The pitch angle control of variable speed wind turbine using PID controller

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Abstract-This paper presents the Pitch angle control of Permanent Magnet Synchronous Generator (PMSG) based on Wind Energy Conversion System (WECS) using PID control technique. The models of WECS consist of a wind turbine, pitch angle control, pitch actuator, drive train, PMSG and power converter. Wind turbine model with controller for generator protection in high wind speed is also presented in this paper. The PMSG and converter model are established. The presented model, simulation results are tested in MATLAB/SIMULINK.

Keywords—*Wind Turbine, Speed Control, PID Controller,pitch actuator, Wind Generating System.*

I. INTRODUCTION

With the growing demand for cost-effective wind energy, optimization of wind turbine components has been gaining increasing attention for its acknowledged contributions made to design enhancement, especially in early stages of product development. One of the major design goals is the accurate determination of structural dynamics and control, which is directly related to fatigue life and cost of energy production: a major design goal in exploiting wind energy. Modern wind turbines are designed with pitch-regulated rotor blades, which have to be able to turn around their longitudinal axis several times per second in order to face the rapidly changing wind direction. This fact emphasizes the need to improve the design of pitch mechanisms using optimization techniques in order to increase availability of the turbines and reduce their maintenance overheads. Demonstrated the different tools for performing the analysis of the interaction between the mechanical system of the wind turbine and the electrical grid as well as the calculation of the dynamic loads on the turbine structure. In case of stronger winds it is necessary to waste part of the excess energy of the wind in order to avoid damaging the wind turbine. All wind turbines are therefore designed with some sort of power control. There are different ways of doing this safely on modern wind turbines: pitch, active stall and passive stall controlled wind turbines.

II. WIND ENERGY CONVERSION SYSTEM

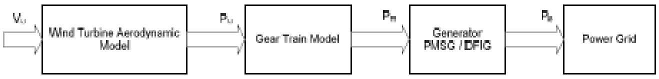
The wind energy conversion system (WECS)includes wind turbines, generators, control system,inter connection apparatus. Wind Turbines are mainly classified into horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). Modern wind turbines use HAWT with two or three blades and operate either downwind or upwind configuration.

This HAWT can be designed for a constant speed application or for the variable speed operation. Among these two types variable speed wind turbine has high efficiency with reduced mechanical stress and less noise. Variable speed turbines produce more power than constant speed type, comparatively, but it needs sophisticated power converters control equipment to provide fixed frequency and constant power factor.

The generators used for the wind energy conversion system mostly of either doubly fed induction generator (DFIG) or permanent magnet synchronous generator (PMSG) type. DFIG have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and grid. In DFIG the converters have to process only about 25-30 percent of total generated power (rotor power connected to grid through converter) and the rest being fed to grid directly from stator. Whereas, converter used in PMSG has to process 100 percent power generated, where 100 percent refers to the standard WECS equipment with three stage gear box in DFIG. Majority of wind turbine manufacturers utilize DFIG for their WECS due to the advantage in terms of cost, weight and size. But the reliability associated with gearbox, the slip rings and brushes in DFIG is unsuitable for certain applications. PMSG does not need a gear box and hence, it has high efficiency with less maintenance. The PMSG drives achieve very high torque at low speeds with less noise and require no external excitation. In the present trend WECS with multibrid concept is interesting and offers the same advantage for large systems in future. Multibrid is a technology where generator, gearbox, main shaft and shaft bearing are all integrated within a common housing. This concept allows reduce in weight and size of generators combined with the gear box technology. The generators with multibrid concept become cheaper and more reliable than that of the standard one, but it loses its efficiency. To achieve high efficient energy conversion on these drives different control strategies can be implemented like direct torque control (DTC), field oriented control (FOC). The FOC using PI controller has linear regulation and the tuning becomes easier. The wind turbine electrical and mechanical parts are mostly linear and modeling will be easier. The blade aerodynamics of the wind turbine is a nonlinear one and hence the overall system model will become nonlinear.

A.WECS modeling

The basic device in the wind energy conversion system is the wind turbine which transfers the kinetic energy into a mechanical energy. The wind turbine is connected to the electrical generator through a coupling device gear train. The output of the generator is given to the electrical grid by employing a proper controller to avoid the disturbances and to protect the system or network.
shows the overall block diagram of the wind energy conversion system (WECS).



Here, $V\omega$ represents wind speed, $P\omega$, Pm and Pe represent wind power, mechanical power and electrical power respectively.

B.PMSG

There are different types of synchronous generators,but the multi-pole permanent magnet synchronous generator (PMSG) is chosen in order to obtain its model. It offers better performance due to higher efficiency and less maintenance since it does not have rotor current and can be used without a gearbox, which also implies a reduction of the weight of the nacelle and a reduction of costs. Due to the advancement in the permanent magnet technology for application in large capacity electrical generators, large wind power plants with permanent magnet synchronous generators (PMSG) are used.

