Pitch Control of Horizontal Axis Wind Turbine

A thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology

in

Electrical Engineering

By

R Vijay

(107EE026)

Aditya Kumar Sethi

(107EE011)

Department of Electrical Engineering

National Institute of Technology, Rourkela

2011

Pitch Control of Horizontal Axis Wind Turbine

A thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology

in

Electrical Engineering

By

R Vijay

(107EE026)

Aditya Kumar Sethi

(107EE011)

Under the guidance of

Prof. S Rauta

Department of Electrical Engineering

National Institute of Technology, Rourkela

2011

ACKNOWLEDGEMENT

We would like to express our deepest gratitude towards our supervisor, **Prof. S Rauta**, *Associate Professor, Department of Electrical Engineering* for his guidance and support. He provided us with motivation and constant encouragement throughout the period this work was carried out. His readiness for consultation at all times, his educative comments, his concern and assistance have been invaluable.

We are grateful to **Dr. B D Subudhi**, *Professor and Head, Dept. of Electrical Engineering* for providing necessary facilities in the department.

Date:

R Vijay
107EE026

Aditya Kumar Sethi
107EE011

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the Project entitled “**Pitch Control of Horizontal Axis Wind Turbine**” submitted by **R Vijay** and **Aditya Kumar Sethi** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Electrical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

Place: NIT Rourkela (Prof. S Rauta)

Date: Department of Electrical Engineering

NIT Rourkela

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Wind energy is fast becoming the most preferable alternative to conventional sources of electric power. Owing to the perennial availability of wind and the considerable range of power control, wind turbines are now coming up in almost all parts of the world. In the early days of development, wind turbines were designed to rotate at constant speed through pitch control or stall control. The modern wind turbines implement pitch control in order to tap maximum energy at wind speeds lower than rated wind speed.

In this project, three different models of pitch actuator system have been studied and a discrete time adaptive PID model has been proposed where the gains of the PID controller are modified based on the time response parameters of the previous time cycle. It is expected to offer better control over a wide range of wind speeds.

Keywords: Pitch control, renewable energy, adaptive PID Control, Wind Energy Conversion Systems

1

Introduction

1.1 Historical Development

Wind has served mankind as a source of power for over 3000 years now. Before steam engine came into existence, wind power was used for sailing ships. In the later years, with the advent of wind mills, wind power was being converted to mechanical power through wind mills for grinding grains and pumping water. Wind mills have also been known to drive water through pipes for irrigation. With the development of the steam engine, the dependence on wind energy dropped drastically. This also resulted in lower interest in research into the field on wind power.

In the late nineteenth century, electricity had become the currency of energy and thermal and hydel power plants became the favoured sources of electricity. But not every country had the luxury of fossil fuel or water resources. Denmark, being one of those, invested in the development of wind turbines to provide for its electricity demand. The 1890s saw Denmark lead the path in the development of wind turbines. (Bhadra S N, 2010)

Nuclear power has also emerged as an alternate source of power. It has the capacity to provide for the world's demand of power, but it does not come without hazards. Extreme exposure to radiation has been realised as one of the worst maladies to occur to man. Since the occurrence of the Chernobyl disaster, the world has shown reluctance to depend wholly on nuclear power. This led to exhaustive research into developing alternate sources of energy for generation of electricity.

Wind energy, being one of the cleanest sources of electricity, has emerged as one of the most preferred sources for electricity generation. It is also abundant and can be tapped in a cost effective way. The maximum extractable energy from the 0-100 m layer of air has been estimated to be of the order of 10^{12} kWh per annum, which is of the same order as hydroelectric potential. (Bhadra S N, 2010)

The present day sees wind power is an entirely different way. Incentives are being offered to customers who are seeking wind power instead of thermal power for their domestic requirements. This has been a welcoming change to the wind energy fraternity as the number of customers opting for wind power has been showing a rise.

1.2 Power contained in wind

The power contained in the wind is the kinetic energy of the flowing air mass per unit time.

If v_{wind} is the velocity of the wind, A is the rotor swept area and ρ is the density of air, then

Kinetic energy of the wind is given by

$$KE = \frac{1}{2} m v_{wind}^2 \tag{1}$$

Volume of air passing through swept area per unit time $= A v_{wind}$

Mass flow rate = $\rho A v_{wind}$

Power contained in the wind $P = \frac{1}{2} (mass\ flow\ rate) v_{wind}^3$

$$P = \frac{\rho A}{2} v_{wind}^3 \tag{2}$$

2

Wind Turbines

2.1 Basic Concepts

By definition, a wind turbine is a rotary device that extracts energy from the wind. If the energy captured from the wind is used for machining purposes such as cutting lumber or grinding stones, the machine is called a windmill. If on the other hand, it is used for pumping water, it is referred to as a wind pump.

Wind turbines can be broadly classified into two types:

a. Horizontal axis wind turbine

b. Vertical axis wind turbine

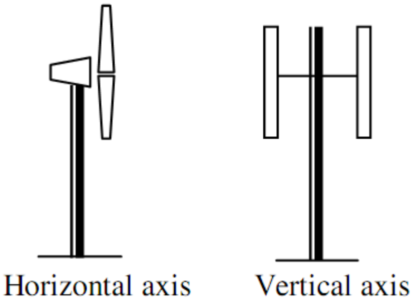


Fig. 2.1: Schematic diagram of a horizontal axis wind turbine and a vertical axis wind turbine

2.2 *Horizontal axis wind turbine*

The main rotor shaft and electrical generator are generally at the top of a tower for a horizontal axis wind turbine (HAWT). A horizontal axis wind turbine has a design which demands that it should be pointed to the wind to capture maximum power. This process is called yawing. 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. Fig. 2 shows the internal equipment in a horizontal axis wind turbine.

