Pitch Control of Wind Turbine through PID, Fuzzy and an Adaptive Fuzzy-PID Controller

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Abstract - *Recently, the renewable energy, especially wind energy, has been paid much attention due to the energy shortage and environmental concern. As the penetration of the wind energy into the electrical power grid is extensively increased, the influence of the wind turbine systems on the frequency and voltage stability becomes more and more significant [1]– [4]. Wind turbine rotor bears different types of loads; aerodynamic loads, gravitational loads and centrifugal loads. These loads cause fatigue and vibration in blades, which cause degradation to the rotor blades. These loads can be overcome and the amount of collected power can be controlled using a good pitch controller (PC) which will tune the attack angle of a wind turbine rotor blade into or out of the wind. Each blade is exposed to different loads due to the variation of the wind speed across the rotor blades. For this reason, individual electric drives can be used in future to control the pitch of the blades in a process called Individual Pitch Control. In this thesis work, a new pitch angle control strategy based on the fuzzy logic control is proposed to cope with the nonlinear characteristics of wind turbine as well as to reduce the loads on the blades. A mathematical model of wind turbine (pitch control system) is developed and is tested with three controllers -PID, Fuzzy and an Adaptive Fuzzy-PID. After comparing the three proposed strategies, the simulation results show that the Adaptive Fuzzy-PID controller has the optimum response as it controls the pitch system as well as the disturbances and uncertain factors associated with the system.*

***Key Words*: Energy, Wind-Power, Pitch Controller, PID, Fuzzy Controller, Adaptive Fuzzy-PID Controller.**

1. INTRODUCTION

Energy crisis is the one of the biggest problems faced by people in the twenty-first century. The increase in the demand for electric energy along with the availability of limited fossil fuels have together contributed to the need for shifting from the human dependency on conventional resources for energy to the renewable energy resources. There are three important renewable energy resources available to us: solar, gravitational and geothermal energy. Wind energy is one of the indirect consequence from the incident solar energy, promoting air circulation between hot and cold zones [1]. The kinetic energy present in the wind can be converted to mechanical energy by using a wind turbine and further into electrical energy by using wind turbine generator.

2. MOTIVATION

To increase the power capacity of the wind turbine, larger rotors are being built which causes an increase in aerodynamics and other loads across the blades. The aerodynamics and other loads contribute to fatigue failure which results in decrease in the lifespan and efficiency of the wind turbine [5]. With the help of good pitch angle controllers, the lift profile of the rotor blades can have altered which results in reduction of the aerodynamics and other loads across the blades. This mechanism uses the fact that much of the fatigue causing loads are partly deterministic, periodic and vary slowly over a fixed time [7]. Therefore, in this thesis the main goal is to design an optimum controller to control the pitch angle of the wind turbine system so that the loads on the blades are reduced. Reduction in the loads on the blades will ultimately help to improve the performance, efficiency and power output daily of the wind turbine.

3. Control Techniques of Wind Turbine System:

It The wind energy captured by the turbine can be increased by the following two control strategies: pitch control and stall control. The initial step in both strategies is to check the turbine's power output several times per second using an electronic controller. In case the output power is too high, a signal is send to the blade pitch mechanism because of which the rotor blades turn slightly out of the wind, adapting the attack angle. Once the wind drops, these blades are turned back into the wind. Turbines with this type of control mechanism is known as pitch controlled wind turbines.

In the stall control technique, the rotor blades are fixed onto the hub at a fixed angle. But the geometry of the rotor blade is aerodynamically designed in such a way that it ensures that from the moment the wind speed becomes too high, it is caused turbulence on the side of the rotor blade which is not facing the wind, creating a stall which prevents the lifting force of the rotor blade from acting on the rotor [1]. In the modern turbines, the pitch control technique is used because it helps in controlling the output power simultaneously operating at variable speed to control tip speed ratio and so the power extraction for different wind speeds [8].

