Experimental and Simulation Investigation on Savonius Turbine: Influence of Inlet-Outlet Ratio Using a Modified Blade Shaped to Improve Performance

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Experimental and Simulation Investigation on Savonius Turbine: Influence of Inlet-Outlet Ratio Using a Modified Blade Shaped to Improve Performance

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Abstract: This study aims to obtain the characteristics of the Savonius turbine based on the ratio of the inlet and outlet blades by using a modified blade shape and analyzing numerical simulations of the speed and pressure around the turbine blades. The use of Savonius turbines can be a solution because it produces large torque even if installed at low wind speed. Savonius blade modification into a double blade with a combination of type L and U aims to capture greater wind energy while generating greater electrical power. The study was tested at speeds of 3, 5, 7, and 9 m/s with variable differences in the side in and out of the turbine. However, what is presented in this article is the test parameters at a wind speed of 7 m/s. The test obtained data in the form of torque, generator speed, voltage, and current produced by the turbine. Once analyzed it can be concluded that the best performance is produced by a single blade rotor, then the rotor is 1:1, 2:1, and the lowest performance is obtained from the 3:1 rotor. The results of the study indicate that the Savonius turbine has optimum performance on a single blade rotor model at 189 rpm, the power coefficient value is 0.039, turbine power is 80.26 W, generator power is 3.08, and system efficiency is 3.84%.

Keywords: Savonius turbine; tip speed ratio; torque; system efficiency; turbine performance

1. Introduction

Nowadays, the demand for fossil fuel energy has increased, necessitating the development of alternative energy sources to prepare for the eventual depletion of fossil fuel sources. Wind energy, fuel cell, and solar energy are environmentally friendly alternative energy with a high potential for development[1-3)]. Indonesia has a large enough potential for wind power and is available all year round because it is located in a tropical climate. However, the turbine is already producing electricity through a generator at this average wind speed (3-5 m/s). The mechanical energy can be converted into electrical energy using the Savonius turbine. The Savonius turbine is simply built at a low cost and can take advantage of winds from all directions.

The Savonius L produced low revs and high torque, while at the same speed, Savonius U produced higher speeds and small torque[6-8)]. To overcome the shortage of Savonius turbines in the form of low efficiency, research was conducted by combining L and U blade types using a double blade model. With these modifications, it is expected that when testing, turbines, blade L first hit the wind based on the torque produced larger so that the self-starting is better. The U-blade turbine is exposed to the wind in a convex position first which results when the wind hits the side can be turned more easily so that the turn speed becomes higher[9,10)]. It is used to overcome the low turn speed on Savonius type L turbines. However, it is less efficient when compared to other turbines. A lot of research has been undertaken to modify the geometry and rotor of the Savonius turbine to enhance its efficiency. A good performance of the Savonius turbine is influenced by the number of blades and the stage of the rotor. One of the parameters to determine the performance of a vertical axis wind turbine is to modify the wind flow along with the blades and the shape of the turbine blades. The more blades will reduce the value of the power coefficient (Cp), because the incoming wind from the concave side of the first blade is reflected in the concave side of the second blade which produces mechanical energy to rotate the turbine shaft. Savonius wind turbines worked due to the pressing stylistic differences of each blade. Because of its curvature, the blade experiences less drag power when the blade moves against the wind than the blade moves with the wind. From this, Savonius turbines extract less wind energy from other elevator turbines of the same size because the energy that is likely to be captured by the blade, is used to push the convex blade, so Savonius turbines have a lower efficiency. The three types of tandem blades tested (overlap type, symmetrically type, and convergence type), the best performance is shown in the third type of convergence type[12,13]. Convergence types are more stable in the face of fluid pressure than the other two types and produce the most turbine power. While in testing with the same fluid pressure, actually experienced stuck or returning blades are not moving and have the potential to cause vibrations due to unbalanced forces between the two blades.

