Indonesian Journal of Computer Science
ISSN 2549-7286 (*online*)
Jln. Khatib Sulaiman Dalam No. 1, Padang, Indonesia
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Modeling of Wind Power Generation in Tegal Region using Matlab Simulink

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Article Information

Submitted : 4 Dec 2023
Reviewed: 19 Jan 2024
Accepted : 15 Feb 2024

Keywords

Fossil energy, renewable energy, wind power generation, Matlab Simulink, wind speed.

Abstract

The increasing energy demands require larger energy production. However, fossil energy sources are depleting, necessitating the use of renewable energy to replace fossil fuels and meet energy needs in Indonesia. Indonesia has a significant wind energy potential. Wind power generation modeling is carried out in one of the cities in Indonesia, namely Tegal. By using Matlab Simulink, it is expected to assist in predicting renewable energy production. Tegal is one of the regions with high wind speeds in Indonesia, specifically at 3 m/s. From the modeling, the optimal blade radius and rotor angular velocity that can generate maximum power at a wind speed of 3 m/s can be determined. Wind power generation in Tegal with a wind speed of 3 m/s has the potential to produce electrical power of 768.55 W.

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A. Introduction

Currently, fossil energy sources such as crude oil, natural gas, and coal continue to be the primary energy sources worldwide [1], [2]. Even in Indonesia, there is still a dependence on fossil energy, with a consumption rate of 74%, consisting of 44% from crude oil and 30% from coal [3]. However, the availability of fossil energy is limited and diminishing. This is due to increasing exploitation to meet the growing energy demands [4], [5]. Furthermore, the use of fossil energy results in significant carbon dioxide emissions [6].

The high energy consumption in Indonesia makes the transition to renewable energy sources increasingly urgent. Renewable energy is a source of energy that is inexhaustible and can be naturally replenished [7], [8]. Indonesia has the potential for renewable energy sources that can be utilized, such as sunlight, geothermal heat, wind, and hydropower. Particularly for harnessing wind energy, Indonesia has good potential due to the presence of coastal and mountainous regions. In Indonesia, the potential wind energy for utilization reaches 60,647 MW. [9]. The development of renewables, including wind energy, is an economical solution for generating electrical energy due to its relatively low operational costs [10]. Indonesia has expertise in the construction and management of wind energy, as evidenced by previous projects such as the Sidrap Wind Power and the Jeneponto Wind Power Plant, each with capacities of 75 MW and 72 MW, respectively [11].

Tegal is one of the regions in Indonesia that has the potential to generate renewable energy, especially wind energy [12]. The average hourly wind speed in the city of Tegal experiences slight seasonal variations throughout the year. The windier period within a year occurs for approximately 2.5 months, from December 19 to March 2, with an average wind speed exceeding 9.5 kilometers per hour. The windiest month in Tegal is August, with an average hourly wind speed of 11.3 kilometers per hour [13].

One step towards enhancing energy resilience in Indonesia is the construction of a Wind Power Plant in Tegal. Modeling the Wind Power Plant using Matlab Simulink can provide estimates of the energy production. The objective of this modeling is to assess the potential energy generated by the wind power plant in Tegal through Matlab Simulink simulation. The benefit of this work is to provide information regarding the energy potential of the wind power plant in Tegal using Matlab Simulink simulation.

Relevant work that has been previously undertaken by others includes the modeling of a 20.5 kW wind turbine. This modeling was conducted by Dr. Khalid Yahia using Matlab Simulink. Dr. Khalid Yahia transformed the mathematical modeling of the wind turbine into Simulink blocks [14]. The power generated by the wind turbine is obtained from the following equation.

$$Pm = 0.5 \times Cp\,(\lambda, \beta) \times \rho \times A \times V^3 \quad (1)$$

