PITCH ANGLE CONTROL OF VARIABLE SPEED WIND TURBINE GENERATION

Prof. Suparna Pal¹, Debasis Jana²

¹Professor, Department of Electrical Engineering, JISCE, Kalyani, India
²Post Graduates student, Department of Electrical Engineering, JISCE, Kalyani, India

ABSTRACT

Wind energy is a variable option to complement other types of pollution-free generation. In the early development of wind energy, the majority of wind turbines were operated at constant speed. Recently, the number of variable-speed wind turbines installed in wind farms has increased and more wind turbine manufacturers are making variable-speed wind turbines.

This paper describes the modeling of the various components in a pitch controlled wind energy system and the design of the pitch controller, and discusses the response of the pitch-controlled system to wind velocity variations. The pitch function provides full control over the mechanical power and is the most common control technique used in variable speed wind turbines. At wind speeds below the rated power of the generator, the pitch angle is at its maximum; however, it can be lowered to help the wind turbine (WT) accelerate faster. At the rated wind speed, the pitch angle is controlled to keep the generator at the rated power by reducing the angle of the blades.

Keywords: Wind Power Generation, Pitch Control of Wind Turbine, Variable Speed Wind Turbine, MATLAB/SIMULINK.

INTRODUCTION

The wind industry has experienced large growth rates over the past decade and wind turbines have been installed around the world in increasing quantities. As wind energy becomes more prevalent there is growing interest in controlling wind turbines or wind plants in an intelligent manner to minimize the cost of wind energy. This can be done by controlling the turbines to extract more energy from the wind and reduce structural loads that can cause component failure and is the focus of ongoing research. Though wind energy makes up a relatively small amount of global energy production, there are certain regions that produce a significant portion of their energy from the wind,
such as Spain, Ireland, and Denmark. The increasing penetrations of wind energy in these countries have raised interest in a new branch of wind turbine control research and development that focuses on wind turbine participation in frequency regulation for the utility grid. Grid operators require conventional utilities to provide regulation in order to maintain the necessary balance between generation and load, which in turn regulates the grid frequency. Wind power has not historically been required to provide grid regulation services, as most modern wind turbines do not intrinsically provide any of the grid regulation services that are available with conventional generators. High wind penetration levels in the aforementioned countries have lead their transmission system operators to impose new requirements for future wind plant installations to be capable of providing power tracking and frequency regulation services when there is ample wind resource available. Variable-speed wind turbine generation has been gaining momentum, as shown by the number of companies joining the variable-speed WTG market. Variable-speed generation is claimed to have a better energy capture and lower loading. The effect of turbulence on energy capture and power fluctuations in variable-speed wind turbines is affected by the overall control algorithm used. The method of controlling the generator strongly affects the electrical power generated by the generator [1].

GROWTH OF THE WIND ENERGY INDUSTRY

Wind energy is a quickly growing alternative energy technology that can provide clean power. According to the World Wind Energy Association, the average growth rate of installed capacity around the world over the last decade has been 27.7% [2]. In 2010, worldwide capacity reached 196,630 MW (megawatts) out of which 37,642 MW was added during 2010, for a growth rate of 23.6% [2]. During 2010, the United States increased installed wind capacity from 35,159 MW to 40,180 MW. China almost doubled installed capacity in 2010, growing from 25,810 MW to 44,733 MW, to pass Germany and the US and become the number one country in installed capacity [2]. 2010 brought a 59% capacity increase in offshore wind, bringing the total to 3,117 MW, all of which is located in Europe, Japan, and China [2]. As wind turbine technology continues to mature, wind energy is becoming a larger portion of the global energy profile.

The ‘penetration’ of wind energy in the local utility grid, which refers to the percentage of electrical energy generation that comes from wind energy sources, is an important metric to measure. Though wind energy provided only 2.5% of the global electrical energy supply in 2010, several countries have a relatively high percentage of their electrical energy produced by wind power. The countries with the highest percentage of electrical energy generated from wind in 2010 were Denmark, Portugal, Spain, and Germany with 21%, 18%, 16%, and 9%, respectively [2]. It should be noted that these percentages are annual averages. At times the instantaneous percentage of total power provided by wind can be much higher. Wind energy achieved a maximum instantaneous penetration level of 59.6% in Spain in 2011. The high wind penetrations in these countries have been achieved not only from having good wind resources available, but also by aggressive national policies to produce more energy from renewable sources.

