A NEW FUZZY CONTROLLER FOR ADJUSTING OF PITCH ANGLE OF WIND TURBINE

Zafer Civelek
Technical and Business College, Çankırı Karatekin University, Çankırı,Turkey

zcivelek@gmail.com

Murat Lüy
Faculty of Engineering, Kırıkkale University
Kırıkkale,Turkey

muratluy@yahoo.com

Ertuğrul Çam
Faculty of Engineering, Kırıkkale University
Kırıkkale,Turkey

ertugrul_cam@yahoo.com

Göksu Görel
Technical and Business College
Çankırı Karatekin University, Çankırı,Turkey

goksugorel@karatekin.edu.tr

Abstract: This paper presents a study on the control of the pitch angle of the wind turbine blades. As fuzzy logic control method is preferred. Output power is stabilized by controlling the pitch angle of the wind turbine blade. They were also able aerodynamic braking at high wind speeds. Fuzzy logic control method is selected as the reason; Fuzzy control is independent of changes in system parameters. The fuzzy is also a suitable control method for nonlinear system. Consequently, using the fuzzy controller wind turbine blade pitch angle has been successfully controlled. Thus, the output power stability and aerodynamic braking is achieved successfully.

Keywords: Wind turbine, pitch control, fuzzy control.

Introduction

Wind energy is one of the most important in clean energy sources. Also it helps to protect the environment (Y. Qi & Meng, 2012, pp. 1635). Wind energy is a rapidly growing energy source. In the international wind power market, megawatt wind turbines have become an important product (Jian-jun, Li-mei, Xiao-ning, Chun-lei, & Jian-ren, 2010). Grid-connected wind turbines that high power has more tendencies due to their high capacity, greater efficiency and more reliable. Due to this reason instead of constant pitch angle and fixed-speed turbine, variable speed, variable pitch angle of wind turbines has been more popular in the market both in terms of both sales and in terms of research (Dou, Cheng, Ling, & Cai, 2010, pp. 56). There are several reasons for the variable speed of wind turbines, they are; to reduce the possible mechanical strength, to reduce the volume of noise, to make the output power is stable also to provide aerodynamic braking at high wind speeds (Fard, Rahmani, & Mustafa, 2011). The most effective method is to control the blade pitch angle to aerodynamic loads (Salim, Zohdy, Abdel-Aty-Zohdy, Dorrah, & Kamel, 2011; Scherillo, Izzo, Coiro, & Lauria, 2012).

The control technology of wind power production systems changed from constant pitch angle, to variable pitch angle (Dou et al., 2010). The improvements of control theory and algorithms in wind power and a better understanding of people to wind power, has developed a wind power control technology (Y. Qi & Meng, 2012, pp. 1635). Variable pitch wind turbine is difficult to mathematically model is very complex. Furthermore the wind energy system is non-linear constrained to control method to be used (J. Qi & Liu, 2010).

Conventional PID controllers are not well suited to compensate the disruptive effects of wind power generation system. It is a need for a control system that compensates the non-linearity of systems and changing parameter. Today, the fuzzy control that holds an important place in modern control theory is the ideal control method to resolve the drawbacks (Dou et al., 2010). One of the biggest advantages of fuzzy controller to the traditional control methods; it doesn't need to know mathematical model of the object that want to be control (J. Qi & Liu, 2010).

The importance of controlling the pitch angle of the wind turbine are better understood when large-scale wind turbines currently in development efforts made. The output power at high wind speeds is kept to constant value by adjusting the pitch angle and the pitch angle at very high wind speeds can be used as aerodynamic brakes (Y. Qi & Meng, 2012, pp. 1635).

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Variable Pitch Angle Wind Turbine Model

Wind power (P); is proportional to the cube of the wind speed, and is given in Equations 1.

$$P = 0.5\rho A v^3 \quad (1)$$

Wherein ρ = air density (kg/m^3), A= area swept by the blades (m^2), v = wind speed (m/s). In Figure 1 the wind speed is given graph of the change in wind force.