In the given formula, where V represents wind speed, ρ is the air density (1.225 kg/m^3), Cp is the power coefficient, A is the area of the wind turbine, and R is πR, with R as the blade radius. The power coefficient is influenced by the angular velocity (λ) and the blade pitch angle (β).

$$Cp\,(\lambda, \beta) = c1\,(c2\;1/\gamma - c3\;\beta - c4\;\beta^{x} - c5)\;e^{-c6\;1/\gamma}) \quad (2)$$

From the equation (2), value of γ, λ, and angular rotor speed (ω_m) is obtained by:

$$1/\gamma = 1/(\lambda + 0.08\beta) - 0.035/(1 + \beta^3) \quad (3)$$

$$\lambda = \omega_m R/v \quad (4)$$

$$T_m = P_m/\omega_m \quad (5)$$

The other research was conducted at a location in Sarawak using MATLAB/SIMULINK to model and simulate various wind energy conversion systems. The findings revealed that Permanent Magnet Synchronous Generators exhibit higher efficiency compared to Squirrel Cage Induction Generators and Doubly Fed Induction Generators [15].

The main difference in this job compared to the previous one is that in this research, the input variable used is the average wind speed in Tegal, Indonesia. According to data from windfinder.com [16], the wind speed in Tegal is 3 m/s. This wind speed affects the radius and angular rotor speed used. In the model created, the radius used is 6 m, and the angular rotor speed used is 4 m/rad. The values of the radius and angular rotor speed are adjusted based on the wind speed to achieve maximum power output.

B. Research Method

The steps used in this research begin with a literature review. Following that, the selection of a location with high wind speed is carried out. In this case study, one of the areas chosen in Indonesia is Tegal. Data on the wind speed in Tegal is collected to conduct wind energy modeling using Simulink. Subsequently, research is conducted to determine the optimal blade radius and rotor angular speed that can generate maximum power at the wind speed in Tegal. The modeling results are comprehensively analyzed to obtain in-depth information about the wind energy potential that can be generated from that location.

This wind energy modeling is divided into four parts. Part 1 involves wind speed cubed, while Part 2 focuses on the swept area. Part 3 considers wind density, and finally, Part 4 involves the power coefficient. Below is an explanation of each block based on Figure 1.

1. Part 1: This section consists of two blocks, In1 and a function.
   - Block In1 signifies the input variable, which is the wind speed.
   - In the function, the wind speed is cubed.
2. Part 2: This section comprises blocks In1, a function, and a gain.
   - Block In1 represents the input variable, which is the blade radius.
   - In the function, the radius is squared.
   - The gain is used to multiply the squared radius by phi 2.
3. Part 3: This section includes a constant block.
   - The constant block is used to input the wind density value.
4. Part 4: This section has subsections A, B, and the overall structure, including blocks In1 and a function.
   - Subsection A (λ): Consists of blocks In1 and Product1.
     - Block In1 signifies the input variable, which is the rotor angular speed.
     - Product1 is used to calculate the λ value using equation (4).

- Subsection B (γ): Comprises a saturation block and a function.
  - Saturation produces an output signal limited within upper and lower saturation values.
  - In the function, the λ value from section A and the β value are input into equation (3).
- Block In1 represents the input variable, which is the blade tilt angle (β).
- In the function, the γ and β values are input into equation (2).

