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Study of PID Controller Based Pitch Actuator System for Variable Speed HAWT using MATLAB

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Abstract: As the energy demand and greenhouse gases emission is increasing day by day the popularity of renewable energy systems is also being raised. One of the most popular renewable energy systems over the past decade has been the wind energy or wind turbines. Wind turbine extracts kinetic energy from the wind. Currently much research has concentrated on improving the aerodynamic performance of wind turbine. Variable speed horizontal axis wind turbines use blade pitch control to meet specified objectives for three regions of operation named low wind, medium wind and high wind conditions.

In this paper a control strategy is being developed for variable speed horizontal axis wind turbine which will allow the turbine to run at its maximum efficiency. For this purpose the PID controller based pitch actuator system is used to control the aerodynamic power of wind turbine. MATLAB Simulink power system tool is used to develop the model of PID controller. In this paper a model for the simulation of the PID controller based pitch actuator system is constructed using properly selected sub blocks. Step response of this PID controller based pitch actuator system will be analyzed. The above presented model can be a useful tool for wind power industry to study the behavior of wind turbines.

Keywords: Wind Energy Conversion System, Wind Energy Conversion System, Wind Turbine Characteristics, Pitch Actuator System Modelling

I. INTRODUCTION

Global warming is considered as one of the most serious problems facing the global community. Certain gases, such as carbon dioxide, when released in the atmosphere through the burning of fossil fuels, create a "greenhouse effect." Clean, renewable energy solutions, such as wind, solar, and hydroelectric systems, that do not rely on fossil fuels for energy generation help curb the effects of global warming. Although wind has been used as an energy source for centuries, only within the last 30 years have advances in technology allowed wind energy to become an increasingly important part of the nation’s energy mix.

Currently, the Indian wind energy sector has an installed capacity of 17,365.03 MW (as on August 31, 2012). In terms of wind power installed capacity, India has the fifth largest capacity in the World. Wind power accounts for 6% of India's total installed power capacity, and it generates 1.6% of the country's power. Research to extract the maximum power out of wind energy is an essential part of making wind energy much more viable and attractive.

II. WIND ENERGY CONVERSION SYSTEM

By definition a wind turbine is a rotating device that converts the kinetic energy in wind into mechanical energy. Wind turbines can be classified into two types based by the axis in which the turbine rotates.

A. HORIZONTAL AXIS WIND TURBINE

In horizontal axis wind turbine the axis of rotation is horizontal with respect to the ground (and roughly parallel to the wind stream). The propeller-type rotor is mounted on a horizontal axis. The main rotor shaft and electrical generator are generally at the top of a tower for a horizontal axis wind turbine (HAWT). The rotor needs to be positioned into the wind direction by means of a tail or active yawing by a yaw motor. The turbine shaft is generally coupled to the shaft of the generator through a gearbox which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator. HAWTs are sensitive to the changes in wind direction and turbulence, which have a negative effect on performance due to the required repositioning of the turbine into the wind flow.

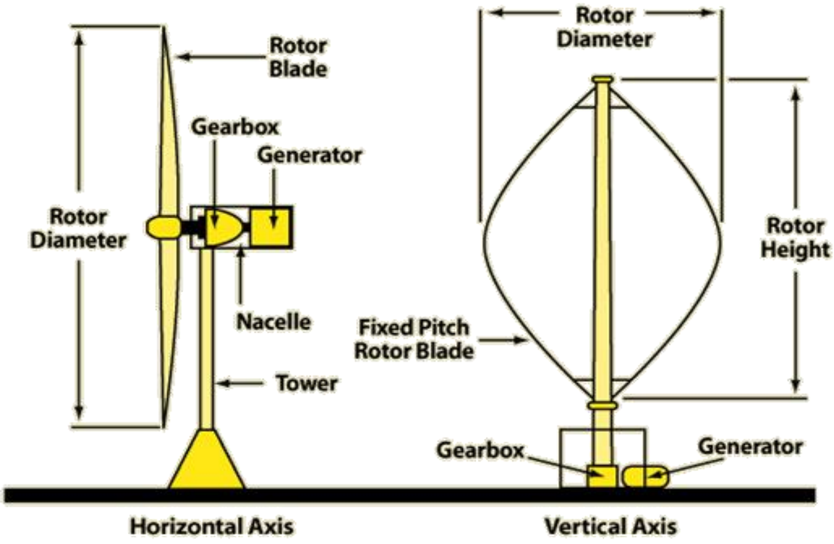

Figure 1 HAWT and VAWT Source: American Wind Energy Association

B. VERTICAL AXIS WIND TURBINE

The vertical axis wind turbines have the axis of rotation vertical with respect to the ground (and roughly perpendicular to the wind stream). The structure of these wind turbines are such that they can capture wind irrespective of its direction, thus changes in wind direction have fewer negative effects on this type of turbine. It is of great benefit in places where the wind direction keeps varying. However, the overall efficiency of these turbines in producing electricity is lower than HAWTs. Unlike the HAWT where the gearbox and generator are placed on top of the tower, the generator and gearbox are generally placed near the ground. This makes it more accessible and easier for maintenance. But they do not come without any drawbacks. Some designs produce pulsating torque which results in fatigue. It is also difficult to mount vertical-axis turbines on towers. They are often installed nearer to the base on which they rest. As the wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine.