4. Model of the Wind Turbine System

The block diagram of a typical wind turbine system model is shown in the figure below [6]. In the following sections, the pitch actuator model and the drive terrain model are explained.

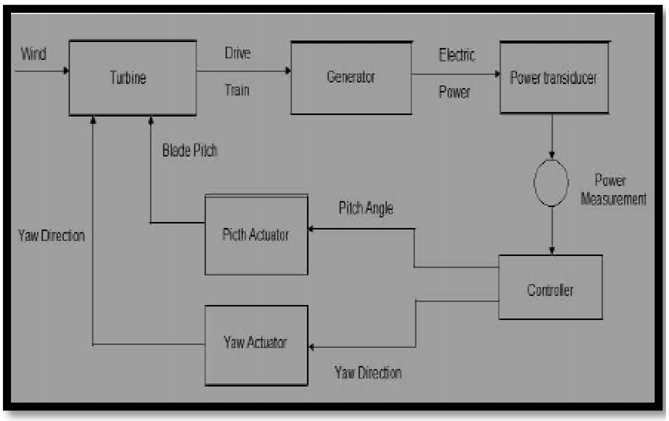

Figure 1: Wind Turbine System Feedback Control System Model

5. Pitch Actuator Model

The pitch actuator is used to turn blades along their longitudinal axis. The actuator model describes a dynamic behavior between a pitch demand, from the pitch controller and measurement of pitch angle [6]

The change in pitch angle is given by

$$d\beta / dt = (\beta_d - \beta) / T_\beta$$

$$T_\beta . d\beta / dt = (\beta_d - \beta)$$

$$T_\beta . d\beta / dt + \beta = \beta_d$$

Applying Laplace transforms, we get

$$T_\beta . \beta_s + \beta = \beta_d$$

$$\beta_s (T_\beta . + 1) = \beta_d$$

$$\beta / \beta_d = 1 / (s . T_\beta + 1)$$

This is the required Transfer Function. The value of time constant of pitch actuator, T p can be calculated from initial parameters of Wind Turbine [6] shown in Table I.

Table 1: Parameters of Wind Turbine

Rated generator power , P_e	1000 KW
Rated generator speed, W_g	1500 rpm
Rated turning speed of rotor, W_t	20 rpm
Wind turbine blade radius,R	35 m
Reference pitch angle, β_d	0 to 90 deg
Rate of change of pitch angle	0.6 deg / sec
Control accuracy of pitch angle	0.3 deg
Damping coefficient, B	2 N.m./ rad /sec
Drive-train inertia , J_t	0.75 N.m2

$$T_\beta = (\beta_d - \beta) / (\frac{d\beta}{dt}) = 0.3 / 0.6 = 0.5$$

$$\beta / \beta_d = 1 / (0.5s + 1)$$

6. Drive Terrain Model

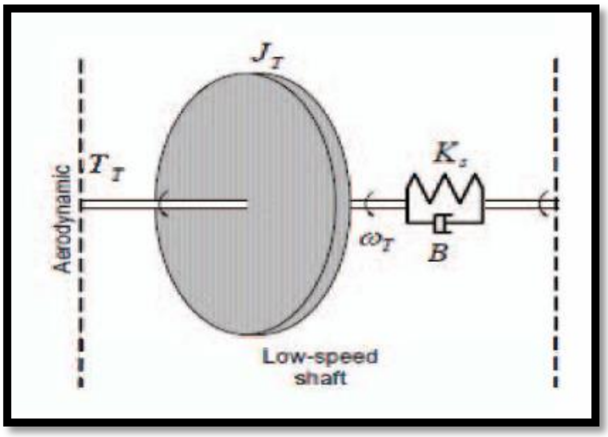

Figure 2: Mechanical model of drive train

The parameters taken while modelling the drive train are shown in Table 2

Table 2: Mechanical Model Parameters of Drive Train

Parameter	Description	Parameter	Description
J_T	Wind turbine inertia [kg.m2]	w_T	Wind turbine shaft speed [rad/s]
J_G	Generator inertia [kg.m2]	w_g	Generator shaft speed [rad/s]
K_s	Stiffness coefficient [N.m/rad]	θ_T	Wind turbine shaft angle [rad]
B	Damper coefficient [N.m/rad/sec]	θ_g	Generator shaft angle [rad]
T_T	Wind turbine torque [N.m]	$1{:}n_{gear}$	Gear ratio
T_G	Generator electro-mechanical torque [N.m]		