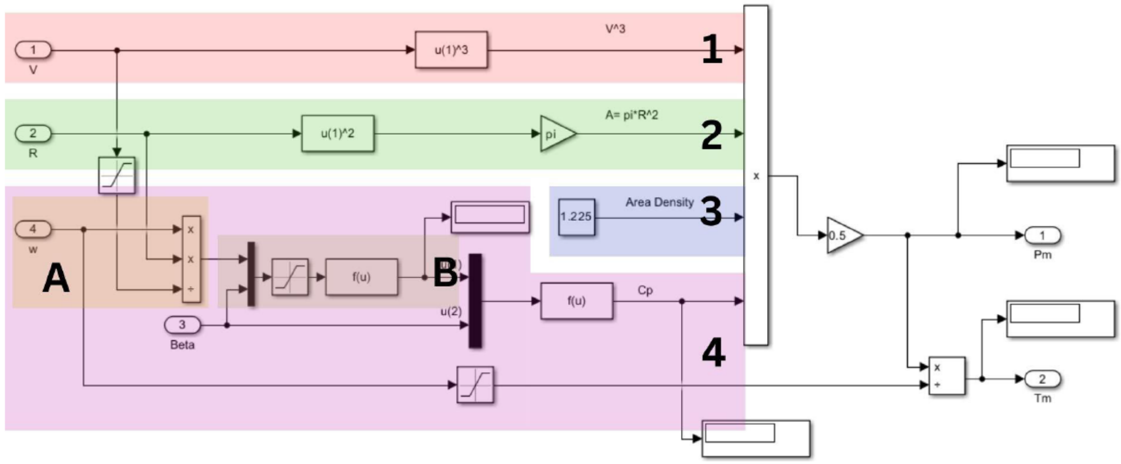

Figure 1. Block part of the system in Simulink

These four sections are utilized to determine the power (P_m) and rotor torque (T_m). According to equation (1), calculating the power (P_m) requires information such as wind speed, wind turbine swept area, wind density, and power coefficient influenced by angular speed and blade tilt angle. Furthermore, from equation (5), it is established that to calculate rotor torque (T_m), both power and rotor angular speed are essential parameters.

C. Result and Discussion

In this modeling scenario, several variables are employed to characterize the wind turbine system. These variables include a wind speed (V) of 3 m/s, a blade radius (R) measuring 6 m, wind density (ρ) set at 1.225 kg/m^3, a blade tilt angle adjusted to 0 degrees, and a rotor angular speed (ω) of 4 rad/s. By configuring these values, the model can offer an accurate representation of the operational conditions of the wind turbine. This setup enables a more in-depth analysis of the wind energy potential that can be generated by the system.

This model utilizes a wind speed of 3 m/s, a blade radius of 6 m, a blade tilt angle of 0 degrees, and a rotor angular speed of 4 rad/s. From the variables used, the power output is determined to be 768.55 W, and the rotor torque is 192.1 Nm, as seen in Figure 2.

The wind power plant modeling in Tegal using Matlab Simulink is conducted to predict the produced energy. The power generated by the wind power plant is influenced by factors such as wind speed, wind turbine swept area, wind density, and power coefficient derived from rotor angular speed and blade tilt angle. The values of these variables affect the generated power. Tegal has a wind speed of 3 m/s, which is higher than some regions in Indonesia. To achieve maximum power, adjustments to the wind turbine swept area and rotor angular speed are required based on the wind speed. After experimenting with different values, it is found that a blade radius of 6 m and a rotor angular speed of 4 rad/s yield the maximum power.

