PERMANENT MAGNET SYNCHROUNOUS GENERATOR WIND TURBINE PITCH ANGLE CONTROL BY FUZZY AND PID CONTROL

B.Chinna Rao[1], M.Durga Prasada Rao[2],

[1]*Pg scholar, Department of EEE, Bapatla engineering college, Andhra Pradesh, India.*
[2]*Assistant Professor, Department of EEE, Bapatla engineering college, Andhra Pradesh, India.*

Abstract - *The pitch angle control is one of the best method to control the torque on top of blades of the wind turbine at high wind speeds. As the incursion of the wind energy into the electrical power grid is widely improved, the persuade of the wind turbine systems on the frequency and voltage stability becomes extra momentous. Existing pitch angle control includes Proportional Integral(PI) controller, Proportional-Integral-Derivative (PID) controller, PI with gain scheduling ,fuzzy logic controller and sliding mode control. By combining existing methods it will give better results in controlling output power and rotor speeds. this controller is intended to control Pitch angle, it doesn't require much knowledge of system representation. Inputs to Fuzzy controller are error in PMSG output power and speed of rotor thus Fuzzy controller gives reference angle to compensate non-linear nature of the wind turbine. This technique is carried out on a 5MW PMSG wind turbine system at wind speeds of 13m/s in MATLAB.*

Key words: Proportional-Integral-Derivative controller, Fuzzy logic controller, PMSG, pitch angle.

1. INTRODUCTION

Wind energy is a source of renewable power which comes from air across the earth's surface. Wind turbines produce this kinetic energy and exchange it into utilizable power which can supply electricity for house, ranch, school or commerce applications on various scales. Here basic diagram of horizontal axis wind turbines (HAWT). The main elements of a two-bladed horizontal axis wind turbines.

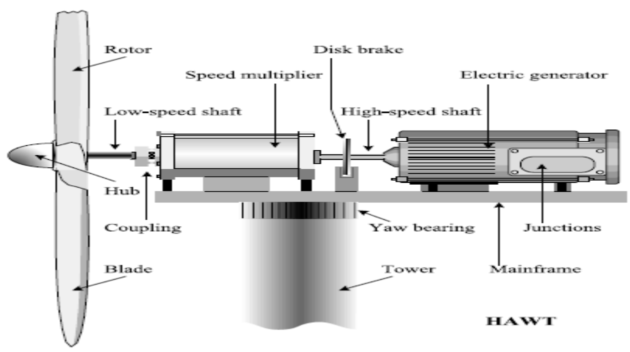

Figure 1. Main elements of a two-bladed HAWT

HAWT is comprised of the tower and the nacelle, mounted on the top of the tower (Fig.1). Except for the energy conversion chain elements, the nacelle contains some control subsystems and some auxiliary elements The variable-speed, variable-pitch wind turbine systems in general have two working regions according to the wind speed. . Existing pitch angle control includes Proportional Integral(PI) controller, Proportional-Integral-Derivative (PID) controller, PI with Gain Scheduling, Linear Quadratic Gaussian method, sliding mode control and fuzzy logic controller. But there are many problems with existing control methods. In PI/PID controller method drawback is control performance is deteriorated when the operating points are changed as the controller design is based on the turbine model which is linearized at the operating points by a small signal analysis. Other method is H_∞ Controller with a linear matrix dissimilarity approach which gives constant power output and toughness to the change in wind speed and turbine parameters. Though it is complex since the parameters of the model and the controller need to be redesigned due to time to time changes in weighting functions by the constraints. In Linear Quadratic Gaussian method have very restricted performance as wind turbine has non linear properties. In Generalized Predictive Control (GPC) scheme is another process but if output power has large error then control system will be unstable as this law depends on error of power output. To compensate this problem variance of power output from wind turbines farm taken and gave to fuzzy controller. In gain scheduling control method nonlinearity of the turbine is compensated and by changing operating conditions of turbine controller gains are updated endlessly.This method won't require any online parameter assessment, and gives relatively swift response to the changes of operating conditions. A main problem of this controller is performance depends on the model of the wind turbines linearized at the definite operating points. In addition, it is not so simple to propose the scheduling function updating the controller gains at the various working points. Methods with fuzzy logic control have been proposed for the pitch angle control but There is a drawback is the wind speed is necessary. By using anemometer wind speed is measured in those methods. Anemometer is a bit costly, so this method is not feasible. So to eliminate some of these drawbacks the new proposed model is combining the fuzzy logic controller and PID controller and simulate the model in MATLAB software. The results shows less fluctuations and ripple power output and speed of turbine.

