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RESEARCH ARTICLE

Analysis of wind turbine blade pitch angle control with fuzzy logic

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Abstract

Wind energy systems (WES) are systems that convert the energy they receive from the wind into electricity in the generator. Turbines, which cause less damage to the environment, have become more credible after the radical climate changes. Considering other renewable energy sources, the use of wind energy has increased rapidly. The energy efficiency of WECSs is important and this value can be measured by considering the output power. In this study, a more efficient and stable output is tried to be obtained by controlling the wind turbine blade with fuzzy logic. When the parameters of the fuzzy logic system are changed, the results are satisfactory.

1. Introduction

Wind energy has been used for hundreds of years for various work [1]. The use of windmills to generate electricity can be traced to the late nineteenth. Wind energy is one of the fastest growing renewable energy source [2]. There are two types of wind turbines. One is fixed speed wind turbine and the other is variable speed wind turbine. In this study, a variable speed wind turbine was simulated. The pitch angle control method was used in the simulation. The pitch angle control was created using a fuzzy logic system of Lutfi A. Zadeh [3]. For this purpose, a control that gives the wind turbine pitch angle output is designed. This controller uses the wind turbine output power error and the derivative of the error as inputs.

In the literature, there are studies that offer solutions with different approaches regarding the angle control of wind turbine blades. Some of them are designed using P, PI, PID controllers. Others try to create a better control mechanism by adding methods such as artificial neural network and fuzzy logic to the control block. Summaries of some of these studies are presented below.

The wind turbine blade angle is modeled mathematically. In this study, both methods were compared with wing angle adjustment with PID and Fuzzy-PID methods. Simulation results with a fuzzy-PID controller were found to be more accurate. The motivation in the study was explained as increasing the life of the wind turbine. The focus is on reducing loads. Ultimately, a performance improvement was observed. The output generator power of this study is 1000 KW. A fuzzy logic controller with 49 rules is used. According to the uncontrolled situation, it is seen that the rise time decreases because of the simulation made with the PID controller. As a result of the study with fuzzy logic, it was seen that there was almost no overshoot. However, it has been explained that the performance is not good in all conditions, for example, the rise time is slightly better in the classical PID method [6].

PI, fractional PI and fuzzy logic systems were compared in another study,. In this study, realistic environmental conditions and double feed induction generator were used. The rotor speed was tried to be adjusted by controlling the blade angle. Although the current PI controller approach is not very stable, it is written that in the fractional PI approach, it can adjust the gains better and reduce the overshoots, but it is more complex and may require high continuous calculations. The fuzzy logic system does not require a mathematical model and can overcome problems more easily. In this study, there are 25 rules used in fuzzy logic and it performed better than other methods [7].

In another study, the power to be obtained from the wind turbine was tried to be adjusted by changing the blade angle with PI, Fuzzy control and Fuzzy-PI controller. Ramp signal is used as wind input. A steady-state error of less than 1% was considered a good control criterion. The system designed with a PI controller was able to drop below 1% in 1.5 seconds. In the system made with a fuzzy controller, it dropped below 1% in 3.5 seconds. In the system made with Fuzzy-PID, it never exceeded 1% and the system became stable in 0.35 seconds. It is clear that the wind turbine simulation set up with fuzzy-PID led to a much more accurate study [8].

R. Tiwari at al., designed controller delivered 4.623% and 9.893% more power under rated speed. It has been observed that fuzzy logic control gives much better results than PI [9].

The wing angle reference was created by fuzzy logic in another study. A more linear output power was observed even at high speeds. A 2 MW permanent magnet synchronous generator is used. The rotor speed is determined as a fuzzy logic input. It has been observed that fuzzy logic systems give better results than the PI system. It has been observed that the average generator speed is 1.38% higher in fuzzy logic.[10]

In another study trying to prevent output power fluctuations, fuzzy logic controller was used and applied successfully. The fuzzy logic controller adjusting the output power gave better results at dynamic wind speed. A fuzzy logic controller with 35 rules is designed [11].

In a study conducted in 2007, a fixed wind type wind turbine was used. Good results were obtained in this study, in which the

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fuzzy system was used. Less rise time was obtained than in general studies [12].