The dynamics of drive-train are described by following differential equations

$$J_T.d/dt(w_T) = T_T - (K_S\delta\theta + B\delta w)$$

$$d/dt(\delta\theta) = \delta w$$

Then by using Newton's second law of motion, we get

$$Jdw/dt = T - Bw$$

Applying Laplace transform on both sides

$$J.Ws = T - BW$$

$$J.Ws + BW = T$$

$$W(Js + B) = T$$

$$W/T = 1/(Js + B)$$

This is the required first order Transfer function of Drivetrain. This can also be represented as

$$W/T = (1/B)/((J/B).s + 1)$$

$$W/T = (1/2)/((0.75/2).s + 1) = 0.5/(0.375s + 1)$$

Thus, the mathematical model of wind turbine is derived.

7. Implementation of Conventional PID Controller

The Simulink model of wind turbine pitch control system with conventional PID Controller is shown in Fig. 3 and the control parameters for the PID controller are shown in Fg.4.

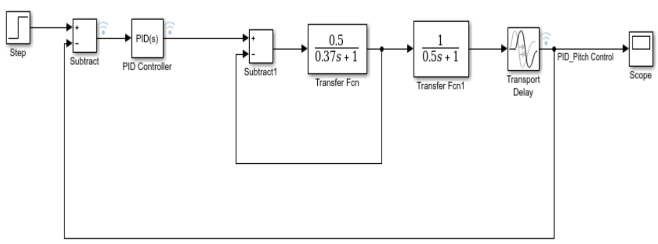

Figure 3: Simulink diagram of PID Controller Implementation

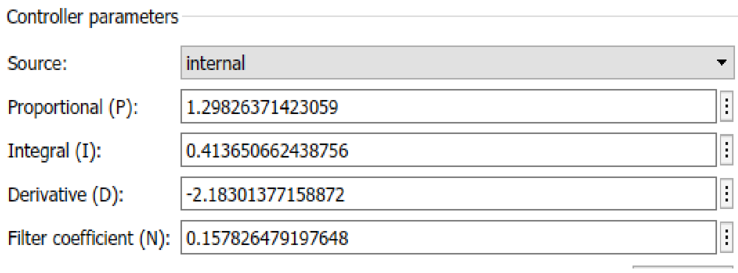

Figure 4: PID Controller Parameters

8. Implementation of Fuzzy Logic Controller

First the rules-surface diagrams for each parameter Kp, Ki, Kd are shown in the figures 5,6 and 7. Then all the 49 rules are displayed in the figure 8. Finally, the Simulink model of wind turbine pitch control system with fuzzy logic is shown in Fig. 9 and the subsystems are shown in Fig 10 and Fig 11.

