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Performance Analysis of Horizontal Shaft Wind Turbine Through Blade Design Modification

Enzo W.B Siahaan[1], Rotama Arifin Sidabutar[2], Hodmiantua Sitanggang[3]

Jurusan Teknik Mesin, Universitas Darma Agung (1),(2),(3)

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✉ Corresponding author:

[enzo.battra84@gmail.com]

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Abstract

The objective of this study is to investigate the performance of a horizontal shaft wind turbine model with variations in blade shapes. The focus of the research lies in examining the impact of different blade shapes, specifically the curved shape, inverted linear taper, and rectangular shape measuring 8 cm x 20 cm at a 20^0 tilt angle. The experiments are conducted at various wind speeds: 7, 8, 9, 10, and 11 m/s. The findings reveal that changes in blade shape significantly influence the operation of the horizontal shaft wind turbine. The Brake Horse Power (BHP) reaches its maximum with a rectangular blade shape, achieving 1.1 watts at a wind speed of 11 m/s and a corresponding torque of 0.0221 Nm. Additionally, the highest efficiency is attained with the rectangular blade shape at a wind speed of 7 m/s, reaching 21%.

1. INTRODUCTION

Energy is one of the basic needs in human life, and with the increase in population and industrial growth, the demand for energy continues to increase. One solution to meet energy needs is to utilize alternative energy sources, such as wind power to generate electricity. A horizontal shaft wind turbine is a device that uses wind energy as a power source, converts kinetic energy into mechanical energy, and then drives a generator to produce electrical energy (Mansouri et al., 2023).

Previous research, conducted by Prasetya (2015), focused on a horizontal shaft wind turbine with 6 blades, 1.5 meters in diameter, and using the NACA 4412 design. The results showed that the wind turbine started rotating at a wind speed of 2.7 m/s, producing a current of 0.7 amperes at a wind speed of 7.5 m/s. The output power of the turbine ranges from 2.4 to 16.8 Watts, with an efficiency level reaching 3.9%.

According to Aryanto (2013) in his research, horizontal shaft wind turbines with variations in the number of blades produce the largest rotation at the number of blades 5. The maximum system efficiency (η) of the horizontal shaft wind turbine reaches 3.07% with the number of blades 5 at a wind speed of 4 m/s. The maximum top speed ratio (TSR) λ: 2.11 occurred at a blade count of 5 at a wind speed of 4 m/s.

In another study, Koehuan (2014) stated that variations in wind turbine blade angle also affect performance. At 0° blade angle with a wind speed of 4.03 m/s, the efficiency reached 54.7%, while at 5° blade angle it was 59.9%, and at 10° blade angle the efficiency reached 70.1%. However, with the addition of wind

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speed to 5.05 m/s and 6.08 m/s, the efficiency dropped to 32.5% and 25% at the same blade angle. This shows that the contra rotating horizontal shaft wind turbine model is more suitable for operation at low wind speeds, especially at 4.03 m/s with a blade angle of 10°.

The investigation of the impact of blade shape on the performance of horizontal shaft wind turbines has the following problem limitations:

a. The wind turbine uses 3 blades.
b. Tests were conducted with three blade shape variations, namely: curved blade, linear taper blade, and rectangular blade.
c. The blade area remains the same for each variation, with a blade height of 200 mm and a blade width of 80 mm.

1.1. Wind Turbines

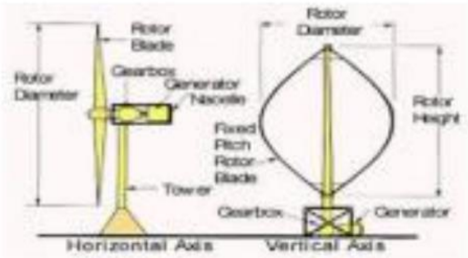

Fig 1. HAWT and VAWT Windmills

Wind turbines are devices that convert kinetic energy or wind speed into mechanical energy. This tool is commonly found in various European countries and is often known as a windmill. The blade component has a crucial role, because it functions to convert kinetic energy from the wind into mechanical energy (Fox et al., 2002).