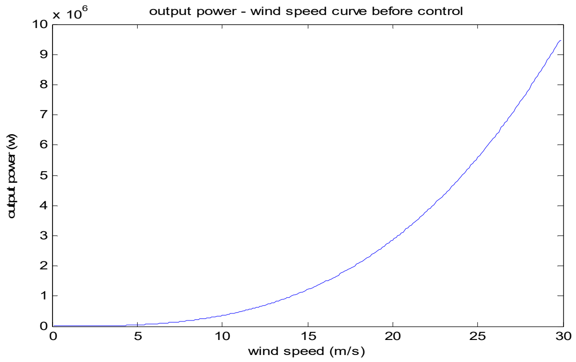

Fig. 1. The wind speed-output power curve without control

Wind turbines can be turned into energy from wind power and is limited to a portion of the Betz limit cannot exceed 59% of (Tong, 2010). The amount of power that can be taken from the wind turbine blades pitch angle (β) and the blade tip speed ratio (λ) a function of the power coefficient of the wind turbine (C_p) is determined by (Hemami, 2011). In Figure 2 the power coefficient (C_p) variation curve is given by the blade tip speed ratio.

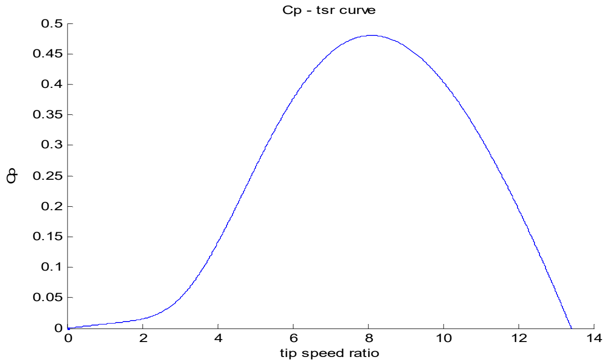

Fig. 2. Power factor (C_p)-blade tip speed ratio (λ) curve

Mechanical power of the wind turbine will be able to get the wind is given in Equation 2.

$$P_{\omega t} = P\, C_p(\beta, \lambda) \quad (2)$$

Equation 1 to Equation 2, if we added;

$$P_{\omega t} = 0.5\rho A v^3 C_p(\beta, \lambda) \quad (3)$$

Wherein $C_p(\beta, \lambda)$= turbine power coefficient, β = blade pitch angle, λ = blade tip speed ratio (TSR)

C_p That highly nonlinear and changing with wind speed is given in Equation 4.

$$C_p = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{\frac{-21}{\lambda_i}} + 0.0068\lambda \quad (4)$$

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λ_i In Equation 5 is placed into where in Equation 4 is calculated C_p.

$$\frac{1}{\lambda i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{3\beta + 1} \quad (5)$$

Blade tip speed ratio TSR is ratio of blade angular velocity and wind speed and given in Equation 6.

$$\lambda = \frac{\omega_{\omega t} R}{v} \quad (6)$$

Wherein $\omega_{\omega t}$= turbine rotor angular velocity (rad/s), R = radius of the wind turbine blade (m).

In Figure 3 the power coefficient (C_p) variation curve is given by the blade tip speed ratio for the different pitch angle β.

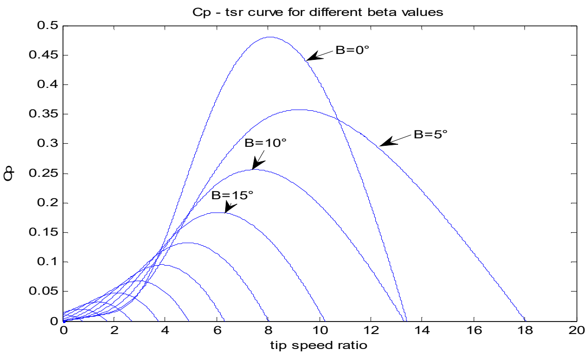

Fig. 3. C_p-TSR curve for different β angles

Any change in the wind turbine rotor speed or wind speed changes the blade tip speed ratio, which changes the power factor. Power factor will change the amount of power derived from the wind. Equation 4 and Equation 5 by C_p changing the angle β, the power factor is changed. Wind turbine power control operates on this principle.

