Performance Comparison of Pitch Angle Controllers for 2MW Wind Turbine

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Abstract
As wind energy is becoming more and more significant for renewable energy, effectiveness of pitch angle controller plays crucial role to achieve higher performance and optimized turbine designs. Aerodynamic performance of wind turbine rotor and consecutively electrical power production of turbine depend on the efficiency of pitch controller design. This work presents the effects of two different pitch angle controllers on a 2MW DFIG type wind turbine under Matlab Simulink environment. The main objective of the pitch controller is to regulate the rotor and generator speed as the input of the controller was generator speed where the output of the controller is to determine the pitch angle. PI and PID control methodologies are used to design pitch controller of the turbine. Through the controller design, iterations, settling time, overshoot value, error values and power output values are decided for comparison parameters. Both controller performances in terms of transient and steady state are evaluated.

Keywords: Wind Energy, Pitch Angle Controller, Speed Regulation, Power Output

Introduction

Wind turbine (WT) systems with large power scales, blade pitches have to be controlled in order to prevent excessive amount of energy, over speed of a rotor and not to damage the system over nominal wind speeds. [1] This reasoning can be stated as the variable speed WTs provide an opportunity to generate more energy than fixed speed wind turbines. [2]

On the other hand, the output power of the variable speed WTs varies due to the uncertainties of the wind speeds. The fluctuations of the wind speeds leads to changes of the voltage and the frequency. However, fixed voltage and a fixed frequency are two of the most important criteria for a quality of electrical energy. In order to improve quality of the output power, appropriate control methods gave to be applied on wind turbine systems. [3]

The variable-speed, variable-pitch wind turbine systems typically have two operating regions according to the wind speed. In partial-load region where the wind speed is lower than the rated wind speed v_{rated}, the turbine speed is controlled at the optimal value so that the maximum energy is extracted from the wind turbine. [4] [5] In the full load region where the wind speed exceeds its rated value, the generator output power is limited at the rated value by controlling the pitch angle are limited. [6] [7]

One of the most important problems of horizontal axis large-scale wind turbines is that to maximize the power efficiency below the nominal wind speed and limit the nominal power above the nominal wind speeds. [8] In order to resolve this problem, variable speed variable pitch angle wind turbines can have different torque controller to maximize the power efficiency and pitch controllers to limit the nominal power. [9] [10]

Pitch control is one of the most significant subsystem of a modern wind turbine and different control techniques have been applied so far to achieve more efficient wind turbines. Even though many research groups have used many control theories, classical PID controllers are frequently used in today’s modern wind turbines commercially. PID controllers have been used in a great deal of wind turbine control applications because of their simple structures, high safety and robustness. [11] [12] Therefore, PID controllers have been employed in order to control system outputs of particular systems that have mathematical models. [13] [14]

In this paper, conventional PI and PID controllers were applied to regulate a 2MW DFIG type variable speed wind turbine in Matlab Simulink environment. The main aim of the both controllers is to limit the turbine output power and the generator speed in the full load region. Performance comparison criteria for both controllers are rise time, overshoot, settling time for transient dynamics whereas the error in speed and expected power are for steady state operation. In addition, energy production difference can be taken into account as comparison criterion. The comparative simulation results for a 2-MW doubly fed induction generator (DFIG) wind turbine system for both controllers shown for a certain wind speed profile.

Methodology

Wind turbine modelling and system definition. Wind turbines consists of several subsystems, which can be stated as aerodynamic, mechanical, electromechanical and electrical subsystems. In addition, control systems are also designed separately for all of the subsystem above however, torque control and pitch controllers can be considered as the most significant ones among the others. [8]