It causes the first blade to rotate in the opposite direction. The optimal number of steps is two, increasing the number of stages reduces turbine performance due to increased rotor inertia. The coefficient of power tends to decrease as the number of rotor stages increases[14]. Additional types of equipment to the turbine can be used to improve the performance of the Savonius turbine. To optimize blade form, applied an obstacle shielding on the returning blade side. Savonius type U, the airflow is equally large. While in Savonius type L, the airflow of straight blades is greater than a quarter-circle blade. In Savonius type L, the wind pounded one of the blades causing the rotor to spin and the center point of thrust to shift away from the shaft[15,16]. Savonius U produced a large rotary speed, while the torque tended to be small. But on Savonius L produced low rotary speed and high torque at the same wind speed. Wind power can be reduced with a deflector blade (which has stronger properties) in front of the main blade, as well as the outside of the main blade that offsets out the endplate which ensures better incoming air. This shape produces a good performance improvement compared to Savonius rotor pure arch blades without deflectors[17]. The enhancement of Savonius turbine performance can be done using obstruction and a curtain. The turbine power coefficient (Cp) increases up to 50% using a deflector plate [18,19].

Furthermore, a guide-box tunnel also increases the turbine power coefficient by up to 1.23 times with a guide-box tunnel at the two blades of a Savonius turbine. Enhanced performance through the use of additional equipment will make the Savonius turbine more complex[20-22]. As a result, improving turbine efficiency without the use of additional equipment is preferable. They found that at the same wind speed, the maximum power coefficient (Cp, max) of the conventional blade (11.04) is lower than the Cp, max of the turbine with twist blade (13.99). Helical blades with the same power coefficient (Cp) as conventional blades without shafts and overlap ratio = 0. A unique vertical turbine design (VAWT). They stated that the shape of the rotor on the concave-convex sides should be a focus of turbine development to enhance the torque and make the design more competitive with the existing design[23-25]. Mechanically, at the concave side, the speed of wind results in positive torque, and at the convex side, the power of negative wind results in negative torque. The performance of a turbine with a standard and an elliptical blade numerically[28-31]. The power coefficient of a blade with an elliptical shape is greater than that of a standard blade. The influence of the shaft between the endplates on the performance of changed and unmodified turbines. The use of a shaft reduces wind flow at the overlap[26-28]. When compared to the maximum power coefficients of a turbine without a shaft (0.21), the maximum power coefficients of a turbine using a shaft between the endplates were 0.143, whereas the traditional blade without modification with the shaft has C_{pmax} = 0.175 at TSR 0.69. According to the above description, additional studies and testing in the hopes of boosting the performance of the Savonius turbine in the combination of the concave and convex side models is required with a basic and low-cost wind energy conversion device. The enhancement of Savonius turbine performance as an alternative energy source[32-36], such as water pumping and irrigation in Indonesia farms, is one possibility.

2. Materials and Methodology

2.1 Materials

Savonius wind turbines are made with a diameter of 650 mm and a height of 600 mm with a blade cover (endplate) at the top and bottom, with a diameter shaft of 1 inch in the middle of the turbine blade. The turbine consists of two layers, the main blade is semi-circular overlapped with a diameter of 350 mm and the variable blade is mounted parallel in front of the main blade with the inside attached to the blade.

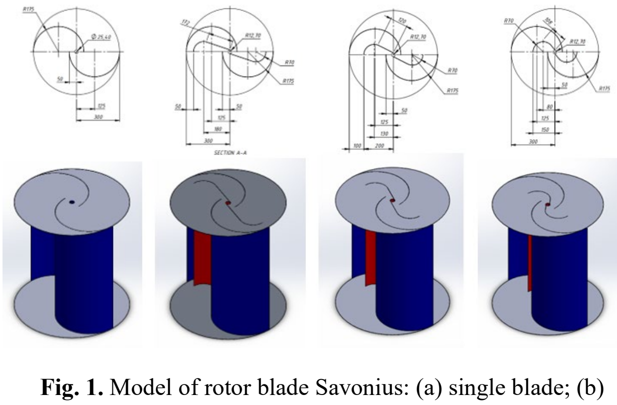


Fig. 1. Model of rotor blade Savonius: (a) single blade; (b) double blade 1;1; (c) double blade 2:1; and (d) double blade 3:1