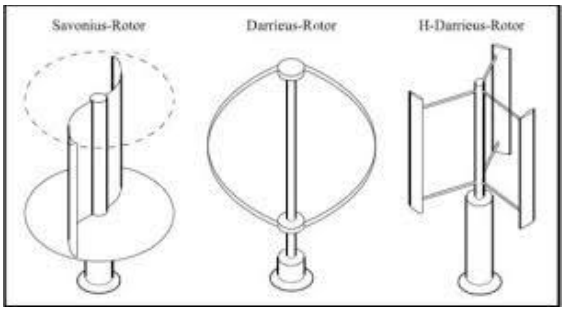

Fig 2. Blade types

The number of blades on a wind turbine rotor can vary, and here are some blade count concepts (Permana & Haryanto, 2015) *:*

a. The single-blade concept, recognized as difficult to balance and requiring very strong winds to rotate. This concept was developed mainly in Germany.
b. Two-blade concept, relatively easy to achieve balance, but the balance can still shift. The blade design must have a sharp curvature to effectively capture wind energy, but rotation is difficult to start at low wind speeds of about 3 m/s.
c. Three-blade concept, offering better balance and smoother blade curvature to capture wind energy effectively.
d. The multi-blade concept (e.g., 8 blades), has low efficiency but can generate a large enough initial moment of force for rotation. Suitable for low wind speeds, even when operated with a 1:10 gear transmission. This concept is often used in wind turbines for water pumping, as they are affordable and capable of operating at low wind speeds, so the tower does not need to be too high, and water can be pumped continuously.

Wind is air that moves due to differences in surrounding air pressure. Wind movement occurs from areas of high air pressure to areas of low air pressure. A decrease in the air's specific gravity causes the air to rise upwards, triggering a process referred to as air displacement which we know as wind.

1.2. Analysis Calculation

1.2.1. Brake Horse Power (BHP)

Brake Horse Power (BHP) is the turbine power measured after loading, such as by a generator, gearbox, pump, or other additional devices. BHP is obtained from the amount of power calculated using the equation :

$$B = \frac{P_i}{\eta_i} \quad (1)$$

$$P_{Generator} = V \times I \quad (2)$$

where:

$P_{generator}$: Electric motor power (watt)
V : Electric motor voltage (volt)
I : Electric current (ampere)

1.2.2. Torque

Torque is defined as a measurement of the effectiveness of force in creating a rotating moment on a shaft axis at a certain rotation. The amount of torque can be calculated using the equation:

$$T = \frac{6 .B}{2 .n} \quad (3)$$

where:

T : Torque (Nm)
n : Shaft rotation (rpm)

1.2.3. Efficiency

Efficiency (η) indicates the performance of a machine, which is the ratio between the energy produced and the energy used. The efficiency value can be calculated using the equation:

$$P_a = 1/2 .\rho .A .v^2 \quad (4)$$

where:

η : Efficiency (%)
P_a : Wind power (watt)
A : Blade cross-sectional area (m^2)
υ : Wind speed (m/s)
ρ : Air density (kg/m^3)

2. METHODS

The following is a scheme of testing equipment carried out in research to obtain Brake Horse Power (BHP), torque, and efficiency.

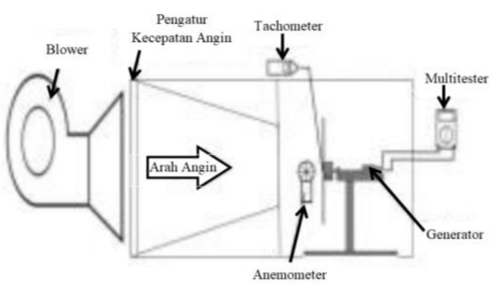

Fig 3. Schematic of Research Tools

Tests have been carried out at the Energy Conversion Laboratory of the University of North Sumatra using experimental methods. The stages in this research include:

a. Research Materials. Consists of a horizontal shaft wind turbine as a test object, a wind tunnel as a wind tunnel, and a DVD motor as an electric generator.
b. Research Tools. Involving a blower as a source of wind energy, an anemometer to measure wind speed, a multitester as a voltage and ampere measuring device, and a tachometer to measure shaft rotation in a wind turbine.
c. Preparation. Before carrying out the research, preparation is carried out by ensuring that the test objects and equipment are in good condition, ready to use, and able to function according to their needs.
d. Data Collection. Several blade shape variations were conducted, including curved blades, inverted linear taper blades, and rectangular blades, with wind speed variations between 7 m/s and 11 m/s.
e. Data Collection. The data collected involved information regarding the shaft rotation, current, and voltage generated during the test.