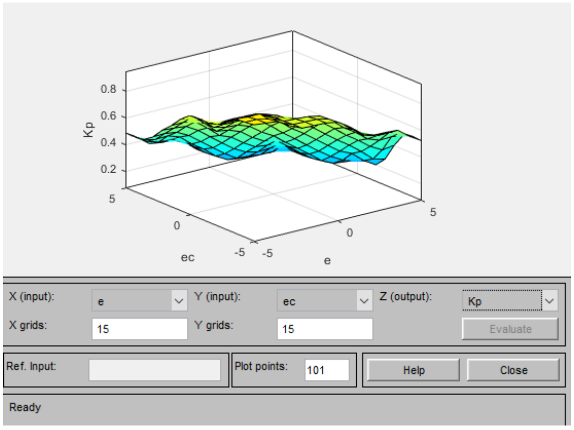

Figure 5:Surface Rule Diagram for Kp

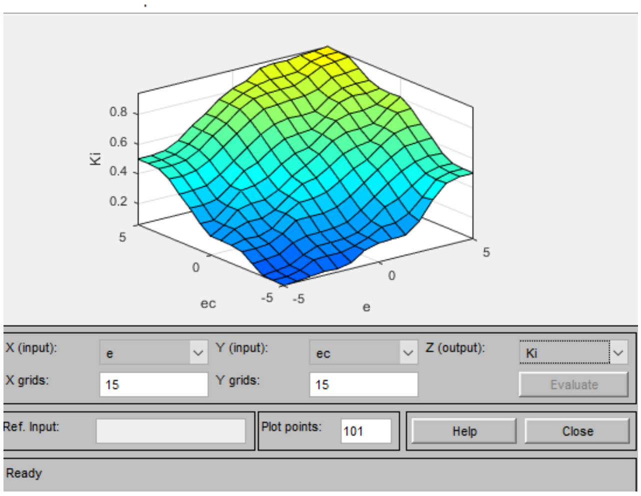

Figure 6:Surface Rule for Ki

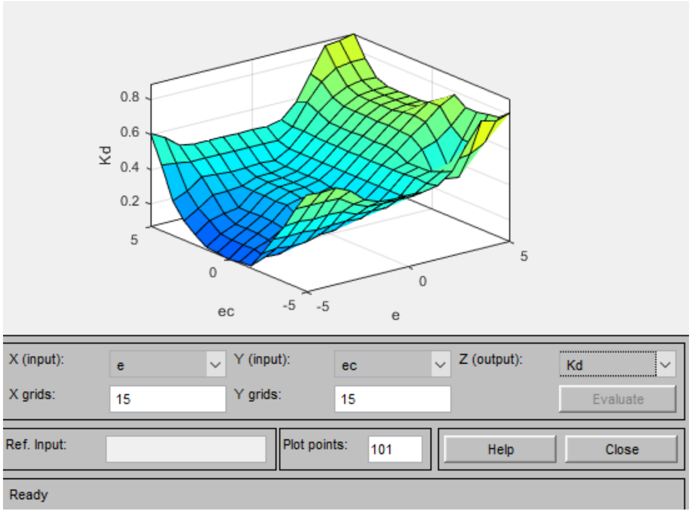

Figure 7:Surface Rule Diagram for Kd

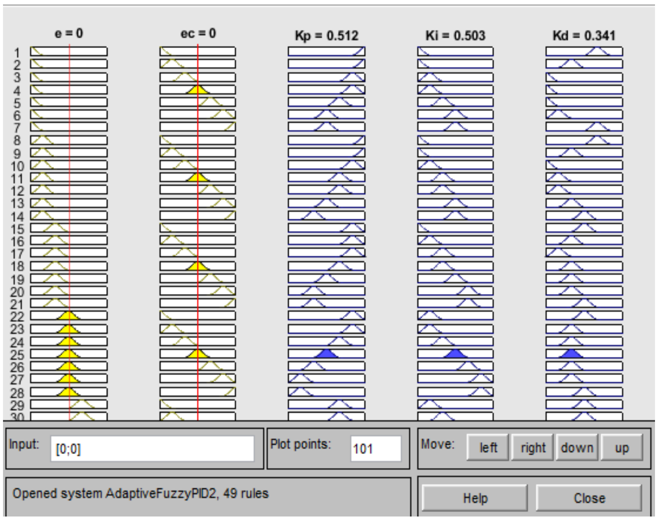

Figure 8:Rule Viewer for Fuzzy Controller

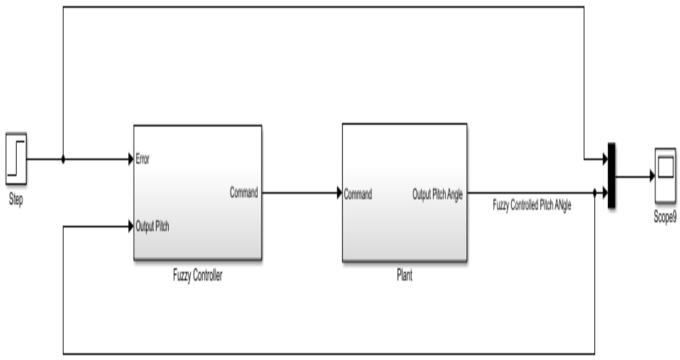