2. Basic Structure Of WECS

General structure of a full variable-speed Wind Energy Conversion Systems (WECS) is shown below figure 2.1

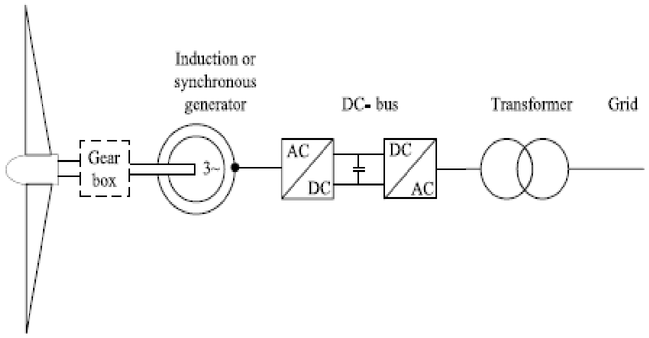

figure 2.1. general structure of variable-speed WECS

The PMSG is considered, in many study articles, a fine choice to be used in WECS, due to its self-excitation possessions, which allows operation at good power factor and efficiency. PMSG won't need energy supply for excitation, as it is given by the permanent magnets. The stator of a PMSG is wound and the rotor has a permanent magnet pole system. The salient pole of PMSG working at low speeds, so the gearbox (Fig.2.1) can be detached. This is a huge benefit of PMSG-based WECS as the gearbox is a sensitive tool in wind power systems. The similar thing can be get by with direct driven multi pole PMSG with more diameter. The solidity of a wind rotor is the ratio of the projected blade area to the area of the wind intercepted. 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 speed of free wind. Power coefficient of a wind turbine is the instantaneous efficiency of conversion of wind energy into mechanical energy of the shaft.

2.1. Pitch Control

Through pitch 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. Basic diagram is shown below.

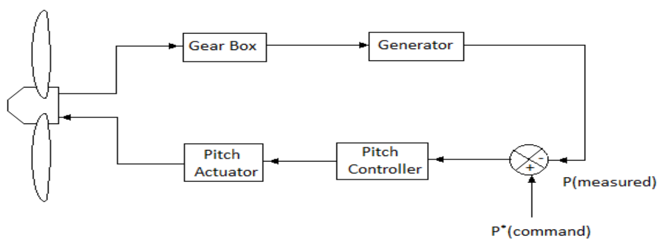

Figure 2.2. Feedback loop for Pitch angle control

2.3. Power Electronic Control

This control is appropriate in systems which include a power electronic interface among the generator and the load. The instant variation between mechanical power and electrical power changes the rotor speed following the equation. By 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 scheme of speed control procedure gives a smooth operation as it does not engage any mechanical action. On the other side, if swift change in speed is preferred, a big difference between the input and output power is necessary. The pressure on the blades is increased on account of the large torque needed. Continuous control of the rotor speed by this method leads to continuous variation of the power output to the grid, which is not desirable. Lastly, the power electronics converter control ensures that the strict power quality standards are met. Recently, the rising necessities for WECS to remain connected and to provide active grid support have added control objectives for the power electronics converters. In the case of a grid fault, the WECS should remain connected. Basically these converters are made up of vsis equipped with switches as igbts body diodes which permit a bi-directional current flow. Output switching harmonics of the GSC is reduced by the filters PMSG Based WECS Connected Power Electronic Control is shown below.