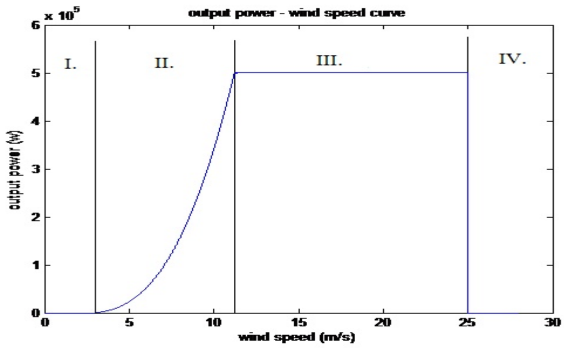

Fig. 4. The operation of the wind turbine

Mechanical power output in a variable-speed wind turbines are also variable (Chen, Hong, & Ou, 2012). As shown Figure 4, variable speed and variable pitch angle wind turbine's wind speed-output power curve has four operation areas. In the I. region, wind speed is smaller than cut-in value, wherein the output power is zero. II. region is between the cut-in the nominal speed. III. cut-out region is between the nominal speeds. In the IV. region, wind speed is upper than cut-out so that in this region wind turbine is stopped because off safety (Hwas & Katebi, 2012). Maximum power point tracking is desired in the II. region. It should be placed power electronic circuits that operate to hold to frequency on constant value between wind turbine generator and grid (Wenjing & Hongze, 2011). At the beginning of the III. region, while wind speed reaches nominal value wind turbine power reaches the nominal power. if wind speed continues to increase, the output power will also increase. Therefore, system needs a control system which controls to output power between control limits. This control system changes blade pitch angle so that power coefficient and output power are changes (Hemami, 2011).

Actuator Model

Pitch actuator systems can be hydraulically or electrically controlled. In the electric actuator; each blade can be individually adjusted by a servo motor (Jha, 2010). The world's largest wind turbine suppliers, uses electric pitch angle control systems. In this article; dc servo motor is used as an actuator. In the servo motor designing, position control transfer function is written by a simply as Equation 7.

$$G_p(s) = \frac{1}{s(s+1)} \tag{7}$$

Fuzzy Logic Controller Design

The system has been developed based on fuzzy logic control algorithm. Fuzzy control is basically an adaptive control system. Two variables were defined as fuzzy input: error and error change. The Mamdani is used as rule base and fuzzy inference system. Defuzzification method is centroid. Output variable is the amount of change in the angle β. The block diagram of the fuzzy logic controller system is shown in Figure 5.

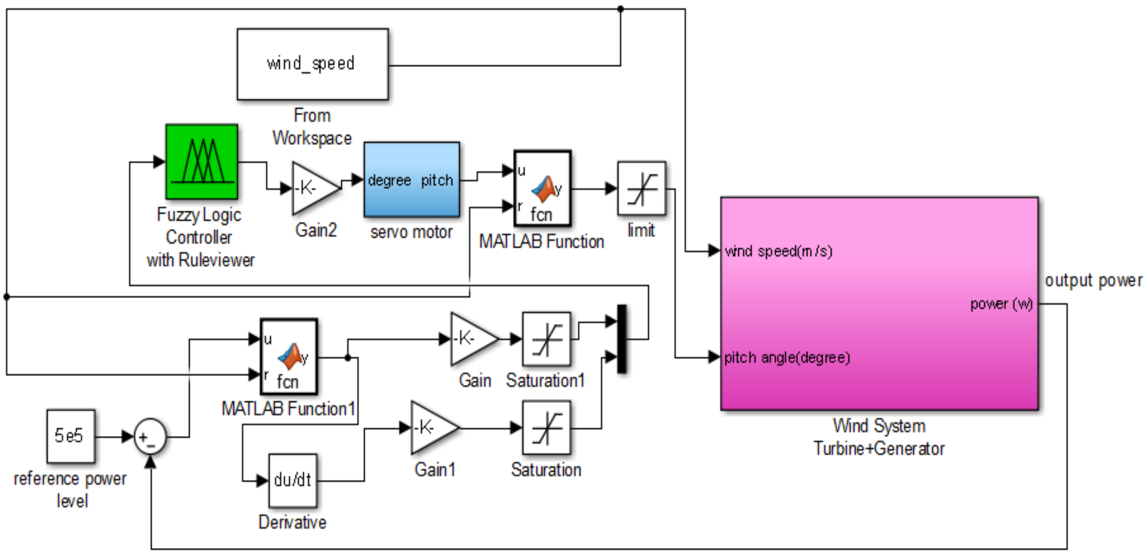

Fig. 5. The block diagram of the fuzzy logic controller system

Error input fuzzy sets in Figure 6, the change error fuzzy sets shown in Figure 7. Output variable fuzzy sets which amount of change in the angle β is shown in Figure 8.