III. WIND TURBINE CHARACTERISTICS

A. CUT IN SPEED

At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the cut-in speed and is typically between 3 and 4 meters per second.

B. RATED OUTPUT WIND SPEED

As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly as shown in figure. However, typically somewhere between 12 and 17 meters per second, the power output reaches the limit that the electrical generator is capable of. This limit to the generator output is called the rated power output and the wind speed at which it is reached is called the rated output wind speed.

C. CUT OUT SPEED

As the speed increases above the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the cut-out speed and is usually around 25 meters per second.

IV. PITCH CONTROLLED WIND TURBINE

In a pitch controlled wind turbine the electronic controller of turbine checks the power output of the turbine several times per second. When the power output cross a threshold limit, it sends an actuating signal to the blade pitch

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mechanism which quickly turns the rotor blades slightly out of the wind. On the other hand, the blades are turned back into the wind whenever the wind goes down again. Thus the rotor blades have to be able to twist around their longitudinal axis (to pitch). This results in variation of the force exerted by the wind on the rotor shaft. The pitch mechanism is usually operated using hydraulics. The advantages of this type of control are good power control, assisted startup and emergency stop.

The maximum rate of change of the pitch angle is in the order of 3 to 10 degrees/second. The Pitch angle controller has a slight over-speeding of the rotor above its nominal value can be allowed without causing problems for the wind turbine structure. Pitch actuators at the roots of the blades directly control the aerodynamic power input to the rotor.

The momentary wind conditions can be divided into four categories, as shown by the power curve in Figure 2

I. Low wind, the generator is not connected to grid
II. Medium wind, the generator is connected, but does not produce nominal power
III. Higher wind, the generator is connected and produces nominal power
IV. Stop wind, the generator is disconnected and the turbine is stopped

When the wind speed is very low and the rotor does not rotate or rotates with a very low speed, the pitch angle will be approximately 45^o. This will provide a maximum start moment to the rotor, permitting a quicker start when the wind speed increases. The controller will then pitch the blades to 0^o, that is, into the wind. The rotating speed for the rotor and the generator will increase towards the nominal level, which the controller will try and maintain with speed control. When the wind speed decreases and the produced power become negative, the generator will be disconnected from the grid and the controller will control the speed.

If the wind continues to decrease, the rotating speed will decrease below the nominal value and the rotor will run freely. At medium wind speed, the rotating speed is regulating to the nominal value, and if the pitch angle can be maintained at 5^o, (or equivalently, there is enough energy in the wind) the generator is connected to the grid. When the generator is connected and there is sufficient energy in the wind to produce nominal power, the pitch angle is regulated as a function of the wind speed. This function, called OptiTip, is precisely calculated, simulated, and evaluated based on measurements. This function is implemented in turbines to optimize the aerodynamics of the blades, which will, in turn, optimize energy production.