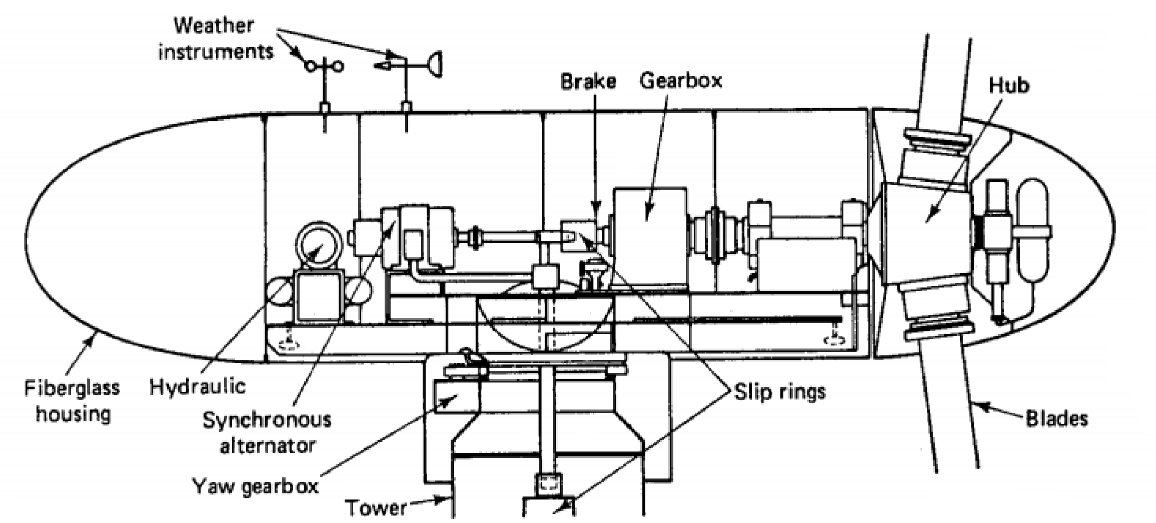


Fig. 2.2: Internal equipment in a horizontal axis wind turbine.(Johnson, 2006)

Horizontal Axis Wind Turbines can be further divided into three types:

i. Dutch Windmills

ii. Multi-blade Water-pumping Windmills

iii. High-speed Propeller type Wind Machines

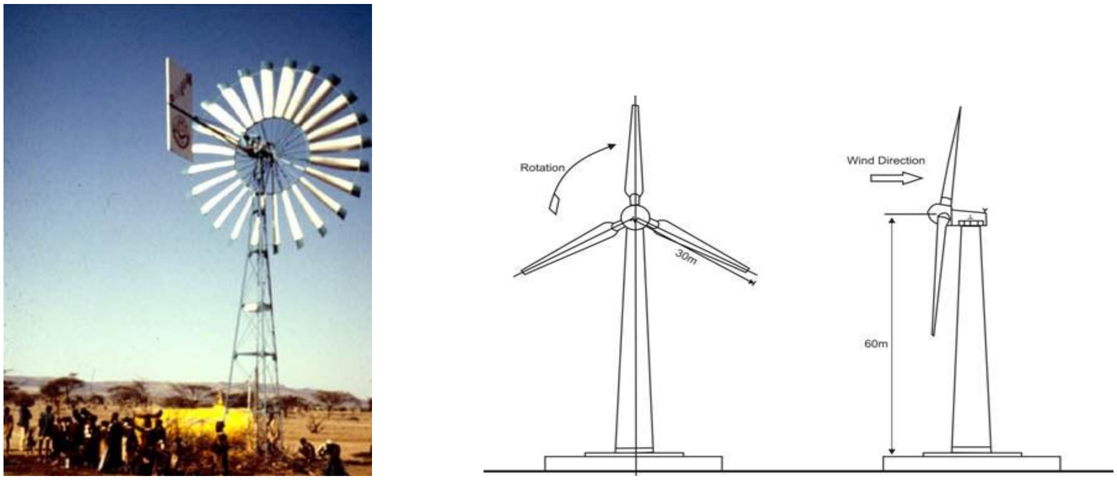
2.2.1 Dutch windmills

Dutch windmills were the frontrunners to the wind mills widely used across Europe for grinding grains. They operated on the thrust exerted by the wind. Their blades were inclined at an angle to the wind to result in rotation. Sails or wooden slats were used to manufacture these blades.(Wind Turbine)

Fig. 2.3: A Dutch Windmill

2.2.2 Multi-blade water-pumping windmills

As the name suggests, the Multi-blade Water-pumping Windmills have a large number of blades. The blades are generally made of wooden or metallic slats. This is used to rotate the shaft of a water pump. The location of the mill is not governed by the availability of wind, but by the availability of water. Hence, it is designed to be able to operate at low wind speeds. Their remote locations and purpose of use make their efficiency to take the backseat. Reliability, sturdiness and low cost are the prime criteria for the design of these wind mills. A tail vane is generally mounted on the turbine to orient it to face the wind.



(a) (b)

Fig. 2.4 (a): Multi-blade Water-pumping Windmill (How to build a Wind pump (Principles), (b): High speed Propeller type Wind Turbine (EIA Report)

2.2.3 *High-speed propeller type wind machines*

This is the kind of wind turbine that is used most widely for the generation of electricity. Instead of working on the thrust force of the wind, as in the former cases, this turbine operates on the aerodynamic forces of the wind. It has been found that wind turbines that work on thrust forces operate at a lower efficiency than the ones which operate on aerodynamic forces. A schematic diagram of the high speed propeller type wind turbine is shown in Fig. 2.4 (b).

2.2.4 *Advantages of horizontal axis wind turbines* (Wind Turbine)

- Variable pitch is possible by which the angle of attack of the turbine blades can be controlled.

- Since the blades are present at a considerable height, they are able to capture stronger winds. Wind speed can increase by 20% and the power output by 34% for every 10 meters in elevation. (Wind Turbine)
- The blades always move perpendicular to the wind. This leads to higher efficiency as the blades receive power throughout the rotation.

2.2.5 *Disadvantages of horizontal axis wind turbines* (Wind Turbine)

- The tall towers of the HAWT are difficult to transport and install.
- The downwind HAWT suffers from fatigue.
- The large HAWTs require additional yaw control systems to point them into the wind.
- Rotations of blades result in cyclic stresses and vibrations in the main bearings of the turbine.

