Experimental Study of the Performance of a Horizontal Axis Wind Turbine with A Flat Taper Type of 4:5 and an Outer Angle of 25° With Variations in The Number of Blades

Faranita Putri Anandia *(1), Sahid(1), Anis Roihatin(1)
1*Department of Mechanical Engineering*, *Politeknik Negeri Semarang*, Semarang, Indonesia
Email address: ***faranitapa@gmail.com***

Abstract—This experimental study investigates the performance of a Horizontal Axis Wind Turbine (HAWT) with a flat taper 4:5 blade design and a 25° exit angle, focusing on the effect of varying the number of blades (6, 9, and 12). The turbine, with a diameter of 1.1 m and blade dimensions of 470 mm length, 110 mm top width, and 137 mm bottom width, was tested at wind speeds of 3 m/s, 5 m/s, 7 m/s, and 9 m/s in a laboratory setting. Parameters such as wind speed, turbine rotation, voltage, and current were measured to analyze system efficiency. The results indicate that blade count and wind speed significantly influence efficiency. The highest efficiency of 12.51% was achieved at 3 m/s with 9 blades, while at 5 m/s, the efficiency peaked at 3.95% with 9 blades. For higher wind speeds (7 m/s and 9 m/s), the optimal efficiency decreased to 2.03% and 0.95%, respectively, both achieved with 6 blades. The study concludes that this turbine design is most effective at low wind speeds (≤5 m/s), making it suitable for regions with similar wind conditions, such as Indonesia. The findings contribute to optimizing blade configurations for small-scale wind energy applications.

Keywords*—*horizontal axis wind turbine, 25° outlet angle, taper 4:5, number of blades, system efficiency

I. INTRODUCTION

The energy crisis is one of the main problems experienced by all countries, including Indonesia. Electricity consumption in Indonesia in 2023 will reach 1,285 kWh per capita and will increase to 1,408 kWh per capita **[1].** As energy consumption increases, fossil reserves will decrease, causing an energy crisis. Based on Government Regulation No. 79 of 2014 concerning National Energy Policy, the target for the new and renewable energy mix by 2025 is at least 23% and 31% by 2050.

The construction and development of new and renewable energy plants (NRE) is one of the energy transition efforts in Indonesia. One type of new and renewable energy power plant in Indonesia that has the potential to be developed is wind power plants (PLTB). Indonesia has considerable potential for wind sources, but with a low average wind speed ranging from 3 m/s to 5 m/s [2].

Wind turbines that are suitable for use in Indonesia, which have low wind speeds, are horizontal shaft turbines, namely flat-type horizontal shaft turbines. This is because there is no pressure difference on the front and back sides of the blade **[3].**

The performance study of horizontal axis wind turbines with a variation in wind speed of 3-4 m/s and a variation in the number of blades of 3,4,5, and was reviewed from the efficiency of the System and Tip Speed Ratio (TSR). This study aims to determine the optimal number of spoons that can be used in low wind speeds. The highest system efficiency is produced at the number of spoons 5 of 3.07% and the wind speed of 4 m/s **[4].**

Various studies have been carried out to reduce drag forces in turbines to improve the system efficiency of wind turbines. The use of taper-type blades with a blade tip design that shrinks from the base of the blade aims to reduce the drag force. Experimental studies prove that turbine blades that have a 4:5 top and bottom blade width produce the highest system efficiency, which is 9.67% compared to the ratios of 3:5 and 2:5 **[5].** Sahid et al (2020) examined the performance of a large blade-type horizontal shaft wind turbine by providing treatment of changes in the output angle of the blade. The study was conducted by comparing the treated and untreated sides of the blade. The highest system efficiency is obtained at a 25° blade angle. Modification of the outer angle of the blade will increase the thrust of the turbine. The absolute speed of the wind on the exit side of the blade will have a tangential direction and the opposite direction to the motion of the blade, so that it will increase the rotation and energy produced by the turbine **[6].** Further experimental studies were conducted by Rahayu. The study was conducted to compare the performance of wind turbines with variations in the number of blades, 6, 9, and 12, at low to high wind speeds, namely 5-9 m/s. The highest system efficiency was obtained when using a 6-spoon variety at a wind speed of 5 m/s of 3.65%. This study proves that multiblade flat wind turbines with an output angle of 25° are suitable for application in areas with low wind speeds ≤5 m/s.

