Scholars Journal of Engineering and Technology
OPEN ACCESS
Abbreviated Key Title: Sch J Eng Tech
ISSN 2347-9523 (Print) | ISSN 2321-435X (Online)
Journal homepage: https://saspublishers.com/journal/sjet/home

Evaluation and Simulation of Pitch Angle with Fuzzy-PD Controller

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| **Received:** 19.03.2019 | **Accepted:** 28.03.2019 | **Published:** 30.03.2019
DOI: 10.36347/sjet.2019.v07i03.004

Abstract **Original Research Article**

Wind turbine dynamics are generally non-linear, time-varying and uncertain. A control system designed for a turbine condition may not provide the desired stability and performance characteristics in the event of a deviation from the equilibrium point. There are many studies on turbine control in the literature. One of them, the fuzzy turbine control system Fuzzy Logic Controllers, has demonstrated a wide range of applicability from the establishment to the processes in which the plant transfer function is not defined, but the control action can be explained in terms of linguistic variables. FLC is also used in combination with improved performance rather than controllers where plant transfer function is known. Most of the applications related to the design of turbid turbine control are at the simulation level. In this study, the design and analysis of the Fuzzy-PD controller for the inclination angle control system were made and the results were compared between three different wind turbines.
Keywords: Wind, Fuzzy, PD, Control, Pitch Angle.

INTRODUCTION

There are numerous studies regarding control in the literature such as adaptive control, neural control, adaptive neural control, gain scheduling control, control system with a genetic algorithm optimization process and Fuzzy control. These methods have many different features. A common feature is that each of them is developed to achieve advantages over techniques. Throughout the design process a "systems approach" strategy should be applied, supported by good requirements, design tools and design models. Application of advanced techniques promises a significant reduction of design time because it would remove the time-consuming "one-loop-at-a time" approach and reduce the number of design points for which a controller has to be designed[1].

Among these methods, Fuzzy systems have different kinds of applications (regulating the velocity of a freight train, optimization trip time and energy consumption of a high-speed railway, helicopter turbine control system, control of heating, ventilating and air conditioning systems, washing machines, microwave devices, industrial control systems, high performance medical instruments, wind power control systems. And autonomous vehicle control, etc. in many areas. Fuzzy control depends on the Fuzzy algorithm between the information of process and control input. Fuzzy controllers from their inception have demonstrated of applicability to processes where the plant transfer function is not defined but the control action can be described in terms of linguistic variables [2].

Fuzzy controllers are also being used to improve the performance of a system where the plant transfer functionis known. In the literature, there are different applications of Fuzzy systems in aviation. Fuzzy control, allows for an easier implementation of a complex nonlinear control system. The nonlinear characteristic of Fuzzy control systems is the biggest advantage over the old linear control system. In the end, the Fuzzy control system's overall performance is better; it is more than the original linear control system. Base line performance for each subject was also collected with a conventional control system [4,5].

Results indicated that the Fuzzy-logic performance control reduced variable error and overshoots, required less time for novices to learn (as evidenced by time to achieve stable performance), required less effort to use (reduced control input activity),and was preferred by researchers. Pitch angle which is one of the most important parameters of a wind power control system. A quite good system performance was obtained previously from a Fuzzy-PD controller. In this study, our intention is to compare the former results with PD controller[6, 7].

Pitch Control System

In this study, the data to the turbines having 3 different characteristics and altitude were taken from meteorology directorate Karaman city of Turkey. Using this data, pitch control was performed for each turbine. Pitch angle control system shown in Fig.1. It can be seen from the Fig.1 that, wind speed (W_n) at the output of the controller is calculated such that the output of system pitch angle (θ) follows the reference pitch angle value (θr). The input of actuator W_n provides the change of wind speed of the input of wind turbine dynamic via actuator transfer function. Controller calculates the appropriate elevator angle at the input of the actuator. In this study, Fuzzy - PD controller for the pitch angle control system is designed and the simulation results for a wind turbine is compared with the results of a PD controller in a MATLAB coded program.