The size of each blade variable is with a distance of 50 mm, 100 mm, and 150 mm to give rise to the ratio of side and exit wind gaps of 1:1, 2:1, and 3:1. The material used for the manufacture of blades is stainless steel because it has high corrosion resistance, is easy to form, easy maintenance, and is resistant to low and high temperatures. Savonius wind turbines are arranged on a frame made using elbow iron measuring 6 mm x 6 mm x 600 mm with the addition of wheels to facilitate the mobilization process.

2.2 Methodology

Turbine performance testing is carried out by measuring the turbine torque using a torsimeter weighed down by a pendulum. Testing was conducted at various speed variations of 3 m/s, 7 m/s, and 9 m/s with a loading of 0.1 kg; 0.15 kg; 0.2 kg; 0.25 kg; 0.3 kg; and 0.5 kg. Measurements of the rotary speed of the turbine shaft use a tachometer. Then an analysis of the kinetic power of the wind (wind power), the mechanical power of the turbine (mechanical power), TSR (Tip Speed Ratio), and the power coefficient (Cp), respectively,

$$P_W = 1/2\,\rho A v^3 \tag{1}$$

$$P_T = 2\pi n T/60 \tag{2}$$

$$Cp = P_T/P_W \tag{3}$$

$$TSR = \pi D n/60 v \tag{4}$$

$$P_G = V.I \tag{5}$$

$$\eta_{s} = (P_G/P_W)\,x\ 100\% \tag{6}$$

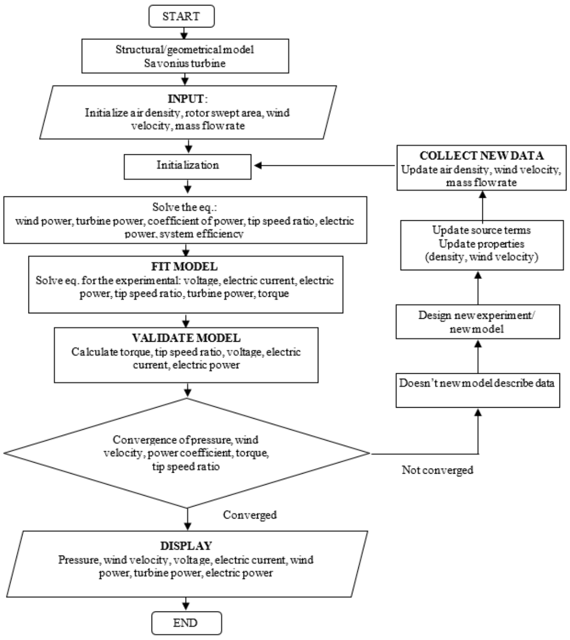


Fig. 2. The voltage-current power (VCP) algorithm of the Savonius turbine

Generator performance testing is done by measuring voltage using a voltmeter and current using an amperemeter. Loading on the electrical circuit uses a set of light loads 5 W. The electrical circuit is connected to a generator whose shaft is connected to the turbine shaft through a transmission in the form of belts and pulleys. Then an analysis of the power generator (electrical power) and system efficiency.

In testing the characteristics of the Savonius turbine to obtain the output voltage, electric current, and electric power, we use a wiring diagram. The wiring diagram shows a series of measuring instruments for voltmeters, ammeters, generators, and loads. The 5 W load is added gradually and then records the required parameters, by increasing the 5 W load gradually until the light flashes and the current saturates.

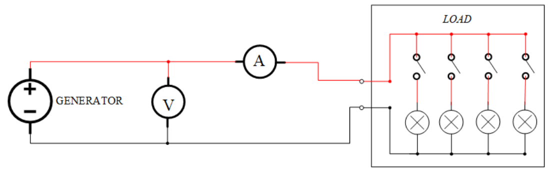


Fig. 3. Wiring diagram of experimental Savonius turbine

3. Results and Discussion

Savonius wind turbine manufacturing produces 4 turbine rotors, namely a single-blade rotor and 3 double blade rotors with variations in the side gap of 1:1, 2:1, and 3:1. Based on Equations 1 to 4 in the turbine performance testing method in turbine rotation and turbine torque. The value is then processed in Equations 1 to 4 so that data is obtained in Table 1.

