The Effect of Angle Variation in the Model V Blade on the Savonius-Type Vertical Axis Wind Turbine's Performance

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Abstract. In this study, the researcher applied an experimental method to examine the performance of the Savonius-type turbine, in which variations in the blade angle were 85°, 95°, 105°, 110°, 115°, and 125°, variations in wind speed were 3 and 4.1 m/s, and variations in balancing force were 0.4 and 0.9 kg. The results showed that, of the five examined variations of the blade angle, the 125° blade produced the highest rotation (n) compared to the others. It generated 115.3 rpm but without a balanced force. Furthermore, the turbine performance at a wind speed (V) of 4.1 m/s, a balancing force (F) of 0.9 kg, and a blade angle of 125° produced the rotational speed (n) of 69.6 rpm, the turbine power (Pt) of 6.43 watts, the torque (T) of 1.765 N.m, the tip-speed ratio (λ) of 0.355, and the turbine efficiency 66.22%. Meanwhile, at a wind speed of 3 m/s, a balancing force (F) of 0.9 kg, and a blade angle of 125°, it generated the rotational speed (n) of 28.6 rpm, the turbine power (Pt) of 2.64 watts, the torque (T) of 1.765 N.m, the tip-speed ratio (λ) of 0.146, and the turbine efficiency 69.47%.

Keyword: Blade Angle, Savonius-type Turbine, Wind Turbine

1 Introduction

In this modern era, renewable energy is highly needed because it is one of the right solutions to overcome the world energy crisis. The fossil energy crisis occurs in almost all parts of the world, including developing countries, such as Indonesia.

Power plants in North Maluku generally use fossil fuels, such as diesel and coal. Meanwhile, fossil energy cannot be renewed, and its availability continues to run low. Furthermore, the natural process to re-produce it takes a long time. Combustion gases in the form of carbon monoxide (CO) and carbon dioxide (CO₂), which have an impact on global warming are exhaust gases from fossil fuels [1]

Based on Government Regulation No. 76/2014 concerning national energy policy, the use of renewable energy must be a priority, while fossil-based fuel, such as diesel and coal, must be minimized. Therefore, the solution is alternative energy.

For these reasons and considering the potential for wind in North Maluku, especially in Ternate and its surroundings, the government may maximize the Wind Power Plant (Indonesian: Pembangkit Listrik Tenaga Bayu (PLTB)). Although it is in the small to medium scale category, namely below the wind speed of 6.0 m/s, its wind potential is highly suitable for vertical axis wind turbines, especially the Savonius type, because they can rotate at low wind speeds and wind direction that often changes.

By considering its development to date, blades on the Savonius-type vertical axis wind turbines are generally in the form of a half-cylinder. However, some researchers develop it by varying the number of blades, namely 2, 3, 4, etc. In general, most of them still use the U and L blade curves.

Luther Sule (2016), in his study entitled "The Performance of Vertical Axis Windmills with 90° Curve Blade Model in Various Blade Numbers (2, 3, and 4 Blades)", found that the 90° curve blade model with an aspect ratio (h/R) of 2.8 can achieve a higher power coefficient. In the variation of 2 blades, the gained maximum capability was 28% at a wind speed of 3.4 m/s. Besides, in the variation of 3 blades, the accumulated maximum capability was 40% at a wind speed of 2.2 m/s. On top of that, in the variation of 4 blades, the gained maximum capability was 25% at a wind speed of 2.4 m/s [2]

The research objectives are to determine the optimum design of the vertical axis wind turbine concerning blade angle.

2 Literature Review

Brusca et al. stated that the Reynold Number affected turbine performance. The research on the performance of vertical wind turbines using numerical methods. The Relationship between Reynold Number and the implementation of the turbine was revealed. [3]. The analysis of turbine curvature at an angle of 90° by

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Pitriadi Peri et al. Concluded that the best performance of a three-blade vertical axis windmill with a curvature of 90° has the highest power coefficient value at wind speed = 2.2 m/s , namely 0.4 . [4].

Rasyid et al. conducted Research on the effect of the number of stages. With the output, namely torque, shaft rotation, and power. It is concluded that the 2-stage vertical axis wind turbine has the highest efficiency on L-shaped blades [5].

The VAWT for household use has been performed previously using the variable arm length under study [6]. The arm's length is modified with gears to produce the most power out of all the variations.

