Pitch angle control of a wind turbine using fuzzy logic control

Dian Budhi Santoso¹, Adam Bagus Pangestu², Ulinuha Latifa³, Ahmad Fauzi⁴, Latifa Zahro⁵

¹,²,³,⁴,⁵ Department of Electrical Engineering, Universitas Singaperbangsa Karawang, Karawang, Indonesia

Abstract. Electricity is one of the primary needs, so we can be sure that the need for electricity for the Indonesian people is very large. This causes the need for development in empowering new and renewable energy power plants, one of which is wind turbines. Currently, technological developments are increasingly advanced, by following existing technological developments, a wind turbine must have more modern controls to make it easier to control the electrical power output generated by wind turbines. In this research control wind turbine blades using pitch angle with fuzzy logic control method, where this control will focus on adjusting the wind turbine blades because the performance coefficient of the wind turbine is very dependent on the wind turbine pitch angle. The fuzzy control is set to be able to maintain the stability of the wind turbine power output at 20KW, it is evident from the simulation results obtained with an average difference of only 0.77%.

Keywords: pitch angle, fuzzy logic control, renewable energy, power system, wind turbine.

1. Introduction

The need for electrical energy for people in this modern era is very important. The need for electrical energy is increasing every year, keep up with the growth in the number of economies and population in the country of Indonesia. The need for electrical energy is increasing every year to become a problem because the energy source used to generate electrical energy still uses fossil fuels which are increasingly depleting. On the other hand, the use of fossil energy has a bad effect on the environment because it has been used in large quantities and has non-renewable properties [1].

From these problems, a solution has been created to use renewable energy to replace fossil fuel energy in generating electricity. This is not a newly discovered energy, but for a long time, European countries have empowered electricity generation with new and renewable energy. For example, Denmark uses renewable energy by 55% with 44% of it produced from wind turbines. Indonesia has great potential for new renewable energy sources, one of which is wind energy, where Indonesia is an archipelago so that it has the potential for large sea breezes.

Wind energy is converted into electrical energy by wind turbines, the wind turbine must be able to work even though it gets a very large wind [2]. Figure 1 shows that the wind turbine is designed to work in a variety of conditions, such as low wind speed, high wind speed, very high wind speed, and its main purpose is to keep the wind turbine components within safe limits. At wind speeds of 7m/s to 20m/s, a pitch control is provided on the wind turbine blades to limit the aerodynamic power generated by wind turbines with an angle value of 0° to an
angle value of 37.16° so that the power generated by the wind turbine does not exceed 20KW, in this paper, using a fuzzy logic system to determine the value of the pitch angle at each change in wind speed.

1.1 Wind turbine model
The mechanical power of a wind turbine is described by the following equation:

\[
P_m = \frac{1}{2} \cdot \rho \cdot A \cdot C_p \cdot v_w^3
\]  

(1)

Where:
- \( \rho \) = wind density
- \( A \) = blades swept area
- \( v_w^3 \) = wind speed
- \( C_p \) = Power coefficient
- \( P_m \) = mechanical power
- \( \lambda \) = tip speed ratio

The power coefficient is a function of the tip speed ratio and pitch angle, the power generated by the wind turbine depends on the power coefficient value.

\[
P_m = P_w \cdot C_p(\lambda, \beta)
\]  

(2)

Where:
- \( \lambda \) = tip speed ratio
- \( \beta \) = Blade pitch angle

Where:

\[
\lambda = \frac{\omega \cdot R}{V_w}
\]  

(3)

\( \omega \) = turbine rotor speed
\( R \) = Wind turbine blade radius

The relationship between \( \lambda \) and \( \beta \) in \( C_p \) is shown in equation (4)

\[
p(\lambda, \beta) = C_1 \left( \frac{C_2}{\lambda_i} - C_3 \cdot \beta - C_4 \right) e^{\frac{-C_5}{\lambda_i}} + C_6 \cdot \lambda
\]  

(4)

Where:

\[
\frac{1}{\lambda_i} = \frac{1}{\lambda + (0,08 \cdot \beta)} - \frac{0,035}{\beta^2 + 1}
\]  

(5)

Following are the coefficient values of C1 to C6: C1 = 0,5176, C2 = 116, C3 = 0,4, C4 = 5, C5 = 21 dan C6 = 0,0068. Where the maximum value of \( C_p \) = 0.48 which this value is obtained when the condition \( \beta = 0 \) and \( \lambda = 8.1 \)

1.2 Pitch Control Using Fuzzy Logic Control
The system designed uses a wind turbine simulation model that is connected to FLC (fuzzy logic control) to control the pitch angle to dynamic-wind speeds. Changes in pitch angle greatly affect the value of \( C_p \) and the amount of \( C_p \) greatly affects the resulting \( P_m \) (mechanical power) as shown in Figure 2.
To design fuzzy logic controller rules, the first step that must be done is to determine the membership function, the second step is to change the crisps value into fuzzy values which are called the fuzzification process, the third step provides rules for fuzzy reasoning and the last step changes the fuzzy values to crisps values which are called the defuzzification process. The diagram block of the fuzzy logic control operation is shown in figure 3. The fuzzy logic system has 2 inputs, the input power error value resulting from the nominal power value and the wind speed value [7], [8].
The rules were made to facilitate the inference process and to get the appropriate pitch value to control the Pm value.

**Table 1.** rules fuzzy logic control

| WindSpeed Mfs’ | Pitch |
|----------------|-------|
| 7              | 0     |
| 8              | 4     |
| 9              | 11,29 |
| 10             | 16,58 |
| 11             | 20,64 |
| 12             | 23,89 |
| 13             | 23,89 |
| 14             | 28,8  |
| 15             | 30,71 |
| 16             | 32,35 |
| 17             | 33,79 |
| 18             | 35,05 |
| 19             | 36,16 |
| 20             | 37,16 |

2. Result and Discussion

The control system is made using SIMULINK and uses a generator as a power generator of 20 KW. The wind used as the input varies from 7 m/s to 20 m/s for 10 seconds.