Table 1. Turbine performance of 7 m/s with a load of 0.25 kg

Rotor model	N (rpm)	T (Nm)	P_w (W)	P_T (W)	TSR	C_P
Single Blade	189	0,159	80,262	3,147	0,848	0,039
Double Blade i/o ratio 1:1	210	0,117	80,262	2,581	0,943	0,032
Double Blade i/o ratio 2:1	181	0.092	80.262	1.732	0.812	0.022
Double Blade i/o ratio 3:1	148,5	0,116	80,262	1,805	0,666	0,022

Based on Equations 5 and 6 in the turbine system performance testing method, test results are obtained in both voltage and electric current form. The value is then processed in Equations 5 and 6 so that the data is obtained in Table 2.

Table 2. Turbine performance of 7 m/s with a load of 0.25 kg

Rotor model	V_{DC} (V)	I_{DC} (A)	P_T (W)	P_G (W)	η_s (%)
Single Blade	4,4	0,7	80,26	3,08	3,84
Double Blade i/o ratio 1:1	4	0,42	80,262	1,68	2,093
Double Blade i/o ratio 2:1	3,5	0,5	80,262	1,75	2,180
Double Blade i/o ratio 3:1	2,4	0,34	80,262	0,816	1,017

The results of this study are shown in Table 1 and Table 2 shows calculation data in the form of torque, mechanical power, kinetic power, TSR, Cp, DC voltage, DC current, electrical power, and system efficiency. The relationship between the turbine performance indicators is illustrated in the form of graphs.

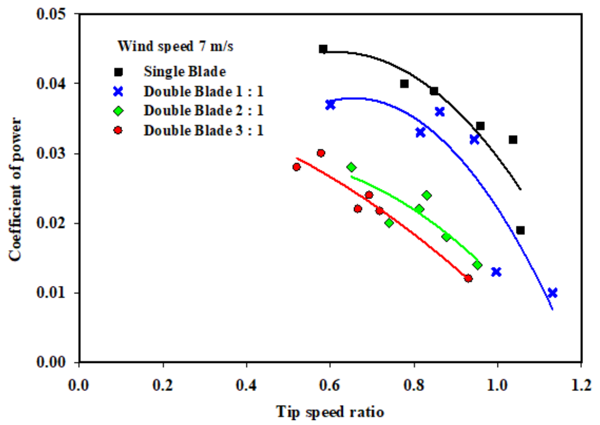


Fig. 4 Characteristic of power coefficient (C_p) and tip speed ratio (TSR)

In experiments with 7 m/s wind speed, the research results were obtained on single blade rotor variations with a Cp value that could be achieved at 0.55 and a TSR value of 0.583. In comparison, the 3:1 double-blade turbine produces the lowest performance with Cp 0.041 and TSR 0.561.

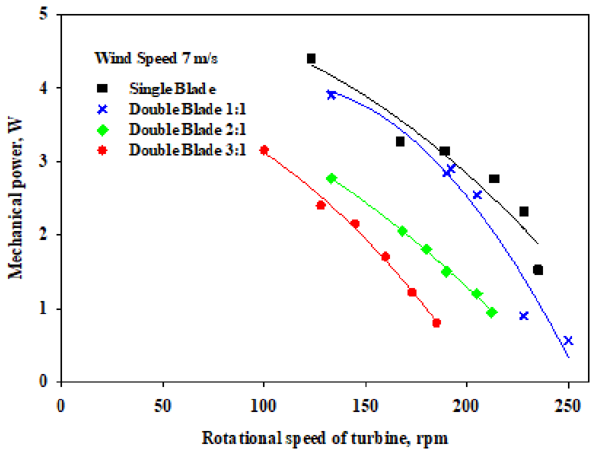


Fig. 5 Characteristic of mechanical power and turbine rotation at a wind speed of 7 m/s

On the graph of the characteristics of turbine rotation to turbine power with the wind speed average of 7 m/s, the best results for turbine beds with single blade types, with a mechanical power value of 4,403 W and turbine rotation is 130 rpm. The lowest performance is a turbine with a variable double blade 1: 3 with a mechanical power value that can be achieved is 3,316 W and a rotation of 125 rpm.