2.3 *Vertical axis wind turbines*

The vertical axis wind turbines, as shown in Fig. 2.1, have the main rotor shaft arranged vertically. The structure of these wind turbines are such that they can capture wind irrespective of its direction. Thus, it is of great benefit in places where the wind direction keeps varying. 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.

2.3.1 Darrieus type wind turbine

The darrieus type of VAWT was invented by French inventor Georges Darrieus. It has the following features.

- Good efficiency
- Produces large torque ripple and cyclic stress
- Starting torque is very less
- External superstructures are needed to hold them up

2.3.2 Savonius type wind turbine

These are drag type turbines which work entirely on the thrust force of the wind. It can be simply described as a drum cut into two halves vertically. The two parts are attached to the opposite sides of a vertical shaft. These turbines have the inherent property of self starting.

(a) **(b)** **(c)**

Fig. 2.5: (a) Savonius Rotor, (b) Darrieus Rotor, and (c) Giromill Rotor

2.3.3 Giromill type wind turbine

These turbines are similar to Darrieus turbines but have straight blades as opposed to curved blades of the Darrieus type. The cycloturbine variety has variable pitch to reduce the torque pulsation and is self-starting. The advantages of variable pitch are: high starting torque; a wide, relatively flat torque curve; a lower blade speed ratio; a higher coefficient of performance; more efficient operation in turbulent winds; and a lower blade speed ratio which lowers blade bending stresses. (Wind Turbine)

2.3.4 Advantages of VAWTs

- Massive superstructures are rarely required.
- Yaw control is not required.
- Wind start-up speeds are lower than HAWTs.
- Noise signature is lower than HAWTs.

2.3.5 Disadvantages of VAWTs

- Guy wires are used which result in stress on the bottom bearing.
- Stress is also caused because the wind loading changes sign twice during one complete rotation.
- Changing parts is very difficult.

3

Control Techniques for HAWTs

3.1 Some Relevant Definitions

Definitions of some important terms realted to the wind turbine have been metioned below. These parameters are used in the control of the wind turbine models appearing in the subsequent chapters.

3.1.1 Solidity

The solidity of a wind rotor is the ratio of the projected blade area to the area of the wind intercepted(Bhadra S N, 2010). The projected blade area over here refers to the blade area met by the wind or projected in the direction of the wind. The area of the wind intercepted is also called the swept area.

$$Solidity = \frac{Projected\ blade\ area}{Rotor\ Swept\ \ Area} \tag{3}$$

The solidity is maximum for the savonius rotor at unity, as the projected blade area and the swept area ae the same, i.e, wind sees no free passage through it. For a multiblade water-pumping windmill, it is typically around 0.7. For high-speed horizontal-axis machines, it lies between 0.01 and 0.1; for the darrieus rotor also it is of the same order(Bhadra S N, 2010).

Solidity has direct relationship with torque and speed. High-solidity rotors have high torque and low speed which suitable for work like pumping water. On the other hand, low-solidity rotors have high speed and low torque.This is typically suited for electrical power generation. Thus, only high speed propeller type and darrieus type of wind turbines are suited for electric power generation.

3.1.2 Tip Speed Ratio

The tip speed ratio (TSR) of a wind turbine is defined as the ratio of the speed of the tip of the blade to the spped of free wind. It iss expressed mathematically as follows.

$$\lambda = \frac{2\pi RN}{V} \tag{4}$$

where λ is the tip speed ratio, R is the radius of the swept area, N is the rotational speed, and V is the free wind speed.

The tip speed ratios of the savonius rotor and the multiblade water-pumping windmills are generally low as they operate at low speeds. In high-speed propeller type horizontal-axis rotors and darrieus rotors, the TSR can reach values as high as 9. In these two types of wind turbines, the outer tip turns much faster than the wind speed because of their aerodynamic shape. It is generally observed that high-solidity rotors have low TSRs and vice versa.

3.1.3 Power Coefficient

Power coefficient of a wind turbine is the instantaneous efficiency of conversion of wind energy into mechanical energy of the shaft.

The power coefficient of a wind energy converter is given by

$$C_p = \frac{power\ output\ from\ the\ wind\ machine}{power\ contained\ in\ wind} \tag{5}$$

The power coefficient is just the efficiency of conversion of wind energy into mechanical energy of the shaft. In high-speed horizontal-axis machines, the theoretical maximum power coefficient is given by the betz limit which is 0.59.

3.2 Control techniques for wind turbines

While power is being captured from the wind it is desired that the power captured may be maximized. Also, it is to be made sure that the turbine safety is not compromised under any cicumstances. Thus, power control is a very important feature of a wind turbine. To avoid damage to the wind turbine at very high wind speeds, the aerodynamic forces on the rotor can be controlled to limit the power captured. The following techniques are employed for the same.

3.2.1 Pitch Control

Through picth control, the blades can be turned out or into the wind. This results in variation of the force exerted by the wind on the rotor shaft. The advantages of this type of control are:

- Good power control,
- Assisted startup, and
- Emergency stop.

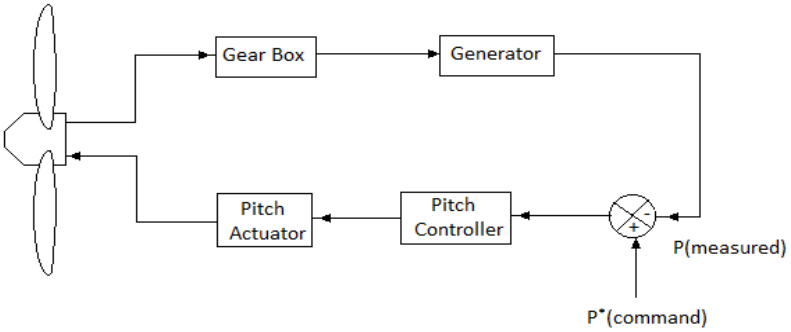


Fig. 3.1: Feedback loop for Pitch angle control (Bhadra S N, 2010)

At high wind speeds, pitch control can be used to keep the power output close to the rated power of the generator. The drawback in this case is extra system complexity in the pitch mechanism and the higher power fluctuations at high wind speeds. Due to presence of gusts, the instantaneous power fluctuates around the rated mean value of the power.

