The Effect of Large Variation of Steering Angle on the Performance of the Elliptical Savonius Wind Turbine

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Abstract: There are still many villages in remote parts of Indonesia that have not enjoyed electricity from the State Electricity Company due to various obstacles, namely the distance between people's houses which are far apart, limited capacity of generating machines. For this reason, it is necessary to develop alternative energy sources that can replace fossil-based energy sources with renewable energy such as water, wind, solar, geothermal, biodiesel, bioethanol, biomass and other energies. The potential renewable energy source in Indonesia is the use of wind energy as a wind power plant. This research was conducted with a real experimental method with the aim of knowing the effect of large variations of the steering angle on the performance of the elliptical Savonius wind turbine, so that it can be used as a reference for designing wind power plants so that they can be applied to the community. The results showed that the guide with an angle of 45 ^{O} produced the highest power coefficient value of 0.41. Then followed by a guide with an angle of 55 ^{O} which produces a power coefficient value of 0.32, while a guide with an angle of 65 ^{O} produces a power coefficient value of 0.18. The highest coefficient occurs at wind speeds of 4 and 5 m/s.

1 INTRODUCTION

There are still many villages in remote areas of East Nusa Tenggara that have not enjoyed electricity from the State Electricity Company due to various obstacles, namely the limited economy of the community in paying for electricity, large investment costs due to the distance between people's houses which are far apart, limited capacity of generating machines, so they are unable to reach the area. rural areas far from urban areas. In addition, the geographical conditions of rural areas are mountainous and difficult to access, making it difficult to access the electricity network. Currently, state power companies are still using Diesel power plants and steam power plants to meet consumer demand. However, electricity from the state electricity company can only serve affordable urban and rural areas, while remote areas are difficult to reach.

Therefore, it is necessary to develop alternative energy sources that can replace fossil-based energy sources with renewable energy such as water energy, wind, solar, geothermal, biodiesel, bioethanol, biomass and other energies. The potential renewable energy source in Indonesia is the use of wind energy as a wind power plant. The kinetic energy of the wind is captured by the blades with a certain area, thus producing a rotational motion to rotate the turbine rotor. The rotation of the turbine rotor is able to rotate the generator shaft so that it will produce electrical energy. Wind energy is able to replace the function of fossil fuels as a source of power for electric generators.

Research on the development of the Savonius wind turbine has been carried out by many previous researchers. Previous research was conducted in 2013 on the design of a vertical wind turbine of the Savonius type with obstacle integration to obtain maximum power. In this study, the obstacle was integrated by providing a plate in front of the returning blade with an angle of 80 ^{O},100 ^{O} and a semicircle. Based on the measurement results for the integration of the obstacle with β=80 ^{O} β =100 ^{O} and is in the form of a semi-circle. The results are obtained if the integration of the semicircular obstacle gets the highest power with a value of 0.00414 W with RPM with 352 loading and without loading 354. These results are much better than the power and RPM produced by wind turbines without the use of obstacles which only produce 0 power. 0019524 W and RPM without loading 175.5 and with loading

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162.9. This shows that the use of obstacles affects the power generated by the Savonius type wind turbine (Salby Cs, 2017).

Furthermore, research is conducted on the analysis of wind flow on the Savonius type U wind turbine blade based on software. In addition to the experimental method by making a prototype of the U-type Savonius wind turbine with 2 blades, a software-based simulation method will be carried out to analyze the air flow in the wind turbine blades. The parameters that are varied only on the aspect ratio of arc length and blade cross-section width, other parameters follow previous research. This analysis will be a comparison of data with the experimental method. The simulation results are expected to get the best blade aspect ratio (Ar) in capturing wind energy. From the results of the study it was concluded that the dimensions of the blades, both radius and cross-sectional width greatly affect the air flow through the turbine blades. Simulations without using a circular sheild show that a blade with a radius of 65 mm and a cross-sectional width of 100 mm is the best variation based on the three airflow simulation parameters. Simulations using circular sheild show that the best blades and cross-sectional widths are R 75 and LP 100 (Candra Cs, 2018).