Figure 9: Simulation diagram of fuzzy controller for pitch control system

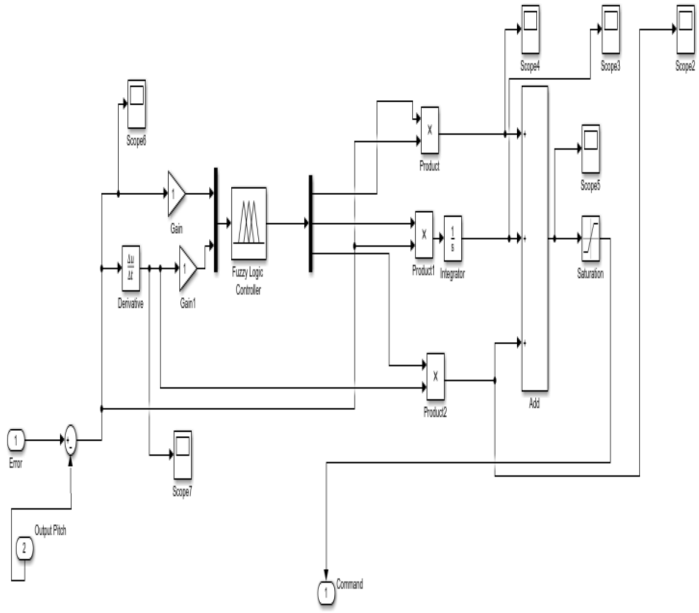

Figure 10: Fuzzy Controller Subsystem

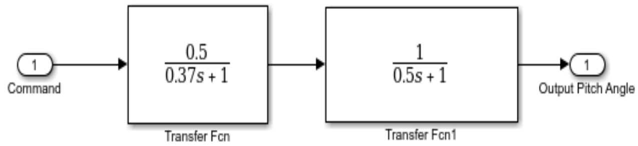

Figure 11: Plant Subsystem

9. Implementation of Fuzzy Adaptive PID Controller

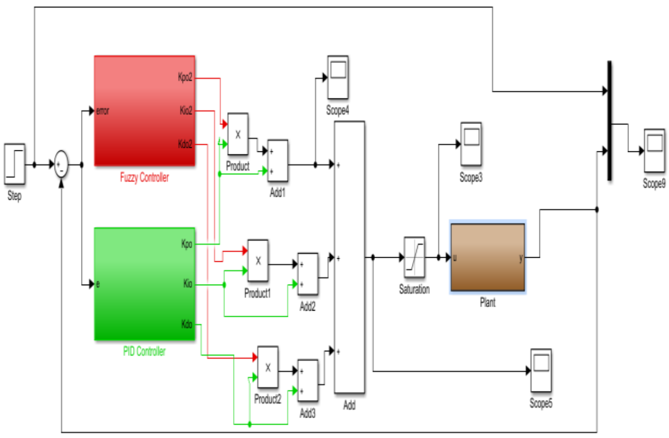

Figure 12: The Simulink model of wind turbine pitch control system with fuzzy adaptive PID