3.2.2 Stall control

(a) Passive stall control

Stall control is the simplest control technique for a wind turbine which the blades are bolted onto the hub at a certain angle. The blades of the rotor are fashioned such that when the wind speeds exceed a certain level, stalling takes place. That is, the lift force on the rotor decreases causing the turbine to stall and restrain itself in the permissible speed limit. Thus, at high wind speeds the turbine is protected. It is the simplest and a very robust technique of power control. The drawback faced is that the turbines operate at an efficiency lower than the rated value at low wind speeds. Also, variations in air density and grid frequencies result in variations in the maximum steady-state power.

(b) Active stall control

The active stall control comes in as a development over the passive stall control. Instead of natural stalling, this system uses pitching to actively control the stall of the blade. Thus, at low wind speeds, maximum efiiciency is achieved by pitching the blades as in a pitch-controlled wind turbine. On the other hand, at high wind speeds the blades are pitched slightly into the direction opposite to that of a pitch-controlled turbine to make them go into a deeper stall. The advantages of this system are

- Smoother limited power can be achieved without high power fluctuations.
- Can compensate variations in air density.
- Easier for the system to carry out emergency stops and to start up the wind turbine.

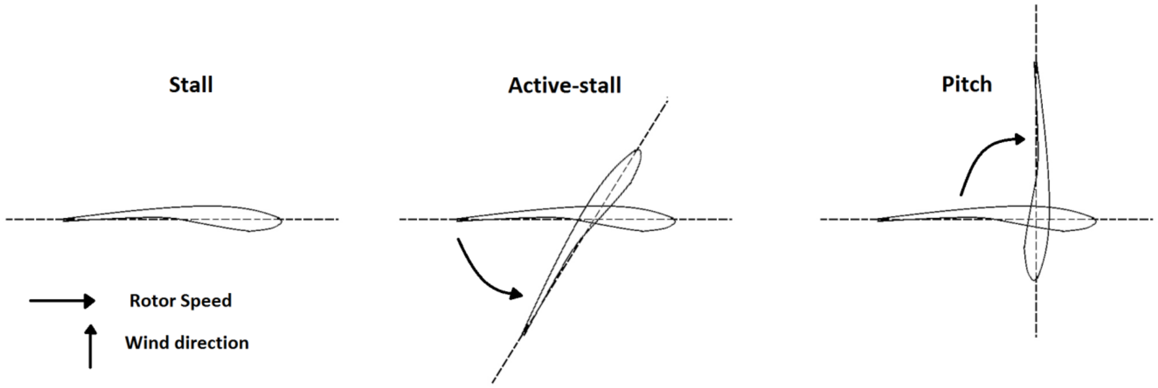


Fig. 3.2: Illustration of stall, pitch and active stall techniques (Stiebler, 2008).

3.2.3 Power Electronic Control

This control is applicable in systems which include a power electronic interface between the generator and the load.

The instantaneous difference between mechanical power and electrical power changes the rotor speed following the equation

$$\frac{Jd\omega}{dt} = \frac{(P_m - P_e)}{\omega} \tag{6}$$

where J is the polar moment of inertia of the rotor, ω is the angular speed of the rotor, P_m is the mechanical power produced by the turbine, and P_e is the electrical power delivered to the load.

Integrating the above equation, we get

$$\frac{1}{2}J(\omega_2^2 - \omega_1^2) = \int_{t1}^{t2}(P_m - P_e)dt \tag{7}$$

Using power electronic converters, the value of P_e can be controlled. Thus, the change is speed and hence, the final speed of rotation of the turbine can be controlled. This method of speed control technique offers a smooth operation as it does not involve any mechanical action. On the flip side, if fast variation of speed is desired, a large difference between the input power and output power is required. The stress on the blades is increased on account of the large torque needed. Continuous control of the rotor speed by this method leads to continuous fluctuation of the power output to the grid, which is not desirable.

3.2.4 Yaw Control

The work of yaw control is to continuously orient the turbines along the direction of wind flow in order to captuture as much wind as possible. In small turbines, a tail-vane is able to serve this purpose. In large machines, motorized control system is used either by a fan-tail, as shown in Fig. 3.3 (a small turbine mounted perpendicular to the main turbine) or, in case of wind farms, by a centralized instrument for the detection of the wind direction (Stiebler, 2008). Downwind turbines have an inherent property to face the wind as the thrust force automatically pushes the turbine in the direction of the wind.

The yaw control mechanism can also be used for speed control. The rotor is made to face away from the wind direction at high wind speeds, thereby reducing the mechanical power. However, this method is seldom used where pitch control is available, because of the stresses it produces on the rotor blades .Yawing often produces loud noise, and it is desirable to restrict the yawing rate in large machines to reduce the noise (Bhadra S N, 2010).

Fig. 3.3: Propeller type wind turbine with tail vane for yaw control

3.3 Control Strategy

The control strategy describes the control technoques used at various wind speeds and indicates the purpose they serve. Shown in the figure below are five different ranges of wind speed, which require different speed control strategies descibed below.

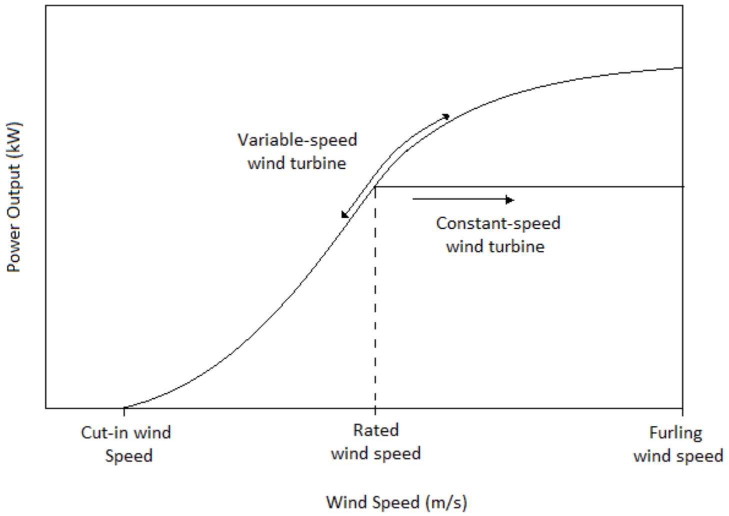


Fig. 3.4: Typical power vs. wind speed characteristics of variable speed wind machines(Bhadra S N, 2010)

(a) Cut-in speed is the speed below which the machine does not produce power. If the rotor has a sufficient staring torque, it may start rotating below this wind speed. However, no power is extracted and the rotor rotates freely. In many modern designs the aerodynamic torque produced at the standstill condition is quite low and the rotor has to be started (by working the generator in the motor mode) at the cut-in wind speed (Bhadra S N, 2010).