IB. Alit et al. Concluded in their Research that increasing the blade angle of the savonius turbine decreased the turbine performance [7].

Research using CFD (Computational Fluid Dynamic) was carried out by A. Alaimo et al. By examining helix and straight vertical wind turbines in 2-dimensional and 3-dimensional modelling. From 3-dimensional modelling, it can be seen that the helix type wind turbine has an average torque of 8.75% compared to the straight type [8].

The VAWT can still rotate at low wind speeds. In another study, Rangga et al. Modified the blade angle of a multilevel savonius type vertical wind turbine with a semi-circular blade. [9].

The portable VAWT design was carried out by Nakhoda et al. [10], namely a small type that can be carried to places with much wind. It is very efficient for small electricity sources like a mobile phone charger.

3 Methodology

In this study, the researcher applied an experimental method to examine the performance of the Savonius-type turbine with variations in the angle of the turbine blade. The researcher used the V model blade, in which variations in the angle were 85° , 95° , 105° , 110° , 115° , and 125° . In addition, the researcher also used a fan as a wind source, in which variations in wind speed were 3 and 4.1 m/s . Furthermore, for the balancing force, the researcher hooked a spring balance to the turbine shaft, in which variations in balancing force were 0.4 and 0.9 kg . Experiment Apparatus can be seen in fig 1.

Fig. 1. Experiment Apparatus (1) Fan (2) Wind Tunnel (3) Anemometer (4) Spring Scala (5) Turbine (6) Tachometer (7) Supports

4 Results And Discussion

The following calculation example is taken from the data with the condition of the wind turbine given the balancing force.

Wind Power

$$P_a = \frac{1}{2} \cdot \rho \cdot A \cdot v^3$$

$$(\rho) = 27,9^\circ \text{C} = 1,17419 \text{ kg/m}^3$$

$$A = t_s \cdot l_s \cdot b_s$$

$$A = (0,4 \text{ m}) \cdot (0,2 \text{ m}) \cdot (3) = 0,24 \text{ m}^2$$

$$P_a = \frac{1}{2} \times (1,17419 \text{ kg/m}^3) \times (0,24 \text{ m}^2) \times (4,1 \text{ m/s})^3$$

$$P_a = 9,71 \text{ watt}$$

Turbine Torsion

$$T = r_{\text{tengan}} \cdot M \cdot g$$

$$T = (0,2 \text{ m}) \times (0,9 \text{ kg}) \times (9,81 \text{ m/s}^2)$$

$$T = 1,76 \text{ Nm}$$

Turbine Power

$$P_t = T \cdot \omega$$

$$\text{Jika } \omega = \frac{\pi \cdot n}{60}$$

$$\omega = \frac{3,14 \cdot 469,6}{60} = \frac{218,54}{60} = 3,64 \text{ rad/s}$$

$$\text{Hence, } P_t = 1,76 \times 3,64$$

$$P_t = 6,43 \text{ watts}$$

Tip Speed Ratio

$$\lambda = \frac{\pi \cdot D \cdot n}{60 \cdot v}$$

$$\pi = 3,14$$

with turbine diameter $0,4 \text{ m}$ rpm s $69,6$ haft rpm and wind velocity $4,1 \text{ m/s}$ the tip speed ratio:

$$\lambda = \frac{3,14 \times 0,4 \times 69,6}{60 \times 4,1} = \frac{87,417}{246}$$

$$\lambda = 0,355 \text{ rad/s}$$

Turbine efficiency

$$\eta_t = \frac{P_t}{P_a} \times 100 \%$$

$$\eta_t = \frac{6,43 \text{ watt}}{9,71 \text{ watt}} \times 100 \%$$

$$\eta_t = 66,22 \%$$

From the calculation, it is found that the wind speed (V) is 4.1 m/s , the temperature is 27.9°C , the turbine shaft rotation (n) is 69.6 rpm , and the balancing force (F) is 0.9 kg .

4.1 The Relationship between Turbine Power (P_t) and Balancing Force (F).

The loading or balancing force provides mechanical resistance (frictional force) on the turbine shaft, resulting in a decrease in the rotation of the turbine shaft and automatically affecting the output power generated by the turbine.

