Pitch Control of Wind Turbines with Fuzzy Controller and Stability Analysis

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Summary
The production of fossil fuels is declining day-by-day, this made the research to think about the alternates and renewable energy especially solar and wind are focused by the researchers. In this paper we have acquired the complete transfer function of wind turbine based on power plant and step response based on analysis has been made for evaluation of best pitch control technique, for this a PID and Fuzzy controller are implemented and compared the step response and obtained the results that plant has best response under Fuzzy controller.

Key Words:
Wind Turbine, Renewable Energy, Pitch Control, PID Controller, Fuzzy Controller, Transfer Function, Stability Analysis.

1. Introduction

In recent years' energy crises in the world is getting worst day by day. Especially in Pakistan it is a hot issue as country is facing major energy deficit for its home and industry users. To solve the problem, the country's researchers are looking for cost effective methods of energy production and storage. Wind power through wind turbines is one of the effective and an efficient way as it works with winds, so there are number of problems faced by the system one of them is wind speed, a variable speed, variable pitch wind turbine has two operating regions. In this paper we tried to solve this issue using various controllers specially PID and Fuzzy Controller are implemented that have good results with comparison to other controllers. There are so many researchers who have been contributed in this area using FC for pitch angle control using up to 7x7 membership functions, but we applied less membership functions 5x5 and also used triangular membership function which has comparatively better results instead of Gaussian and other membership functions and reduced the computational load and safety of the system with increase in lifespan.

2. Literature Review

For increasing the wind turbine's power and capacity, building of larger-rotors are in process which increases the aerodynamics and loads of the blades [1]. Aerodynamics with the loads across could contribute to failure of problems results as decreasing the wind turbine lifetime and efficacy [2]. However, in this paper the goals are achieved for pitch control to increase the stability performance using less rules of 5x5 membership functions.

2.1 Membership Function

The participation of measurement of physical quantities (magnitude) of the inputs received in other words the graphical representation of these magnitudes as input(s) and output(s) called the membership function [3]. The membership function applies the rules of different weighting factors for determining the influences on the output of fuzzy sets as final output. The defuzzification process depends on the scaled, inferred and combined functions, further these are needed to be defuzzified in the output which are crisped derived by the system [4].

2.2 Types of Membership Function

The various membership functions are being used, but more intensively used M-functions are triangular and trapezoid due to their simplicity of efficiency and simplicity in formulas and computation [5]. The M-Functions are composed of segments of straight line; the lines have no smoothness at the corner.
The most commonly used M-functions are:

- Triangular M-Functions
- Trapezoidal M-Functions
- Gaussian M-Functions
- Π-Shaped M-Function
- S-Shaped M-Function
- Generalized-bell M-Functions

2.3 Triangular v/s Gaussian Membership Function

In triangular M-Function, each element of X is mapped with values between 0 and 1. This is defined as the lower-limit of a, upper-limit of b and value of m conditionally checked with $a<m<b$, however; the Gaussian M-Function has always a maximum value of 1, in that case we may

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observe some missing values in the result. That's why we tried to use the triangular function and succeeded for better results to calculate thestep response of the system.

2.4 Modelling of Wind Turbines

As wind turbine works on a general principle, the energy in wind turbines turns two or three propellers like blades around a rotor. The rotor is connected to the main shaft, which rotates a generator to generate electricity.

2.4.1 Pitch Angle Control

The angle of the pitch in turbine model for energy generation is most important factor for handling the controlled inputs and output [6-8]. As air pressure from various direction may cause the damage of blades of the turbine and we may face to control the input as well as if our input is not controlled then the output would be uncontrolled which can damage the convertors and batteries which are used to store the energy. The considered pitch angle is 10 – 20º.

2.4.2 Transfer Function Including Pitch Angle

When we need to realize the stability of any system we need to derive the transfer function of the system, in this paper we have derived the transfer function of wind turbines including pitch angle.