(b) At normal wind speeds, maximum power is extracted from wind. We have seen earlier that the maximum power point is achieved at a specific (constant) value of the TSR. Therefore, to track the maximum power limit point, the rotational speed has to be changed continuously in proportion to the wind speed(Bhadra S N, 2010).

(c) At high winds, the rotor speed is limited to maximum value depending on the design limit of the mechanical components. In this region, the Cp is lower than the maximum, and the power output is not proportional to the cube of the wind speed (Bhadra S N, 2010).

(d) At even higher wind speeds, the power output is kept constant at the maximum value allowed by the electrical components (Bhadra S N, 2010).

(e) At a certain cut-out or furling wind speed , the power generation is shut down and the rotation stopped in order to protect the system components (Bhadra S N, 2010).

The last three control regimes can be realized with yaw control, pitch angle control (if these are installed), and eddy-current or mechanical brakes.

4

Pitch Actuator System Modelling

In this chapter, three models have been discussed for a pitch actuator system. The three models are:

1. Proportional Control,
2. Constant pitching speed, and
3. PID Control

All these models are tested against a standard pitch angle input signal which is shown below.

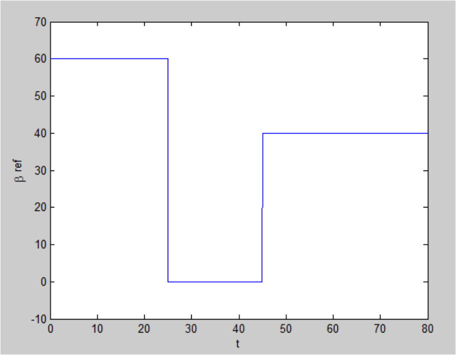


Fig. 4.1: Input used in simulations

4.1 Proportional Control based Pitch Actuator System

The Simulink model for the proportional conrol system is shown below. 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 ‘RL2’ is also a saturation filter which is defines the limiting values of pitching speed. The maximum and minimum permissible value of pitching speed in this system are 8 degrees per unit time and -8 degrees per unit time respecively.

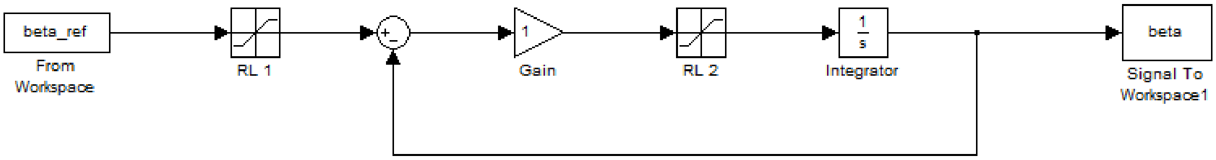


Fig. 4.2: Block Diagram of Proportional Control based Pitch Actuator System

The response of this system has been observed for four different values of proportional gain. See Fig. 4.3 given below.

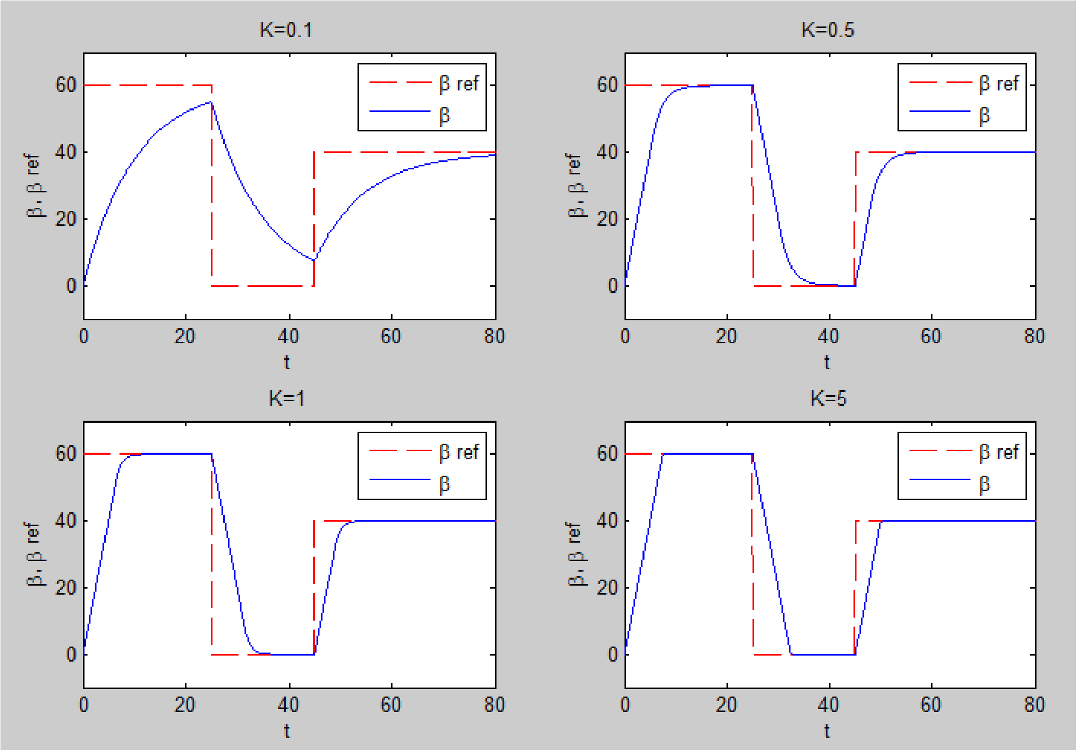


Fig. 4.3: Pitch angle response of Proportional control based Pitch Actuator System

4.2 Pitch Actuator System with constant value of pitching speed

This model was suggested by Yousif El-Tousin his paper “Pitch Angle Control of Variable Speed Wind Turbine”, 2008. In this model, he suggests that the pitching speed of the blades 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 compare 'on line' the proper criterion and then decide, if to increase or decrease the pitch angle, without predicting the future angle like in the first version (El-Tous, 2008).

