Improvement of small scale turbine performance: in West Aceh region using a clark-y type of turbine blades

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Abstract. This study aims to improve the performance of small scale wind turbines in the West Aceh region using a Clark-Y type turbine blade. Aceh Barat is one of the districts in Aceh province which is located at coordinates 04°06’ - 04°47’ NL and 95°52’ - 96°30’ EL and an area is located on the west coast of Aceh province bordering directly on the Indian Ocean, and one of the areas are worst affected by the tsunami disaster in 2004. The reference data shows that the potential of wind energy in the West Aceh region on average is quite varied, which is the lowest of 3.4 m/s to the highest speed of 5.8 m/s. The results of tests on the turbine blades before and after optimization provide increasing the ability of the turbine to produce energy and mechanical power. Based on the characteristics of the rotor rotation, the highest rotation data that occurs on the blades before the optimization is 316.6 rpm, and the highest rotor rotation on the blades after optimization is 361.3 rpm. Accordingly, there is an increase in turbine capability by 12.4%.

1. Introduction

1.1 Potential and wind energy conversion in the West Aceh region

The potential of wind energy in the West Aceh region has the potential to be able to rotate small-scale wind turbines. The average wind speed produced in the Meulaboh region is quite varied; it is as low as 3.4 m/s to the highest speed of 5.8 m/s [1], [2]. Wind turbines convert wind power captured by the turbine blades in the form of mechanical force. Wind turbines convert energy into electrical energy through generators that take the rotational power through the turbine shaft, and then the power generated by the turbine shaft must go through a gear system that regulates the spin power to the generator [3]. The power generated by wind turbines is stated as [3]:

\[ P = \frac{1}{2} \rho \pi R^2 V^3 C_p \]  

\( \rho \) is the density of air in kilograms per cubic meter, \( R \) is the radius of the wind turbine rotor, \( V \) is the air velocity, and \( C_p \) is the power coefficient of the wind turbine, which is a function of the tip speed ratio (TSR). The theoretical maximum \( C_p \) limit, according to Betz theory, is 16/27, but in practice, the maximum \( C_p \) efficiency that can be achieved by wind turbines is 40% - 45%. The efficiency curve of the rotor \( C_p \) (\( \lambda \)) is a nonlinear function of the TSR, which is determined by the design of the turbine blades and pitch angle, as shown in Figures 11 [3], [4].
1.2 The power efficiency of available wind turbines
According to Betz, the maximum amount of energy that can be converted by a wind turbine is 0.59259 from the total energy available [5]. Betz's momentum theory explains the modelling of the flow of wind energy through the turbine blade. The kinetic energy contained in the wind will decrease when pounding the turbine blade, and the airflow will turn and scattered which a much reduced kinetic energy value, and there is a relationship between the ideal power coefficient, \( C_p \), with the value of the ratio between the wind speed before and after pounding the turbine blade, such as shown in figure 2 [5], [6].

Figure 1. Relationship between TSR and power coefficient (Cp), and between maximum Cp power and rotor speed.

Figure 2. Flow model and power coefficient are proportional to wind speed before and after pounding the turbine blade.

1.3 Optimizing the performance of wind turbines
Enhancement of wind turbine performance can be done by improving and testing turbine blade design and developing types of airfoils. Blades and airfoil designs can be done one of them using the Genetic Algorithm method, which is useful for improving the aerodynamic performance of the blade [7], [8]. The process of developing a wind turbine blade as a basis for improving the performance of a wind turbine is divided into two stages, namely aerodynamic and structural design [9], [10]. From these two stages, at the aerodynamic stage, it is necessary to pay attention to the application of new airfoil models that support the performance of the blade. From the formative stage, it is necessary to consider the durability and flexibility of the blade designed for the blade's ability to withstand operating fatigue [9], [11].

Research conducted by Liu et al. [12] provides results of the development of wind turbine blades design that pays attention to the optimization and improvement of the aerodynamic functions of the blades, which provides an increase in wind turbine performance in annual power production by 7.5%. Other relative studies give results in an increase in annual power production by 8.51% [13]. Other studies have shown that the performance ratio of the maximum wind turbine blade is provided by the blade with a maximum thickness of 40% of the length of the chord and the attack angle of the turbine by 20% [8],
Based on the conclusions of a study conducted by Wiratama, I.K. et al. showed that the difference in profile and number of blades greatly influenced the performance of wind turbines. The results of this study indicate that the profile of a sizeable tapered blade gives maximum performance results [8], [15]. One form of the airfoil that is simple in manufacturing and providing maximum results is a Clark-Y type wind turbine blade. This type of wind turbine blade can be made with a simple method because all manufacturing processes are carried out manually. The test results give a TSR value of 7, rotor solidity of 0.57, and the resulting output power of 165.924 Watt [16].

2. Research methodology
2.1 Application area
Aceh Barat is one of the districts in Aceh province which is located at coordinates 04° 06´ - 04° 47´ NL and 95° 52´ - 96° 30´ EL. Aceh Barat is an area which is located on the west coast of Aceh province, and it borders directly with the Indian Ocean and is one of the areas worst affected by the 2004 tsunami [17]. The West Aceh region has an enormous wind power potential which is resulted from the advantage of its geographical location, and it is directly adjacent to the Indian Ocean. The location and map image of the application area of this study are shown in Figure 3.

![Figure 3. Areas of research application](image)

2.2 Estimated energy generation
West Aceh Regency has an average temperature of 26.5 °C, air pressure of 1,010 atm, air humidity of 86%, an average monthly solar radiation of 41.17%, an average rainfall of 255.1 mm and wind direction and speeds an average of 3 knots westward. From these data, West Aceh district is very suitable to be developed as a central area for wind power generation [19].