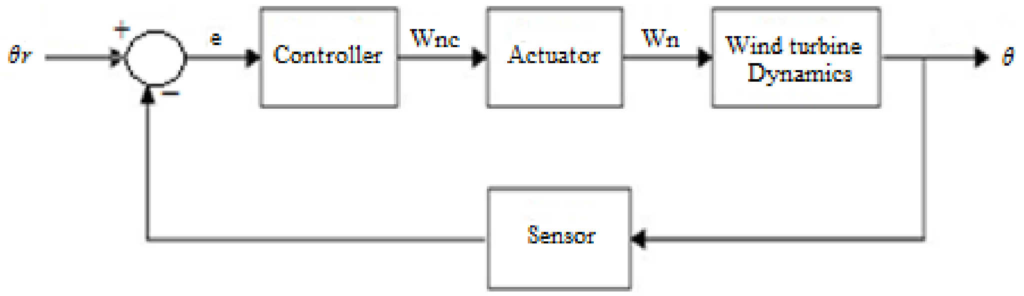


Fig-1: Wind turbine pitch angle control system loop

The proposed Fuzzy-PD controller and PD controller applied to wind turbines data. The turbine parameters of different turbine characteristics of selected wind turbine are given in Table1.

Table-1: Turbine characteristics

Parameter	Turbine-1 Characteristics	Turbine-2 Characteristics	Turbine-3 Characteristics
Altitude (m)	65	50	40
Output Power Voltage	220 Volt	220 Volt	220 Volt
Output Power Frequency	25 Hz	25 Hz	25 Hz
Gear Box Ratio	4	4	4
Wind Speed	14 m/s	12 m/s	10 m/s

In Fig 1, actuator and sensor dynamics are chosen as $\frac{1}{1+0.1s}$ Wind turbine dynamics for the above three turbine condition are given in

Equations1, 2 and 3 respectively.

$$\frac{\theta(s)}{W_n(s)} = \frac{1.067s+0.541}{s^3+0.817s^2+1.35s} \quad (1)$$

$$\frac{\theta(s)}{W_n(s)} = \frac{3.078s+1.456}{s^3+1.445s^2+1.346s} \quad (2)$$

$$\frac{\theta(s)}{W_n(s)} = \frac{1.134s-0.367}{s^3+0.743s^2+0.812s} \quad (3)$$

PD Control

PD type controller used in this study because the deffect ensures a rapid response, increases damping and decreases rise time and settling time. As shown in Fig.2. The controller output is equation,

$$u(s) = (K_P + K_d\ )\ e(s) \quad (4)$$

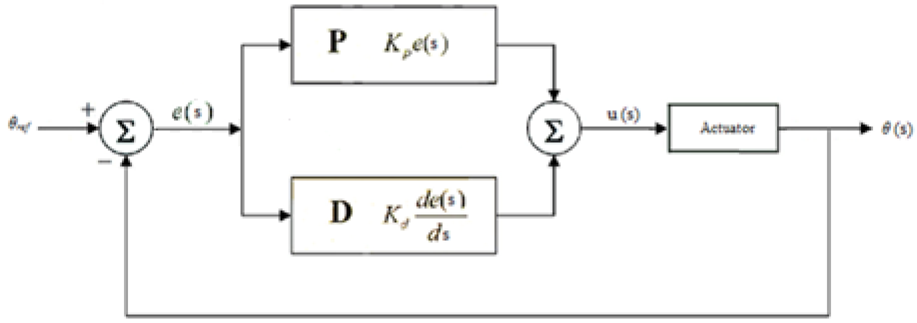
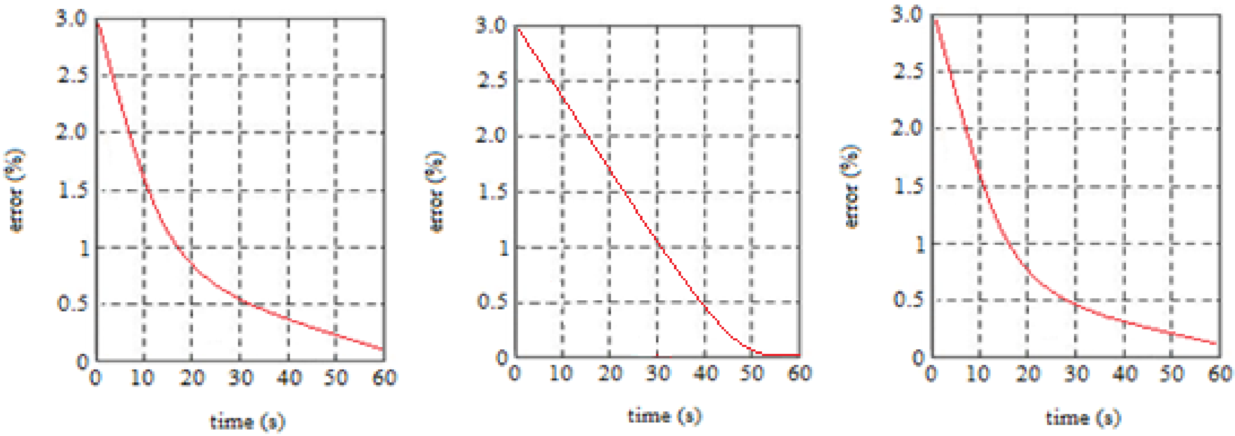