The Simulink model used has been shown below. 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
```

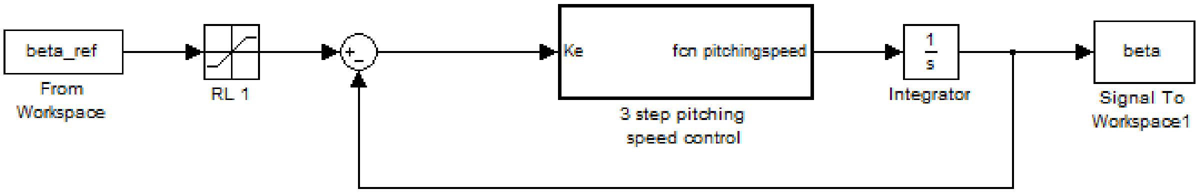


Fig. 4.4: Block Diagram of Pitch Actuator System with constant pitching speed

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 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.

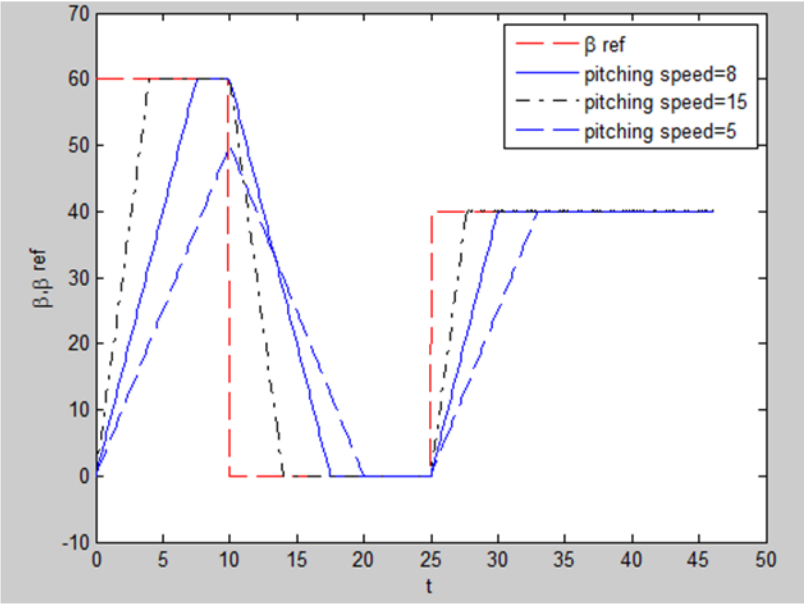


Fig. 4.5: Pitch angle response of Pitch Actuator System with constant pitching speed

4.3. PID Control based 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 has been shown below.

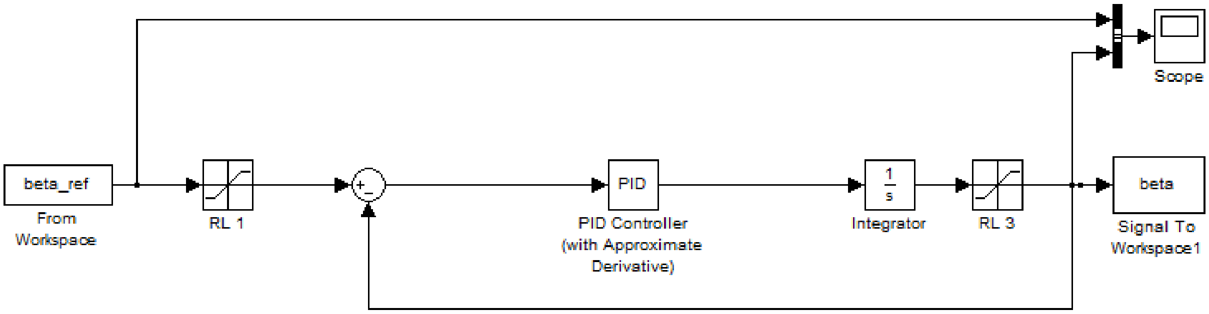


Figure 4.6: PID Control based Pitch Actuator System

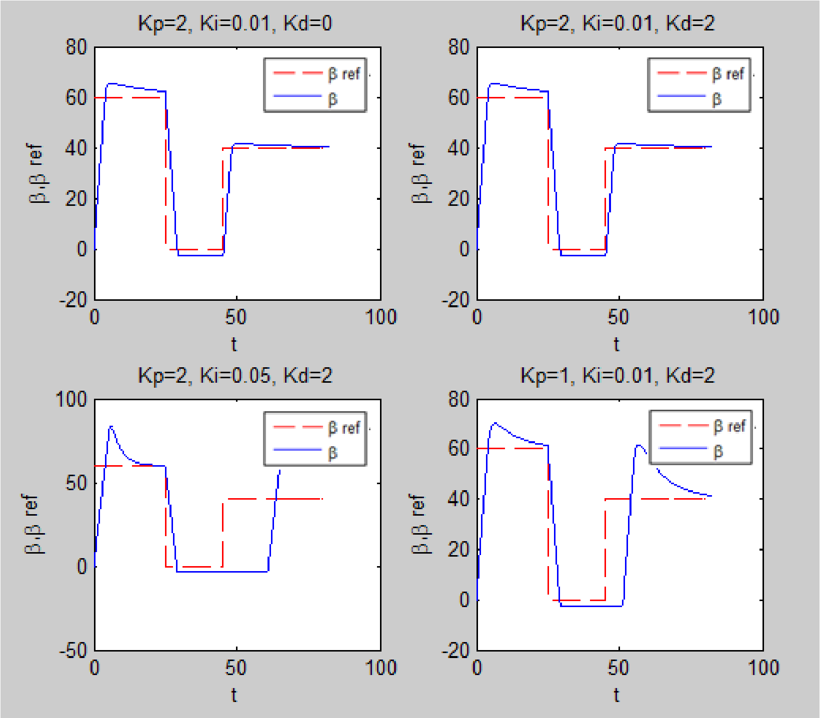


Fig. 4.7: Pitch angle response of PID Control based Pitch Actuator System

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. In the following chapter, an adaptive PID approach has been proposed where the values of gains are revised after every step of input based on the time response parameters.

5

Adaptive PID: A suggested approach to Pitch Control of HAWT

5.1 Wind Turbine Model

As mentioned before, the power contained in the wind is given by

$$P = \frac{\rho A}{2} v_{wind}^3 \tag{8}$$

and the electric power generated by the wind turbine is given by

$$P_m = C_p(\lambda, \beta) \frac{\rho A}{2} v_{wind}^3 \tag{9}$$

The power coefficient is a function of pitch angle and tip speed ratio. The following model has been used to approximate the relation of C_p with TSR and pitch angle

$$C_p(\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3 \beta - C_4 \right) e^{\frac{-C_5}{\lambda_i}} + C_6 \lambda \tag{10}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{11}$$

where Cp = Power Coefficient

β = pitch angle

λ = Tip Speed Ratio

C_1=0.5176, C_2=116, C_3=0.4, C_4=5, C_5=21, and C_6=0.0068

The power characteristics of the above model has been shown in Fig. 5.1.

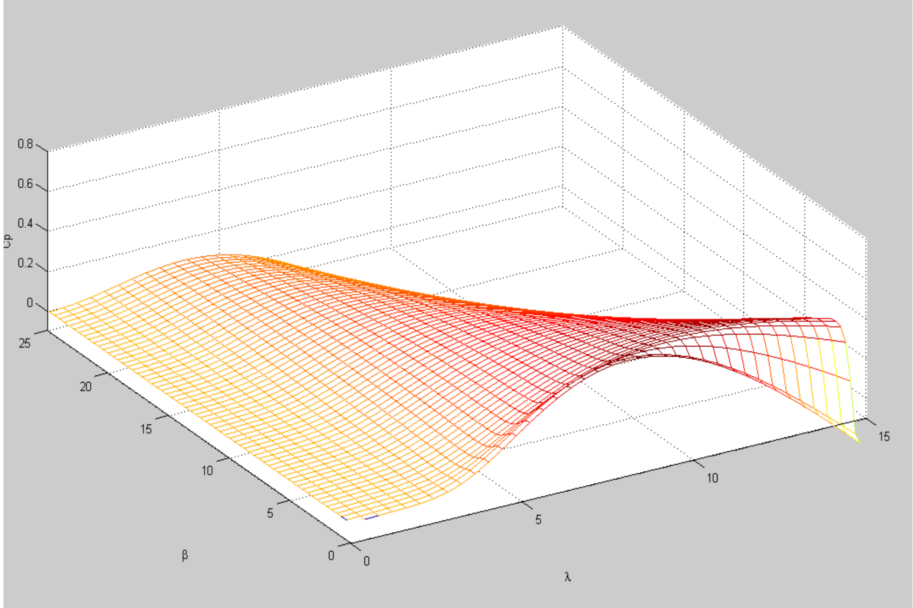


Fig. 5.1: Power Characteristics of Horizontal Axis Wind Turbine

5.2 Algorithm

The algorithm used for the Adaptive PID Control based Pitch Actuator System is as follows

1. Set first set of values for K_p, K_i and K_d
2. Read the value of wind speed.
3. Calculate value of TSR.

   TSR = Ratio of speed of tip of blade to wind speed

   For a fixed speed wind turbine, blade tip speed is constant. (A constant gear ratio between generator and blades is assumed)
4. For values of pitch angle between 0 and 90 degrees, calculate C_p.
5. Find out the value of pitch angle for which C_p is maximum.
6. Sample and hold this value of pitch.

7. Send this value of pitch as command value to the PID Controller for the duration ‘t_1’.
8. The integration of the PID output gives the pitch angle output.