Fuzzy logic system was used to prevent overshoots is analyzed in another study. At rest, PID parameters are used to keep the system at a minimum. As a result, it was stated that the maximum power output was observed. The stator voltage has been checked. It has been observed that the system response is faster than the traditional PI [13].

In another study where the aerodynamic torque of wind turbines is controlled, a blade angle controller is designed. It is stated that in a strong non-linear case of the wind turbine, fuzzy logic controller will always be the favorite. Fuzzy logic controller gave better results compared to PID [14].

As it can be understood, there are many studies in the literature about the control of pitch angle with fuzzy logic systems. In our study, it is aimed to reduce the wind turbine power output oscillations and it was successful. For this purpose, logical expressions are emphasized and the controller was designed considering the various effects of these expressions. Controller design is explained in Fuzzy Logic Controller in part 3.

Variable speed variable blade angle wind turbines have 3 different operation zones. This brings up 3 different situations that may need to be checked. Let's list these 3 regions. In zone 1, the wind speed is lower than the wind speed required for the wind turbine to activate, and the wind turbine is kept closed until the wind speed reaches a certain speed. In the region 2, the wind speed is between the turbine operating wind speed and the nominal power wind speed. Zone 3 the wind speed is higher than the nominal speed of wind turbine generator, so it is controlled for the rated output. This region is the part up to the maximum wind speed that the wind turbine can use. These regions are shown as region1, region2 and region 3 in the Figure below [1].

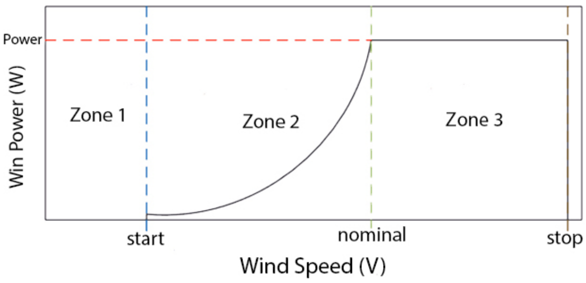

Figure 1. Operation Zones

There is a misconception in wind turbine blade angle control that it is to obtain more power by controlling blade angle at low wind speed, but the main purpose of wind turbine blade angle control is to obtain nominal power from the wind turbine at high wind speeds. In order to obtain maximum power in low wind speed conditions, the value of blade angle is kept constant at 0 degree.

The uncontrolled wind turbine and the controlled 500 kW wind turbine output power are as in the figure 2 below.

2. Materials and methods

Passive blade angle control can be used in variable speed wind turbine blade angle control. In this study, blade angle control was achieved by using a DC servo motor.*2.1. Fuzzy Logic*

Fuzzy Logic is an application popularly used in the literature. It is a logical structure formed as a result of an article published by Lütfü Aliaskerzadeh in 1965. In classical logic, our result value can be either 1 or 0. In fuzzy logic, each object has a membership value. The value of the membership function can be any value between 0 and 1. Fuzzy logic has been used in various fields such as televisions, dishwashers, railroad transportation control, microwaves, and often in solving complex problems. [4].

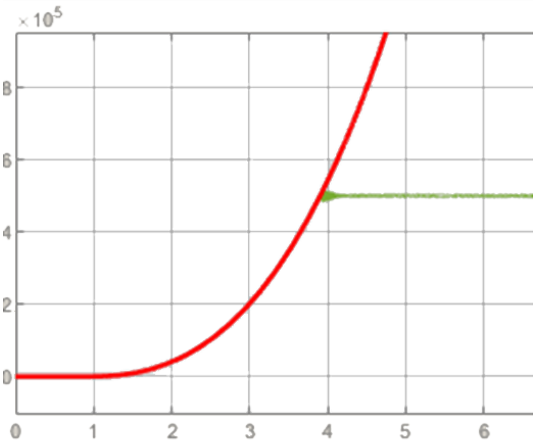

Figure 2. Uncontrolled wind turbine (red) and the controlled 500 kW wind turbine (green) output power

Let the membership degree of a set A be shown as Ü(X1). Although A and B are two subsets of a basic set, their membership degrees are respectively Ü(A), Ü(B). The membership degree of the empty set is 0.