Fig-2: PD control system

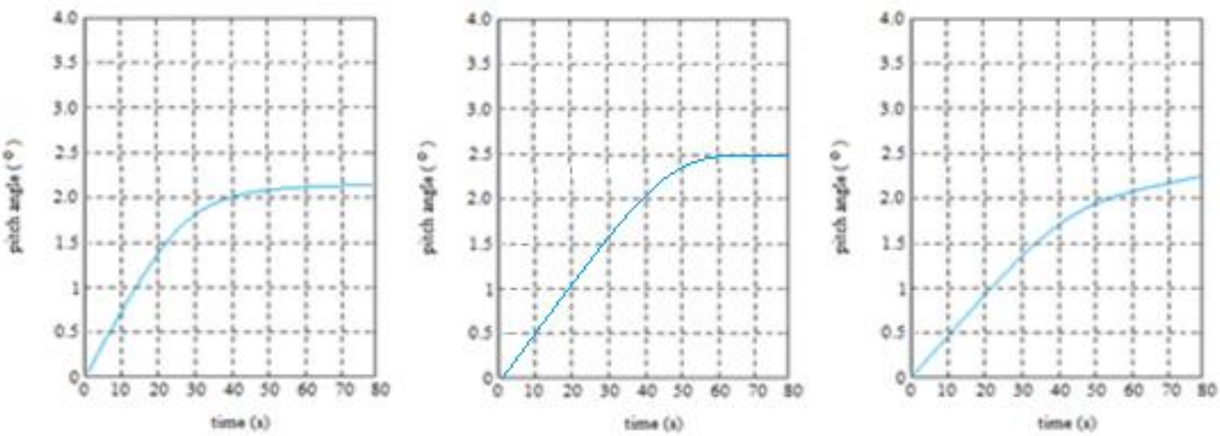
Control methods are also rigorously analyzable, and therefore they can be readily certified, and since they contain relatively few components, the effects of failure of some of those components can be assessed relatively easily. Their principal disadvantage is the time taken to perform the design process. It is common in industry for wind turbine, as opposed to a completely new design being performed, and this reduces the design time. A significant amount of knowledge concerning wind turbine and their characteristics is also required to support the design procedure since the optimization of the controller depends on the knowledge and intuition of the designer and not a computer algorithm[8, 9].

In PD controller $K_P = 0.1$ and $K_d = 0.5$ and gain constants are chosen of beter values and the simulation results ($f\,(t,\, e)$, $f\,(t,\theta\,)$) shown in the Fig. 3-4. respectively are obtained in case of reaching 2.5 rad pitch angle from 0 rad. First turbine is 65m, second turbine is 50 m, third turbine is 40 m of altitude as table 1. According to this turbine performance and pitch angle control curves are shows in Fig.3-4.



First turbine Second turbine Third turbine

Fig-3: Performance of turbines with PD controller



First turbine Second turbine Third turbine

Fig-4: Pitch angle of turbines with PD controller

Fig 3 and 4 show that the turbine performance at 50 m altitude is better and the pitch angle is better controlled.

Fuzzy - PD Control

FLC can be used to realize the closed-loop controlactions directly, i.e. replace conventional closed-loop controllers, or they can complement and extend conventional control algorithms via supervision, tuningor scheduling of local controllers. A general Fuzzy controller consists of four modules: a Fuzzy rule and database, a Fuzzy inference engine, and fuzzification/defuzzification modules. The inter connections among these modules and the controlled process are shown in Fig.5. Most of the systems use Fuzzy controller is PD type controller. In this type of controller, error and change of error knowledge is used in fuzzification and rule base modules[10].