**Figure 6.** wind speed input.

In this test, the simulation will be given input random wind speed with a range of 7-20 m/s, simulation time of 10s, and 1s sample time. This simulation is shown to observe changes in pitch control, mechanical power, and power output by the generator with the ratio of wind speed as input.
Figure 7. (a) pitch control, (b) mechanical power, (c) generator voltage, (d) generator current, (e) generator power output.

Figure 7 shows that the wind turbine is designed to work in various conditions, such as low wind speed, high wind speed, very high wind speed, and the main purpose is to keep the wind turbine components within safe limits. At high wind speeds to limit the aerodynamic power generated by the wind turbine, it is done by giving different pitch angles [4].
Table 2. simulation result with random wind speed input

| Time (s) | Wind Speed (m/s) | Pitch Angle (degree) | Pm (Watt) | Pm (no control) (Watt) | Ampere (A) | Voltage (volt) | Power Generator (watt) |
|----------|------------------|----------------------|-----------|------------------------|------------|----------------|-----------------------|
| 0        | 13.6678          | 28.0559              | 2.0167    | 4.8484                 | 711.5342   | 25.7386        | 1.8314                |
| 1        | 12.9863          | 26.5234              | 2.0039    | 4.8538                 | 712.9088   | 25.6891        | 1.8314                |
| 2        | 11.5551          | 22.4442              | 2.0188    | 4.6773                 | 713.3246   | 25.6740        | 1.8314                |
| 3        | 8.2356           | 5.7175               | 2.0117    | 2.9980                 | 713.8234   | 25.6560        | 1.8314                |
| 4        | 12.6377          | 25.5927              | 2.0176    | 4.8363                 | 712.3246   | 25.6740        | 1.8314                |
| 5        | 16.2201          | 32.6669              | 2.0129    | 4.5220                 | 712.1601   | 25.7161        | 1.8314                |
| 6        | 8.5076           | 7.7003               | 2.0250    | 3.2015                 | 712.4865   | 25.5997        | 1.8239                |
| 7        | 8.0151           | 4.1101               | 2.0067    | 2.8266                 | 712.4865   | 25.5997        | 1.8239                |
| 8        | 11.8003          | 23.2409              | 2.0134    | 4.7284                 | 709.0665   | 25.7230        | 1.8239                |
| 9        | 7.4372           | 1.7487               | 1.9164    | 2.3557                 | 709.2614   | 25.7160        | 1.6545                |
| 10       | 9.4980           | 13.9242              | 2.0219    | 3.8525                 | 676.9864   | 24.4389        | 1.8239                |

This table shows the results of changes in pitch angle to dynamic wind speed. It can be seen from the simulation results show the stability of the mechanical power with a value of 20KW and a power deviation of ± 250 watts until t (s) = 9 there is a decrease in the power of about 1.64% or ± 840 watts, this is because at t (s) = 9 the wind speed that passes through the wind turbine is in the range of 7 m / s, which means that the nominal minimum wind speed of the wind turbine is 7 m / s. In the graph of generator power, generator current and generator voltage also experience the same condition where the decrease is visible when the simulation t (s) = 9 (wind speed range of 7 m / s).

3. Conclusion

The power control system in the wind turbine with a pitch angle has successfully stabilized the output power of the wind turbine with a difference of below 5% or 0.77% and the fuzzy control can produce a good pitch value so that it can control the Cp value optimally.

4. Acknowledgments

This research dedication to Universitas Singaperbangsa Karawang.

References

[1] S. Shaddiq, D. B. Santosito, F. F. Alfarobi, S., and S. P. Hadi, "Optimal Capacity and Placement of Distributed Generation Using Metaheuristic Optimization Algorithm to Reduce Power Losses in Bantul Distribution System," ICITEE, 2016.
[2] D. B. Santosito, "Optimasi Penempatan dan Kapasitas Wind-Based Distributed Generation Untuk Meminimasi Losses Menggunakan Flower Pollination Algorithm.," JTERA, 2017.
[3] D. B. Santosito, "Penentuan Lokasi dan Kapasitas Wind-Based DG pada Sistem Distribusi 20 kV Menggunakan Flower Pollination Algorithm.," JTERA, vol. 5, no. 1, pp. 127-134, 2020.
[4] P. V. B and A. Gopinath, "Pitch Angle Control of Wind Turbine," IJERT, vol. 5, no. 08, 2016.
[5] R. K. Pachauri, H. Kumar, A. Gupta and Y. K. Chauhan, "Pitch Angle Controlling of Wind Turbine System Using Proportional-Integral/Fuzzy Logic Controller," in Proceedings of 3rd International Conference on Advanced Computing, Networking and Informatics, Smart Innovation, Systems and Technologies, Greater Noida, 2016.
[6] J. Zhang, M. Cheng, Z. Chen and X. Fu, "Pitch Angle Control for Variable Speed Wind Turbines," in DRPT, Nanjing, 2008.
[7] S. Khan, M. H. Mahar, A. Khowaja, H. Nawaz, and Shafiq-ur-Rehman, "Pitch Control of Wind Turbines with Fuzzy Controller and Stability Analysis," IJCSNS International Journal of Computer Science and Network Security, vol. 19, no. 3, 2019.
[8] A. P. Parayil and D. A. Ismail, "FUZZY LOGIC PITCH CONTROL OF VARIABLE SPEED WIND TURBINE," \textit{IRJET}, vol. 04, no. 09, 2017.