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Design of the Savonius Wind Turbine with Combined Blade

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Abstract**—***The Savonius wind turbine is a turbine with simple construction and is environmentally friendly, but the efficiency is still low compared to other types of wind turbines, so it needs development, among others, by modifying the conventional model into a combination blade. The purpose of this article is to determine and analyze the dimensions and performance of a wind turbine combined blade without load through a rotation and determine the Tip Speed Ratio (TSR) directly on a turbine designed with a diameter of rotors (D=180 cm). The results of the analysis show that wind turbines with combined Blade can operate and rotate well at low wind velocity and are stable against changes in wind direction so that they can be developed by the community as an alternative energy source.*

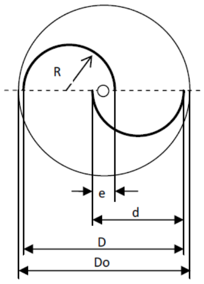
Keywords**—** *Savonius wind turbine, Blade combined, Design blade, Without load.*

I. INTRODUCTION

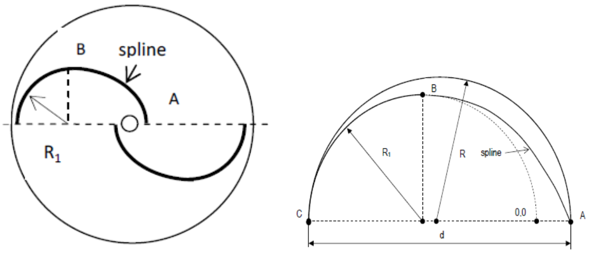
The Savonius wind turbine is a vertical shaft wind turbine (VAWT) with a simple construction that utilizes wind from all directions, can work at low wind speeds, and does not require a very high mast. Therefore, it needs to be implemented and developed by making dimensions that match the wind potential to be utilized as an environmentally friendly energy source. However, the Savonius turbine still has low efficiency compared to other types of turbines, so it is necessary to continue to develop its shape and dimensions to suit the existing wind potential. The performance of the Savonius rotor is influenced by flow parameters and turbine geometry, where certain flow configurations at different geometries give different results [1]. In an effort to improve the performance of the Savonius turbine, researchers have conducted research and modified the construction of conventional Savonius turbine rotors and blades using different methods. The addition of three blades can reduce the power coefficient, where air from the first blade is reflected back to the next blade (2nd blade) so that it rotates in the opposite direction to the first blade, and the multi-staged rotor affects the increase in turbine rotor inertia [2]. Comparison between one, two, and three stages (multi-stage) to the modification of the Savonius rotor indicates that the power coefficient tends to decrease with an increasing number of stage rotors [3]. Savonius turbine performance can be increased by adding additional equipment to the turbine rotor. The addition of obstacles and curtains can improve the performance of the Savonius wind turbine [4, 5]. At the same time, the use of a deflector plate can increase the power coefficient (Cp) by up to 50% compared to without the use of a plate deflector [6]. The use of a guide-box tunnel in a two-blade Savonius turbine is greater than without using a guide-box [7]. However, the addition of additional equipment will cause complexity in manufacturing due to the increasingly complex turbine construction. The Savonius wind turbine was modified by made a combination of the rotor blade between the concave and convex sides, which was carried out experimentally, showing an increase in the Cp power coefficient of 11% over conventional blades (8). For field applications, wind turbines are made on a larger scale (180cm x 180cm) and installed directly in areas that have sufficient wind potential. Therefore, this paper focuses on the analysis of the combination Savonius blade-type wind turbine that has been installed in the field so that it can be applied directly as an alternative energy source by the community.

II. MATERIAL AND METHODS

The Savonius wind turbine with the combined blade**,** namely a combination of the conventional model figure 1(a) as a concave side and the elliptical model figure 1(b) as a convex side into a blade combined figure 1(c).