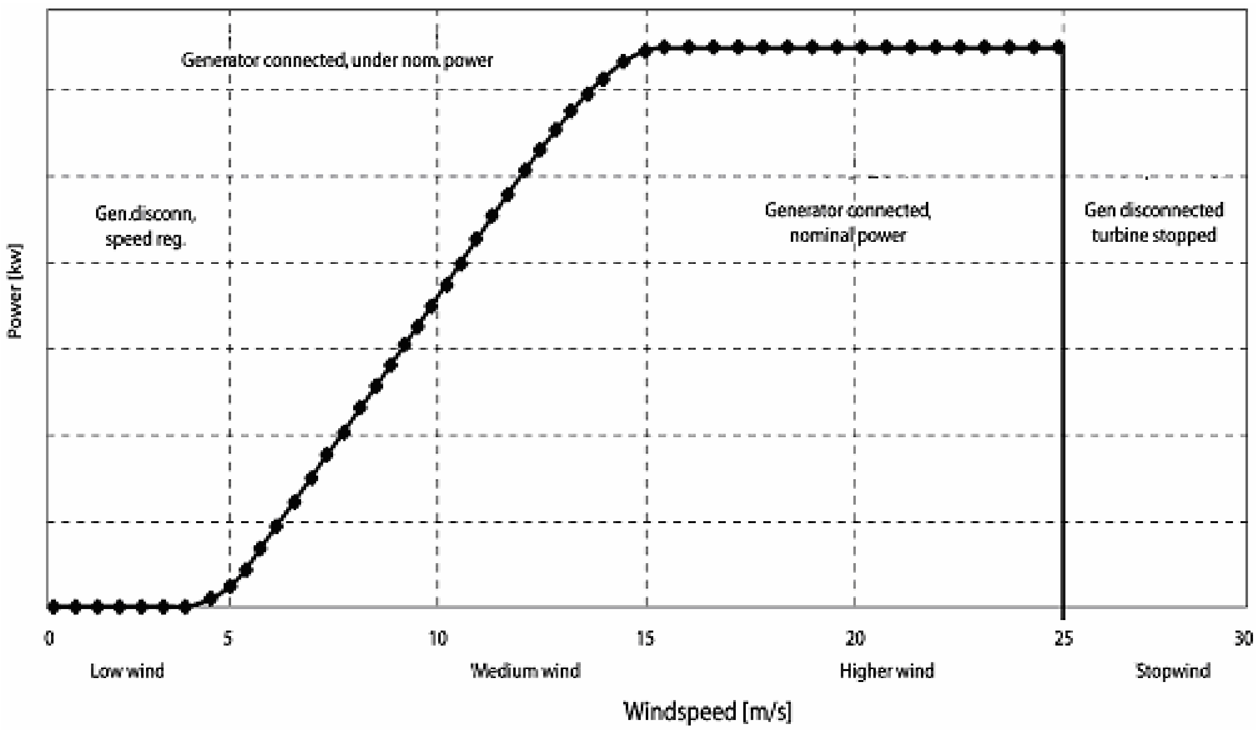

Figure 2 Power Curves

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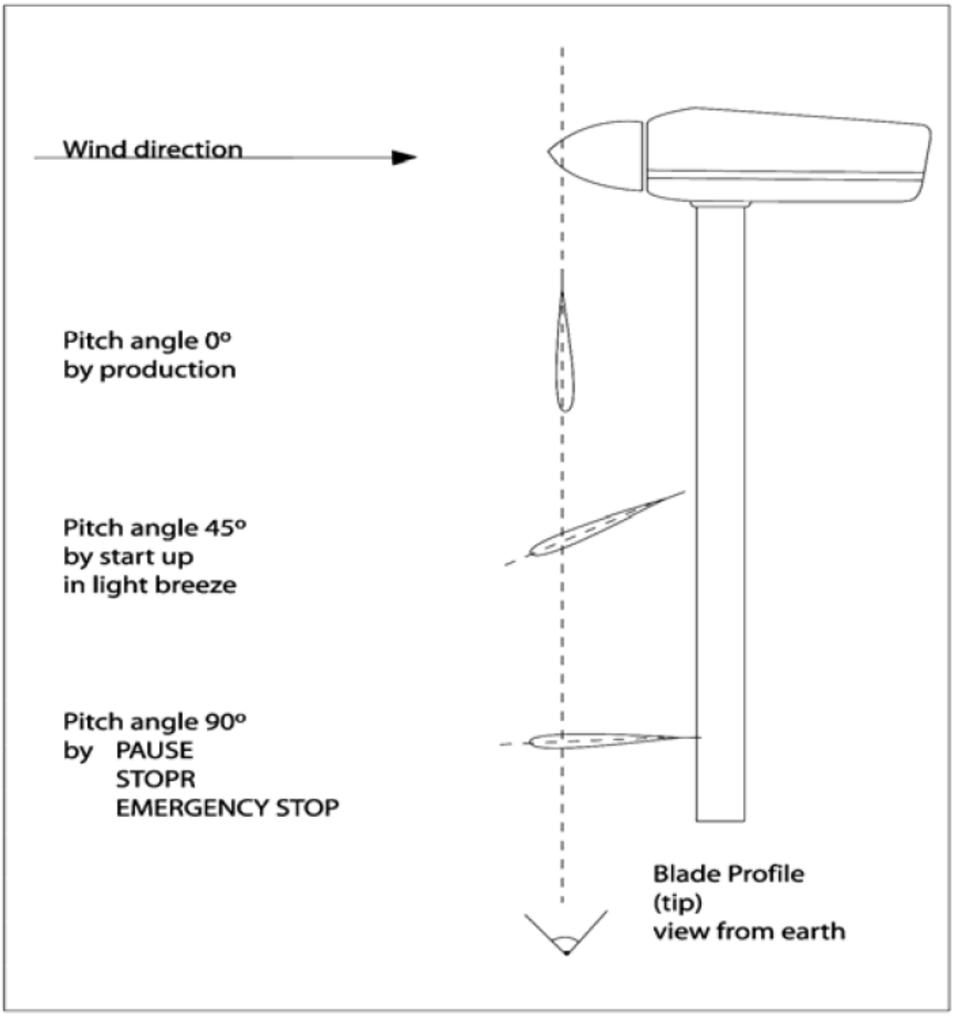

Figure 3 Pitch Settings at different operating states

V. PITCH ACTUATOR SYSTEM MODELLING

For modeling of pitch actuator system three models have been developed in MATLAB. The three models are:

1. Proportional Control based Pitch Actuator System
2. Pitch Actuator System with constant value of pitching speed
3. PID Control based Pitch Actuator System

All these models are tested against a standard pitch angle input signal which is shown in figure 4 below:

A. *PROPORTIONAL CONTROL BAESD PITCH ACTUATOR SYSTEM*

The Simulink model for the proportional control system is shown in figure 5. The input, “beta_ref” is received as input which is passed through a saturation filter. The purpose of the saturation filter is to limit the pitch input within the range of -3 degrees to 90 degrees which is the range of valid pitch angle values. Next comes the gain block defining the proportional gain of the system. The block named “Saturation 1” is also a saturation filter which defines the limiting values of pitching speed. The maximum and minimum permissible values of pitching speed in this system are 8 degrees per unit time and -8 degrees per unit time respectively.