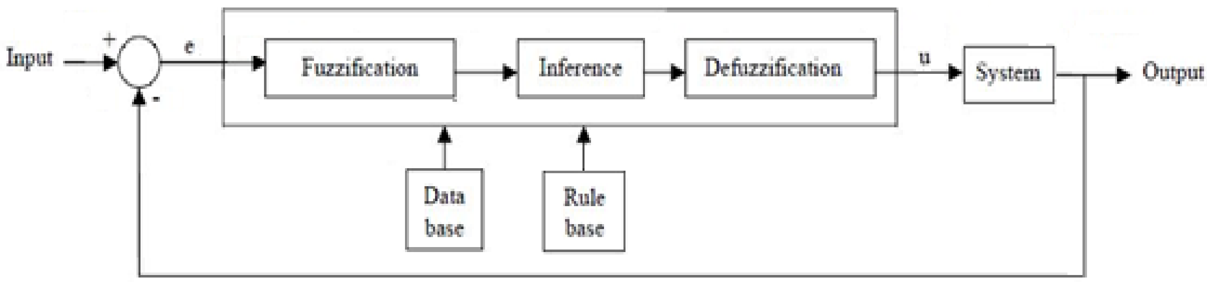


Fig-5: Fuzzy control system

Fuzzy-PD controller calculates the appropriate control at the input of the system according to the error and changeof error at the input. While developing such a system the most important process is encoding the knowledge base of Fuzzy controller. The knowledge base of the Fuzzy-PD controller consists of data and rule bases. Membership function distributions of system input and output variables are defined in data base. Membership functions may be selected as a triangular, trapezoid or other appropriate forms. The number of membership functions changes depending on the problem. The number of these linguistic variable sspecifies the quality of control, which can be achieve dusing Fuzzy controller. As the number of linguistic variables increases, the quality of control increases at the cost of increased computer memory and computational time[11].

In this study, type of the designed Fuzzy controller is Mamdani. There are 25 weight values. According to intuition method, list of linguistic rules is shown in Table 2. In Table 2 error and change of error membership functions are denoted with N++ (negative very small), N+ (negative small), ZE (zero), P+ (positive big) and P++ (positive very big). Units of values are given in degree but these values are converted to radian in coded program.

Table-2: Rule weight values

W_{n_c}			e			
		N++	**N+**	**ZE**	**P+**	**P++**
	N++	-20	-16	-15	-11	0
$\dot{e}$	**N+**	-11	-11	-14	0	11
	ZO	-2	-7	0	14	17
	P+	-11	0	11	15	18
	P++	0	12	20	18	20

In Fuzzy PD controller, five tri angular error membership function forms and change of error membership function forms for error are shown in Fig. 6-7. Constraints values are ± 2.5 rad. in both.

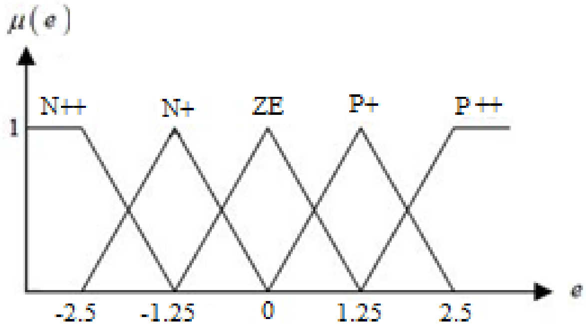


Fig-6: Error membership functions

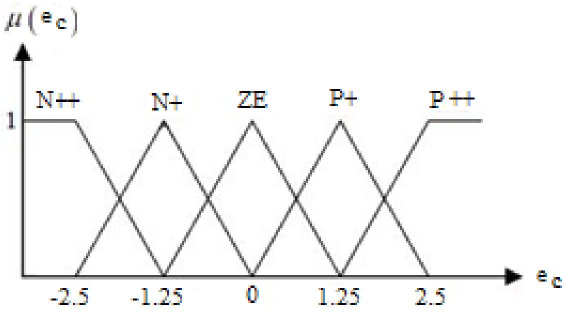
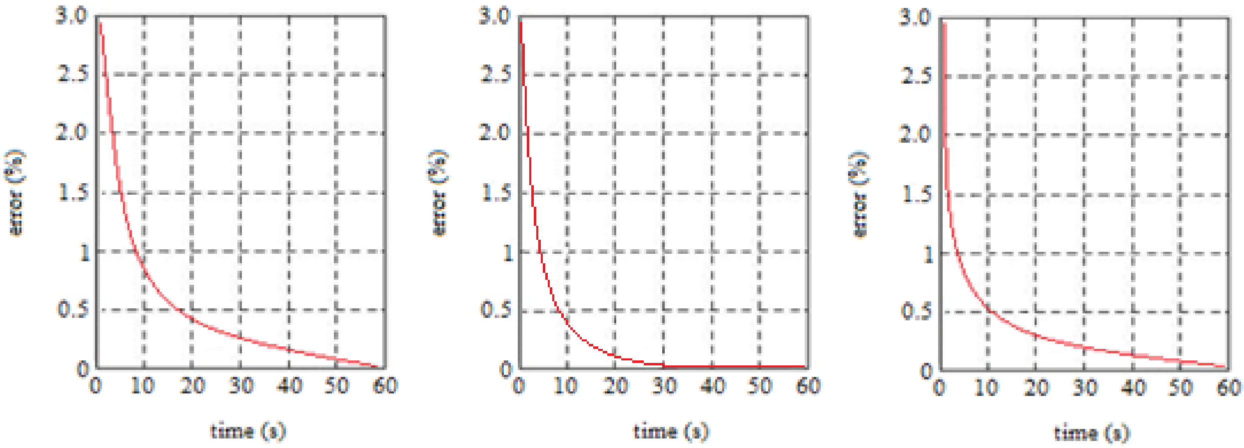


