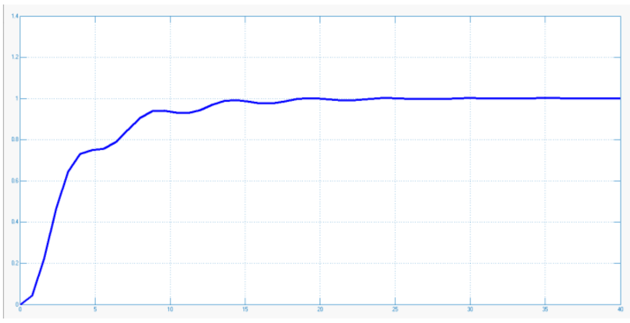


Figure 20: step response with Fuzzy control

Simulation with Adaptive Fuzzy control

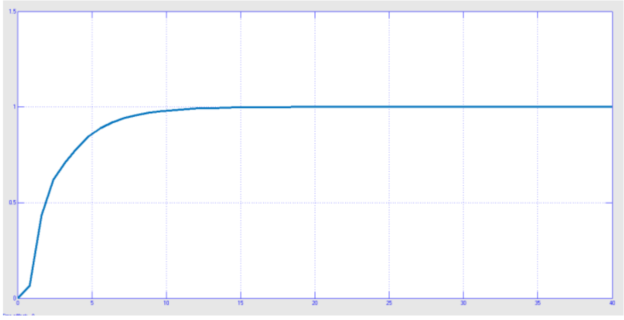


Figure 21:step response of with Adaptive Fuzzy control

X. CONCLUSION AND FUTURE WORKS

Performance of wind generator is analyzed with the help of wind turbine generator model by comparing different parameters of wind generator such as Torque ,voltage, current with different pitches and different wind speeds and observed that pitch and wind speed plays crucial role in extracting maximum power. Mathematical model of wind pitch actuator, drive train are developed and response of the system is studied with out any controllers.

PID ,Fuzzy, Adaptive Fuzzy logic controllers are designed and response is observed with the plant with out controllers. It is observed that Adaptive fuzzy logic controller gives good time response characteristics compared with PID and Fuzzy controller.In future Artificial Intelligence techniques may play major role in obtaining good pitch controller to get desired performance.

REFERENCES

[1]. A.V.A. Macedo, and W.S. Mota, "Wind Turbine Pitch Angle Control Using Fuzzy Logic," IEEE, pp. 1-6, 2012.

[2]. A. Rolán, “An Approach to the Performance-Oriented Model of Variable-Speed Wind Turbines,”978-1-4244-6392-3IEEE, pp 3853-3858, 2010.

[3]. Civelek, Zafer, ErtuğrulÇam, Murat Lüy, and HayatiMamur. "Proportional– integral– derivative Parameter Optimisation of Blade Pitch Controller in Wind Turbines by a New Intelligent Genetic Algorithm," *IET Renewable Power Generation*, vol. 10, pp.1220-1228, 2016.

[4]. C. Tan and H. Wang, "A Review on Pitch Angle Control Strategy of Variable Pitch Wind Turbines," *Advanced Materials Research*, vol. 772, pp. 744-748, 2013.

[5]. Dunne, F. "Optimizing Blade Pitch Control of Wind Turbines with Preview Measurements of the Wind." Order No. 10108716 University of Colorado at Boulder, 2016.

[6]. Han, Bing, Lawu Zhou, Fan Yang, and Zeng Xiang, "Individual Pitch Controller Based on Fuzzy Logic Control for Wind Turbine Load Mitigation," *IET Renewable Power Generation*, vol.10.5, pp.687-693, 2016.

[7]. H. Bevrani, F. Daneshfar& R. P. Daneshmand, "Intelligent Power System Frequency Regulations Concerning the Integration of Wind Power Units," Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-13250-6_15.