CHAPTER VI

WIND ENERGY CONVERSION SYSTEM CONTROL BASED ON PI CONTROLLER

6.1 Introduction

In this chapter, the application of a novel Pitch Angle controller based on conventional PI logic for control of Wind Energy Control System is presented.

6.2 Conventional Controller Design

P, PI, PID controllers offer the simplest and yet most efficient solution to many real world control problems. Therefore, they are the most widely used controller structures in the industry, [Ang05]. The user has to tune three controller parameters in this setting. With the advancement in the technology, automatic control area can now offer a wide range of controller structures. However, PID controllers are the most dominating. More than 90% of the controller loops used in the industry consists of PID controllers, [Ast01]. PID controllers are used in various applications such as: process control, motor drives, magnetic and optic memories, automotive, tight control, instrumentation, etc. Strength of the PID controller is that it deals with some practical issues such as actuator saturation and integrator windup. The PID controllers of interest are in the following form:

\[ C(S) = K_p + \frac{K_i}{S} + \frac{K_d S}{\tau_d S + 1} \]  

(6.1)

where \(K_p\) is the proportional constant, \(K_i\) is the integral constant, \(K_d\) is the derivative constant and \(\tau_d > 0\) is a small time constant. The derivative part of the controller is implemented as in equation 6.1 to make it a proper transfer function.
Traditionally, the derivative part of a standard PID controller is filtered with a low-pass filter to prevent the high frequency gain of the controller growing too much [Kri97]. The filter has not been regarded as a part of the design but added afterwards with the filter constant adjusted appropriately for the system to meet the specifications and small enough not to influence mid-frequency components. Also, note that when $K_d$ is an arbitrary positive number equation 6.1 represents a stable controller structure. Such controllers are also having practical significant importance in the framework of low order strongly stabilizing controller design for unstable time delay systems as discussed in [Gum08] and [Ozb07].

Figure 6.1 PI Controller based WECS design
Due to the ample use of Proportional Integral (PI) controllers in process industry, there always has been a significant endeavor to obtain effective PI controller design methods, which will meet certain design criteria and provide system robustness.

6.3 PI Based Pitch Angle Controller Design

The Proportional Integral Based Pitch Angle Controller (PIPAC) is designed with inputs the change in the rotor speed. The reference speed is compared with the actual rotor speed and the error signal is given as input to the designed PI controller. The output is the PI based Pitch Angle Controller alters the pitch angle for extracting the maximum power. The PI Control system designed is shown in Figure 6.1.

6.4 Ziegler-Nichols Rules for Tuning PID Controller

It has been observed that step responses of many processes to which PID controllers are applied have monotonically increasing the characteristics. So most traditional design methods for PID controllers have been developed implicitly assuming this property. However, there exist some processes that exhibit oscillatory responses to step inputs.

Table 6.1 Ziegler-Nichols Based Controller Design

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>$K_p$</th>
<th>$T_i$</th>
<th>$T_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>$0.5K_{cr}$</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>PI</td>
<td>$0.45K_{cr}$</td>
<td>$0.833T_{cr}$</td>
<td>0</td>
</tr>
<tr>
<td>PID</td>
<td>$0.6K_{cr}$</td>
<td>$0.5T_{cr}$</td>
<td>$0.125T_{cr}$</td>
</tr>
</tbody>
</table>
Two tuning methods were proposed by Ziegler and Nichols in 1942 and have been widely utilized either in the original form or in modified forms [Ast01]. One of them, referred to as Ziegler–Nichols ultimate sensitivity method, is used to determine the parameters as given in Table 6.1 using the data $K_{cr}$ and $T_{cr}$ obtained from the ultimate sensitivity test and the other, referred to as Ziegler–Nichols step response method which are determined from the step response test.

Frequency-domain stability analysis tells that the above way of applying the Ziegler–Nichols step response method to processes with self-regulation tends to set the parameters on the safe side, in the sense that the actual gain and phase margins become larger than the values expected in the case of integrating processes.

These methods to determine PID parameter, using empirical formula, as well as several other tuning methods developed on the same principle, are often referred to as “classical” tuning methods. Some of the other classical tuning methods are, Chien–Hrones–Reswick formula, Cohen–Coon formula, refined Ziegler–Nichols tuning, Wang–Juang–Chan formula.