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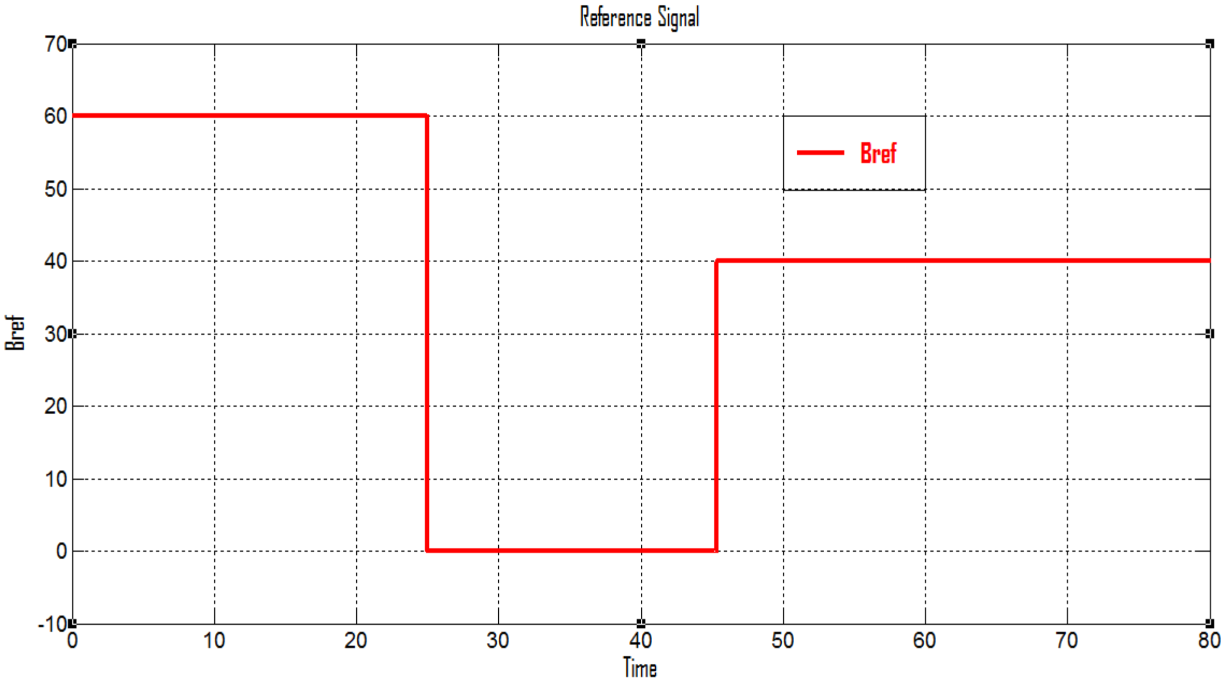

Figure 4 Reference input used in simulations

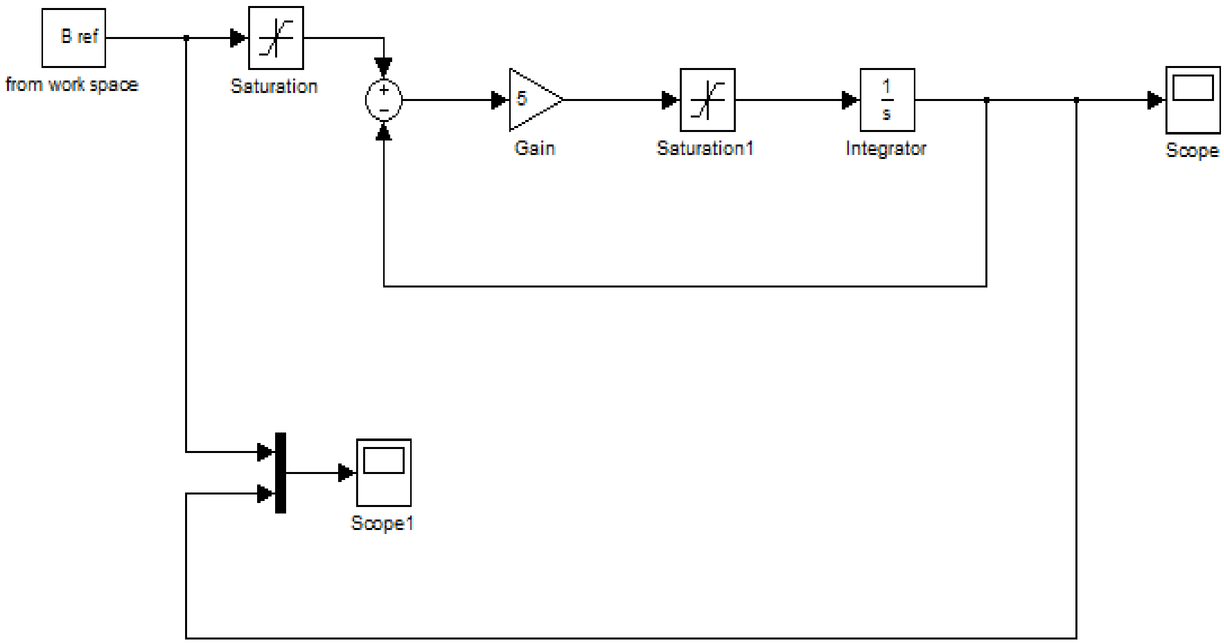

Figure 5 Block diagram of proportional control based pitch actuator system

The response of this system has been observed for four different values of proportional gain and shown in figure 6, 7, 8 and 9.