9. From the PID response, estimate rise time t_r (or peak time t_p), peak overshoot M_p, settling time t_s and steady state error e_{ss}.
10. Based on the values of the time response parameters calculated, tune the values of K_p, K_i and K_d for the next time cycle.

NOTE: The pitch angle input is assumed to be able to take input values which are multiples of 5 only.

The system is allowed to operate for a period of 100 units of time in each cycle after which the time response parameters are evaluated and necessary changes are inflicted to the proportional, integral and derivative gains.

The initial set of values of the gains were K_p=0.5, K_i=0.8 and K_d=0.

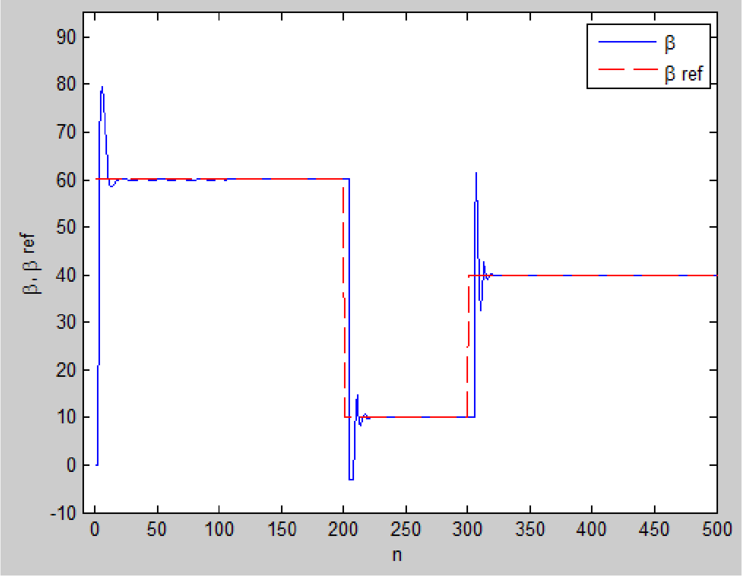


Fig. 5.2: Pitch angle response of Adaptive PID based Pitch Actuator System with initial value of K_p=0.5, K_i=0.8 and K_d=0

Table 5.1: Values of gains and time response parameters after cycle

Cycle no.	K_p	K_i	K_d	M_p	t_p	t_s	e_{ss}
1	0.5000	0.8000	0	19.5540	5.0000	10.0000	0
2	0.5000	0.8000	0	0	1.0000	1.0000	0
3	0.5000	0.8000	0	13.0000	2.0000	10.0000	0
4	0.5000	0.8000	0	21.3000	3.0000	8.0000	0
5	0.5000	0.8000	0.1000	0	1.0000	1.0000	0

The spikes are visible in the response due to the implementation of a discrete time PID algorithm instead of a continuous time model as used in the previous chapter. The values of the gains after each cycle have been mentioned in Table 5.1. As can be seen from the table, when the value of peak overshoot M_p exceeds 20, a derivative component is brought in to compensate. The derivative gain can be increased only upto a certain limit beyond which system becomes unstable. In the event that the derivative gain is at its maximum permissible value and the peak overshoot crosses 20, the value of proportional gain is reduced.

In the second trial, the initial set of values of the gains were K_p=1, K_i=0.2 and K_d=0. The response is shown in Fig. 5.

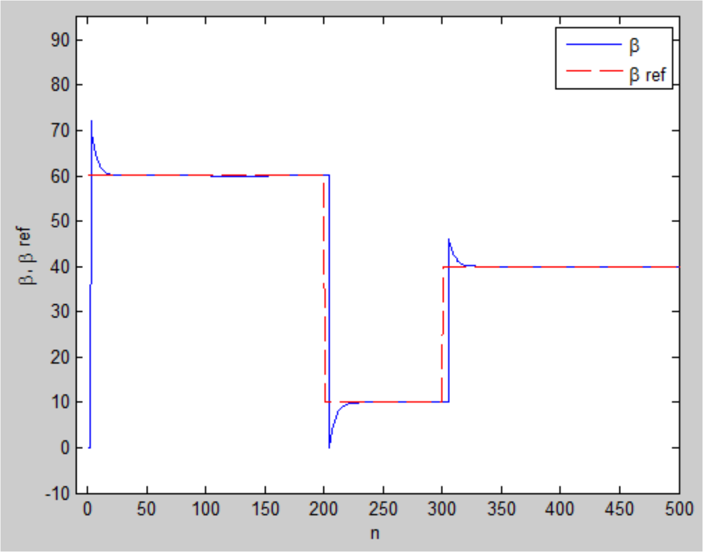


Fig. 5.2: Pitch angle response of Adaptive PID based Pitch Actuator System with initial value of Kp=1, Ki=0.2 and Kd=0

The values of the gains after each cycle have been mentioned in Table 5.2.

Table 5.2: Values of gains and time response parameters after cycle

Cycle no.	K_p	K_i	K_d	M_p	t_p	t_s	e_{ss}
1	1.0000	0.2000	0	12.0000	2.0000	8.0000	0
2	1.0000	0.2000	0	0	1.0000	1.0000	0
3	1.0000	0.2000	0	10.0000	2.0000	8.0000	0
4	1.0000	0.2000	0	6.0000	2.0000	5.0000	0
5	1.0000	0.2000	0	0	1.0000	1.0000	0

The response obtained in this case is a very stable one and the values of time response parameters in each time cycle are found to be within tolerable limits. Hence, no change has been inflicted in the values of the gains K_p, K_i and K_d in any time cycle.

6

Conclusion

6.1 Conclusion