(a) conventional blade



(b) elliptical blade (c) combined blade

Figure 1. Savonius turbine blade rotor

Combined blade Fig. 1(c) form is specified by coordinate points on the x-y axis, A (e/2, 0), B (D/4, D/4), and C (- D/2, 0). The dimensions of the rotor and blade combination of the Savonius wind turbine are based on Patents [9]

D: Diameter of the rotor (determined according to the desired dimensions)

Do: Diameter of the end plate (Do=1,1D)
d: Chord Diameter (d= (D + e)/2)
e: Overlap distance (e=0.15D)
H: Height of rotor (H=D)
R: Radius of the conventional Blade (convex side) (R=d/2)
R1: Radius of the elliptical Blade (concave side) (R1=D/4)

Based on the specifications above with a rotor diameter = 180 cm, the model and dimensions of the elliptical Blade are curved lines that connect the x-axis coordinates, namely A (13,5 cm ; 0), B (45 cm; 45 cm), C (- 90 cm ; 0) the line connecting points A and B is a spline and connecting points B and C is a quarter circle with radius R_1 = 45 cm. The conventional model is a concave side that is semicircular with a radius (R) = 51,75 cm. From that point, a turbine rotor with a diameter will be formed (D) = 180 cm, height of rotor(H) = 180 cm, diameter of end plat (D_0)= 198 cm, diameter of chord d = 103,5 cm, overlap distance (e) = 27 cm. The turbine rotor blade is made of 0.6 mm aluminum plate both on the concave and convex sides, and the end plate is made of steel plate 1 mm, which is reinforced with a frame using 2 x 20 mm iron strips.

Measurement of installed turbines with naturally available wind speeds. Wind velocity is measured using a Manometer with an accuracy of ± 0.3 %, while the rotor rotation uses a Tachometer with an accuracy of ± (0.05 % + 1 digit). Rotation measurements were made on the rotor pulley with a diameter of 12 inches (drive pulley) placed on the endplate with the hope of increasing the rotation of the alternator using a pulley diameter of 3 inches (driven pulley), resulting in an increase in rotation of 4 times that of the turbine rotor rotation. The power transmission system uses a type “A” V-belt which connects the drive pulley and the alternator pulley, as shown in Fig. 2.

Figure 2. Assembled the turbine rotor blades

Figure 3. Measured of turbine rotation and power

Figure 3, measurement of rotor rotation through the drive pulley by released the power transmission system (V-belt) between the turbine rotor and alternator so that the rotor rotation is obtained without load and tested the turbine self-start. Meanwhile, the load measurement is carried out by connecting the turbine pulley to the alternator by measuring the power generated through the electric voltage from the alternator.

III. THEORY/CALCULATION

The basic concept of the Savonius turbine rotor is to cut the cylinder into two parts along the central plane so that the cross-section resembles the letter "S" in the figure.

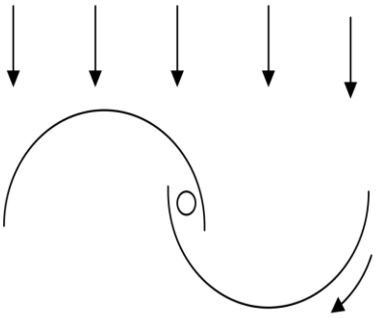


Figure 4. The principle of the Savonius turbine

The amount of power generated by the wind is the derivative of kinetic energy with respect to time and is proportional to the density of the air flowing through a certain surface and the speed of the wind through the surface area of the rotor sweep. The wind power equation (E) is obtained from the kinetic energy equation Mathew, 2006 namely;

$$E = \frac{1}{2} m V^2 \quad (1)$$

$$E = \frac{1}{2} \rho_a v V^2 \quad (2)$$

and the power (P_T) generated from a turbine with an (A_T) rotor sweep area is;

$$P_T = \frac{1}{2} \rho_a A_T V^3 \quad (3)$$

and turbine torque

$$T_T = \frac{1}{2} \rho_a A_T V^2 R \quad (4)$$

The reality in the field is that not all wind energy can be utilized because it really depends on the efficiency of the turbine used, both the power coefficient (C_p) and the torque coefficient (C_t) produced from the turbine by using the equation:

$$C_p = \frac{2 P_T}{\rho_a A_T V^3} \quad (5)$$

$$C_t = \frac{2 T_T}{\rho_a A_T V^2 R} \quad (6)$$

$$P_T = T_T . \omega \quad \text{and} \quad \omega = \frac{2 \pi n}{60}$$

so that

$$C_p = \frac{2 T_T . \omega}{\rho_a A_T V^3} \quad (7)$$

The coefficient above is also related to the tip speed ratio (TSR), which is the ratio between the speed at the tip of the wind turbine blade and the wind speed, which is written in the following equation:

$$TSR\ (\lambda) = \frac{\omega.R}{V} \qquad (8)$$

IV. RESULTS AND DISCUSSION

The wind pushing the blade on the concave side of the Savonius rotor (advancing Blade) at a certain speed produces a positive wind force which is a positive torque (Mr^+), and a negative wind force which inhibits the convex blade on the returning blade, (Mr^-). Because the torque on the concave side (advancing blade) is higher than the torque on the convex side (returning Blade), it causes rotational movement in the turbine rotor [5]. The difference in the large moment of force will result in the greater performance of the turbine. Increasing the center of rotation distance on the concave side of the advancing blade will cause an increase in the positive moment of the rotor. Conversely, the smaller the distance of the center of rotation on the convex side of the returning blade will reduce the negative moment. This is in accordance with the combination model performed on conventional and elliptical blade modifications. The use of an elliptical blade model on the concave side can increase the distance from the point of capture to the center of rotation, while the convex side using the conventional model (semi-circle) has a smaller distance from the point of capture to the center of rotation than using the elliptical model [8].

The results of the analysis that has been carried out experimentally show that the combination blade shows an increase in performance in the form of a power coefficient (Cp) of 11% [8], and the spin without load shows that the combination blade produces the highest rotation.

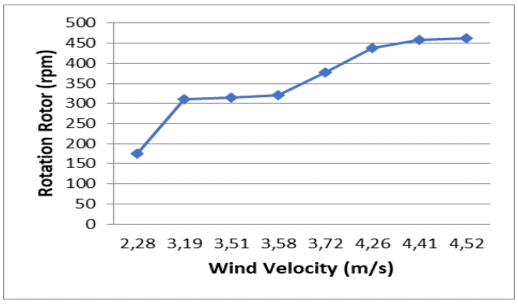


Figure 5. Rotation rotor without load vs wind velocity

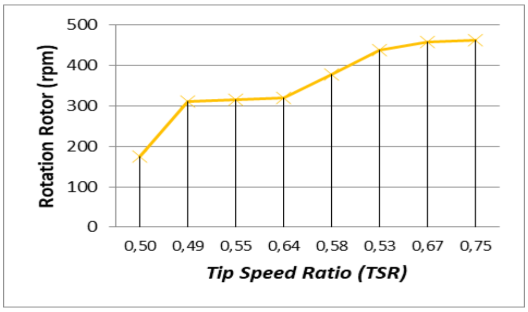


Figure 6. Rotation rotor without load vs TSR

Figure 5 shows a graph of turbine rotor rotation to wind speed which is measured directly in the field based on the wind speed that occurs. From these data, it can be seen that wind turbines start rotating at wind speeds of more than 2 m/s. This shows that the wind turbine has a low initial speed. In addition, at wind speeds of up to 3 m/s, the rotation speed increases to more than 300 rpm. Figure 6 shows a graph of the turbine rotor rotation to the tip speed ratio (TSR), which is measured directly in the field, showing the wind speed that occurs and has a graphic model that tends to be the same as the rotor rotation. Based on the graph, it can be seen that wind turbines tend to stabilize and increase after reaching a wind speed of 3.72 m/s. However, the tip speed ratio decreases at a certain wind speed. This is due to the presence of a wind vortex at the time of measurement, causing the wind direction to be not fixed. The change in TSR is caused by a decrease in rotation with a fixed wind velocity.

V. CONCLUSION

From the results of direct measurements and analysis of the combination blade wind turbine above, it can be concluded that the following matters:

1. Wind turbines with combined rotor blades can operate and rotate well at low wind speeds
2. The turbine can rotate stably with changes in wind direction but still affects the TSR.
3. The rotation of the turbine rotor is relatively stable at wind speeds of more than 4 m/s.

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