Further research was conducted on the efficiency of the Savonius turbine prototype at low wind speeds. This research was conducted on a small scale in the field, namely on the beach to determine the highest efficiency by using a prototype Savonius turbine at low wind speeds. The results showed that the voltage generated by the generator increased as the wind speed increased. The Savonius wind turbine starts rotating at a wind speed of 2.4 m/s. The average efficiency of Savonius turbine for Y connected load is 4.8% and for delta connected load is 14.5% (Rudianto and Ahmadi, 2016).

Further research was conducted on the design of the Savonius vertical axis turbine using 8 curved blades. This research was conducted using experimental methods in the field, with the aim of knowing the magnitude of the power coefficient and turbine efficiency. The results of the overall calculation of the Savonius vertical wind turbine just want to tell you how to design and build this wind turbine. In this design, a Savonius turbine will be produced which will produce 132 Watts of electricity which can be used on a small scale such as a lamp at home. While the coefficient of performance (Cp) produced is 0.5275, the resulting tip speed ratio (λ) is 0.372 and the turbine rotor efficiency is 0.5911 (Napitupulu and Siregar, 2013).

The next research was conducted on the design of a two-level Savonius type wind turbine with a capacity of 100 Watt for the Solo Syariah building. The research was conducted using experimental methods in the field with the aim of producing 100 Watts of electrical energy. The results show that the wind turbine design has a power coefficient (Cp) of 0.18 and a tip speed ratio (λ) of 1. The aspect ratio (α) and wind turbine overlap ratio are 2 and 0.2, respectively. The turbine has 2 semicircular blades and has a height (H) of 1.85 m and a rotor diameter (D) of 0.92 m (Latif, 2013).

The last research is about the design of the Savonius 200 Watt turbine. The research was conducted using direct experimental methods in the field. The results showed that the turbine rotates at a speed of 54.2 revolutions per minute at a wind speed of 2 m/s; 86.8 revolutions per minute at a wind speed of 4 m/s; and 124.2 revolutions per minute at a wind speed of 6 m/s. The results of the theoretical calculation, the turbine will produce an actual power of 17.51 Watt at V = 2 m/s; 140.05 Watts at V = 4 m/s; and 472.67 Watts at V = 6 m/s. The test results and calculations show that the turbine will be able to produce more than 200 Watts of electrical power at a wind speed of 6 m/s (Rizkiyanto Cs, 2015).

2 RESEARCH METHODOLOGY

This research was conducted using a real experimental method, namely making observations to find causal data in a process through experimentation so that it can determine the effect of large variations of the steering angle on the performance of the elliptical Savonius wind turbine where the same treatment is carried out by varying the steering angle on the performance of the wind turbine. Then compare them, so that a pattern of interconnected events is obtained.

The aim of this laboratory-scale research is to improve the performance of the Savonius wind turbine with a variation of the steering angle which serves to reduce the negative torque on the rotor blades, so as to improve the performance of the Savonius wind turbine. The data collection process is carried out by providing a load (kg) on the turbine rotor, so that it can calculate the amount of torque, power and power coefficient obtained by the elliptical Savonius wind turbine. Data retrieval was carried out repeatedly, namely 3 times, then the average value was searched. The research instrument or installation on the effect of large variations of the steering angle on the performance of the elliptical Savonius wind turbine can be seen in Figure 1 below:

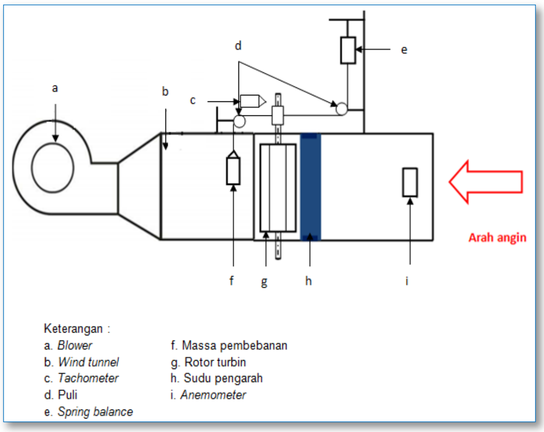

Figure 1: Savonius. Wind turbine research instrument.