Wind turbines have increased in size to take advantage of economies of scale. The turbines installed in the U.S. during 2010 had an average rated power of 1.79 MW with average hub heights and rotor diameters of 79.8 and 84.3 meters, respectively [3]. The average rated power of turbines installed in the US has not increased significantly during the past 3 years due to the challenges associated with transporting extremely large turbines over land and the popularity of a particular 1.5 MW turbine model. The installation of turbines is also subject to economies of scale, as it is more profitable to cluster wind turbines together to reduce the cost of installation, maintenance, and transmission line construction.
WIND TURBINE OVERVIEW

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.

**Figure 1:** Schematic diagram of a horizontal axis wind turbine and a vertical axis wind turbine

**Horizontal Axis Wind Turbine**

A turbine with rotor axis of rotation that is horizontal to the ground is called a HAWT (Horizontal Axis Wind Turbine). HAWTs are representative of the majority of all large scale wind turbines today. These turbines are operated in an upwind manner, where the rotor plane is actively positioned to be directly upwind of the tower through the use of a yaw motor that rotates the entire nacelle.

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

Figure 2 shows the internal equipment in a horizontal axis wind turbine.
Vertical Axis Wind Turbine

Vertical-axis wind turbines (VAWTs) are a type of wind turbine where the main rotor shaft is set vertically and the main components are located at the base of the turbine. Among the advantages of this arrangement are that generators and gearboxes can be placed close to the ground, which makes these components easier to service and repair, and that VAWTs do not need to be pointed into the wind. Major drawbacks for the early designs (Savonius, Darrieus and giromill) included the pulsatory torque that can be produced during each revolution and the huge bending moments on the blades. Later designs solved the torque issue by using the helical twist of the blades almost similar to Gorlov's water turbines [4].

A VAWT tipped sideways, with the axis perpendicular to the wind streamlines, functions similarly. A more general term that includes this option is "transverse axis wind turbine". Drag-type VAWTs, such as the Savonius rotor, typically operate at lower tip speed ratios than lift-based VAWTs such as Darrieus rotors and cyclo turbines [4].

Figure 3 shows the internal diagram of a vertical axis wind turbine.
WIND TURBINE CHARACTERISTICS

The wind turbine can be characterized by its CP-TSR (curve as shown in Figure 4), where the TSR is the tip-speed ratio; that is, the ratio between the linear speed of the tip of the blade with respect to the wind speed. It is shown that the power coefficient CP varies with the tip-speed ratio. It is assumed that the wind turbine is operated at high CP values most of the time. In a fixed-frequency application, the rotor speed of the induction generator varies by a few percent (based on the slip) above the synchronous speed while the speed of the wind may vary across a wide range.
In Figure 4, the change of the CP-TSR curve as the pitch angle is adjusted is also shown. In low to medium wind speeds, the pitch angle is controlled to allow the wind turbine to operate at its optimum condition. In the high wind speed region, the pitch angle is increased to shed some of the aerodynamic power.

The mechanical power $P_m$ is extracted from the wind. The following formula describes $P_m$

$$P_m = 0.5 \rho \pi R^2 v^3 C_p(\lambda, \Theta)$$

Where, $P_m$ is the mechanical power

$\rho$ is the air density

$R$ is the turbine’s radius

$v$ is the wind speed

$C_p$ is the power coefficient

$\lambda$ is the tip speed ratio

$\Theta$ is the pitch angle

$\lambda$ is defined as:

$$\lambda = \frac{\omega_m R}{v}$$

Where $\omega_m$ is the turbine rotation speed

$R$ is the turbine’s radius

$v$ is the wind speed

The extracted mechanical power $P_m$ is proportional to the cube of the wind speed $v$. The power coefficient $C_p$ affects $P_m$. $C_p$ is a function of the tip speed ratio $\lambda$ and of the pitch angle $\Theta$. $\lambda$ describes the ratio between the system rotational speed $\omega_m$ and $v$. $\Theta$ is the angle between the wind flow direction and the turbine blade. Increasing $\Theta$ moves the blades out of the wind, thereby reducing the effective wind area.
The Ideal Operation Curve of the Wind Turbine

Wind turbines operate in a certain range of wind speed. When the wind speed is less than normal, usually 12 meters per second (m/s), the turbine extracts less energy than the rated power. In this case, the turbine is expected to operate at its most efficient point by using the variable-speed, constant-frequency operation and to extract as much energy as possible. When the wind speed is greater than normal, the turbine must limit its energy utilization to keep the extracted energy at the maximum allowable level. Otherwise, if the turbine generates too much energy, the over-load might damage the whole turbine system. Usually the controller leverages the pitch angle control to limit the power absorption. Figure 3 shows this ideal operation curve. You can see the power optimization phase, below 12 m/s, and the power limitation phase above 12 m/s.