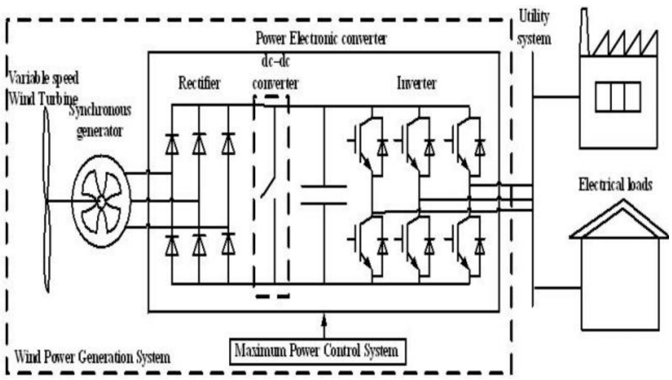

Fig.3.4 PMSG Based WECS Connected Power Electronic Control

3. TURBINE MODEL

The mathematical model of wind turbine model is given below. The energy drawn by wind turbine is given by

$$W_w = V_a \frac{1}{2} \rho (V_1^2 - V_3^2)$$

where W_w = Energy drawn by wind turbine,
ρ = Air density,
V_1 = Undistributed far upstream wind speed,
V_3 = Decelerated wind far-downstream turbine.

Airstream around the turbine figure is given below

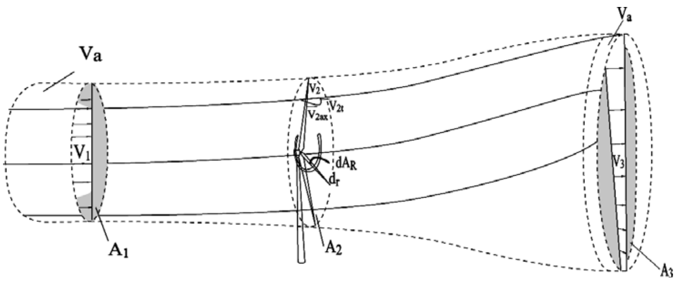

Figure 3.1 Airstream around the turbine

V_a = Air stream volume element,
V_1 = Undistributed far-upstream wind speed,
V_2 = Wind speed at turbine,
V_3 = Decelerated wind far-downstream turbine,
A_1 = Far-upstream cross section of flow,
A_2 = Cross section of flow at turbine,
A_3 = Broading downstream cross section of flow and
A_R = Rotor swept area.

4. PI/PID Controllers

The general pitch control approach uses the PI/PID controllers to control the rotor speed or turbine output power. In the less load operation, B_{Ref} Is set at zero and the maximum power point tracking (MPPT) technique is done, so that the energy change coefficient is maximized in the less load area. In the full-load area, the pitch controller is activated to control the generator output power or speed to follow their reference values. Block diagram of pitch control using PI controller for linearized wind turbine.

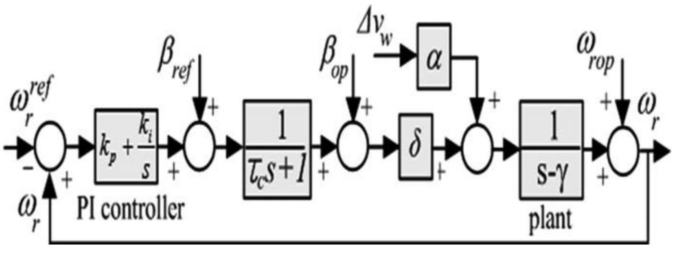

Figure 4.1. Block diagram of pitch control using PI controller for linearized wind turbine.

4.1. PI/PID Controllers With Gain Scheduling

The gain scheduling for the pitch control is to compensate for the changes of the sensitivity of the aerodynamic torque to the pitch angle. In gain scheduling control method nonlinearity of the turbine is compensated and by changing operating conditions of turbine controller gains are updated endlessly. .This method won't require any online parameter assessment, and gives relatively swift response to the changes of operating conditions.

Block diagram for the pitch control system using PI and PID controllers with Gain Scheduling is shown here.