6.5 Simulation Studies

The SIMULINK of MATLAB [Ned06] is used for modeling the power system and designing the PIPAC was shown in Figure 6.2. A number of studies have been performed to investigate the effect of Pitch Angle Controller designed by the conventional PI control approach. The simulation block diagram of controlling of blade pitch angle of WECS with PIPAC is given in Figure 6.2. The difference between mechanic angular speed of asynchronous generator and nominal mechanic angular speed gives an error signal.
The input signals of PIPAC is the error signal $e(t)$ and is expressed with correlations as

$$e(t) = \omega_m - \omega_{m\, \text{nominal}}$$  \hspace{1cm} (6.2)

The pitch angle controller is used to control wind flow around the turbine blades by controlling the moment spent on the turbine shaft. If the wind speed is lower than the rated speed of wind turbine, pitch angle is constant in its optimum value. It must be considered that the pitch angle can be changed in limited rate. This rate may be completely low because of rotor blade dimension. The maximum change rate for blade gap angle is about 10 degree/s. The designed $K_p$ and $K_i$ values of the PI controller using Ziegler-Nichols method is shown below.

**Table 6.2 PI Controller Designed parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$K_p$</th>
<th>$K_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Maximum pitch angle 45°

Maximum Rate of change of pitch angle 2°/sec
By means of blade pitch angle control, in speeds of rotor above slow and nominal values, no problem may occur with respect to the structure of the wind turbine. As long as the wind turbine output power is lower than that of the rated speed of wind turbine, the error signal will have a negative value and gap angle will be have optimum value. But, if the turbine output power is above the reference value, the error signal will be positive and gap angle will be replaced with a new value in limited rate.

While controlling the blade pitch angle of the wind turbine, attempt is made to keep the mechanical angular rate of the asynchronous generator at rated value. Frequency of the system is put under control of the pitch angle control, thereby controlling the electrical output frequency and voltage at specified values.

### 6.6 Algorithm

The Algorithm used for the Controllers based Pitch Actuator Systems as follows

1. Set first set of values for $K_p$ and $k_i$
2. Read the values of wind speed
3. Calculate value of TSR

   $\text{TSR} \rightarrow \text{ratio of speed of tip of blade to wind speed}$

   For a fixed speed turbine, blade to wind tip speed is constant (A Constant gear ratio between generator and blades is assumed)

4. For values of pitch angle between 0 and 90 degree calculate $C_p$.
5. Find of the value of Pitch angle for which $C_p$ is maximum
6. Sample and hold this value of pitch.
7. Send the value of pitch as command value to the Controller for the duration $T_1$
8. The integration of the controller output gives the pitch angle output.
9. From the Controller response, estimate rise time \( t_r \) (or peak time \( t_p \)) peak overshoot \( M_p \) setting time \( t_s \) and steady state error \( e_{ss} \).

10. Based on the values of the time response parameters calculated tune the values of the \( K_p \) and \( k_i \) for the next time cycle.

The fundamental characteristics of a PI Controller, which is used to control the blade pitch angle for maximum power extraction is the basis of all the three proposed techniques. Three different soft computing techniques (Fuzzy, Neuro – Fuzzy and Genetic algorithms) are applied for achieving better performance and are listed below.

FPAC - Fuzzy based Pitch Angle Controller

NFPAC - Neuro - Fuzzy based Pitch Angle Controller

GFPAC – Genetic Algorithm based Pitch Angle Controller

These controllers are discussed in the following chapters, with details as to how these controllers are applied to achieve maximum power output.

When Fuzzy controller is applied to change the pitch angle degree with respect to the wind speed and rotor speed, the maximum power is attained. Like that way, maximum power output is measured for every controller and comparative study is done to find out the optimum controller.

6.7 Simulation Results

To develop operational performance of the power generation system for obtaining maximum power in desired quality and value, a PIPAC has been designed to regulate the blade pitch angle for variable speed. As frequency of output voltage of WECS is directly proportional to the speed of asynchronous generator, frequency adjustment can be made
at the simultaneously. The voltage, current and rotor speed of the WECS with respect to time are shown in Figure 6.3, 6.4 and 6.5 respectively.

Figure 6.3 Voltage response of the WECS in pu for 10m/sec wind speed

Figure 6.4 Current response of the WECS in pu for 10m/sec wind speed
Figure 6.5 Rotor Speed response of the WECS in pu for 10m/sec wind speed

Figure 6.6 Graphical Result Using PIPAC
The designed PIPAC system for pitch angle control effectively controls the system and maximizes the power efficiency put in Table 9.1 and Figure 6.6.

6.8 Summary

The proportional pitch angle controller (PI) change the rotor speed according to the varying wind speed i.e whether wind speed is below or above rated wind speed. If there is any difference between reference speed and rotor speed, the error signal or the difference is fed into designed pitch controllers which, in turn, makes necessary change in the pitch angle and maximize energy capture.