The development of the modification was carried out again by Sahid et al (2022). The blade used is a combination of the 4:5 taper model developed by Herlambang et al (2019) and the blade model with external angles developed by Sahid et al (2020).

Sahid studied the performance of wind turbines with 3-blade models, namely the 4:5 taper blade, the flat blade model with an external angle of 25°, and the 4:5 taper blade model with an external angle of 25°. The results show that a large blade-type horizontal shaft wind turbine with a taper of 4:5 and an output angle of 25° is a blade model that is suitable for use at low wind speeds, namely ≤7 m/s. The 25° output angle blade model is suitable for use at a speed of 9 m/s **[7].** Although the increase in system efficiency with blade modification has been proven, research on variation in the number of blades with modifications is still limited. Most of the previous research was done on a fixed number of spoons, which is 9 pieces. This study aims to experimentally examine the performance of 4:5 flat taper type horizontal shaft wind turbines and 25° output angles with variations in the number of blades, 6, 9, and 12, at wind speeds of 3 m/s, 5 m/s, 7 m/s, and 9 m/s. The turbine's performance is reviewed from system efficiency, output power, and TSR. The influence of variations in the number of blades and wind speed is also being studied. The results of the study are expected to provide insight into the performance of turbines with a number of blades, as well as evaluate the feasibility of using turbines at low wind speeds, especially in Indonesia.

II. METHODS

2.1 Device testing

This study employed a 4:5 *flat taper* blade and an output angle of 25° with dimensions of 470 mm in length, 110 mm in top side width, 137 mm in bottom side width, and 10 mm blade thickness, reduced to the turbine inlet side to 5 mm as shown in Figure 1 (a). This blade model is designed using the blade design that was made by Herlambang and Sahid**.** Variations in the number of 6, 9, and 12 blades were tested for performance in wind power generation systems and compared.

2.1.1 Experimental

The airflow is generated from the HXUR 208A2 blower with a maximum rotation of 1410 rpm, placed in front of the turbine. The airflow velocity was measured using the Lutron AM-4200 anemometer. Wind speed is different as an independent variable in this study is regulated in such a way by regulating the distance between the blower and the turbine. The test installation used in this study is shown in Figure 2.

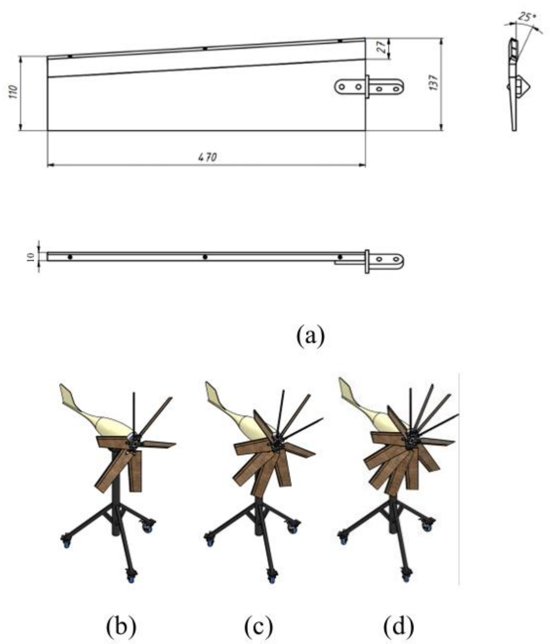

Figure 1. Blade details (a) Blade dimensions, (b) Number of blades 6, (c) Number of blades 9, (d) Number of blades 12

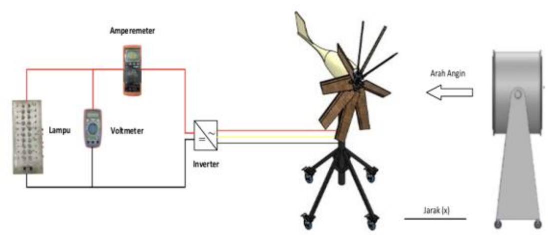

Figure 2. Testing Installation

In the test section, the airflow interacts with the blades and is converted into electrical energy by a 400-Watt DC generator.