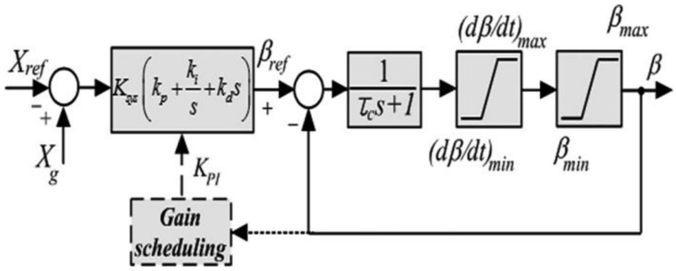

Figure 4.2. Block diagram of the pitch control system using PI and PID controllers.

4.2. Fuzzy Logic Controller

The design of the FLC is based on human practice through a set of the empirically determined design rules, has been used for controlling the pitch angle The control block diagram using the fuzzy logic is shown in, in which the generator output power and wind speed are taken as the control inputs of the FLC. The benefit of this technique is that the parameters of the wind turbine system do not need to be acknowledged accurately. Though, this method requires the wind speed information. Block diagram of pitch controller using fuzzy logic is shown below.

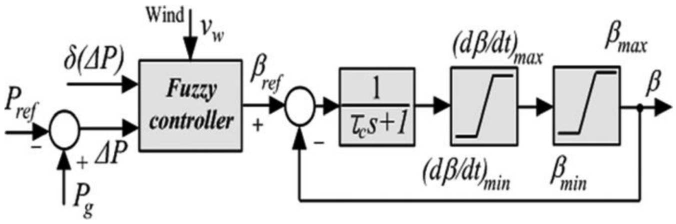

Figure 4.3 Block diagram of pitch controller using fuzzy logic

5. Proposed Fuzzy Logic Controller With PID

The block diagram of the planned pitch angle control based on the fuzzy logic and PID controller is shown in below. The combined effects are simulated in MATLAB

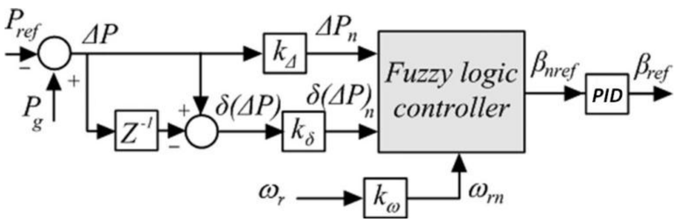

Figure 5.1 Block diagram of pitch control system using FLC and PID controller

w_r		PS					PM					PB				
ΔP		NB	NS	ZE	PS	PB	NB	NS	ZE	PS	PB	NB	NS	ZE	PS	PB
	NB	NB	NB	NB	NB	NMB	NS	NS	NS	PM	PMB	PS	PS	PM	PMB	PB
	NS	NB	NB	NB	NMB	NMB	NS	NS	ZE	PM	PMB	PS	PS	PMB	PMB	PB
	ZE	NB	NB	NMB	NMB	NM	NS	ZE	ZE	PM	PMB	PS	PM	PMB	PB	PB
$\delta\Delta P$	PS	NB	NMB	NMB	NM	NM	NS	ZE	ZE	PMB	PMB	PM	PM	PB	PB	PB
	PB	NMB	NMB	NM	NM	NM	ZE	ZE	PS	PMB	PMB	PM	PM	PB	PB	PB

Table 5.1 Rules of Fuzzy Logic Controller

Rules of Fuzzy Logic Controller is shown in above table. The Fuzzy inference system consists of Membership Functions. some of fuzzy rules are given below