In set operations, the membership degrees of the association feature are equal to the one with the greater membership degree of the common element. If there is no common element, the intersection is 0 and is the empty set [5].

$$ÜAvB(x) = EB\{ÜA(x), ÜB(x)\} \quad (1)$$

It is equal to the smaller of the membership degrees of the common element. If there is no common element, the intersection is the empty set and the membership degree is 0. The negation feature is obtained by subtracting the membership degrees of each element from 1. This can also be called the inversion process.

3. Fuzzy Logic Controller

The blade angle control of the wind turbine system can be done with a fuzzy logic controller. The fuzzy logic controller generates a signal as an input to the DC servo motor by using the error and the derivative of the error with respect to the reference. DC servo motor sets blade angle as output signal. The wind turbine output power can be calculated with the blade angle signal, which is the input signal to the plant block

As the wind, the ramp signal is selected. Wind speed (v), rotor area (A), air density (p), power coefficient (Cp) and the power obtained from the wind are calculated.

$$P = 0.5 * A * p * Cp(\beta, \lambda) * v^3 \quad (2)$$

The plant block used in the simulation refers to the wind turbine. It is shown in Figure 3. The wind turbine input is ramp wind speed and pitch angle, respectively. These two signals calculate the power coefficient as shown in equation 2. The power coefficient output value is shown in equation 4. In addition to the power coefficient, the blade diameter length is also important in terms of formulation. The blade diameter value is multiplied by the power coefficient. Wind speeds that change over time also play an important role. As a result, the wind turbine output power signal is obtained from the plant block and this signal is sent to be compared with the reference value. Power coefficient variation with respect pitch angle and tip speed ratio in three dimensional wives is shown in figure 4.

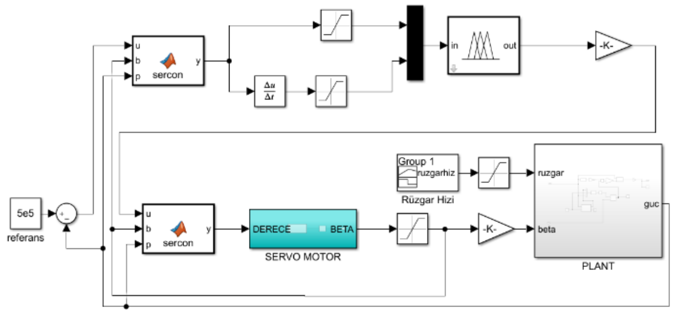

Figure 3. System Blocks

Cp, that is, the power coefficient, shows how much of the power we can get from the wind turbine can be used. This coefficient cannot be more than 0.593. This means that the efficiency we can get from a wind turbine can be at most 59.3%. This situation, known as Betz's law or Betz limit, indicates the maximum electrical energy that can be obtained from the kinetic energy of the wind turbine. It was found in 1919 [15].