Fig.2. The Relationship between Turbine Power (P_t) and Balancing Force (F) at a Wind Speed of 4.1 m/s

As seen in Figure 2, the output power produced by a turbine with a blade angle of 125° is higher in the balancing force of 0.9 kg than others, namely 6.43 watts. The same also happens to the 115°, 105°, 95°, and 85° blades. In other words, the greater the balancing force given is, the higher the produced turbine output power will be.

Fig.3. The Relationship between Turbine Power (P_t) and Balancing Force (F) at a Wind Speed of 3 m/s

In the figure above, the output power produced by the turbine at a wind speed of 3 m/s with a balancing force of 0.9 kg is more significant than that with a balancing force of 0.4 kg, namely 2.64 watts. It also happens to all variations of the blade angle. Therefore, the greater the balancing force given is, the higher the produced turbine output power will be.

4.2 The Relationship between the Tip-Speed Ratio (λ) and Balancing Force (F)

The tip-speed ratio (TSR) has the same trend as the RPM because it represents the ratio of the output speed (rotor) to the input speed (wind).

Figure 4 shows that the tip-speed ratio (λ) of the 125° blade turbine is higher than that of other turbines with different blade curves. It is followed by the 115°, 105°, 95°, and 85° blade turbines consecutively.

Fig.4. The Relationship between Tip-Speed Ratio (λ) and Balancing Force (F) at a Wind Speed of 4.1 m/s

Meanwhile, Figure 5 indicates that the tip-speed ratio (λ) at a wind speed of 3 m/s tends to change according to the rotational speed of the shaft produced by the turbine. This happens at all blade angles, in which the lowest number of rotations is gained at the blade angle of 85°. At the blade angle of 95°, it has increased and continues to grow at the blade angle of 105°, 115°, and so on. It happens until reaching the blade angle of 125°, recording the highest tip-speed ratio for this blade angle.

Fig.5. The Relationship between Tip-Speed Ratio (λ) and Balancing Force (F) at a Wind Speed of 3 m/s

4.3 The Relationship between the Turbine Efficiency (η_t) and Balancing Force (F)

As seen in Figure 6, the highest efficiency (η_t) of the Savonius-type wind turbine is found at the blade angle of 125°, namely 48.06%, at the balancing force of 0.9 kg. However, based on overall observation, the turbine's efficiency will be better if the power generated by the turbine is greater.

Fig.6. Relationship between Turbine Efficiency (η_t) and Balancing Force (F) at a Wind Speed of 4.1 m/s

Furthermore, Figure 7 shows that the smaller the blade angle is, the smaller the gained turbine efficiency (η_t). Likewise, the smaller the balancing force given is, the smaller the gained turbine efficiency (η_t).

Fig.7. Relationship between Turbine Efficiency (η_t) and Balancing Force (F) at a Wind Speed of 3 m/s

5 Conclusion

After all stages in this study are carried out, examining all prototypes of Savonius-type vertical axis wind turbines with the model V blade in various blade angles, balancing forces, and wind speeds, it can be concluded as follows.

1. Of the five examined variations of the blade angle, the 125° blade generated the highest rotation (n) compared to the others at a wind speed of 4.1 m/s, namely 115.3 rpm without given the balancing force, 93.2 rpm with the balancing force of 0.4 kg, and 69.6 rpm with the balancing force of 0.9 kg. Furthermore, at a wind speed of 3 m/s, the rotation (n) produced by the 125° blade was 81.2 rpm without the balancing force, 62.2 rpm with the balancing force of 0.4 kg, and 28.6 rpm with the balancing force of 0.9 kg.
2. The calculation results from the obtained data indicated that the variation of the blade angle that generated the optimum results was the 125° blade producing 115.3 rpm but without the balanced force. Furthermore, the turbine performance at a wind speed (V) of 4.1 m/s, a balancing force (F) of 0.9 kg, and a blade angle of 125° produced the rotational speed (n) of 69.6 rpm, the turbine power (P_t) of 6.43 watts, the torque (T) of 1.765 N.m, the tip-speed ratio (λ) of 0.355, and the turbine efficiency (η_t) of 66.22%. Meanwhile, at a wind speed of 3 m/s, a balancing force (F) of 0.9 kg, and a blade angle of 125°, it generated the rotational speed (n) of 28.6 rpm, the turbine power (P_t) of 2.64 watts, the torque (T) of 1.765 N.m, the tip-speed ratio (λ) of 0.146, and the turbine efficiency (η_t) of 69.47%.

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