A Review on Different Control Techniques used for Pitch Control of Horizontal Axis Wind Turbine

Manash Protim Saikia[1], Jyoti Kumar Barman[2]

[1,2] Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University, *Airport Road, Azara, Guwahati -781017, Assam, INDIA.*
[1] *manash90p@gmail.com*, [2] *jyoti.barman@dbuniversity.ac.in*

Abstract: ***In wind turbine technology, the pitch control mechanism of blades is a very important factor for the efficient power output of a wind turbine. Various control techniques can be implemented for pitch control. This paper deals with the study and review of different control methodologies used by the researchers and engineers to control the pitch angle of the blades of a horizontal axis wind turbine to optimize the power in low rated wind speed. This paper involves the study of PI, PID, Fuzzy logic control, Sliding mode control and Adaptive control methodologies.***

Keywords: Renewable energy, variable Speed Pitch Control, PI, PID, Sliding mode, Fuzzy logic control, Adaptive control

1. Introduction

Due to ever-increasing power demands and the requirements for reduction of carbon emissions, the application of wind energy for electricity production experienced an accelerating growth. There are many technical challenges arises in the integration of wind turbine to the power systems such as reliability, security of supply, availability and power quality. The output electrical power of a wind turbine mainly depends upon the speed of the wind. There are two types of wind turbine, variable speed wind turbine and fixed speed wind turbine. Variable speed wind turbine is preferred over fixed speed wind turbine due to the 10% more power generation as compared to the fixed speed wind turbine. In variable speed wind turbine mainly three control techniques are used to obtain the maximum power output, i.e. pitch control, Yaw control and Power electronic control.

In a variable-speed wind turbine, blade pitch control is very important parameters for efficient energy capture. Different control engineers developed different control strategies for controlling the pitch angle of blades. This paper makes a comparative study of the response of different control techniques used for pitch control. This paper reviews the response of PI, PID, Sliding Mode controller, Fuzzy Logic controller and Adaptive Pitch controller. Due to the different control techniques employed for control the pitch angle, a review study is needed on these recent control techniques used and proposed the best control strategy which gives the desired response and relevant to the nonlinear characteristics of the wind turbine.

2. Evolution of Pitch Control Strategy for Horizontal Axis Wind Turbine

Along with the development of the wind industry, a development in the control of mechanical components, as well as the electrical components, began for maximum power output. Although initially, there were two control concepts proposed for an efficient power output of a wind turbine, i.e., stall control and pitch control, so as to maintain the angle of attack of the blades; however finally, the pitch control concept has been widely accepted due to its adaptability to variable wind speed [3].

The controller for pitch angle can be achieved in two ways, i.e. collective pitch control and Individual pitch control.

In the collective pitch angle, the pitch angle of all the blades is controlled by the same amount [7]. Individual pitch angle control method controls each blade in distinctive manners [8]. In the year of 1999, the researchers presented the pitch control mechanism, where wind turbine operated at an optimum energy level and minimized the load for a wide range of speed [9]. For a wind turbine, implementation of PI controller has been presented by J. G. Slootweg [1] and N. W. Miller *et al*. [2], in 2003. For variable speed wind turbine, a variable pitch angle control using PI controller was presented in the year 2004 by A. D. Hansen *et al*. [4] and by G. Gail *et al*. in 2006 [3]. In the year 2008, Wright A.D and L. J. Fingeresh presented the idea of the non-linear PID pitch control technique [5]. Pitch control using the fuzzy logic controller was presented by J. Zhang in the year 2008 [10]. Implementation of fuzzy logic controllers helps in the improvement of the output power of a wind turbine. It helps to optimize the power at low wind speed and limits the power when the wind speed is high. The sliding mode approach for variable speed wind turbine was presented by H. De Battista *et al*. in 2000 [13] and by B. Beltran *et al*. in 2008 [12]. In high-speed region, using sliding mode approach gives a good power regulation against turbulence and parametric uncertainties. The strategy of adaptive pitch control has been proposed by many researchers, eg., K.E. Johnson and L. Fingersh [14], S. A. Frost *et al*. [15], S. A. Frost *et al*. [16] and S. A. Frost, M. J. Balas and A. D. Wright [17]. This strategy is used when there is a need of a small change of pitch angle under low rated wind speed until the wind turbine reaches its optimum power value. In this paper, we make a comparative study of all these techniques evolved for pitch angle control.