3. RESULT AND DISCUSSION

The following graph displays the results of power testing with different blade shapes and wind speeds:

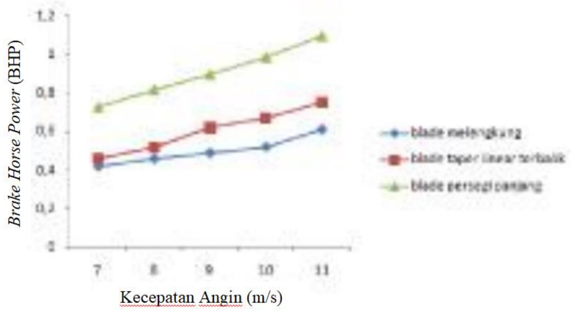

Fig 4. Graph of the Relationship Between BHP and Wind Speed

From Figure 4, it can be seen that the relationship between wind speed and blade shape has a very significant impact on the Brake Horse Power (BHP) generated. This can be observed from the increase in power in the rectangular blade shape, especially in the wind speed range between 7 m/s to 11 m/s.

The maximum power achieved using the rectangular blade shape reaches 1.1 Watt at a wind speed of 11 m/s. It should be noted that an increase in wind speed is followed by an increase in power, as wind speed directly affects shaft rotation, which in turn increases the power generated.

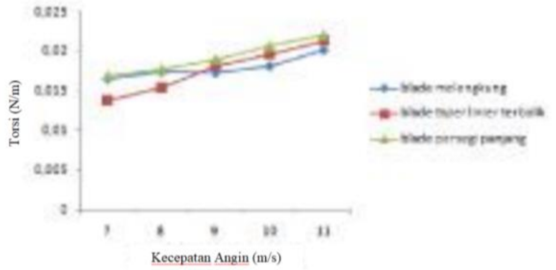

Fig 5. Graph of the Relationship Between Wind Speed and Torque

In Figure 5, there is a significant correlation between power and torque. It can be seen that the torque reaches the maximum value when using a rectangular blade shape, which is 0.0221 N.m at a wind speed of 11 m/s. There is a pattern that an increase in wind speed is followed by an increase in both power and torque, as wind speed has a direct impact on the shaft rotation generated by the wind turbine.

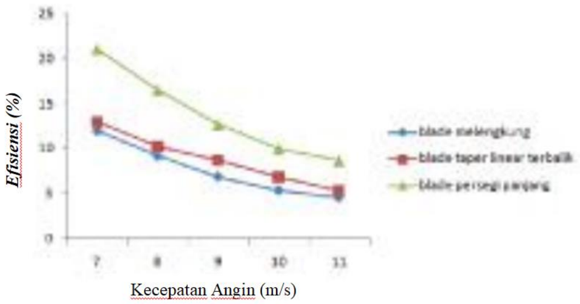

Fig 6. Graph of the Relationship Between Wind Speed and Efficiency

Based on the graph in Figure 6 illustrating the relationship between wind speed and efficiency, it can be seen that the rectangular blade shape achieves the highest efficiency when compared to the curved blade shape and linear taper blade shape. This efficiency remains consistent from the lowest wind speed (7 m/s) to the highest wind speed (11 m/s). This can be explained by the fact that variations in wind speed result in an increase in shaft rotation in the wind turbine, which is then followed by an increase in shaft power and torque produced by the horizontal shaft type wind turbine.

4. CONCLUSION

From the results of the research that has been carried out, the following conclusions can be drawn:

a. The blade shape of the horizontal type wind turbine has a significant impact on the turbine performance. This can be observed from the increase in power, torque, and efficiency in turbines that use a rectangular blade shape.
b. Maximum efficiency is achieved by using a rectangular blade shape at a wind speed of 11 m/sec, reaching a value of 21%.

5. ACKNOWLEDGMENTS (Optional)

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