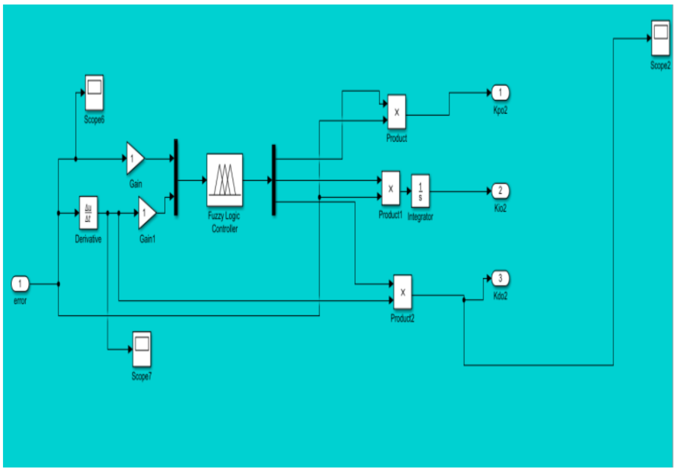

Figure 13: Fuzzy Controller Subsystem

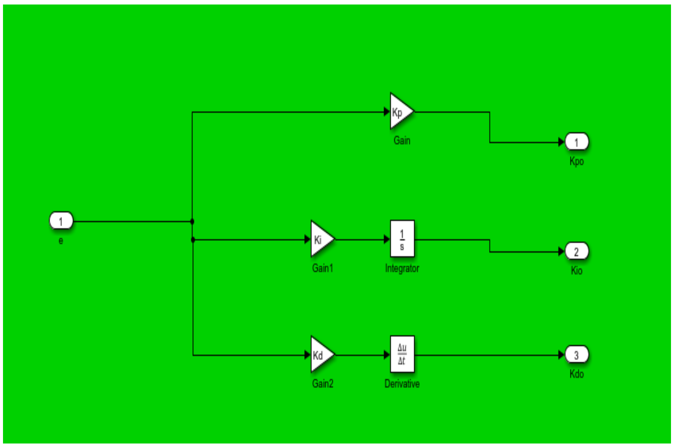

Figure 14: PID Subsystem

Values for PID are Kp= 0.5, Ki=0.75, Kd=0

10. Simulation and Result of System without Controllers

The figures below show the Simulink model of wind turbine without any controllers and the output graph

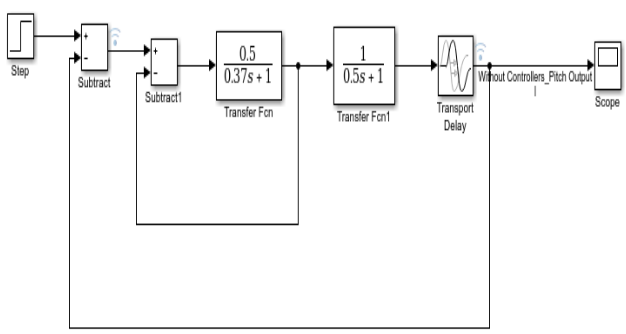

Figure 15: Wind Turbine System Without Controllers

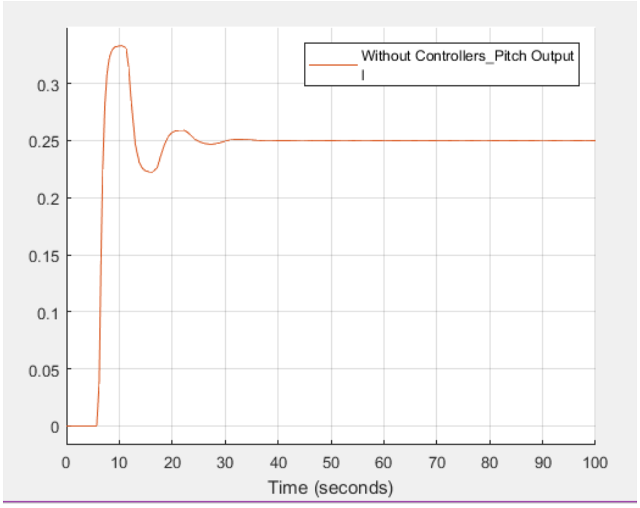

Figure 16:The unit step response of wind turbine without controllers

We see that the desired output is not reached as well Settling time very high. Also the Overshoot and Undershoot is high. Hence, we need to implement controller to overcome these drawbacks.