Table 1 shows the standard parameters of Wind Turbines for 1000 KW which are used for modelling and simulation.

Table 1: Standard Parameters of Wind Turbines of 1000 KW

Parameters	**Specification**
RG Power, Pe	1000 KW
RG Speed, Wg	1500 rpm
RT Speed of Rotor, Wt	20 rpm
Radius of Blades, R	35 m
Ref. Pitch Angle, Bd	0 to 90o
Rate of Change of Pitch Angle	0.6o/sec
Control Accuracy of Pitch Angle	0.3o
Damping Coefficient, B	2 N.m / Rad/Sec
Drive train Inertia, Jt	0.75 N.m2

Table 2 shows the description of variable used for 1000 KW of wind turbines

Table 2: Description of variables used

Parameters	Description
Wg	RG Speed
Wt	RT Speed of Rotor
B	Damping Coefficient
Jt	Drive train Inertia kgm2
Jg	Generator Inertia kgm2
Ks	Stiffness Coefficient
Tt	Turbine Torque
Tg	Generator Torque
Φt	WT Shaft Angle
Φg	Generator Shaft Angle `
1:n Gear	Gear Ratio

To achieve the transfer function, we need to apply following formulas and obtain the TF.

2.4.3 Equations of Wind Turbines

The Change in pitch angle is given by the equation

$$\frac{d\beta}{dt} = \frac{(\beta d - \beta)}{T_\beta} \text{-------------1}$$

$$T_\beta \frac{d\beta}{dt} + \beta = \beta d \text{-------------(2)}$$

On both sides apply Laplace transform

$$T_\beta . \beta s + \beta = \beta d \qquad \text{-------------(3)}$$

$$\frac{\beta}{\beta d} = \frac{1}{(T_\beta s + 1)} \qquad \text{-------------(4)}$$

$$\frac{\beta}{\beta d} = \frac{1}{(0.5s + 1)} \text{-------------(5)}$$

The Dynamics of the drive train are represnted by the equations below

$$J_t . \frac{d}{dt}(Wt) = T_t - (Ks\delta\phi + B\ \delta w) \text{-----(6)}$$

$$\frac{d}{dt}(\delta\phi) = \delta w \qquad \text{-------------(7)}$$

Using Newtons Second Law of Motion

$$J_t . \frac{d}{dt}(W) = T - BW \text{-------------(8)}$$

On both sides applying Laplace transform

$$J . Ws = T - BW \text{-------------(9)}$$

$$J . Ws + BW = T \text{-------------(10)}$$

$$W(Js + B) = T \text{-------------(11)}$$

$$\frac{W}{T} = \frac{1}{(Js + B)} \qquad \text{-------------(12)}$$

Now by putting the values from the table 1 we will get

$$\frac{W}{T} = \frac{0.5}{(0.37s + 1)} \text{-------------(13)}$$

From equation 5 and equation 13

3. Methodology

This manuscript is followed by simulations of wind turbines by using fuzzy controller and stability analysis of pitch control [9-16]. The triangular functions are used for input and output of fuzzy controller to maintain the stability of system. In previous research Gaussian membership functions are used but here we tried to simulate the system with more appropriate ways and techniques and achieved the better system response on 5x5 rules for the controller.