The efficiency of these WPPs is higher than that of induction generators, as the excitation is provided without any external energy supply. With their property of self-excitation the application of PMSG as large diameter multi-pole generators or a smaller diameter conventional generators in WPPs, allows an operation at a high power factor and a high efficiency.

C

The power in the wind is proportional to the cube of the wind
speed and can be expressed as:

P □□0.5□□*A*v3 (1)

where ρ is air density, *A* is the area swept by blades and v is
wind speed.

A wind turbine can only extract part of the power from the

wind, which is limited by the Betz limit (maximum 59%).
This fraction is described by the power coefficient of the turbine, which is a function of the blade pitch angle and the tip speed ratio. Therefore, the mechanical power of the wind turbine extracted from the wind is:

$$P_{wt} = 0.5\,\rho A v3\, C_p(\beta, \lambda) \qquad (2)$$

where *Cp* is the power coefficient of the wind turbine, β is the blade pitch angle and λ is the tip speed ratio. The value of C*p* is highly non-linear and varies with the wind speed, the rotational speed of the turbine, and the turbine blade parameters such as a pitch angle. In this paper value of the Cp(β ,λ) is calculated as:

$$C_p = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{-21}{\lambda_i}} + .0068\,\lambda \qquad (3)$$

where:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \qquad (4)$$

The tip speed ratio is defined as the ratio between the blade tip speed and the wind speed.

$$\lambda = \frac{\omega_{wt} R}{v}$$

where *wt* □□the turbine rotor speed, and R is is the radius of the wind turbine blade.
Thus any change in the rotor speed or the wind speed induces a change in the tip speed ratio leading to power coefficient variation.

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.

III. PITCH ANGLE CONTROL

On a pitch controlled wind turbine the turbine's electronic controller checks the power output of the turbine several times per second. When the wind speed exceeds the rated value, the pitch controller will reduce the angle of attack, turning the blades (pitching) gradually out of the wind. The pressure difference in front and on the back of the blade is reduced, leading to a reduction in the lifting force on the blade. When the power output becomes too high, it sends an order to the blade pitch mechanism which immediately pitches (turns) the rotor blades slightly out of the wind. Conversely, the blades are turned back into the wind whenever the wind drops again. The rotor blades thus have to be able to turn around their longitudinal axis (to pitch) as shown in

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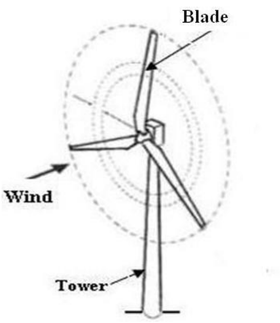
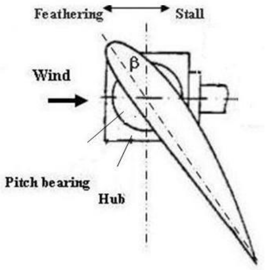
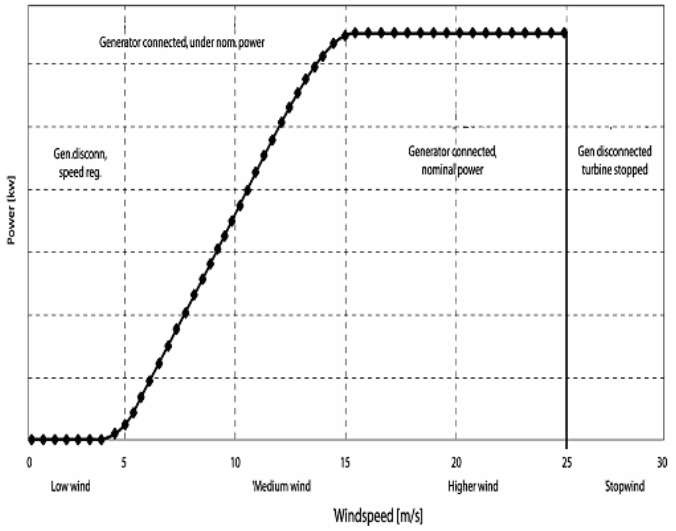
below.





The pitch mechanism is usually operated using hydraulics or electric stepper motors. Fig. 2 shows the optimal operational conditions of a pitch-controlled 2 MW wind turbine. During normal operation the blades will pitch a fraction of a degree at a time, and the rotor will be turning at the same time. The computer will generally pitch the blades a few degrees every time the wind changes in order to keep the rotor blades at the optimum angle to maximize output power for all wind speeds. 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 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 windturbine 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,