2.1.2 Test Parameters

The parameters measured to evaluate the performance of a wind turbine are wind speed (V) measured using an anemometer, turbine shaft rotation (n) measured with a tachometer, voltage (V) measured with a voltmeter, and current (A) measured by an amperemeter. These parameters are used to calculate kinetic power (P_{input}), generator power (P_{output}), rotor solidity, *tip speed ratio*, and system efficiency (ɳs).

2.1.3 Kinetic Power

The kinetic energy generated from the wind is then captured by the turbine to rotate the rotor. Kinetic energy can be calculated using Equation (1).

$$Pk = \frac{1}{2} \times \rho A v^3 \tag{1}$$

With
Pk = Turbine wind power (Watt)
ρ = Air density (kg/m3)
v = Wind speed (m/s)
A = Turbine rotor stroke area (m^2)

2.1.3 Generator Power

The power of the generator is generated from the rotation of the turbine shaft, so that the generator generates the value of the voltage and current that comes out of the generator, Equation (2).

$$Poutput = V \times I \tag{2}$$

With,
P_{output} = Generator Power (Watt)
V = Alternator Volt (Volts)
I = Generator Current (Ampere)

2.1.4 System Efficiency

System efficiency is the ratio between the power generated by the generator and the kinetic power. The efficiency of the system can be obtained from equation (3).

$$\eta S = \frac{Poutput}{Pkinetik} \times 100\% \tag{3}$$

2.1.5 Tip Speed Ratio

The tip speed ratio is a comparison of the speed of the spoon to the speed of the free wind (air). TSR is a dimensionless parameter used to analyze the performance of wind turbines. The tip speed ratio can be obtained using equation 4.

$$\boldsymbol{\lambda} = \frac{\pi \times D \times n}{60 \times v} \tag{4}$$

With
$\boldsymbol{\lambda}$ = Tip Speed Ratio
n = Rotation (rpm)
D = Diameter of turbine (m)
V = Wind speed (m/s)

2.1.6 Rotor Solidity

Rotor solidity is the ratio between the total blade area and the swept area. The value of the rotor solidity can be obtained from equation 5.

$$Rotor\ Solidity = \frac{Blade\ Area}{Rotor\ Area} = \frac{b \times c}{D} \tag{5}$$

III. RESULTS AND DISCUSSION

3.1. Characteristics of the system's efficiency against turbine rotation at low wind speeds

Figure 3 is the curves of the characteristics of the system efficiency relationship with the rotation (rpm) of a 4:5 flat taper type horizontal shaft wind turbine and an output angle of 25° at a wind speed of 3 m/s for each variation in the number of blades. There are three curves on the graph of the characteristics of the relationship between the efficiency of the system and the rotation of the turbine at a wind speed of 3 m/s, with each curve representing the variation in the number of blades used. The resulting curve is parabolic, which shows that as the load increases, the rotation will decrease, while the efficiency will change when the load is increased and will decrease when the efficiency condition has passed the peak condition. As the results of research conducted by Sahid et al, the curve trend in the efficiency graph will decrease when it reaches its optimal point. Testing at a wind speed of 3 m/s resulted in the highest efficiency of 12.51% on the number of blades 9.