1. If (deltaP is NB) and (delta(deltaP) is NB) and (Wr is PS) then (Betaref is NB) (1)
2. If (deltaP is NS) and (delta(deltaP) is NB) and (Wr is PS) then (Betaref is NB) (1)
3. If (deltaP is ZE) and (delta(deltaP) is NB) and (Wr is PS) then (Betaref is NB) (1)
4. If (deltaP is PS) and (delta(deltaP) is NB) and (Wr is PS) then (Betaref is NB) (1)
5. If (deltaP is PB) and (delta(deltaP) is NB) and (Wr is PS) then (Betaref is NMB) (1)
6. If (deltaP is NB) and (delta(deltaP) is NS) and (Wr is PS) then (Betaref is NB) (1)
7. If (deltaP is NS) and (delta(deltaP) is NS) and (Wr is PS) then (Betaref is NB) (1)
8. If (deltaP is ZE) and (delta(deltaP) is NS) and (Wr is PS) then (Betaref is NB) (1)
9. If (deltaP is PS) and (delta(deltaP) is NS) and (Wr is PS) then (Betaref is NMB) (1)
10. If (deltaP is PB) and (delta(deltaP) is NS) and (Wr is PS) then (Betaref is NMB) (1)
11. If (deltaP is NB) and (delta(deltaP) is ZE) and (Wr is PS) then (Betaref is NB) (1)
12. If (deltaP is NS) and (delta(deltaP) is ZE) and (Wr is PS) then (Betaref is NB) (1)
13. If (deltaP is ZE) and (delta(deltaP) is ZE) and (Wr is PS) then (Betaref is NMB) (1)
14. If (deltaP is PS) and (delta(deltaP) is ZE) and (Wr is PS) then (Betaref is NMB) (1)
15. If (deltaP is PB) and (delta(deltaP) is ZE) and (Wr is PS) then (Betaref is NM) (1)

Fuzzy sets are designed by using the triangular membership functions with the overlap are used. The linguistic variables are represented by Negative Big (NB), Negative Medium Big (NMB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Medium Big (PMB), and Positive Big (PB). The control rules are derived from knowledge in the control system. The fuzzy mapping of the input variables to the output is expressed by the like above rules. Two input variable has five membership functions and third one has three membership functions hence a total of seventy five rules can be framed. These rules are framed in rule editor, Sugeno weighted average method is employed to get the output fuzzy set for every rule. The design of a fuzzy logic controller requires the choice of membership functions. The membership functions should be chosen such that they cover the whole universe of discourse.

6. MATLAB Simulation Results

MATLAB simulation diagram of FLC and PID have the following values which are listed in below table. The simulation results of BETA Ref , Rotor speed, Wind speed, Power coefficient, Torque of turbine, Change in power output and error of power output change. By observing the simulation results the harmonics and variation of change in output power is also less.PID controllers helps Fuzzy Logic to have constant power output.
The tables of PMSG parameters for simulation shown below.

Power Output Rated	5 MW
Voltage Of Grid	690 V
Stator Voltage	690 V
Stator Frequency	16.6Hz
Stator Inductance	0.00359H
Generator Inertia	48000 $kg.m^2$
Stator Resistance	0.008556Ω

Table 6.1. PMSG parameters for simulation

To examine the performance of the Fuzzy and PID controllers and the at the dissimilar operating point, the rated wind speed which classifies the less and full-load regions is set as 13 m/s, The gain parameters for both the PI/PID controllers and the membership function of the FLC are the same as previous case. The wind speed model is also equal in both cases. All pitch angle control technique can control both the generator power and rotor speed at their rated values. Though, the pitch angle control employing the planned FLC and PID method gives good results than other controllers. The graphs of generator output power, rotor speed, and mechanical torque are shown here. In the meantime, they are kept typically at the rated value in the high wind- speed area with the planned control method. So, to assurance that the system works fine at each operating point, these gains should be redesigned. In contrast, even though the operating point is distorted, the pitch angle control using the planned FLC and PID method even gives good results. It is observed that in the high-wind-speed area, the average generator output power with the proposed method is more than other controllers.