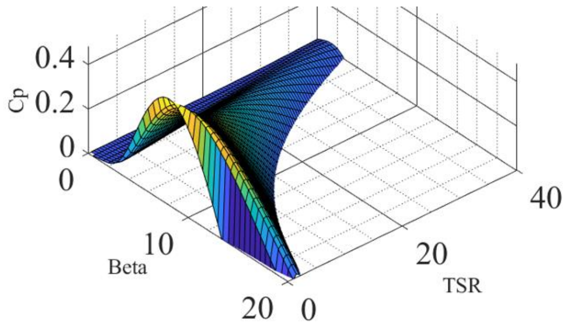

Figure 4. Power Coefficient

1. If (e is NB) and (de is NB) then (deb is PB) (1)
2. If (e is NB) and (de is NS) then (deb is PS) (1)
3. If (e is NB) and (de is Z) then (deb is PS) (1)
4. If (e is NB) and (de is PS) then (deb is PB) (1)
5. If (e is NB) and (de is PB) then (deb is PB) (1)
6. If (e is NS) and (de is NB) then (deb is PS) (1)
7. If (e is NS) and (de is NS) then (deb is PS) (1)
8. If (e is NS) and (de is Z) then (deb is PS) (1)
9. If (e is NS) and (de is PS) then (deb is PS) (1)
10. If (e is NS) and (de is PB) then (deb is PS) (1)
11. If (e is Z) and (de is NB) then (deb is Z) (1)
12. If (e is Z) and (de is NS) then (deb is Z) (1)
13. If (e is Z) and (de is Z) then (deb is Z) (1)
14. If (e is Z) and (de is PS) then (deb is Z) (1)
15. If (e is Z) and (de is PB) then (deb is Z) (1)
16. If (e is PS) and (de is NB) then (deb is NS) (1)
17. If (e is PS) and (de is NS) then (deb is NS) (1)
18. If (e is PS) and (de is Z) then (deb is NS) (1)
19. If (e is PS) and (de is PS) then (deb is NS) (1)
20. If (e is PS) and (de is PB) then (deb is NS) (1)
21. If (e is PB) and (de is NB) then (deb is NB) (1)
22. If (e is PB) and (de is NS) then (deb is NB) (1)
23. If (e is PB) and (de is Z) then (deb is NS) (1)
24. If (e is PB) and (de is PS) then (deb is NB) (1)
25. If (e is PB) and (de is PB) then (deb is NB) (1)

Figure 5. Fuzzy Logic Rules

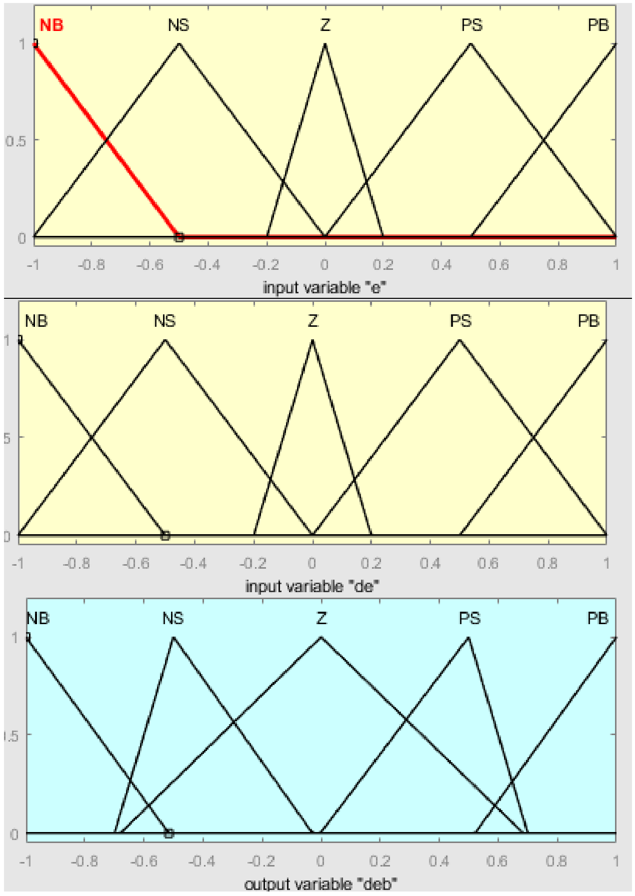

Figure 6. Fuzzy Logic Controller Inputs and Output

The power factor (Cp) takes value according to two variables. These are obtained by dividing the blade angle (β) and the blade tip-speed ratio, lambda (λ), the product of the wind turbine turbine speed (rad/sec) and the rotor radius length by the current wind speed. The formula for Cp(β, λ) and lambda used in this study are as follows.

$$P_{elec} = P_{turbin} * C_p \tag{3}$$

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

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{3\beta+1} \tag{4}$$

$$\lambda = \frac{w_t r}{v} \tag{5}$$

Fuzzy system design inputs and outputs used in the study are as shown in figure 6.