3. Control Strategy

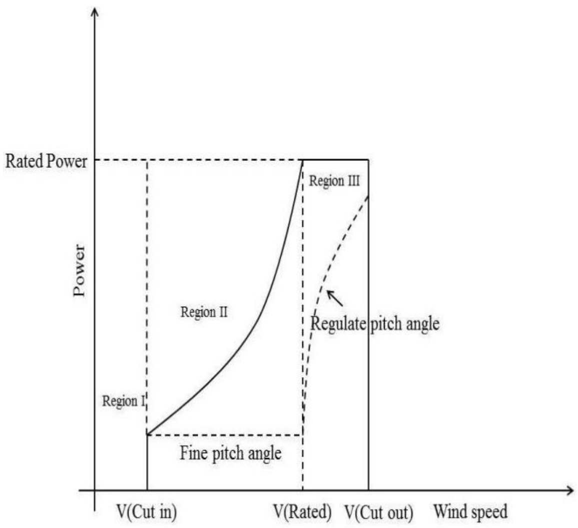

Fig. 1: Power v/s wind characteristics

Fig. 1 shows the relationship between the generated power and wind speed. There are three regions indicated in the characteristics curve. The minimum wind speed required to produce power is called as the cut-in wind speed, wind speed required to produce the rated power is called the rated wind speed and the maximum speed of wind that can be processed for power generation is denoted as cut-out or furling wind speed. In region-1, when the wind speed is lower than V_{cut-in}, the turbine fails to produce any output power. Here in general, pitch angle exclusively remains at 90° due to a less valuable amount of wind speed. Region-2 defined between cut-in (V_{cut-in}) and rated wind speed (V_{rated}) is considered as the operational region where the wind is captured and transformed into valuable power. Region-3 located between rated wind (V_{rated}) and cut-out wind ($V_{cut-out}$) is termed as full load region where a consistent generation of rated-power is realized.

The controller is designed such that in the below-rated region, the turbine's work is to lower power coefficient to increase the wind power for fully exploiting the capacity of the generator. The position of blade pitch angle (β) is kept constant at some fine angle such a way that the wind turbine work remains at its optimal aerodynamic efficiency or power coefficient.

In the above-rated power region, the control strategy is to maintain the rated power constant and reduce the aerodynamic loads of the wind turbine. These two quantities are kept constant by regulating the blade pitch at a different amount of angle.

4. Pitch Controller

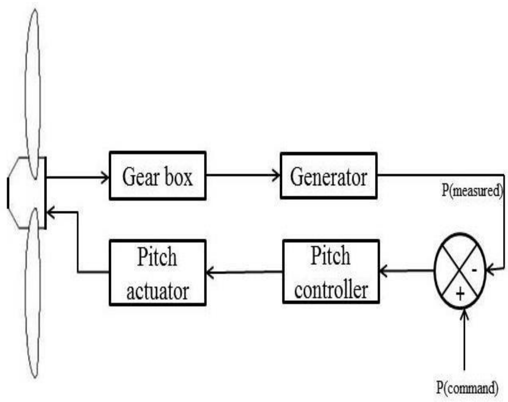

Fig. 2: Control loop for pitch control [25]

The control loop for a pitch controller is shown in Fig. 2. The error signal is generated by the difference between the generated power and given command power value. If the rated power of the wind turbine is known, a command signal can be given to the controller. Pitch control primarily relies on the time constant and rate limiter response of pitch actuator.