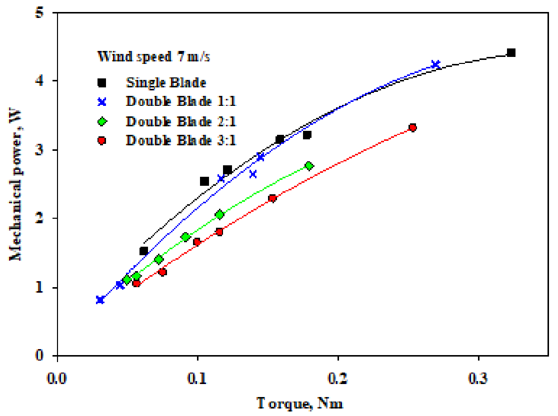


Fig. 6 Characteristic of mechanical power and torque at a wind speed of 7 m/s

The torque characteristics of turbine power with 7 m/s wind speed obtained turbine with the best work is a turbine with a variable single blade capable of having a torque of 0.324 Nm and a mechanical power value of 4,403 W. For turbines with the lowest yield is Savonius double blade turbine 3:1, with a result of 0.253 Nm, and mechanical power is 3,361 W. At 7 m/s wind speed for each turbine variable has almost similar characteristics; the higher the turbine torque, the greater the power. Table 2 shows calculation data in the form of generator power, kinetic power, and system efficiency. The relationship between the turbine system performance indicators is illustrated in the form of a graph.

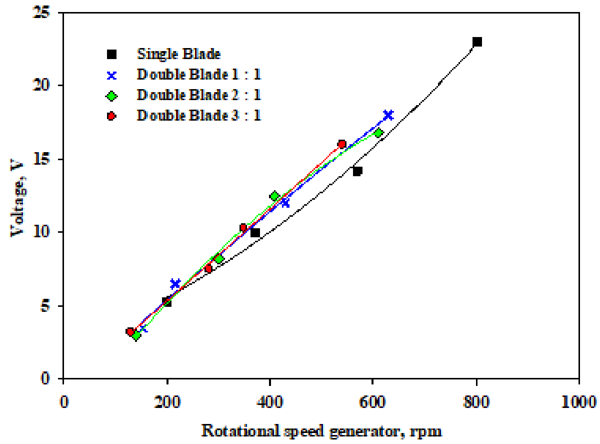


Fig. 7 Characteristic of voltage and rotational speed generator of zero loads at a wind speed of 7 m/s

On the zero load graph in abovementioned, it can be analyzed that the four blades, namely single blade, double blade 1:1, double blade 2:1, and double blade 3:1, have different characteristics when tested with variations in wind speed 3 m/s, 7 m/s, and 9 m/s. At wind speeds of 3 m/s can be analyzed single blade is superior to other blade variations. The single blade generates a generator rotation of 200 rpm and generates a DC voltage of 5.3 V. The 3:1 double blade has the lowest performance by producing a generator rotation of 129 rpm and generates a DC voltage of 3.2 V. At wind speeds of can be analyzed single blade is superior to other blade variations. The single blade produces generator rotation of 370 rpm and generates a DC voltage of 10 V. The 1:1 double blade has the lowest performance by producing a generator rotation of 216 rpm and generates a DC voltage of 6.5 V. At 7 m/s wind speed can be analyzed single blade is superior to other blade variations. The single blade produces a generator rotation of 569 rpm and generates a DC voltage of 14.2 V. The 3:1 double blade has the lowest performance by producing a generator rotation of 348 rpm and generates a DC voltage of 10.3 V. At wind speeds of 9 m/s single blade is superior to other blade variations. The single blade generates a generator rotation of 801 rpm and generates a DC voltage of 23 V. The 3:1 double blade has the lowest performance by producing generator rotation of 540 rpm and generates a DC voltage of 16 V. The Savonius turbine test was carried out at the best performance of 7 m/s, because in the previous test the wind speeds at 3 m/s, 5 m/s, and 9 m/s had low performance.