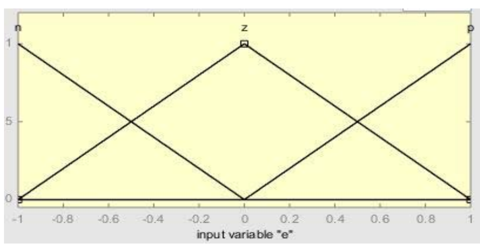

Fig. 6. The fuzzy sets of input variable error

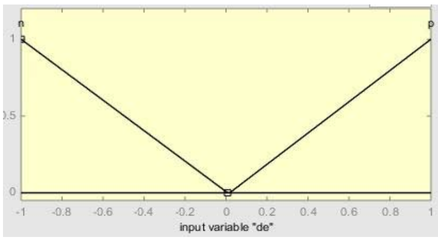

Fig. 7. The fuzzy sets of input variable derivative of error

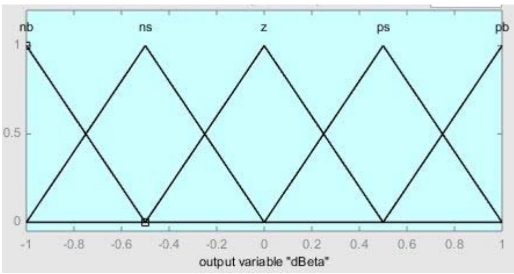

Fig. 8. The fuzzy sets of amount of change in output variable beta angle

Surface showing the relationship between input and output variables graph in Figure 9, while the rule table shown in Table I.

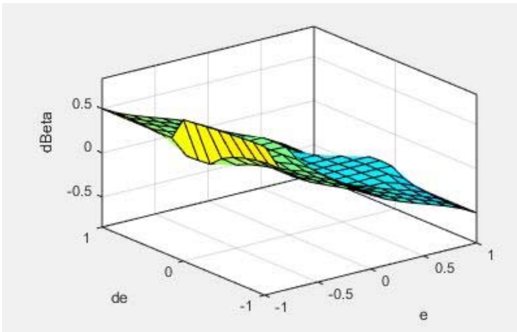

Fig. 9. Fuzzy logic controller input and output variables' three dimensional graphics

Table 1. Fuzzy logic controller rule table

dbeta		derivative of error	
		n	p
error	n	pb	ps
	z	z	z
	p	ns	nb

I. WIND TURBINE MODELING AND SIMULATION WITH MATLAB

Mathematical formulas of the wind turbine are modeled by Matlab / Simulink program. The internal structure of the model is shown in Figure 10. Internal structure; the wind turbine formula is transferred to Matlab / Simulink. Simulated system parameters shown in Table 2.

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Table 2. Simulated system parameters

Simulated System Parameters	
Nominal output power	500 kw
Working mode	Network connection
Cut in wind speed	3 m/s
Nominal wind speed	12 m/s
Cut out wind speed	25 m/s
Rotor diameter	48 m
Sweep area	1810 m^2
Blade number	3
Nominal rotor speed	30 rpm
Rotor speed range	10-30 rpm
Gear box rate	01:50
Generator number	2
Generator type	Asynchronous squirrel cage
Generator nominal output	250 kw
Generator nominal cycle	1500 rpm
Generator voltage	690 v

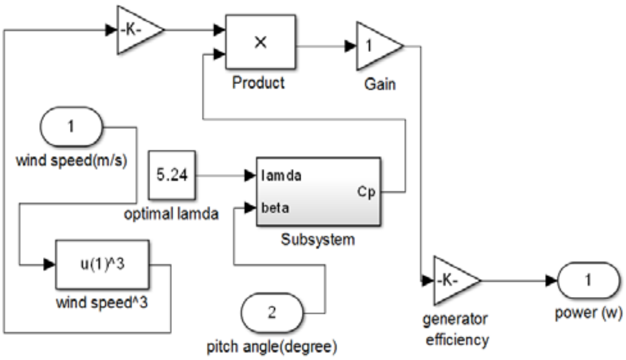

Fig. 10. The wind energy conversion system block diagram of the internal structure