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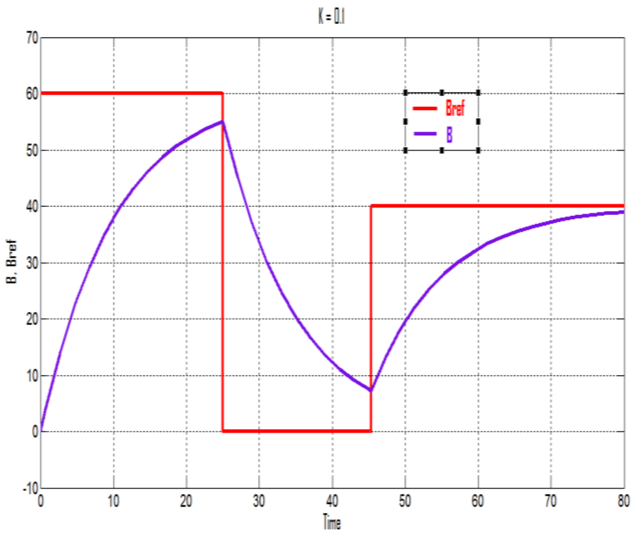

Figure 6 Pitch angle response when K = 0.1

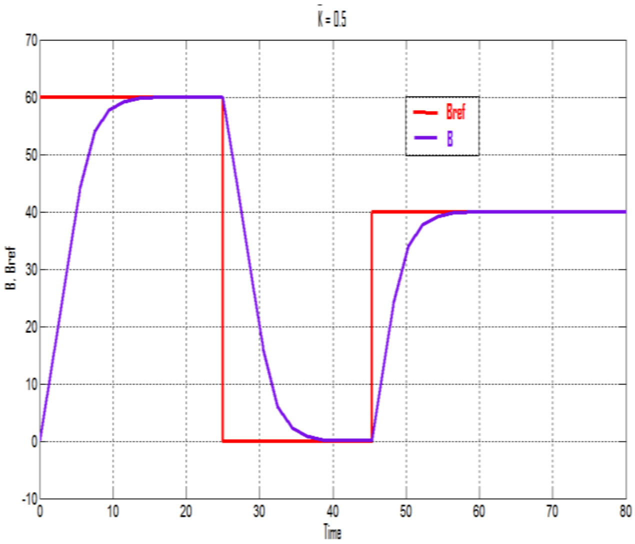

Figure 7 Pitch angle response when K=0.5

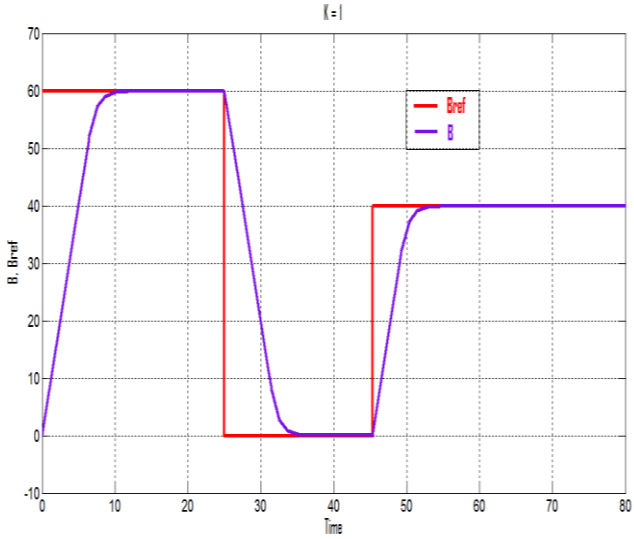

Figure 8 Pitch angle response when K=1

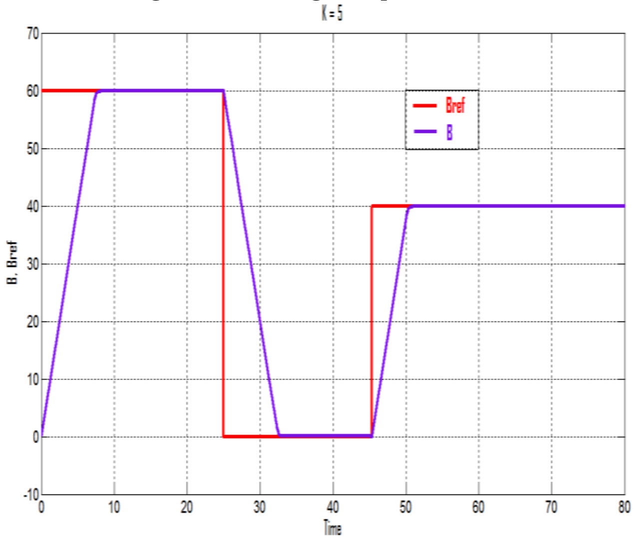

Figure 9 Pitch angle response when K=5

B. *PITCH ACTUATOR SYSTEM WITH CONSTANT VALUE OF PITCHING SPEED*

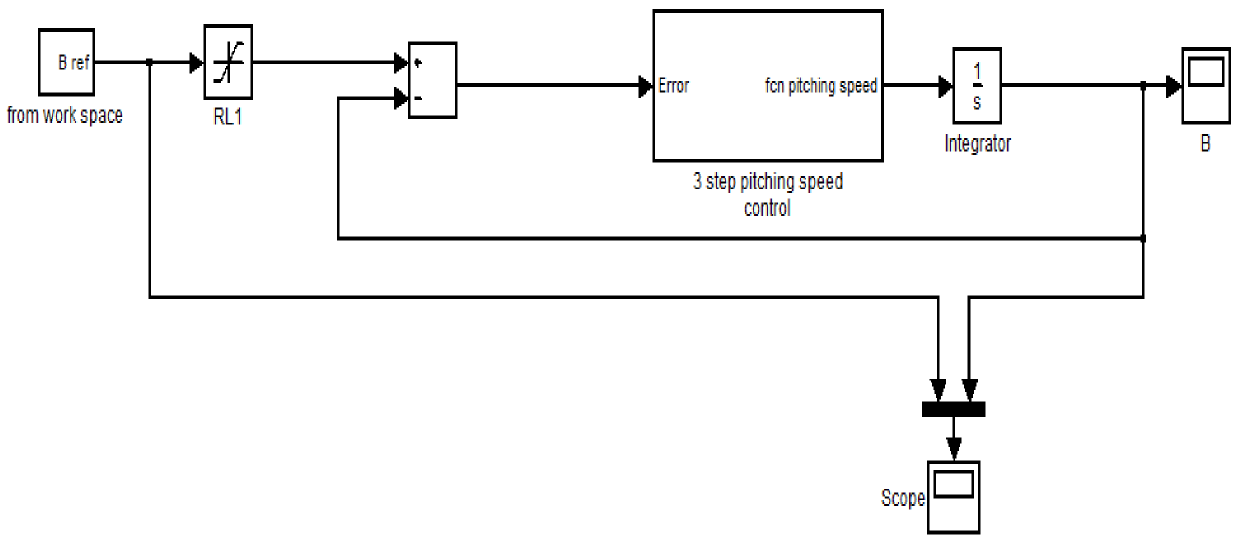

Figure 10 Block Diagram of Pitch Actuator System with constant pitching speed

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In this model, the pitching speeds of the blades are to be kept constant. This way, the actuator system is not only simple but the stress on the blades is also considerably reduced. The main disadvantage of the first version actuator is that we cannot predict which pitch angle will be needed at that time when the actuator has reached command value. At this time the wind condition may have changed and then we will need another setting. The second version compares ‘on line’ the proper criterion and then decides if to increase or decrease the pitch angle, without predicting the future angle like in the first version.

The Simulink model used has been shown in figure 10 above. An embedded model block has been used where it has been defined that:

If (error in pitch angle is positive)

then pitching speed = s (where “s” is a previously chosen value of speed)

If (error in pitch angle is negative)

then pitching speed = (-s)

Else pitching speed = 0

The response of this system has been observed for three different values of pitching speed viz. 5 deg./sec, 8 deg./sec, and 15 deg. /sec. The result of these tests has been shown in figure 11 below. It can be seen that if the pitching speed is set too low, it cannot effectively track the input signal causing an error to prevail at all times. Also a very high value of pitching speed demands a very high torque to be exerted on the blades which may lead to undesirable stresses on the blade and actuator.