5. Different Control Techniques Used In Pitch Control

A) Proportional, Integral and Differential control

Proportional Integral (PI) and Proportional Integral and Differential (PID) control techniques are the two most widely used control techniques of pitch control. A proportional controller is used when a slight overspending of the rotor above its nominal value can be allowed and poses no problems for the wind turbine construction. The nonlinear PID pitch control technique for uncertain blade pitch of wind turbine is used for high wind speed.

Fig. 3 shows the response of the pitch angle of PID based pitch actuator system. The system produces a decent response for different values of K_p, K_i and K_d. The gains of the PID controller are chosen according to the methods explained by M. M. Hand [18] and T. Burton *et al.* [19]. There is also another method for selecting the gain of PID pitch control, which is known as symmetric method [6].

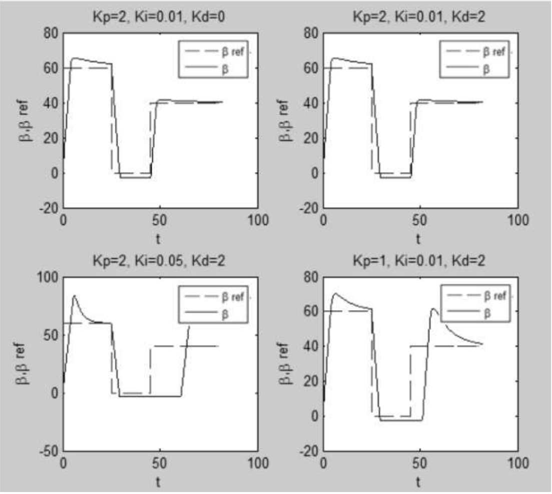

Fig. 3: Pitch-angle response of PID Control based Pitch Actuator System [26]

B) Sliding Mode Control

In the case of nonlinear systems having time-varying parameters, sliding mode control technique is used. A discrete control signal is applied to a system in order to push the nonlinearities of the system to slide along a cross-section of the system's normal trajectory [20].

In case of variable speed wind turbine, sliding mode controller is used. This control technique gives output power regulation against turbulence and parametric uncertainties in the high-speed region. One drawback of using this sliding mode control technique is that due to high frequency switching, the trajectory does not follow the sliding path that leads to chattering and a static error occurs [13]. This issue can be minimized by combining SMC with other control methods. Therefore, SMC is integrated with Artificial Neural Network (ANN) controller for best performances.

Table 1 shows the performance comparison of SMC integrated with the ANN controller and PI controller [21], which shows that the average output power using SMC integrated with ANN is more than the PI controller. The speed tracking error and the maximum power tracking error also less in the SMC controller compared to the PI controller.

Table 1: Performance comparison between PI and SMC

Controller	Average power	Max. speed tracking error	Max power tracking error
SMC with ANN controller	805 W	0.67 rad/sec	120 W
PI controller	770 W	1.2 rad/sec	145 W

C) Fuzzy Logic Control

The variable-speed wind turbines with blade pitch linear control provide an excellent performance of the closed-loop system. Using fuzzy logic control technique, we can obtain enhanced performance improving the transition between power optimization and power limitation of the wind turbine [23]. Fuzzy logic provides a better performance and it is more robust. It also delivers better mechanical response [22]. Fuzzy logic controller prefers over PI and PID because it can able to process several rule implications simultaneously and produce a complete output.