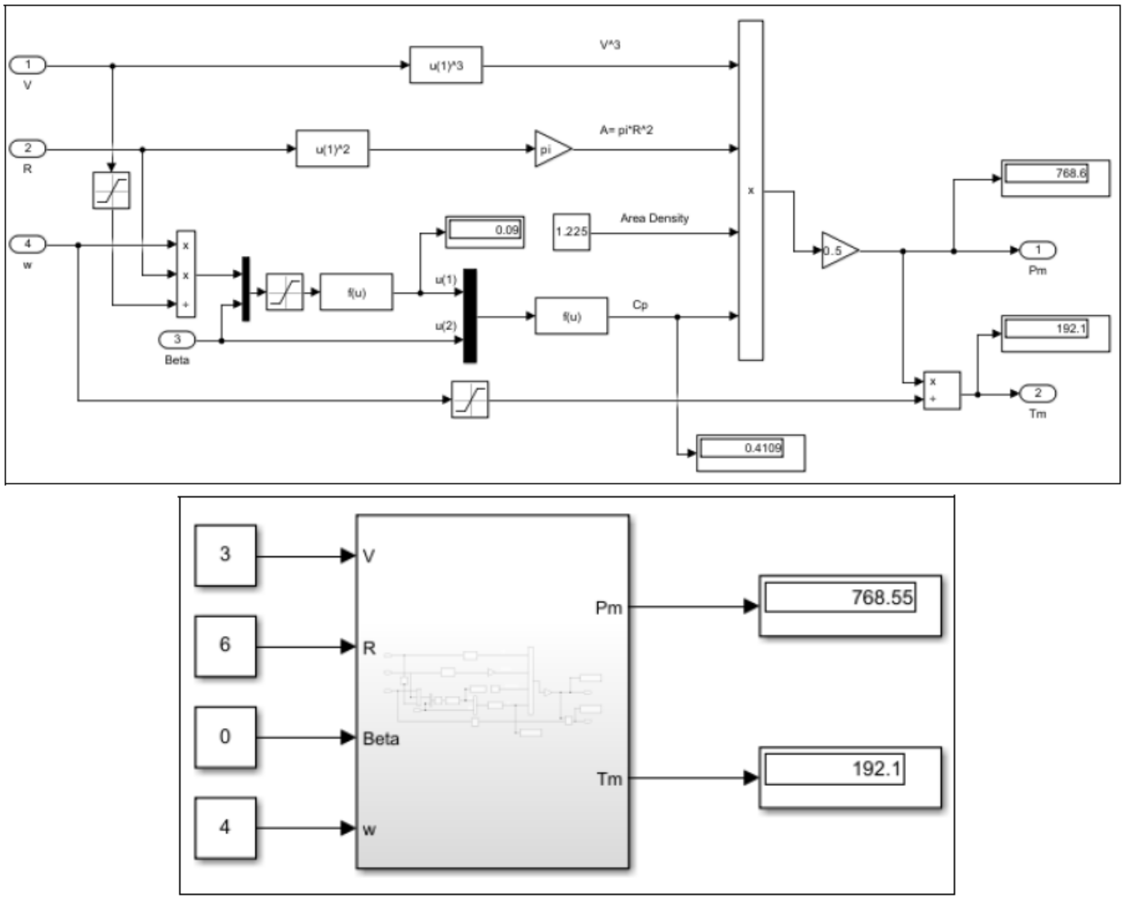

Figure 2. The results of the wind power plant in Tegal simulation

Environmental factors affecting the system's performance are primarily influenced by wind speed. The blade radius and rotor angular speed have been adjusted to a wind speed of 3 m/s. Changes in wind speed alter the generated power, affecting its maximum potential.

From the conducted modeling, it is determined that the wind power plant in Tegal with a wind speed of 3 m/s has the potential to generate electrical power of 768.55 W. This power output is substantial, especially when employing multiple wind turbines. The development of a Wind Power Plant in Tegal can contribute to energy resilience and transition in Indonesia.

D. Conclusion

From the conducted energy modeling, several conclusions can be drawn. Firstly, wind speed significantly influences the generated power. Secondly, adjusting the blade radius and rotor angular speed according to the wind speed is essential to achieve maximum power. Thirdly, a wind speed of 3 m/s produces the maximum power when the blade radius is 6 m, and the rotor angular speed is 4 rad/s. Fourthly, the wind turbine modeling in Tegal with a wind speed of 3 m/s has the potential to produce renewable energy of 768.55 W.

To obtain higher power results, further exploration can involve fine-tuning the blade radius and rotor angular speed to decimal values. Additionally, modeling can be extended to regions with higher wind speeds than Tegal. This approach aims to generate even greater power output than predicted by this specific model.

E. Acknowledgment

The author would like to express heartfelt gratitude to Universitas Multimedia Nusantara for providing facilities to support this research. Thank you for the support and resources that have facilitated the smooth execution of this study.

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