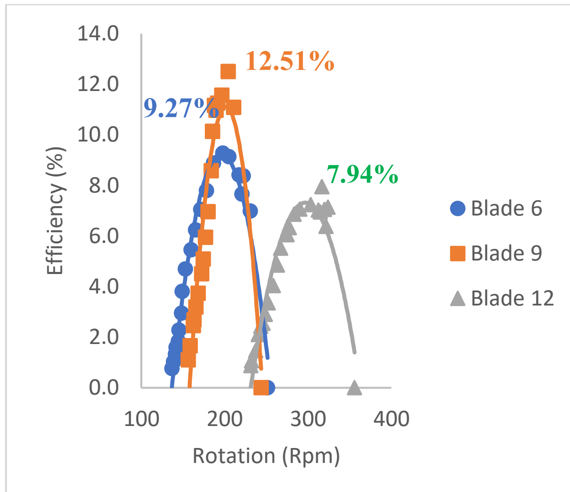

Figure 3. Characteristics of the system efficiency relationship with the wind turbine rotation at a speed of 3 m/s with variation in the number of blades

Figure 4 is a graph of the characteristics of the relationship between system efficiency and turbine rotation (rpm) at a wind speed of 5 m/s at each variation in the number of blades. The highest performance of wind turbines was tested on each variation of the number of blades, obtained results with a total of 6 blade of system efficiency of 3.86% with a rotation of 267.5 rpm and an output power of 2.63 Watts at a load of 12.5 Watts, the number of 9 blade produced a system efficiency of 3.95% with a rotation of 284.1 rpm and an output power of 2.69 Watts at a load of 15 Watts, while the number of 12 blade produced an efficiency of 3.84% with a rotation of 321.5 rpm and an output power of 2.64 Watts at a load of 5 Watt.

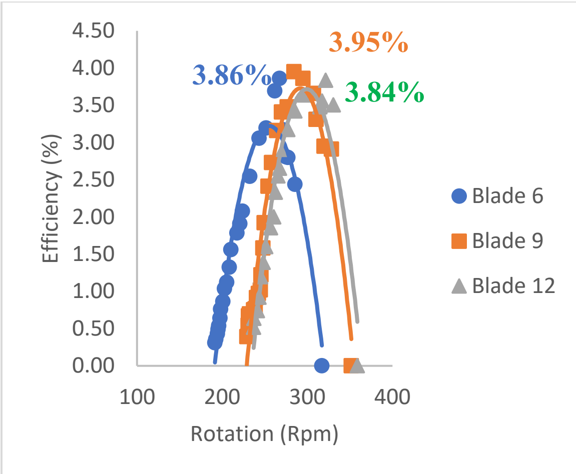

Figure 4. Characteristics of system efficiency relationship with wind turbine rotation at speed of 5 m/s with variation in number of blades

Referring to the research conducted by Aryanto, a smaller number of blades has a long distance between spoons, so that the distribution of wind received by the blade cannot be maximized because many losses are lost through blade gaps. Meanwhile, in the number of 12 blades, the more spoons, the closer the distance between blades, and the more surface area of the blade exposed to the wind. Referring to equation 2.1 regarding the magnitude of the value of the drag force coefficient, namely, that the magnitude of the drag force is influenced by the surface area of the blade (A). So that the drag force will increase, air turbulence will occur, and reduce the efficiency of the turbine even though the maximum rotation is produced on a blade totaling 12 pieces. In addition, the value of the solidity rotor in this study with the numbers 6, 9, and 12 blades was 0.3299, 0.4706, and 0.6013.

According to the results of research that has been carried out wind turbines that have a large number of blades will have high solidity, this is because the value of solidity is directly proportional to the number of blades, so if the number of blades is more and the number of blades the amount of initial torque produced will also be larger, the turbine rotation is low, and the efficiency produced is not too high. This is reinforced by research conducted by Bourhis et al **[9]** that an oversized solidity rotor can prevent airflow from passing through the space between the blades. The blade behaves like a solid wall against the flow of wind, making it seem as if it cannot touch the breadth of the blade, and the wind cannot pass through the blade efficiently. This solid wall effect will inhibit the conversion process from wind energy to mechanical energy, so that the resulting system efficiency cannot be maximized.