11. Simulation of the Plant with PID Controller

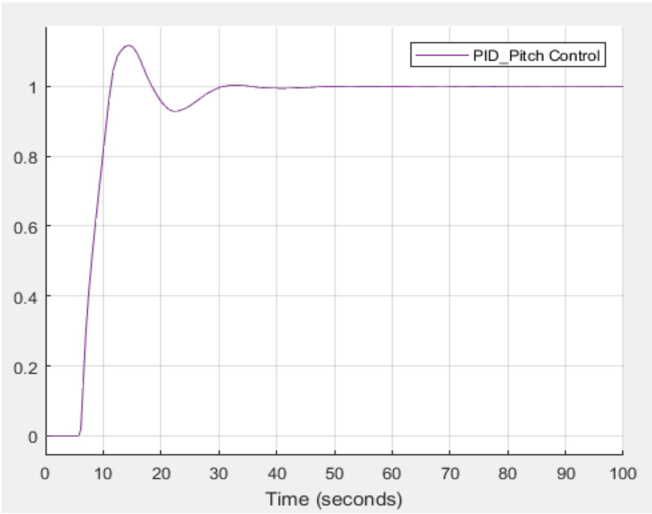

Figure 17:The unit step response of wind turbine with PID controller

The unit step response of wind turbine pitch control system is shown in Fig. 17. Time domain specifications are observed from the response graphs and tabulated in Table 6. With PID controller, we observed less rise time, settling time and peak overshoot when compared to the wind turbine model without any controllers.

12. Simulation of the Plant with Fuzzy Controller

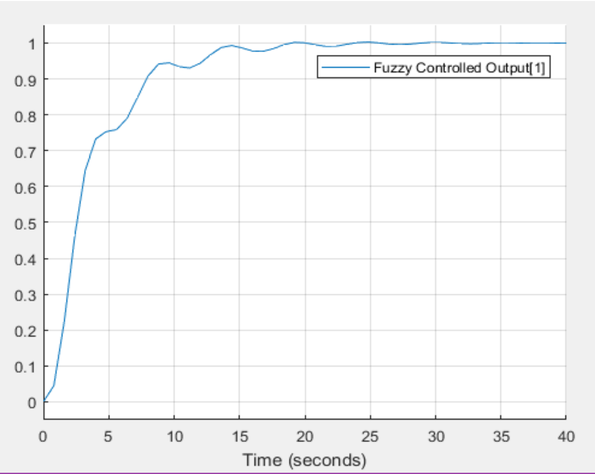

Figure 18:The unit step response of wind turbine with Fuzzy controller

The unit step response of wind turbine pitch control system is shown in Fig.18. Time domain specifications are observed from the response graphs and tabulated in Table 6. With fuzzy controller, we observed more rise time and less settling time compared to conventional PID controller and a very little overshoot.

13. Simulation of the Plant with Adaptive Fuzzy-PID Controller

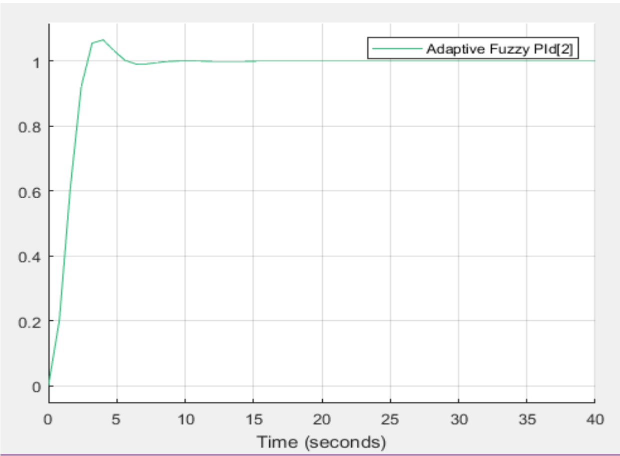

Figure 19:The unit step response of wind turbine with Adaptive Fuzzy PID controller