![Figure 5: Ideal Operation Curve of a Wind Turbine](image)

WIND TURBINE CONTROL

When a generator reaches its rated power, the turbines must limit the magnitude of mechanical power delivered to the generator. For example a generator in typical wind turbines reaches its rated power at wind speeds of 15 m/s to 25 m/s, and thus, must decrease in energy collection at higher wind speeds. This energy collection control is achieved by either stall, pitch, or a combination of them both, called active stall. There are no moving parts in stall-controlled blades, and the challenge in this control technique is proper blade construction to avoid vibration and permit a gradual stalling. The pitch function provides full control over the mechanical power. The pitch angle is controlled to keep the generator at the rated power by reducing the angle of the blades. By actuating the blade angle to be at the limit of the stalling, fast torque changes in the wind speed can be tolerated.
PITCH CONTROL OF WIND TURBINE

PITCH

The pitch angle is the angle at which the blade surface contacts the wind. It is often variable to ensure optimum operation of the turbine in varying wind conditions and to prevent electrical overload and over speed in high winds. Gears in the hub of the rotor allow the pitch to be varied.

PITCH CONTROL ACTION

Pitch control means that the blades can pivot upon their own longitudinal axis. The pitch control used for speed control, optimization of power production and to start and step the turbine. A control technique applied to the pitch angle is done by comparing the current active power of the engine with the value of active power at the rated engine speed (active power reference). Control of the pitch angle in this case is done with a PI controller controls. However, in order to have a realistic response to the control system of the pitch angle, the actuator uses the time constant $T$, an integrator and limiters so as the pitch angle to be from $0^\circ$ to $30^\circ$ with a rate of change ($\pm 10^\circ$ per sec).

Figure 7: Basic diagram for pitch angle control

From the figure 8 at the right, the reference pitch angle is compared with the actual pitch angle $b$ and then the error is corrected by the actuator. The reference pitch angle, which comes from the PI controller, goes through a limiter. Restrictions on limits are very important to maintain the pitch angle in real terms. Also, limiting the rate of change is very important especially during faults in the network. The importance is due to the fact that the controller decides how quickly it can reduce the aerodynamic energy to avoid acceleration during errors.

Figure 8: pitch controller
SIMULINK MODEL FOR PITCH CONTROL

MODEL DESCRIPTION

In our project we used MTALAB tools for simulation of our model. Our model is shown in the figure 9. The main block parameter used in our model is described below,

Wind Turbine

This block implements a variable pitch wind turbine model. The performance coefficient $C_p$ of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle ($\beta$). $C_p$ reaches its maximum value at zero beta. The first input is the generator speed in per unit of the generator base speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load. The second input is the blade pitch angle ($\beta$) in degrees. The third input is the wind speed in m/s. The output is the torque applied to the generator shaft in per unit of the generator ratings.
Asynchronous Machine

We used a three-phase asynchronous machine of squirrel cage type modeled in a selectable dq reference frame (rotor, stator, or synchronous). Stator and rotor windings are connected in wye to an internal neutral point. The Machine rating is 5HP, 460 V, 60 Hz, 1750 rpm.

RESULT AND ANALYSIS

The simulation results obtained from the MATLAB/SIMULINK wind turbine model are given below (for various wind speed).

Wind is very much turbulent in nature. So it is very much essential to control the rotor speed for a desired output power. When a generator reaches its rated power, the turbines must limit the magnitude of mechanical power delivered to the generator. For example a generator in typical wind turbines reaches its rated power at wind speeds of 15 m/s to 25 m/s, and thus, must decrease in energy collection at higher wind speeds. Here this energy collection control is achieved by pitch angle control. The pitch angle is controlled to keep the generator at the rated power by reducing the angle of the blades. By actuating the blade angle to be at the limit of the stalling, fast torque changes in the wind speed can be tolerated.

A control technique applied to the pitch angle is done by comparing the current active power of the engine with the value of active power at the rated engine speed. Control of the pitch angle in this case is done with a PI controller controls.

The SIMULATION result for different wind speed is shown below.

Fig: variation of pitch angle, rotor speed and output power for a wind speed of 10 m/s
From the above result it is seen that the output power is constant for different wind speed. The PI controller changes the pitch angle of the blade to keep the output power of the system at a constant value.

**CONCLUSION**

Thus by using pitch controller the output power has been limited at variable wind speed and wind turbine can operate safely. The results are taken at the values which are inherent in the simulink blocks and from the simulink results it is clear that as the wind speed changes then there is a corresponding change in the values of rotor speed, PI controller, Pitch angle to maintain the output at some constant value.

**ACKNOWLEDGEMENT**

We are acknowledge to the TEQIP grant scheme of JIS College of Engineering.

**REFERENCES**