The blower will suck air through the wind tunnel, so that the wind can flow at a certain speed and will hit the rotor blades so that the turbine rotor can rotate with a certain rotation according to the given wind speed. Thus, there will be a change or conversion of wind energy into motion energy in the form of rotation of the Savonius turbine rotor shaft. Furthermore, the rotation of the turbine rotor shaft moves the loaded pulley to obtain the torque value and will be used to determine the mechanical power value of the turbine rotor. The rotation of the turbine rotor and the given load will be measured in each treatment according to the specified wind speed variations, namely 3, 4, 5 and 6 m/s as well as variations in the direction of the angle. The dimensions of the turbine rotor blades are equipped with guide angles as shown in the fig. 2 below:

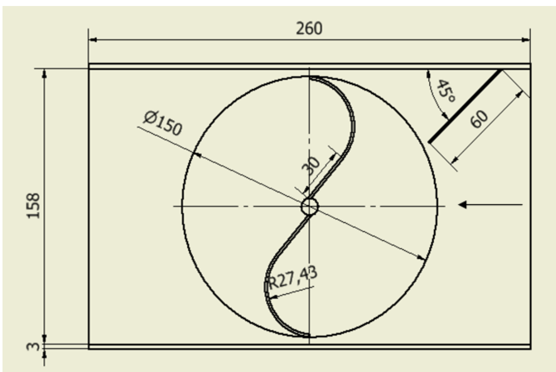

Figure 2: Turbine rotor equipped with a guide with an angle of 45.

2.1 Shaft Turn (n)

The Savonius wind turbine will rotate when there is wind at a certain speed, so that the rotation of the shaft produced by the Savonius turbine rotor can be directly measured using a digital tachometer when the rotor rotates.

2.2 Tip Speed Ratio (λ)

The tip speed ratio is the ratio of the speed at the end of the rotor to the free air velocity. Tip speed ratio can be calculated by the following formula :

$$\lambda = \frac{\pi \, D \, n}{60 \, . \, v} \tag{1}$$

Where :

D : rotor diameter (m);
n : shaft rotation (rpm);
v : air flow velocity (m/s).

2.3 Power Wind (P_w)

Wind power can be defined as the energy produced per unit time as follows :

$$P_w = E \text{ per unit time}$$

$$= \frac{1}{2} \rho \, . \, A \, . \, v^3 \tag{2}$$

$$= \frac{N \, . \, m}{dtk} = \frac{Joule}{dtk} = Watt$$

Where :

P_w : power wind (Watt);
ρ : air mass density (kg/m^3);
v : air flow velocity (m/s);
A : cross sectional area (m ^{2}).

2.4 Torque (T)

Torque is also known as moment or force which states that an object rotates about an axis. Torque can also be defined as a measure of the effectiveness of the force in producing rotation or rotation around the axis. The torque can be calculated using the formula:

$$T = F. \, r \text{ (N.m)} \tag{3}$$

$$F = (m-s) \times g \text{ (N)} \tag{4}$$

Where :

T = torque (N.m);
` F = force acting on the shaft (N);
m = loading mass (kg);
s = spring balance(kg);
r = pulley radius (m);
g = gravity (m/s^2)

2.5 Power of Mechanical

Mechanical power is measured by loading the shaft to get the torque value to calculate the angular speed. Furthermore, the shaft power is obtained by multiplying the torque value by the angular speed as shown in the following equation:

$$P_m = T \ x \ \omega \quad \text{(Watt)} \qquad (5)$$

$$\omega = \frac{2 \ x \ \pi \ x \ n}{60} \quad \text{(rad/s)} \qquad (6)$$

Where: P_m = Power of mechanical (Watt);
ω = The anguler velocity (rad/s);
n = Shaft rotation (rpm).