3.2. Characteristics of the system's efficiency against turbine rotation at high wind speeds

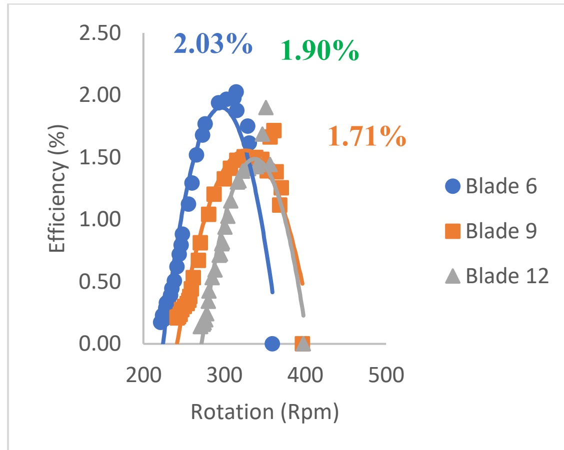

Figure 5. Characteristics of the system efficiency relationship with wind turbine rotation at a speed of 7 m/s with variation in the number of blades

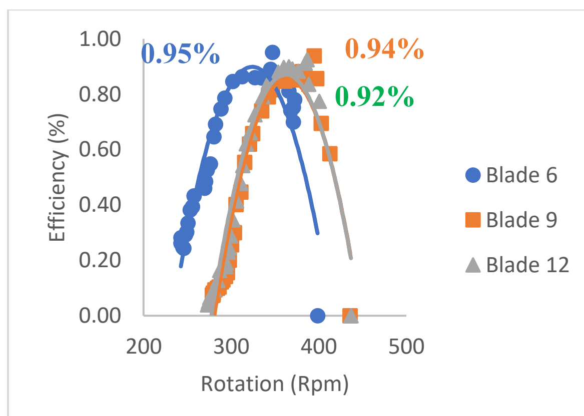

Figure 6. Characteristics of the system efficiency relationship with wind turbine rotation at a speed of 9 m/s with variation in the number of blades

Figure 5 is a graph of the characteristics of the efficiency relationship to the rotation of the flat *taper* type horizontal shaft wind turbine 4:5, which was tested at a wind speed of 7 m/s with variations in the number of blades of 6 pieces, 9 pieces, and 12 pieces. In this 7 m/s speed test, the turbine using a variation of the number of 6 blades produced the highest system efficiency of 2.03%.

Figure 6 is a graph of the characteristics of the efficiency relationship to the rotation of the horizontal shaft wind turbine of the flat taper type 4:5 which shows that the efficiency of the system is affected by the number of blades used. The highest performance of the wind turbine was tested on each variation of the number of blades. The result was obtained with a total of 6 blades, resulting in a system efficiency of 0.95% with a rotation of 347.4 rpm. Based on research that has been conducted **[10],** the size of the rotor rotation is influenced by the number of blades. The more blades, the closer the distance between one blade and the other. Thus, the rotor rotation will increase. Testing with low wind speeds requires a large number of blades, because the rotor rotation produced is high, so the required starting torque is low. Meanwhile, high wind speed testing requires a small blade. This is strengthened by research conducted by Dicky, namely that the more blades used, the solidity of the rotor will increase so that the starting torque of the turbine will be smaller **[11]**.

3.3. Characteristics of System Efficiency Against Turbine Rotation with Wind Speed Variation at the Number of Spoons 6, 9, and 12 Pieces

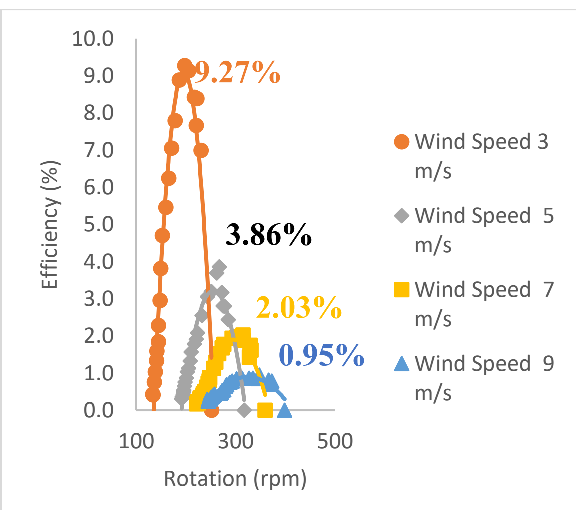

Figure 7. Characteristics of the relationship between system efficiency and wind turbine rotation at the number of 6 pieces with wind speed variation