The unit step response of wind turbine pitch control system is shown in Fig. 19. Time domain specifications are observed from the response graphs and tabulated in Table 6. With Fuzzy adaptive PID controller, we observed very less settling time compared to both conventional PID and fuzzy logic controller and almost no overshoot. However, the performance is not better in terms of rise time when compared to conventional PID controller.

14. Comparison of Simulation Results of the Plant using PID, Fuzzy and an Adaptive Fuzzy-PID Controller

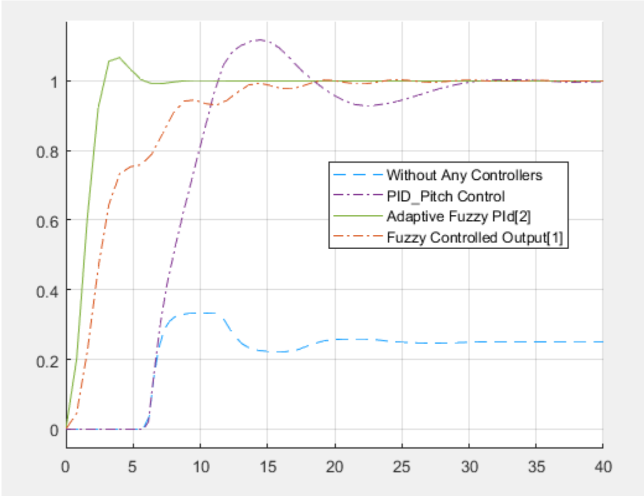

Figure 20:Comparision of unit step response of wind turbine pitch controllers

Table 3:Comparison of Time Domain Specifications of Pitch Control System for Unit Step Input Using

Time Domain	Without Controller	PID	Fuzzy	Adaptive Fuzzy-PID
Delay Time(s)	8	6	4	3.5
Rise Time(s)	0.813	4.21	6.81	0.63
Settling Time(s)	38	27	25	8
Peak Overshoot (%)	32.157	11.8	0.5	0.02
Steady State Error	0.75	0	0	0

From the Table above and Fig.20, we can see that the Adaptive Fuzzy PID controller has the best response when compared to the other controllers. The settling time is fast and overshoot is very less, hence the Adaptive Fuzzy PID gives a better control for the pitch angle of the wind turbine system.

15. CONCLUSIONS AND FUTURE WORK

In this paper, we developed the wind turbine pitch control system mathematical model and simulated with conventional PID, fuzzy and fuzzy adaptive PID controllers using MATLAB/Simulink to achieve optimum response. We compared the responses in terms of time domain specifications for unit step input using conventional PID, fuzzy and fuzzy adaptive PID controllers. Even though, the PID controller produces the response with lower delay time and rise time, it has oscillations with a peak overshoot of 11.8%, which causes the damage in the system performance. To suppress these oscillations fuzzy logic controller is proposed to use. From the results, it can be observed that, this controller can effectively suppress the oscillations and produces smooth response, but it has more delay time, rise time and settling time. By using fuzzy adaptive PID controller, where the PID gains are tuned by using fuzzy logic concepts, the results showed that this design can effectively suppress the steady state error and the system has minimum delay time, fast rising, quick settling and stability. From the analysis, we conclude that fuzzy adaptive PID controller gives relatively fast response for unit step input. This technique is much better to realize the control of pitch system and to guarantee the stability of wind turbine output power.

In future, one can use artificial neural networks to control the pitch angle of the wind turbine system and check its performance with the Adaptive Fuzzy PID controller. Also, Individual pitch control method can be used along with the Adaptive Fuzzy PID controller to improve the overall performance of the system.

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BIOGRAPHIES

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