Wind energy sources as a renewable energy source provide wind data that will be used by power plants. Measurement of wind energy potential is done by measuring wind speed using anemometer and for annual data obtained from the Metrology and Geophysics Agency of Meulaboh Station. The wind data is converted at the height of 15 meters, so it follows the height of the wind turbine hub at the time of testing using equation (2) [20], [21].

\[ V_{hub} = V_{ane} \times \left( \frac{H_{hub}}{H_{ane}} \right)^{\alpha} \]  

(2)

Where \( V_{hub}, V_{ane}, H_{hub}, H_{ane}, \) and \( \alpha \) are the speed and height of the hub at the time of testing.

The condition of the wind turbine installation is in the "High and Protected Plant" area with a friction coefficient (\( \alpha \)) of 0.20. An annual average wind speed of 4.8 m/s is obtained with maximum values occurring in October and December of 5.8 m/s, and the minimum value occurred in September of 3.4 m/s, as shown in tables 1 [1], [21], [22].
Table 1. Average wind speed per month for a year after correction.

| No. | Month   | Average wind speed per month (m/s) |
|-----|---------|------------------------------------|
| 1   | January | 4.1                                |
| 2   | February| 5.6                                |
| 3   | March   | 4.5                                |
| 4   | April   | 4.0                                |
| 5   | May     | 4.8                                |
| 6   | June    | 5.6                                |
| 7   | July    | 4.9                                |
| 8   | August  | 4.7                                |
| 9   | September | 3.4                       |
| 10  | October | 5.8                                |
| 11  | November| 4.1                                |
| 12  | December| 5.8                                |

The average wind speed overall m/s 4.8

2.3 Design and optimization of turbine blades

The theory about the working principle of the turbine blades has been developed by Glauret [23]. The theory explains the theory of blade elements and momentum [24]. The BEM theory is divided into two parts in designing of the aerodynamics blade. For the first part, a blade model is divided into the smallest sections, as shown in Figure 4. In the second part, the aerodynamic force calculation of the blade is calculated as a two-dimensional airfoil, which is linked to the flow conditions, as shown in Figure 5 [13].

Figure 4. The smallest parts of the blade [13].
Figure 5. The aerodynamic force of the blades [13].

The design of a wind turbine is always aimed at achieving maximum turbine performance. The performance of the wind turbine is influenced by the blade design and operating conditions that allow the wind turbine to work with excellent efficiency, as shown in Figure 6 [25]. A genetic algorithm theory has been developed in perfecting a product. A genetic algorithm is a non-gradient-based algorithm to solve the optimization problems which are found in a product. In general, optimization is given by the following equation [13]:

\[ x = (x_i) \quad \forall i = 1, 2, \ldots N. \]  

Minimize \( f(x) \)

\[ h_j(x) \leq 0 \quad \forall j = 1, 2, \ldots n. \]  

Where \( x, N, f(x) \) and \( h_j(x) \) are vector design parameters, the number of design parameters, objective functions, and design constraints.

Figure 6. Flowchart of the optimization process [13].
3. Results and Discussion

The research results are the optimization values of the blade, which is designed to increase the value of Annual Energy Production (AEP). Before the optimization is done, a test is performed to get the characteristic value of the bar, which is then plotted in a graph. Afterward, the blade design optimization process is carried out concerning Annual Energy Production (AEP), which is done by looking at the characteristics of the blade performance that are plotted in a graph as well.

3.1 Design of Blade

The design of Blade starts with determining the type of blades that are designed. For this study, the airfoil model, which is used, is the Clark-Y type. Then, from the literature analysis and reference has taken a rotor diameter of 2 m, a TSR value of 7, and a rotor solidity value of 0.57. CAD design and animation are given in Figure 7 [16].

![Figure 7. CAD design.](image)

3.2 Test results of the blade before and after optimization

Wind turbine testing using blades before the optimization is done within a few days of testing. The testing is carried out to get the value of the characteristics of the wind turbine that illustrates its ability to produce Annual Energy Production (AEP). The test results are given in Figure 8 below.

![Figure 8. Blade type Clark-Y animation.](image)
Testing on the blades that have been carried out optimization gives different values. The process of optimizing the turbine blades has given the addition of mechanical power from the wind turbine in energy production, as shown in Figure 9.

Figure 9. Results of the blade test before optimization for data 1.

Figure 10. Results of the blade test before optimization for data 2.

Figure 11. Results of the blade test after optimization for data 1.
Figure 12. Results of the blade test after optimization for data 2.

From the results of tests on the turbine blades before and after optimization provides data on the increase in the ability of the turbine to produce energy and an increase in mechanical power. Based on the characteristics of the rotor rotation, the highest rotation data that occurs on the blades before the optimization is 316.6 rpm, and the highest rotor rotation on the blades after optimization is 361.6 rpm. As a result, there is an increase in turbine capability by 12.4%.

4. Conclusion

The theory about the working principle of the turbine blades has been developed by Glauret. The theory explains the theory of blade elements and momentum. The design of a wind turbine is always aimed at achieving maximum turbine performance. The performance of the wind turbine is influenced by the blade design and operating conditions that allow the wind turbine to work with good efficiency. Therefore, a genetic algorithm theory has been developed in product optimization. From the results of tests on the turbine blades before and after optimization provides data on the increase in the ability of the turbine to produce energy and an increase in mechanical power. Based on the characteristics of the rotor rotation, the highest rotation data that occurs on the blades before the optimization is 316.6 rpm, and the highest rotor rotation on the blades after optimization is 361.6 rpm. As a result, there is an increase in turbine capability by 12.4%.

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