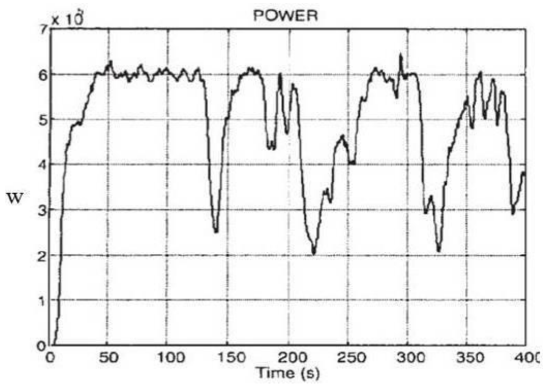

Fig. 4: Generator power for the rated wind time series of the PI control system [23]

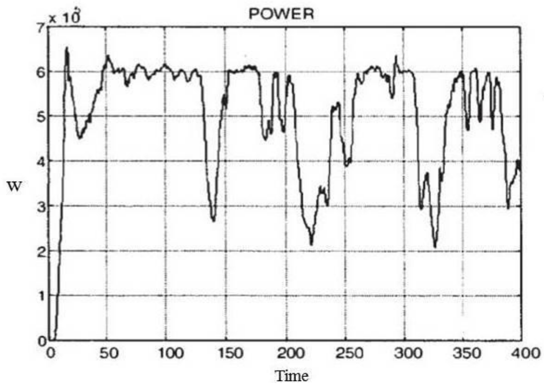

Fig. 5: Generator power for the rated wind-time series of the Fuzzy control system [23].

Table 2: Performance comparison of PI and Fuzzy control

Controller	PI	Fuzzy
Energy(kW)	54.658	55.703
Max. Rotor speed(m/s)	1618	1630

Table 2 shows the performance comparison between the PI controller and the Fuzzy logic controller [23]. By using a fuzzy logic controller, we can get better power output and rotor speed.

D) Adaptive Pitch Control

In the case of below-rated wind speed, it is difficult to identify accurate parameters for the controller. Proper knowledge of power coefficient (C_P) is required to achieve optimal efficiency with a constant gain controller. By using an adaptive control technique, we can overcome the inefficiencies caused by inaccurate knowledge of the C_P [24]. We have to extract maximum possible energy in the below-rated wind speed from a wind turbine. The adaptive pitch controller uses a discrete hill-climbing method to change the blade pitch angle until maximum aerodynamic efficiency is achieved. The discrete time step is known as adoption period number.

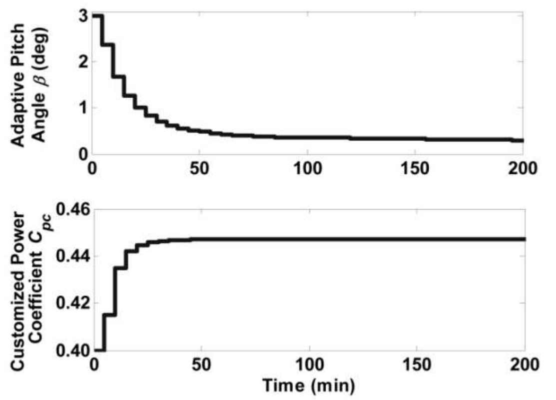

Fig. 6: Simulation Results from constant wind speed adaptive pitch simulation. (Constant wind speed input of 8 m/s and a 5-min. adaptation period.)

The simulation results of adaptive pitch angle and C_{pc} with a constant wind speed of 8 m/s is shown in Fig. 6.The simulation results show that the adaptive pitch angle lies within 3% of the optimal pitch angle of 0.3°. The time is about 200 min and the initial pitch angle is 3°. The adaptation period length is 5 min. As the adaptive pitch angle approaches its optimal value, C_{pc} also approaches $C_{p(max)}$, which equals to 0.447 in this simulation[24].

6. Conclusion

The pitch control of a wind turbine system is reviewed in this paper. This paper mainly deals with the controlling of the pitch angle of a horizontal axis wind turbine in case of varying wind speed. Pitch control is a very important strategy for varying the speed of wind turbines for better speed regulation, which results in maximum power output. Due to the nonlinear behaviour of the moment of inertia of wind turbine, it is a challenging task to implement pitch control mechanism. This study gives some tradeoffs between output response, speed, precision, complexity etc., which helps the researchers to developed new ideas regarding this field.

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