2.6 Coefficient of Power

The power coefficient is important in designing a wind turbine because it shows how much wind kinetic energy is converted into shaft power with the help of the turbine rotor. The power coefficient is the ratio between the energy used (input) and the energy produced (output). The power coefficient formula is as follows:

$$Cp = \frac{Pm}{Pw} \qquad (7)$$

Where :

Cp = Coefficient of power;

P_m = Power of mechanical (Watt);

P_w = Power of wind (Watt).

3 RESULT AND DISCUSSION

3.1 Result

Based on the test data in the field, data processing is carried out for further analysis based on its tendency, as shown in tables 1 and 2 below:

Table 1: The results of data processing on a guide with an angle of 45 ^{O}.

No	Variable	3 m/s	4 m/s	5 m/s	6 m/s
1.	Shaft Rot.	222.9	367.4	425.8	458.2
2.	Torque	0.008	0.018	0.030	0.037
3.	Power water	0.711	1.687	3.295	5.693
4.	Power turbin	0.194	0.697	1.355	1.811
5.	Coeff. power	0.273	0.413	0.411	0.318

Table 2: The results of data processing on a guide with an angle of 55 ^{O}.

No	Variable	3 m/s	4 m/s	5 m/s	6 m/s
1.	Shaft Rot.	197.3	313.3	367.8	431.6
2.	Torque	0.005	0.015	0.027	0.031
3.	Power water	0.711	1.687	3.295	5.693
4.	Power turbin	0.121	0.514	1.076	1.407
5.	Coeff. power	0.270	0.305	0.326	0.247

Table 3: The results of data processing on a guide with an angle of 65 ^{O}.

No	Variable	3 m/s	4 m/s	5 m/s	6 m/s
1.	Shaft Rot.	169.3	227.7	326.2	368.0
2.	Torque	0.004	0.013	0.016	0.020
3.	Power water	0.711	1.687	3.295	5.693
4.	Power turbin	0.073	0.315	0.561	0.793
5.	Coeff. power	0.103	0.187	0.170	0.139

3.2 Discussion

After processing the data, it is displayed in graphical form, so that it can be discussed based on the trends shown in the graph. The discussion in question can be seen in Figure 3, 4,5 and 6 below, namely:

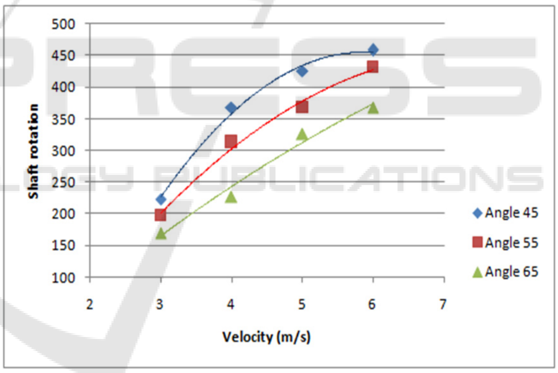

Figure 3: The relationship between wind speed and shaft rotation.

Based on the graph above, it can be seen that the rotation (rpm) will increase linearly with the addition of wind speed (m/s) on the three variations of the guide angle. The magnitude of the increase in the rotation value is determined by the wind speed received by the rotor blades and also the magnitude of the existing guide angle. The 45 ^{O} directional angle has the highest rotation value of 458.20 rpm, followed by the 55 ^{O} directional angle of 431.60 rpm and the 65 ^{O} directional angle of 368.03 rpm where everything occurs at a maximum wind speed of 6 m/s. The rotation value is also determined by the angular speed (rad/s) and torque (N. m) generated by the wind turbine.

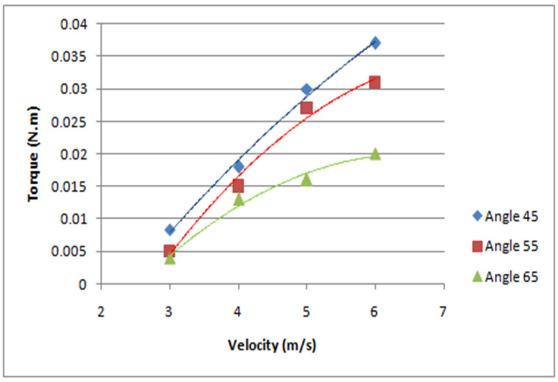

Figure 4: The relationship between wind speed and torque.