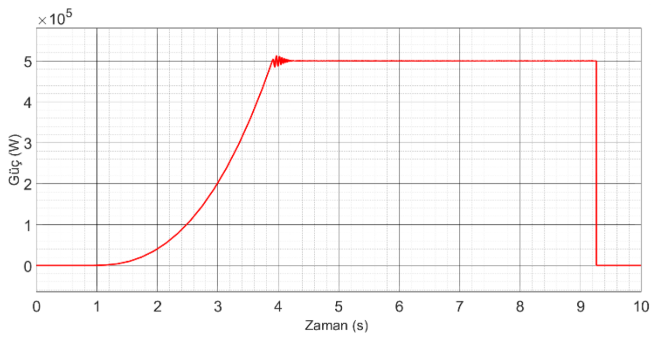

Figure 7. Output Power of the Wind Turbine

4. Conclusion

In this study, pitch angle control of a variable speed wind turbine is analyzed with Fuzzy logic controller. Output power is controlled by adjusting the pitch angle. The main aim of the pitch controller is to maintain the generator power to their rated value. The control system is developed for zone 3 operating region in order to improve the quality of output power. The validity of the studied wind energy conversion system has been verified by simulation results using Matlab/Simulink. In the simulation, the reference value block is shown as 500 kW. This value is because our turbine should operate at 500 kW. The reference value is compared with the wind turbine power output signal from the plant block. The error between the reference value and the value output from the plant block is sent to the fuzzy logic controller as a signal.

The fuzzy logic controller takes the error and its derivative as input. At its output, it produces a signal that controls the servo motor. The controlled servo motor gave the desired output. The desired output signal is the pitch angle. The pitch angle is the signal that controls the wind turbine.

Wind turbine power controller can be done in many ways as well as with fuzzy logic. It can be seen that fuzzy logic gives better results. In this study, the oscillation is reduced by changing the linguistic logical conditions and logical intervals of the fuzzy logic controller. It is seen that the overshoots can be reduced by the gain changes.

The maximum overshoot of the system is 3.2% as seen in Figure 8. It reaches the maximum overshoot in 4 seconds. It is observed that the maximum overshoot becomes much smaller when the proportional gain is increased. The rise time of the system is 3.9 seconds. These results can be compared with other studies [8] in the literature in terms of oscillation, and it is seen that it catches the permanent value more quickly after the about fifth second.

In the system with increased proportional gain, it can be seen that the maximum exceeding of the ratios to the other system is much smaller. The rise times of the system are also similar. However, as can be seen in Figure 8, the frequency of the system has increased. Even if the error rate of the system is reduced, the time to reach the steady state has increased. In this study, the response time is shortened.

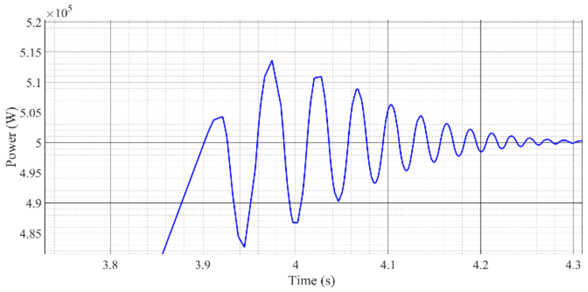

Figure 8. Output Power of the Wind Turbine

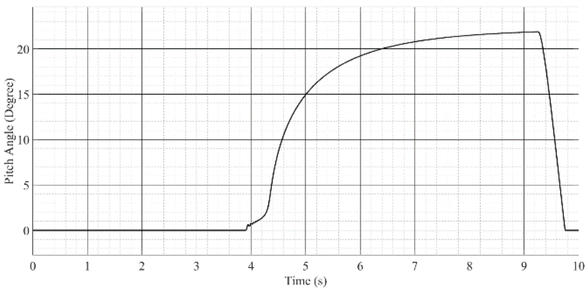

Figure 9. Wind turbine pitch angle variation.

The pitch angle output signal is shown in Figure 9. The pitch angle signal remained at zero for a while. Then, with the activation of the system, instant rises were seen. 3.9. After seconds, a rapid increase was observed, but did not reach a high value. Then, oscillations were observed in the values it received in accordance with the controller signal. These oscillations are very small and may not be taken into account. After a short time, the pitch angle increased rapidly in the face of the rising wind speed. Although the pitch angle did not take sharp values, it gave a sloping output. Wind turbine pitch angle deviation is high when the wind turbine generator output power oscillates. It is due to the fact that it tries to stabilize the output power by adjusting pitch angle. Looking at Figure 7, it is seen that the output power is properly controlled. Output power characteristic is in the desired form. Output power has maintained its optimal value.

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Author contributions

Atakan Arslan did the followings; Visualization; Writing draft and original; Formal analysis; Validation

Halil Erol did the followings, Conceptualization; Funding acquisition; Investigation; Supervision; Validation; review & editing**.**

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