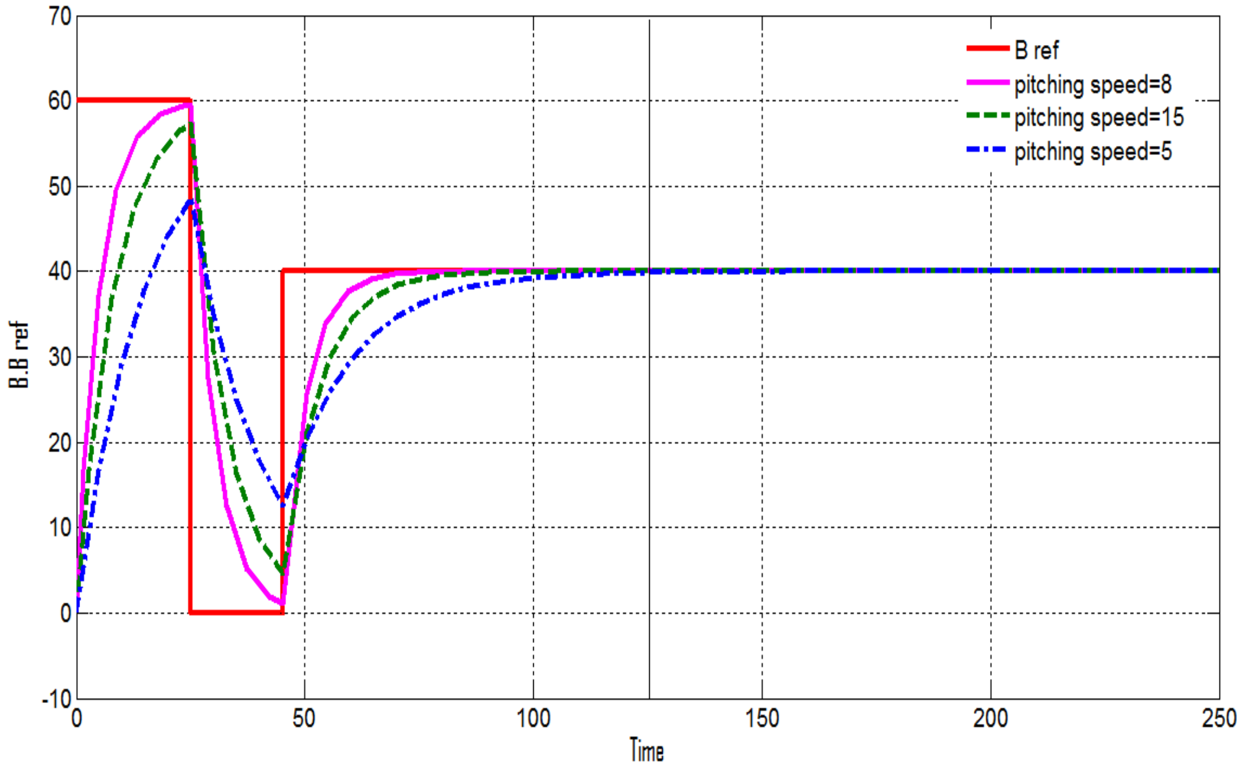

Figure 11 Pitch angle response of Pitch Actuator System with constant pitching speed

C. *PID CONTROLLER BAESD PITCH ACTUATOR SYSTEM*

The third model which has been studied is the PID control based Pitch Actuator System. The gains of the PID controller are changed one at a time and the response has been noted. The Simulink model for the actuator is shown in figure 12 below:

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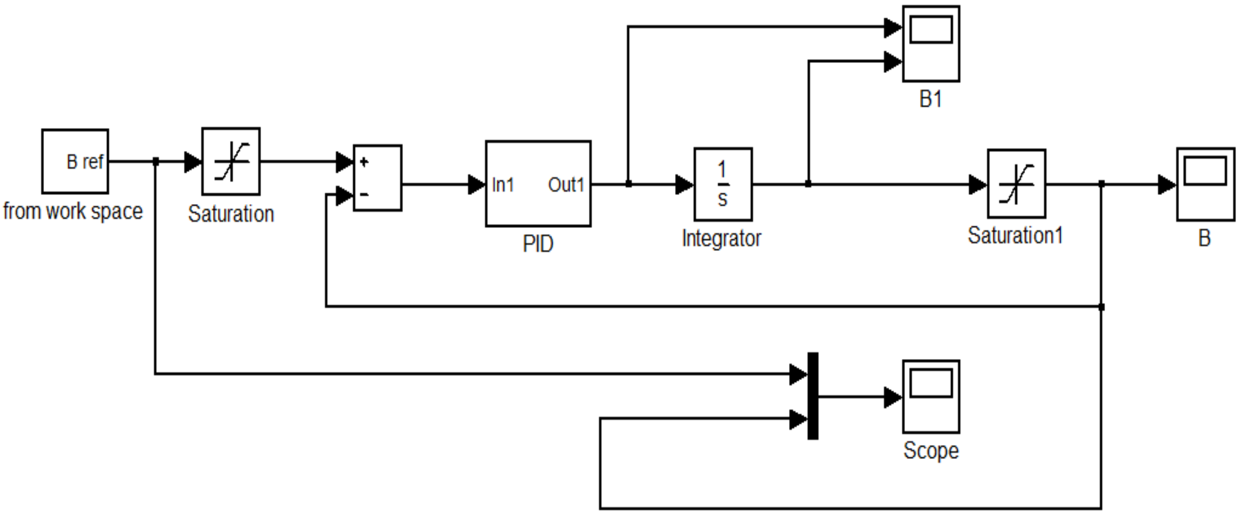