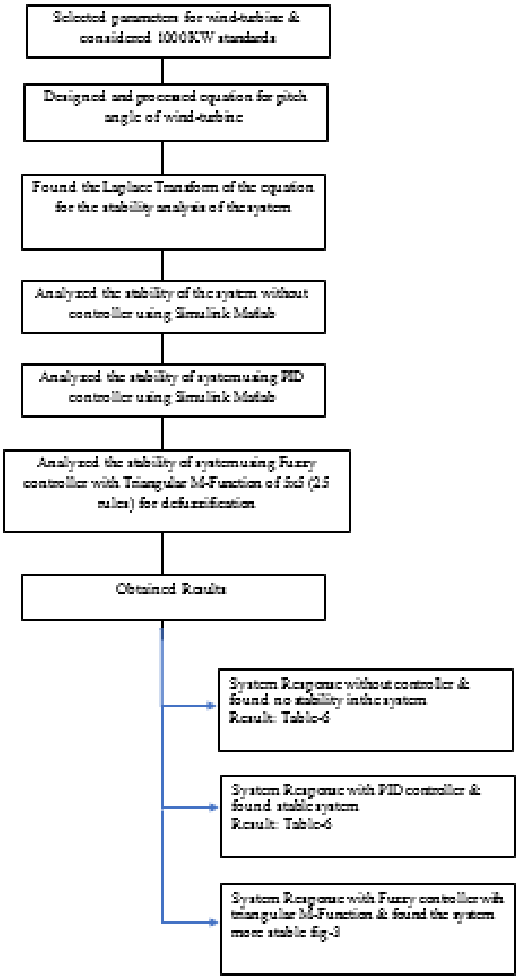

Fig. 1 Flow chart of experimental work

3.1 Rules for the Fuzzy Controller

Table 3 shows the rules for Kp (Proportional Gain), table 4 demonstrates the rules for Ki (Integral Gain) and table 5 reflects the rules for Kd (Differential Gain) are used for input of fuzzy controller to check the system stability. The error (e) and the differential of error (de) are two inputs of FC, while the NL, NS, ZE, PS, PL are membership functions for (e) and (de) for the input whereas; PMS, PM, PVS and PS are membership functions for the output of the FC.

Table 3: Rule base for Kp

Error (e)	Differential of Error (de)				
	NL	NS	ZE	PS	PL
NL	PM	PM	PM	PM	PM
NS	PMS	PMS	PMS	PMS	PMS
ZE	PS	PS	PVS	PS	PS
PS	PMS	PMS	PMS	PMS	PMS
PL	PM	PM	PM	PM	PM

Table 4: Rule base for Ki

Error (e)	Differential of Error (de)				
	NL	NS	ZE	PS	PL
NL	PM	PM	PM	PM	PM
NS	PMS	PMS	PMS	PMS	PMS
ZE	PS	PS	PVS	PS	PS
PS	PMS	PMS	PMS	PMS	PMS
PL	PM	PM	PM	PM	PM

Table 5: Rule base for Kd

Error (e)	Differential of Error (de)				
	NL	NS	ZE	PS	PL
NL	PVS	PMS	PM	PL	PVL
NS	PMS	PML	PL	PVL	PVL
ZE	PM	PL	PL	PVL	PVL
PS	PML	PVL	PVL	PVL	PVL
PL	PVL	PVL	PVL	PVL	PVL