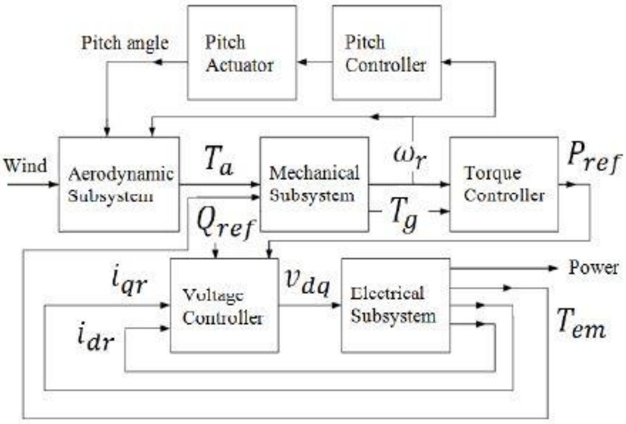


Figure 1: Wind Turbine Block Diagram

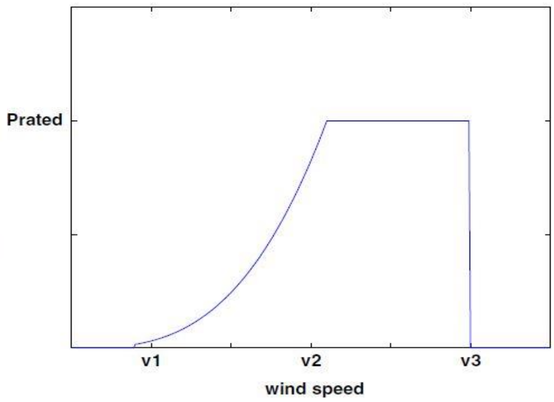


Figure 2: Wind Speed Regions

As illustrated in figure 1, wind turbines may have a different subsystem from different engineering disciplines where many of them require different controllers. Torque controllers are generally used for DFIG type generators to regulate the powers where pitch controllers are used to regulate the speed of the rotor. In addition, another highly important concept for wind turbine technologies is to classify operating regions since many important descriptions for the turbine are made by the wind regime graphs such as operating speed, determination of maximum power production, maximum available aeromechanical power and so on. Figure 2 shows the operating regions of the 2MW wind turbine that is used to complete this study. As can be seen from the figure, wind profile is divided in three zone according to wind speed in which zone 1, zone 2, zone 3 can be named as cut in, rated and active and cut off respectively. Wind turbines generally starts to produce electricity with the wind speed of cut in. Until the rated wind speed, pitch system operates as Maximum Power Point Tracking (MPPT) mode with 0 degrees of pitch. While the wind speed increases, pitch system keeps maximizing the power output from the available aeromechanical power. Zone 2 is generally considered as partial load region where pitch system may start to become active to have more efficient power output performance. If the wind speed is more than rated speed, than pitch system becomes active while the wind speed increases, rotation and power is limited with higher pitch angles. Zone 3 can be considered as active pitch region above rated wind speed where the power is regulated by active pitching. After wind speed exceeds or gets near to cut off speed wind turbines are stopped due to mechanical safety reason by using pitch control. [15]

Modelling of aerodynamic, mechanical, electromechanical, grid side converters on a simulation environment is a significant issue to conduct a better study for performance comparison. Throughout the study, 2MW DFIG type variable speed and variable pitch wind turbine is under Matlab/Simulink environment used with a wind regime that is above rated speed. The aim of this certain wind regime is to observe the effect of pitching under abrupt changes of wind speed and the power regulation characteristics. Table 1 depicts the parameters for the wind turbine simulated throughout the controller design study.

Table 1: Wind Turbine System Parameters

Simulated System Characteristics			
Nominal Output Power	2 MW	Nominal Rotor Speed	15.8 rpm
Working Mode	Grid Connected	Gear Box Rate	1:94.7
Cut in wind speed	3 m/s	Generator Pole Pair	2
Nominal wind speed	12 m/s	Generator Type	DFIG
Cut out wind speed	25 m/s	Generator Synchronous Speed	1500 rpm
Rotor Diameter	82.6 m	Generator Voltage	690 V
Rotor Swept Area	5359 m^2		

Pitch Control Subsystem. One of the most important subsystems of a wind turbine can be pitch control since it affects the mechanical strength, aeromechanical power, rotation dynamics and consecutively electrical power regulation. Pitch controllers are actively used in the full load-operating region in order to prevent any kind of mechanical damage from the excessive loading at high wind speeds. Moreover, in order to regulate the power with the aid of speed regulation, different pitch controlling techniques are used in the modern commercial wind turbines. Throughout this study, PI and PID controllers are implemented and simulated for 2MW DFIG wind turbine as mentioned above. Pitch controller uses the rotor angular speed as an input and error is regulated with the PID controller. In this study, normalized error is calculated and applied to controller as per unit (p.u).