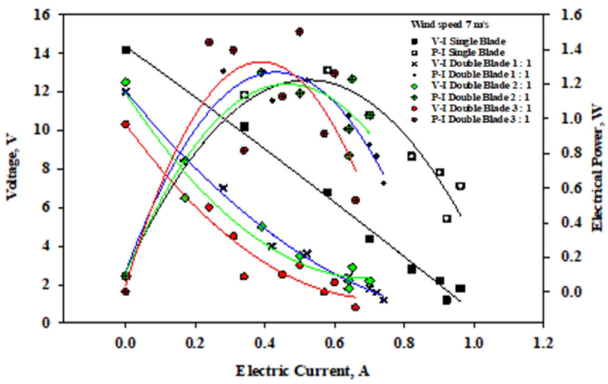
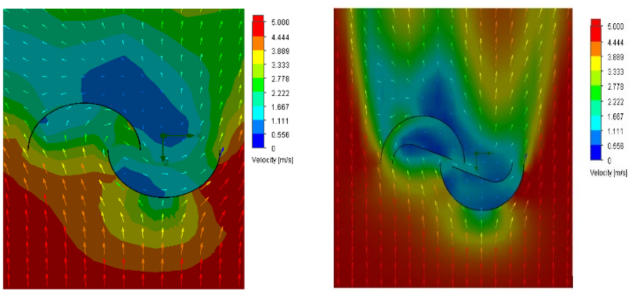


Fig. 8 Characteristic of VIP curve (voltage, current, and power) at a wind speed of 7 m/s

The graph above shows that the higher the current, the lower the voltage due to the occurrence; therefore, the current is conversely proportional to voltage; on the power graph, the longer the decrease because the current value is saturated while the voltage is decreasing. The graph also shows that the best system performance is on a single blade while the lowest is produced on the 3:1 variation blade. Simulation modeling was performed based on Solidwork 2020.



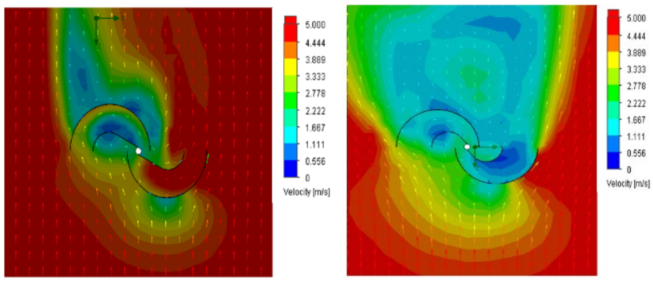


Fig. 9 Simulation modeling Savonius rotor with the velocity along the blade: (a) single blade; (b) double blade 1:1; (c) double blade 2:1; and (d) double blade 3:1

Savonius type U rotor, equal airflow. While on the Savonius type L rotor, the straight blade airflow is greater than the semi-circular blade. In the Savonius rotor, the wind strikes one of the blades, causing the rotor to rotate, and the center of the thrust force will shift away from the shaft. This is intended so that the torque generated by the rotation of the rotor is greater. Savonius U produces a large rotational speed, while the torque tends to be small. However, the Savonius L produces low rotational speed and high torque at the same wind speed.