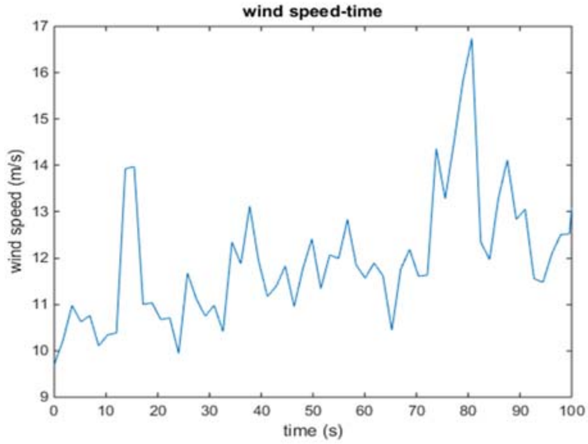

Fig. 11 Wind speed-time diagram

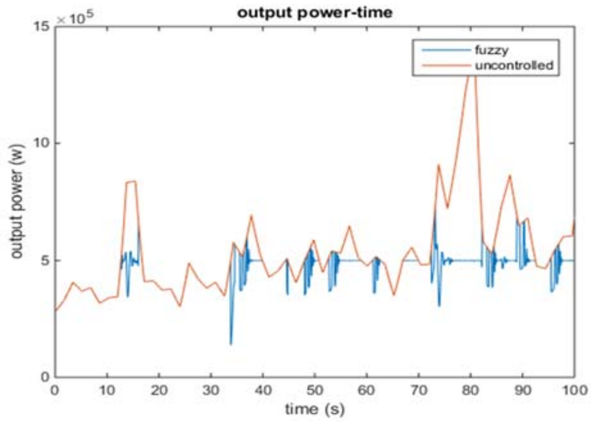

Fig. 12 Output Power diagrams

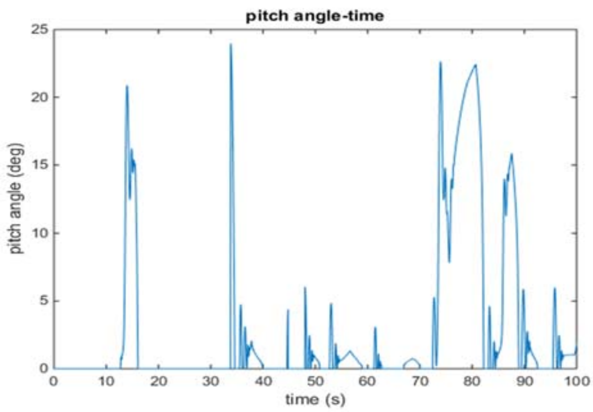

Fig. 13 Pitch angle diagram

Matlab Simulation Results

Modified true wind speed is used in simulation. Figure 11 shows wind speed used in the simulation. Wind energy system has two 250-kW generators that produce energy. Therefore, the rated output power of 500 kW. Rated wind speed 12 m/s. The wind speed of 10 m/s to 17 m/s between the sections were taken because of to see the performance of controller. Because any blade pitch angle control is not mentioned when the wind speed is lower than rated value. Both the transition of from lower of rated speed to upper of rated speed and the transition of from upper of rated speed to lower of rated speed is seen controller performance. In Figure 12, the output power of the uncontrolled situation in this case generator system will suffer losses due to overload, were compared with the output of the fuzzy controller status. In Figure 12, the fuzzy controller limited output power and prevent damage to the system. In addition, output power has remained stable value. Figure 13 shows the change in pitch angle.

Conclusion

The wind turbine blades pitch angle is controlled by using fuzzy controller. Output power is maintained constant value within certain limits. Thus generator protected from the upper value on rated output power and provided to work longer time by safely. It has also become more stable energy supplied to the grid.

We prefer the fuzzy controller because of fuzzy is good adaptation against to changes in system. Therefore, changes that may occur during the time the system parameters will not affect the performance of the control system. In addition, the fuzzy controller compensate to control difficulties that according to nonlinear system.

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