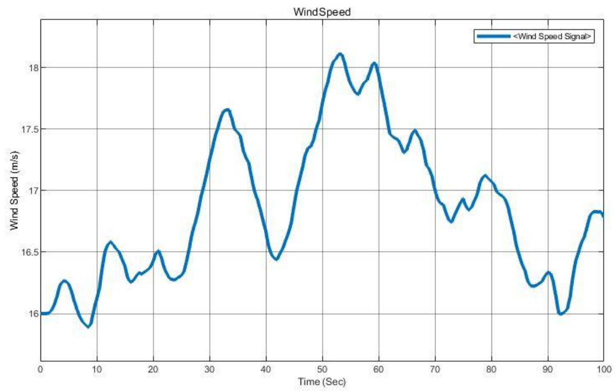
Classical PID controller. In conventional control methods, PID controllers have feedback structures. After an error is passed through proportional, integral and derivative actions, the error is applied again to the system input in accordance with and the system output is controlled as desired. [2] Clarification of the continuous equation of the PID controller is as in Eq. 1. Where u (t) is the controlled output , K_p is the proportional gain , K_i is the integral gain , K_d is the derivative gain and e(t) is also the error signal between the system output and the system input value. [2] Discrete version of the PID controller can be stated as follows in Eq. 2.

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \quad (1)$$

$$\Delta u(k) = K_p[e(k) - e(k-1)] + K_i T_s e(k) + \frac{K_d}{T_s}[e(k) - 2e(k-1) + e(k-2)] \quad (2)$$

Results and Discussion

As mentioned previously, PI and PID controllers for a 2MW DFIG type wind turbine are implemented for a certain wind regime which has a mean value of 17m/s. Transient and steady state dynamics with the arguments of overshoot, rise time, settling time, steady state error and power productions are compared.



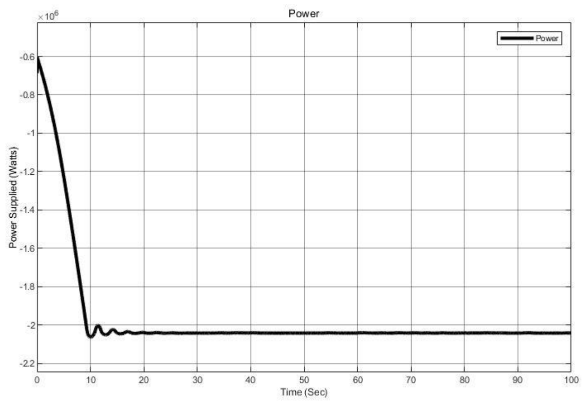
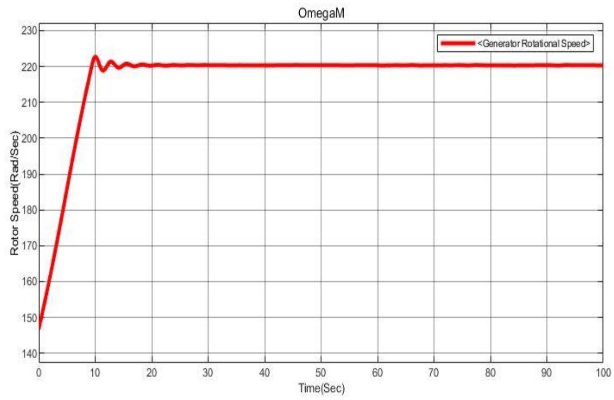


Figure 5: Applied wind speed

Figure 6: Power Output of Turbine

As illustrated in figure 5, wind speed input is designed for 100 seconds of simulations to observe the turbine outputs including pitch angle, power output, and Cp values to compare performances of the implemented PI and PID controllers. Wind speed has abrupt increases to observe the response of the controllers.

Under the depicted wind profile several simulations conducted to compare performances of both PI and PID controllers for transient and steady state situations. As figure 6 and 7 show, the main aim of the controller is to maximize the power output by keeping the generator rotational speed steady at 220rad/sec. As previously mentioned, pitch controllers aim to regulate the rotational speed of the turbine and consecutively regulate the power while full load wind regions.