The proportional control based pitch actuator system has the merits and demerit of every proportional controller. If the gain chosen is kept low, then the system response is slow and there will exist a steady state error. Also, if the gain is made too high, the system would become oscillatory. Thus, an integral component is required for satisfactory performance of the system.

The model with the constant pitching speed has the merits of being extremely simple in design and implementation. The drawback it faces is that when the response needs to be faster, the system cannot deliver. The system also faces the problem of sudden stops in the turning of the blades when the reference pitch angle is reached. Lack of a smooth stop may result in the wear and tear of the actuator.

The PID controller boasts of its rugged performance statistics in industrial environments and has thus, been the most favourable choice for a controller. But, fine tuning of the controller parameters online is usually necessary to obtain acceptable control performance (Gopal, 2010). This led us to attempt to conceive an adaptive PID algorithm where the values of time response parameters of the pitch actuator system are observed and the fine tuning of the controller parameters is performed.

6.2 Future Work

The adaptive PID system model proposed here may be tested in real time wherein the monitoring and actuating system may be able to operate simultaneously such that the system may respond faster and a steady state set of gain values be obtained in a shorter span of time.

The model designed here is not capable of overcoming an oscillatory response. So, improvements may be done to the tuning algorithm in order to stabilize an oscillatory system.

References

1. (2009). *Indian Wind Energy Outlook.* Chennai: Indian Wind Turbine Manufacturers Association.
2. Bhadra S N, K. D. (2010). *Wind Electrical Systems.* Oxford University Press.
3. *EIA Report*. (n.d.). Retrieved from www.epd.gov.hk: http://www.epd.gov.hk/eia/register/report/eiareport/eia_1242006/html/EIA_Report/Section_3.htm
4. El-Tous, Y. (2008). Pitch Angle Control of Variable Speed Wind Turbine. *American J. of Engineering and Applied Sciences 1 (2): 118-120*, 3.
5. Gopal, M. (2010). *Digital Control and State Variable Methods.* New Delhi: Tata McGraw Hill Eduction Private Limited.
6. *How to build a Windpump (Principles)*. (n.d.). Retrieved from Howtopedia: http://en.howtopedia.org/wiki/How_to_Build_a_Windpump_%28Principles%29
7. Johnson, G. L. (2006). *Wind Energy Systems.*
8. Stiebler, M. (2008). *Wind Energy Systems for Electric Power Generation.* Springer.
9. *Wind Turbine*. (n.d.). Retrieved May 6, 2011, from Wikipedia: www.en.wikipedia.org/wiki/Wind_turbine