I. Low wind, the generator is not connected to grid

II. Medium wind, the generator is connected, but does not produce nominal power

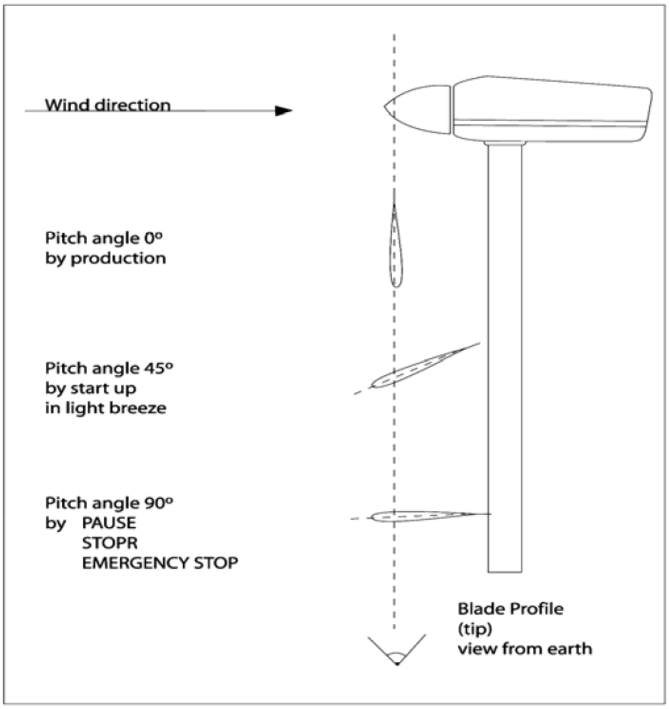
III. Higher wind, the generator is connected and produces nominal power

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 45o. 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 0o, 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 5o, (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 energyproduction.



Pitch Settings at different operating states

IV. PITCH ACTUATOR SYSTEM MODELLING

The pitch actuator consists of a mechanical and a hydraulic
system, which is used to turn the blades along their longitudinal axis. The actuator model describes the dynamic
behaviour between a pitch demand □*d* from the pitch
controller and the measurement of a pitch angle□□.
The dynamics of the blades are non-linear with saturation
limits on both pitch angle and pitch rate. This saturation is
caused by high frequency components of the pitch demand
spectrum, via measurement noise, and spectral peaks induced
by rotational sampling (Feng et al., 2008). In this paper, the
constraint is not considered. The actuator dynamic is
modelled as in (Eisenhut et al., 2007). The change in the
pitch angle is:

$$\dot{\beta} = \frac{\beta_d - \beta}{\tau_\beta} \qquad (6)$$

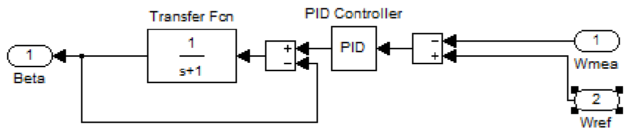
From above equation, the transfer function for the actuator is:

$$\frac{\beta}{\beta_d} = \frac{1}{\tau_\beta s + 1} \qquad (7)$$

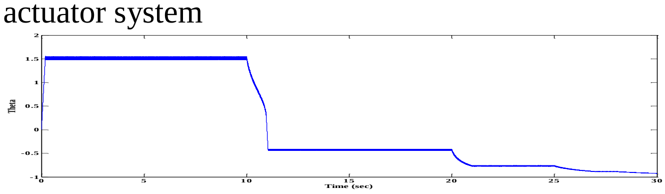
where τ_β is a time constant depends on the pitch actuator.

where □□□□is a time constant depends +on the pitch actuator.

A..PID controller based pitch actuator system

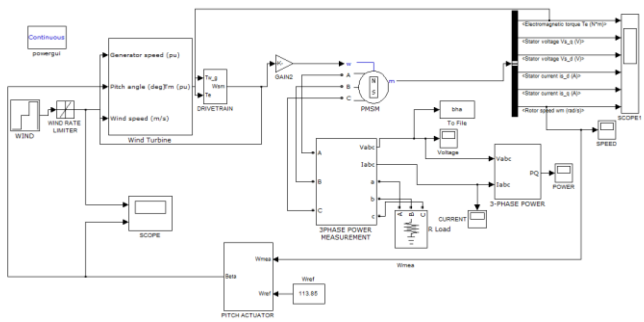


Block diagram of PID controller based pitch actuator system



Output of Pitch Control

Simulation diagram:



speed output

CONCLUSION

In this study the wind turbine, drive train are mathematically modeled and simulated. The power output characteristics of the wind turbine are studied. We used permanent magnet synchronous generator for loss less and cost efficient operation. To control the power output of the turbine we employed three pitch actuator system. This varies the pitch angle of the wind turbine, so as to minimize the power output deviation from the preset value. That is the power output of the turbine is maintained constant when the speed varies over a range of 4-25m/sec. This leads to reduction of mechanical stresses that develop in turbine, drive turbine and also gives reliable power output.

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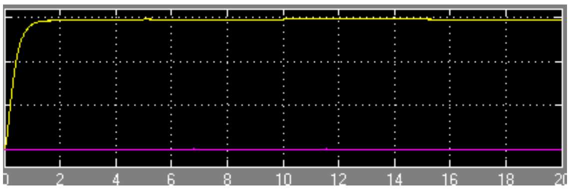

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