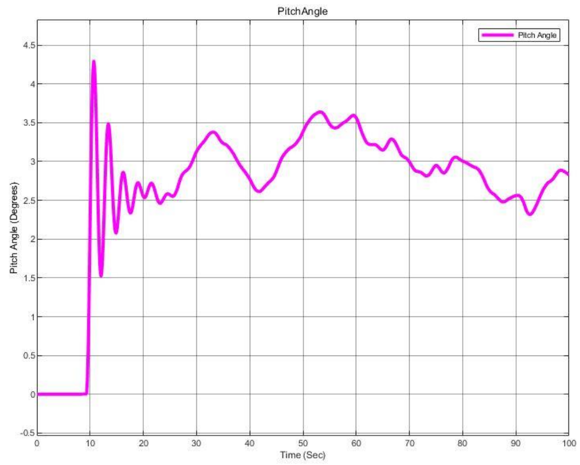


Figure 7: Generator Rotational Speed

Figure 8: Pitch Angle Change

As wind speed fluctuates and abruptly change overrated speed, pitch angle of blades change also drastically. Figure 8 shows from the simulation results of a PID controller configuration.

Comparison of Transient Response. In this study, both PI and PID configuration of pitch controllers were compared initially with transient responses. Successively, steady state responses for both controllers are also shown. Both controllers perform successful performances as they have stable outputs in terms of reaching maximum power output and generator speed stability. However, their transient dynamics alter in terms of overshoot and settling time. In this manner, PI controller performance can be more efficient.

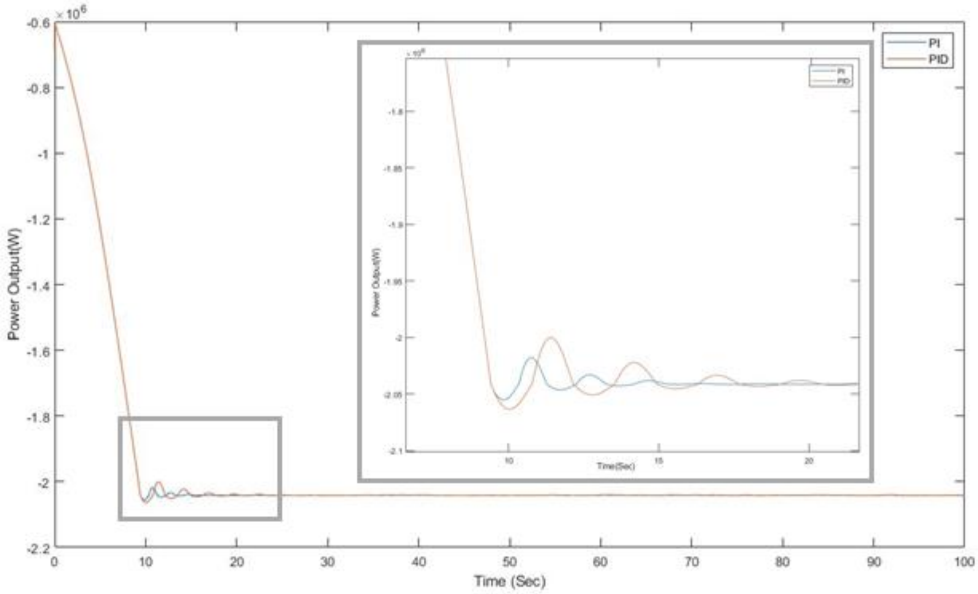


Figure 9: PI&PID Controller Results and Transient Response

As denoted in figure 9, both controllers perform successful operations for 100 second simulation for steady state characteristics. However, for transient response performances vary. PI and PID controllers denote different transients as overshooting is more stable for PI controller. In addition, rise time, overshoot and settling time for PI and PID controllers are tabulated at table 2 that is shown below.

Table 2: Transient Response Results

Controllers	**PI**	**PID**
Overshoot (Δ_h)	2%	4,5%
Rise Time (t_r)	10s	11s
Settling Time (t_s)	20s	25.8s

Comparison of Steady State Response. Unlike the previous transient response, PID controller yields better results than PI controller under steady state in terms of both steady state error and total power production. Necessary results for comparison are tabulated at table 3.

Table 3: Steady State Results

Controllers	**PI**	**PID**
Steady State Error (e_{ss})	0,002	0,001
Total Power Production		2,4%(More than PI)

Conclusions

In this study, 2MW wind turbine with DFIG configuration model was used to perform controller designs with PI and PID techniques. Several simulations were conducted under MATLAB/SIMULINK for a certain wind speed profile that is above rated wind speed. A comparison for the performance under transient response and steady state conditions. It is shown that PI controller performed better under transient state of simulation results whereas PID controller can be stated better for steady state since more power production and less steady state error can be observed.

As a future work of this study, both controllers will be developed for gust wind profiles and tuned to find best parameters.

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