Based on the graph above, it can be seen that the value of torque (N.m) increases linearly with the addition of wind speed (m/s) given to the three variations of the existing guide angles. The magnitude of the increase in the torque value is largely determined by the amount of load received by the turbine rotor and also the amount of wind speed received by the turbine rotor blades. The greater the wind speed, the greater the torque value produced. The 45 ^{O} steering angle produces the highest torque of 0.037 N.m, followed by the 55 ^{O} steering angle of 0.031 N.m and the 65 ^{O} steering angle produces a torque of 0.020 N.m where everything occurs at a maximum wind speed of 6 m/s.

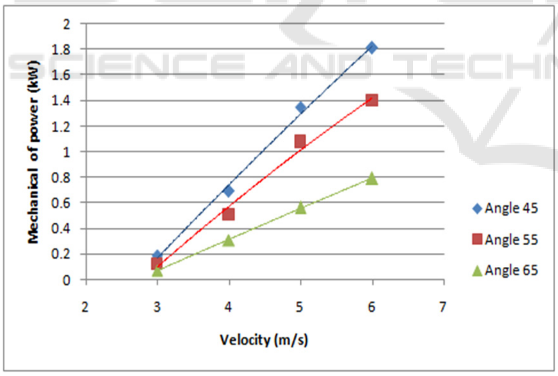

Figure 5: The relationship between wind speed and mechanical power.

Based on the graph above, it can be seen that the mechanical power of the turbine increases significantly at various variations in the number of rotor blades with the addition of a given wind speed. The magnitude of the increase in the value of the mechanical power of the turbine is determined by the torque, angular speed, rotation value and the magnitude of the existing steering angle. The 45 ^{O} steering angle can produce the maximum turbine mechanical power of 1.81 Watt, followed by the 55 ^{O} steering angle which is 1.40 Watt and the 65 ^{O} steering angle produces the highest turbine mechanical power of 0.79 Watt. The highest turbine mechanical power occurs at a wind speed of 6 m/s which is the highest given wind speed.

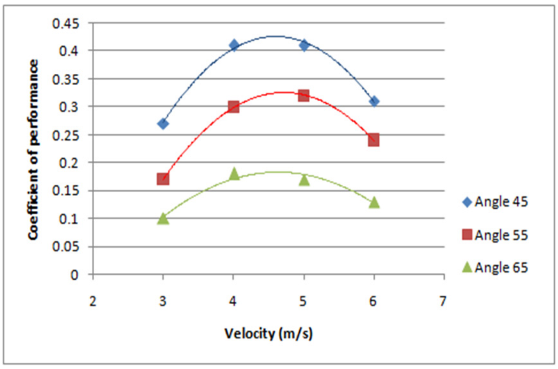

Figure 6: The relationship between wind speed and power coefficient.

Based on the graph above, it can be seen that the power coefficient increases parabolicly with the addition of a given wind speed value. The magnitude of the power coefficient is strongly influenced by the value of rotation, angular speed, torque and power as well as the existing steering angle. The guide angle of 45 ^{O} produces the highest power coefficient value of 0.41 followed by the guiding angle of 55 ^{O} produces the highest power coefficient of 0.32 and the steering angle of 65 ^{O} produces the highest power coefficient of 0.18. The highest efficiency in the variation of the number of rotor blades occurs at a flow speed of 5 m/s.

4 CONCLUSIONS

Based on the results of the discussion above, several conclusions can be drawn, including: the guiding angle of 45 ^{O} produces the highest power coefficient value of 0.41 at a wind speed of 5 m/s. The guide angle of 55 ^{O} produces the highest power coefficient value of 0.32 at a wind speed of 5 m/s.

The directional angle of 65 ^{O} produces the highest power coefficient value of 0.18 at a wind speed of 4 m/s.

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