1. If (**e** is NL) and (**de** is NL) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PVS) (1)
2. If (**e** is NL) and (**de** is NL) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PVS) (1)
3. If (**e** is NL) and (**de** is ZE) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PM) (1)
4. If (**e** is NL) and (**de** is PS) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PL) (1)
5. If (**e** is NL) and (**de** is PL) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PVL) (1)
6. If (**e** is NS) and (**de** is NL) then (**Kp** is PML)(**Ki** is PMS) (**Kd** is PMS) (1)
7. If (**e** is NS) and (**de** is NS) then (**Kp** is PML)(**Ki** is PMS) (**Kd** is PML) (1)
8. If (**e** is NS) and (**de** is ZE) then (**Kp** is PML)(**Ki** is PMS) (**Kd** is PL) (1)
9. If (**e** is NS) and (**de** is PS) then (**Kp** is PL)(**Ki** is PMS) (**Kd** is PVL) (1)
10. If (**e** is NS) and (**de** is PL) then (**Kp** is PVL)(**Ki** is PMS) (**Kd** is PVL) (1)
11. If (**e** is ZE) and (**de** is NL) then (**Kp** is PVS)(**Ki** is PS) (**Kd** is PM) (1)
12. If (**e** is ZE) and (**de** is NS) then (**Kp** is PVS)(**Ki** is PS) (**Kd** is PL) (1)
13. If (**e** is ZE) and (**de** is ZE) then (**Kp** is PS)(**Ki** is PVS) (**Kd** is PL) (1)
14. If (**e** is ZE) and (**de** is PS) then (**Kp** is PMS)(**Ki** is PS) (**Kd** is PVL) (1)
15. If (**e** is ZE) and (**de** is PL) then (**Kp** is PMS)(**Ki** is PS) (**Kd** is PVL) (1)
16. If (**e** is PS) and (**de** is NL) then (**Kp** is PML)(**Ki** is PMS) (**Kd** is PML) (1)
17. If (**e** is PS) and (**de** is NS) then (**Kp** is PML)(**Ki** is PMS) (**Kd** is PVL) (1)
18. If (**e** is PS) and (**de** is ZE) then (**Kp** is PML)(**Ki** is PMS) (**Kd** is PVL) (1)
19. If (**e** is PS) and (**de** is PS) then (**Kp** is PL)(**Ki** is PMS) (**Kd** is PVL) (1)
20. If (**e** is PS) and (**de** is PL) then (**Kp** is PVL)(**Ki** is PMS) (**Kd** is PVL) (1)
21. If (**e** is PL) and (**de** is NL) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PVL) (1)
22. If (**e** is PL) and (**de** is NS) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PVL) (1)
23. If (**e** is PL) and (**de** is ZE) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PVL) (1)
24. If (**e** is PL) and (**de** is PS) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PVL) (1)
25. If (**e** is PL) and (**de** is PL) then (**Kp** is PVL)(**Ki** is PM) (**Kd** is PVL) (1)

Fig. 2 Rule viewer of Rule based for Kp, Ki and Kd

4. Simulated Results and Discussions

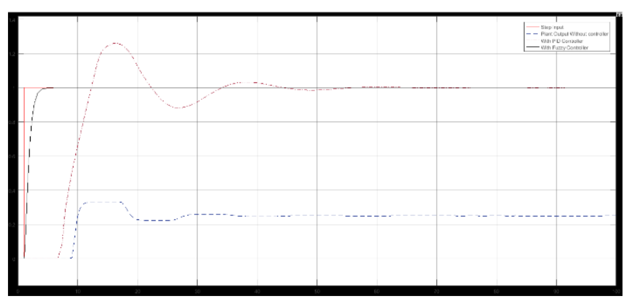

Fig. 3 Step Response of the plant using different controllers

Table 6: Stability Analysis of the system

Compared Parameters	Plant Response	Plant Response with PID	Plant Response with Fuzzy Controller
Rise Time (s)	0.8 secs	6	0.75
Steady state error	0.75	0	0
Peak Overshoot%	32.157	11.8	0
Settling time (s)	38	27	4
Delay time (s)	8	6	0

4.1 Without Controller (Open Loop Control)

Fig 3 and table 6 show the output of the plant without feedback (OLC) is slower than expected with slight overshoot can be observed at the output of the plant.

4.2 Output of the plant with PID Controller

Output reveals that, with PID controller as controlling strategy, output of the plant having major overshoot and slight undershoot with no steady state error.

4.3 Output of the plant with Fuzzy Logic Controller

With fuzzy logic control strategy, fig 3and table 6 reveal that there is no overshoot and undershoot observed at the output of the plant with zero steady state error. This predicts the successful implementation of fuzzy logic control strategy to control plant under observation.

5. Conclusion

In this paper we have concluded the results of the system for stability analysis on the basis of mathematical model of pitch control system of wind turbine. However, the steady state error and Oscillations issue in system response highlighted and designed PID Controller system which provided the better response. Then we designed and added Fuzzy Controller instead of PID to overcome the problem of Pitch control of wind turbines and we got all the Oscillations in system step response to minimum (zero) and got the better system response on the less membership functions of 5x5.

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