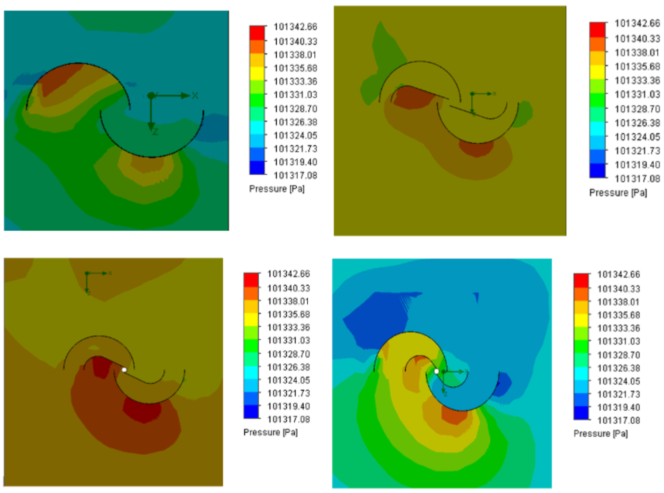


Fig. 10 Simulation modeling Savonius rotor with the pressure along the blade: (a) single blade; (b) double blade 1:1; (c) double blade 2:1; and (d) double blade 3:1

The Savonius wind turbine operates due to each blade's force pushing difference. Wind flowing through the convex blades causes the rotor to rotate around its axis, whereas wind flowing into the concave blades causes the rotor to rotate around its axis (convex blades). Due to its curvature, the blade does not facelessly drag when moving with than against the wind. As a result, the Savonius turbine captures less wind energy than other lift turbines of the same size since the energy received by the blades is actually used to push the convex blades, resulting in a lower efficiency for the Savonius turbine. The results of the study indicate that the Savonius turbine has optimum performance on a single blade rotor model at 189 rpm, the power coefficient value is 0.039, turbine power is 80.26 W, generator power is 3.08, and system efficiency is

3.84%.

4. Conclusion

According to the study's findings, the single-stage Savonius double blade wind turbine model has a diameter of 650 mm with a turbine height of 600 mm, with a variation of the inlet and outlet ratios of 1: 1, 2:1, and 3:1, with a blade gap of 50 mm. The tests were carried out with variations in wind speeds of 3 m/s, 5 m/s, 7 m/s, and 9 m/s. Based on the parameters of the performance of the Savonius wind turbines test with a single blade model, the highest rotor rotation value is 186 rpm at an average wind speed of 3, 5, 7, 9 m/s and an average loading of 0.1, 0.15, 0.2, 0.25, 0.3, 0.5 kilograms. Then followed by a 1:1 double blade model with a rotor rotation value of 175 rpm. The next model is a 2:1 double blade with a rotor rotation value of 158 rpm. Then the lowest rotation value in the 3:1 double blade model is 155 rpm. The best system efficiency is 4.19 % based on the specifications of the Savonius wind turbine performance test using a single blade model. Meanwhile, for turbines with changes in inlet and outlet ratios, the 2:1 double blade model has the best system efficiency value of 2.42%. Based on the parameters of the Savonius wind turbine performance test with a 3:1 double-blade model, the highest turbine efficiency is 20.3% at a wind speed of 3 m/s. Based on the performance test parameters of the Savonius wind turbine with a single blade model, the highest efficiency is 24.4% at a wind speed of 3 m/s. Based on the performance test parameters, the Savonius wind turbine with a 3:1 double-blade model produces the best performance for low wind speeds between 3-5 m/s. Then for the 1:1 double blade model, it produces the best performance at high wind speeds between 5 – 9 m/s.

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Conflict of Interest

The authors declare no conflicts of interest.

Nomenclature

P_w	Wind power (W)
P_T	Turbine or mechanical power (W)
P_G	Generator power (W)
C_p	Coefficient of power
TSR	The ratio of tip speed
N	The rotational speed of turbine (rpm)
T	Torque (Nm)
D	Diameter (m)
A	Area swept by the rotor (m^2)
v	The wind's speed (m/s)
V	Voltage (V)
I	Electric current (A)

Greek symbols

η	efficiency (%)

Subscripts

i	Input wind flow of the blade
o	Output wind flow of the blade

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