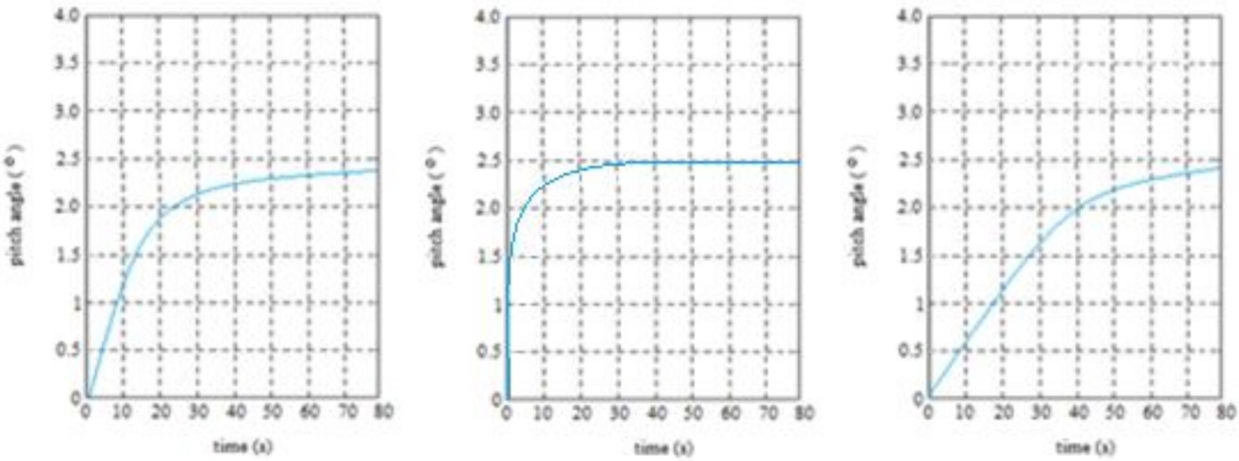
Fig-7: Change of error membership functions

In coded Matlab 14b based program, Fuzzy -PD controller simulation results ($f(t, e)$, $f(t,\theta)$) shown in the Fig. 8-9. respectively are obtained in case of reaching 2.5 rad pitch angle from 0 rad in different turbine conditions shown in Table 2 (first turbine condition: 65 m, second turbine condition: 50 m, third turbine condition: 40 m). Time axes scaled where responses reach steady state values.



First turbine Second turbine Third turbine

Fig-8: Performance of turbines with Fuzzy-PD controller



First turbine Second turbine Third turbine

Fig-9: Pitch angles of turbines with Fuzzy-PD controller

Fig. 8 and 9 show that the turbine performance at 50 m altitude is better and pitch angle is better controlled. If the results of Fuzzy-PD controllers in Fig. 3 and 4 are compared with those of Fig. 8 and 9, the control of Fig. and pitch angle is better controlled. While the PD deceleration of the error value to 0% was 52 seconds, Fuzzy-PD was also 30 s. Pitch angle of 2.5 degrees in the PD to capture the PD at 60 s, although Fuzzy-PD was also at 31 s.

CONCLUSİON

In this study, PD controller and Fuzzy-PD controller are used respectively to control pitch angle which is a main control parameter of a wind turbine control system. Designed controllers are applied to wind turbine parameters to compare the results of study PD and Fuzzy-PD controllers. Simulation results, as shown in Figures. When Fuzzy-PD controller applied, the settling time of responses is shorter than study PD controller. In study controller, different K_P and K_d parameter values are tried to reach a smooth pitch angle deviation versus time. For the different turbine condition parameters are analyzed to evaluate performance characteristics of controllers. Using different methods such as intuitions, inference, rank ordering, angular Fuzzy sets, neural networks, genetic algorithms, inductive reasoning, soft partitioning, meta rules and Fuzzy statistics in developing membership functions and rule weights, performance of the Fuzzy controller can be improved.

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