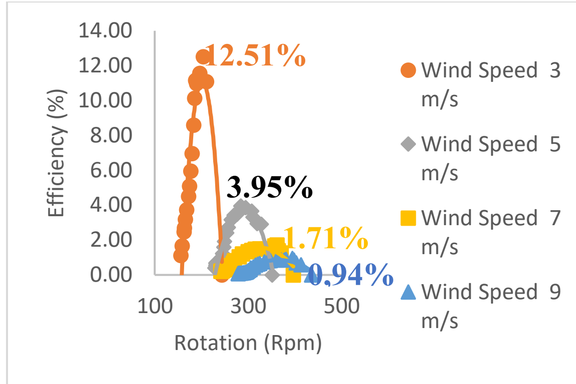

Figure 8. Characteristics of the relationship of system efficiency with wind turbine rotation at the number of 9 pieces with wind speed variation

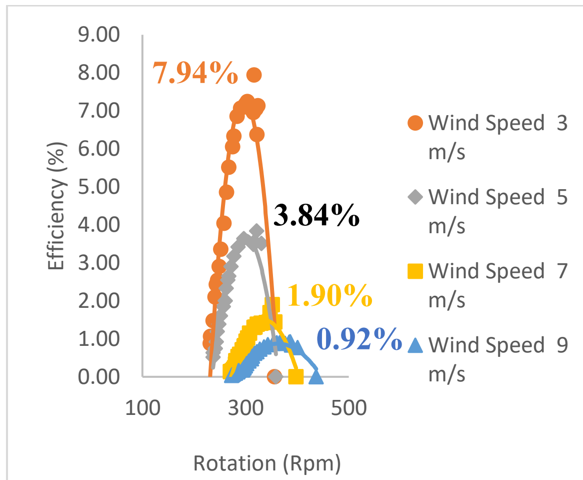

Figure 9. Characteristics of the relationship of system efficiency with wind turbine rotation at the number of 12 pieces with wind speed variation

The efficiency of the system in the test decreased as the wind speed increased. The decrease in efficiency is caused by the influence of rotor solidity; the results of research conducted by Dony show that the value of rotor solidity is inversely proportional to efficiency **[12].** The higher the rotor solidity, the higher the thrust will result in a higher thrust force, so that the efficiency of the system will decrease, because TAPH is a turbine that requires lift. Tests with 6, 9, and 12 blades resulted in the highest system efficiency at a wind speed of 3 m/s. Based on the data from the research results, it can be seen that the efficiency of the turbine system decreases with the increase in the wind speed used in the test. This shows that flat-blade-type horizontal shaft wind turbines are widely suitable for low wind speeds (<7 m/s) **[13]**.

According to the results of a study that has been conducted by Siregar et al, the airflow that hits the turbine blade will increase along with the increase in wind speed **[14].** This causes resistance because the wind that builds up becomes a load of the blade and blocks the flow of wind that sweeps over the surface of the blade of the wind turbine. If you look at the influence of the fluid that hits the turbine, namely the wind, the greater the wind speed, the greater the Reynolds number. The Reynolds number is used to characterize fluid flow patterns. If the value is very large, the flow of the fluid will become turbulent, which is a condition in which the movement of the fluid is unstable and irregular. This irregularity affects the kinetic energy conversion in the turbine blades. So that the energy produced by the generator does not reach the optimal level. However, testing at high wind speeds results in greater output power than testing at low wind speeds.

IV. CONCLUSION

The best system efficiency from the test of the horizontal shaft wind turbine of the flat taper type 4:5 and the output angle of 25° with a variation in the number of blades occurred at a wind speed of 3 m/s and the number of blades of 9 pieces, which was 8.85%. Meanwhile, at a wind speed of 5 m/s, the highest system efficiency is 3.7%. Trendlines with a variation of 9 spoons have a high system efficiency value compared to the number of 6 and 12 spoons. Thus, 9 pieces of spoons are considered more optimal to be applied in low wind speeds.

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