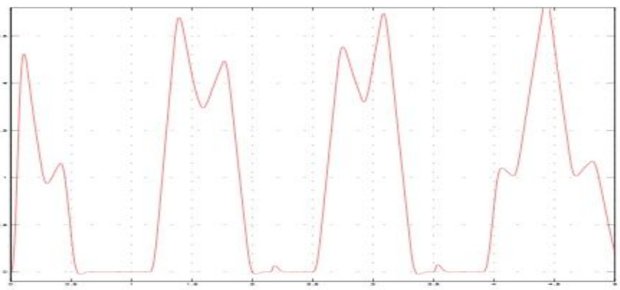

Figure 6.1. Beta Ref simulation

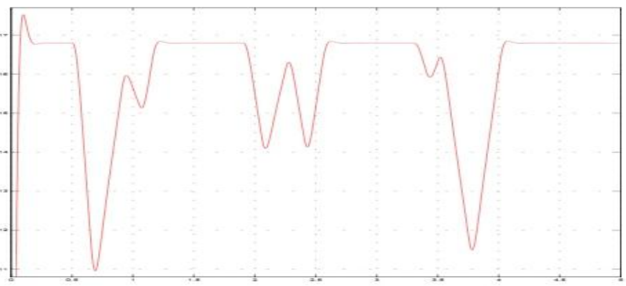

Figure 6.2. Rotor Speed

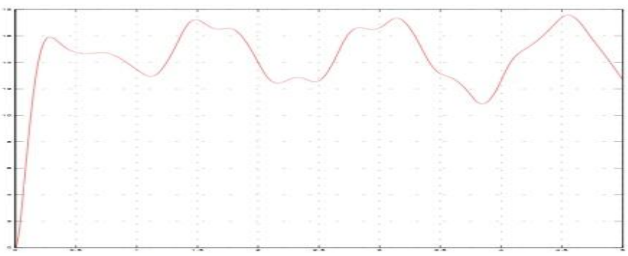

Figure 6.3. Wind Speed

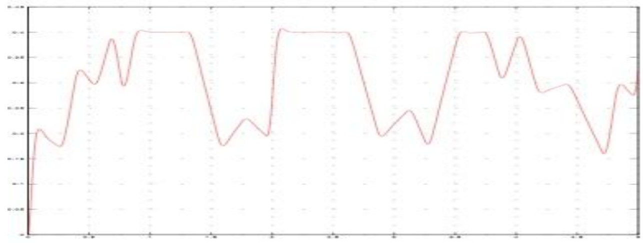

Figure 6.4. Power Coefficient

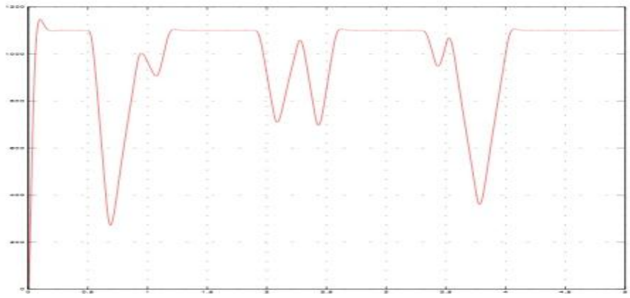

Figure 6.5. Torque of turbine

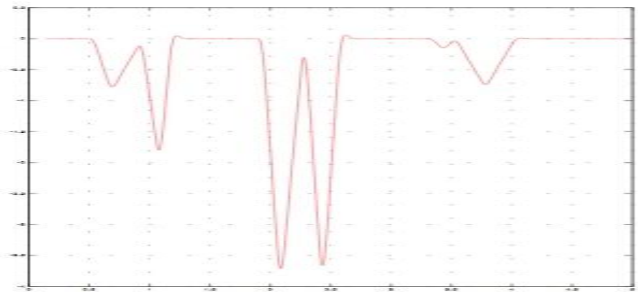

Figure 6.6. Change in power output

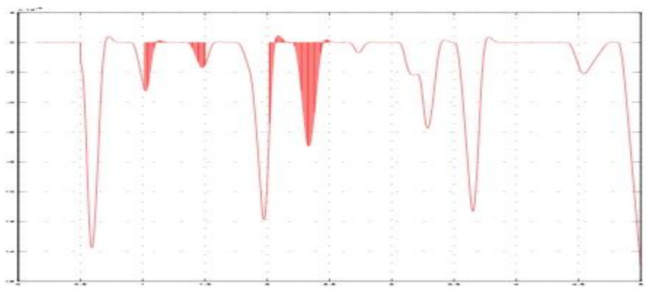

Figure 6.7. error in delta P

7. Conclusions

The FLC and PID is more beneficial compared to general controllers like PI/PID, PI controller with gain Scheduling, Sliding-Mode controller used to pitch angle control. As the generator output power and the generator speed are considered as control variables in its place of the wind speed, which removes the use of an costly anemometer. And as well the Fuzzy logic controller and PID is more consistent and tough to the nonlinear properties of the pitch angle with the wind speed.

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