Figure 12 Block diagram of PID controller based pitch actuator system

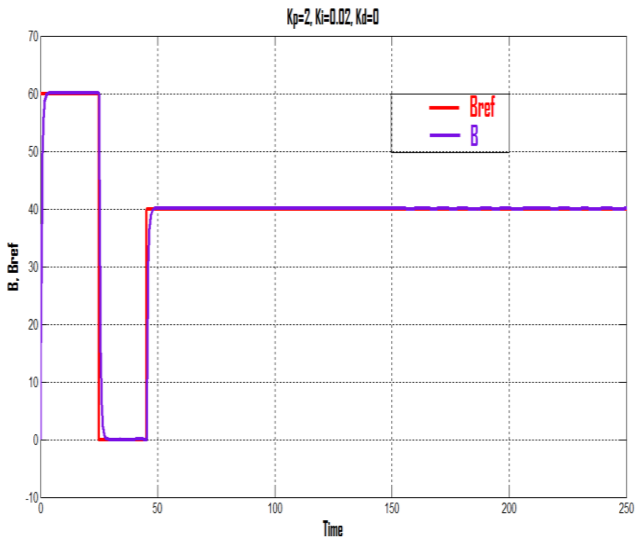

Figure 13 Pitch angle response of PID controller when K_p=2, K_i=0.01 and K_d=0

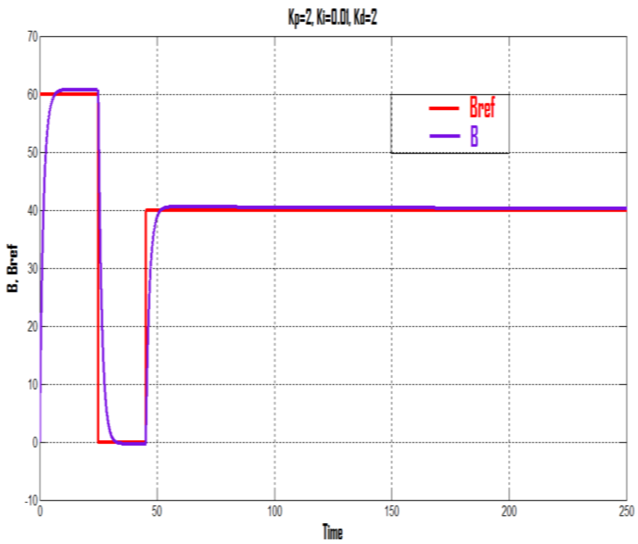

Figure 14 Pitch angle response of PID controller when K_p=2, K_i=0.01 and K_d=2

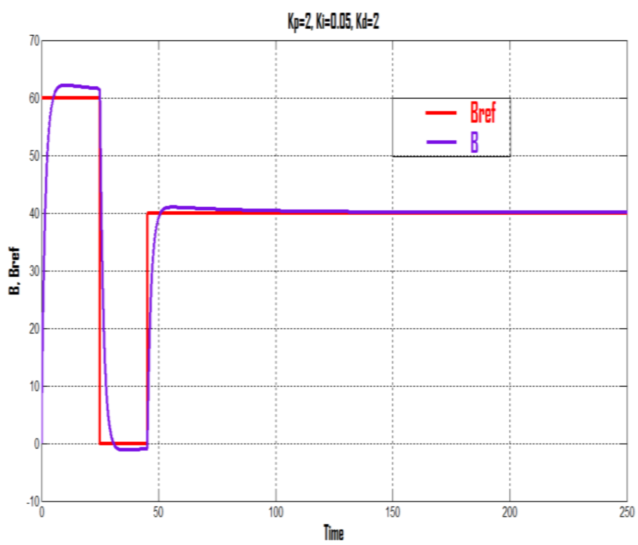

Figure 15 Pitch angle response of PID controller when K_p=2, K_i=0.05 and K_d=2

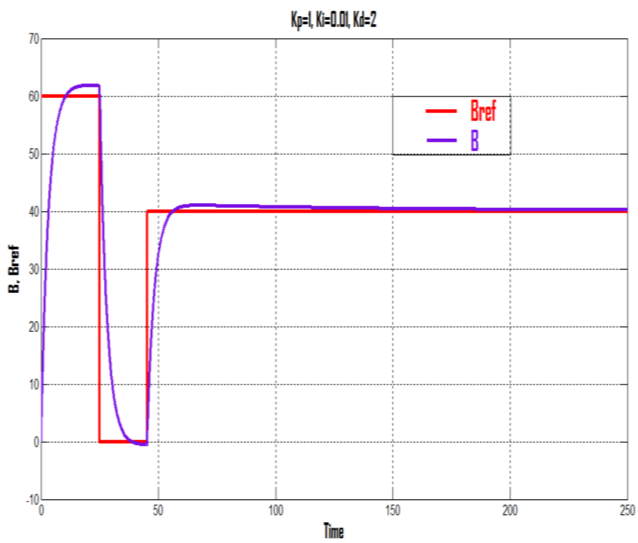

Figure 16 Pitch angle response of PID controller when K_p=1, K_i=0.05 and K_d=2

The response of this system has been observed for different values of proportional gain K_p, integral gain K_i and derivative gain K_d and shown in figure 13, 14, 15 and 16 above

As can be seen, the system produces a decent response in the first case where the gains are K_p=2, K_i=0.01 and K_d=0. The general approach is that the values of gains, once set, are not changed.

VI. CONCLUSION

A complete model for the study of PID controller based pitch actuator system for variable speed horizontal axis wind turbine is developed using MATLAB-Simulink. A variety of component blocks have been used from various simulink libraries and also from other compatible tool boxes such as power system blocksets, control system toolbox etc. The user can easily select or modify the step sizes, tolerances, simulation periods, output options, etc. with the help of appropriate menu from within simulink blocks. Any parameter within any block or subsystem of the model can be easily modified. The values of time response parameters of the pitch actuator system are observed and the fine tuning of the controller parameters is performed. For PID control based pitch actuator system when the values of K_p, K_i and K_d is taken as 2,0.01 and 2 it gives decent response. It can be seen that if the pitching speed is set too low, it cannot effectively track the input signal causing an error to prevail at all times. Also a very high value of pitching speed demands a very high torque to be exerted on the blades which may lead to undesirable stresses on the blade and actuator.

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