SavoniusTurbine Mechanical Power is calculated based on Wind Force, Rotor Friction and Turbine Weight

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Abstract—The Force of Wind is wind power divided by the speed of the wind. Electric generator power generated from the data of wind speed and wind turbine shaft speed is by utilizing the kinetic energy of wind into the effective area of the turbine. The broad sweep of the Savonius wind turbine is designed with a rotor diameter, D = 52 cm, and height of the rotor, H = 36 cm. The Savonius rotor is designed with two blades. Two semi-circular shapes covered with a sheet of aluminum. Savonius wind turbine is a device that utilizes wind energy to generate mechanical power. Two Savonius turbine design is done in this study, has an aspect ratio of 0.7. Design 1 Savonius turbine has a mass of 3.29 kg load and design 2 Savonius turbine has a mass of 2.32 kg load. Design 1 was not spinning in the wind speed interval of 1-4 m/s. Design 2 can rotate in the wind speed interval. The mechanical power in this research was found at the power range 0,4 – 2 W. By changing the broad sweep of the Savonius turbine, power generation purposes in the power range of the generator 7-25 Watt can be obtained.

Keywords —wind power, rotor, savonius, wind turbine, turbine power, effective turbine

1 Introduction

WIND Power Generation System in Coastal Tegal based on the curiosity of researchers in expressing a concept of wind power on Tegal beach can be used to generate electricity. Wind energy is very important as one of clean energy resources. Wind rotors are the most important tool of the wind energy. Savonius wind rotor is one of the vertical axis wind turbines. It is simple in structure, has good starting characteristics, relatively low operating speeds, and an ability to capture wind from any direction [6].

The Savonius wind turbine is a simple vertical axis device having a shape of half-cylindrical parts attached to the opposite sides of a vertical shaft (for two-bladed arrangement) and operate on the drag force, so it can't rotate faster than the wind speed. As the wind blows into the structure and comes into contact with the opposite faced surfaces (one convex and other concave), two different forces (drag and lift) are exerted on those two surfaces. The basic principle is based on the difference of the drag force between the convex and the concave parts of the rotor blades when they rotate around a vertical shaft. Thus, drag force is the main driving force of the savonius rotor [2].

Wind Power is one of the renewable energy power plants that are environmentally friendly. The working principle of Wind Power is by utilizing the kinetic energy of wind into the effective area of the turbine to rotate the Savonius wind turbine, then the energy is transmitted to the generator to generate electricity. In the manufacture of the wind power generation system, the input data used is the wind speed and rotation speed of Savonius wind turbine shaft. The data is processed to obtain the calculation of wind power, rotational speed, force, torque, and power turbine Savonius. The data of rotational frequency in units of rotations per minute (rpm), the torque, and the number of magnetic poles are provided in this study used to calculate the electric power generator as a result (output) obtained in this study.

2 LITERATURE REVIEW

2.1 Mechanical Power of Savonius Rotor

The mechanical power for the tested Savonius rotor is determined by measuring the mechanical torque on the rotating shaft and rotational speed at different values of wind speed.The wind speed is measured by a propeller type digital anemometer. While the shaft rotational speed is measured using a digital tachometer [6].
From the measured values of mechanical torque and rotational speed, the mechanical power can be estimated at each wind speed.

$$P_m = T\omega$$

$$T = Fr$$

$$\omega = \frac{2\pi n}{60}$$

$$F = (m - s)g$$

where T is the mechanical torque (Nm), ω is the angular speed (rad/s), P_m is mechanical power (W), n is the shaft rotational speed (rpm), r is the pulley radius (m), F is The force acting on the rotor shaft (N), m is the mass loaded on the pan (kg), s is the spring balance reading in kg and g is the gravitational acceleration.

The power coefficient C_p and static torque coefficient C_{ts} can be determined from the following equations:

$$C_P = \frac{P_m}{P_w}$$

$$P_w = \frac{1}{2}\rho A V^3$$

Where ρ is air density (kg/m^3), A is the projected area for the rotor (m^2) and V is the wind speed (m/s).

The static torque coefficient is calculated from

$$C_{ts} = \frac{4T}{\rho D^2 V^2 H}$$

The ratio between rotor height (H) and rotor diameter (D) is called the aspect ratio (α).

$$\alpha = \frac{H}{D}$$

2.2 The Rotor Concept on the Savonius turbine

S.J. Savonius initially developed the vertical-axis Savonius rotor in the late 1920s. The concept of the conventional rotor is based on cutting a cylinder into two halves along the central plane and then moving the two half cylinders sideways along the cutting plane, so that the cross-section resembles the letter S (Figure 1) [5].

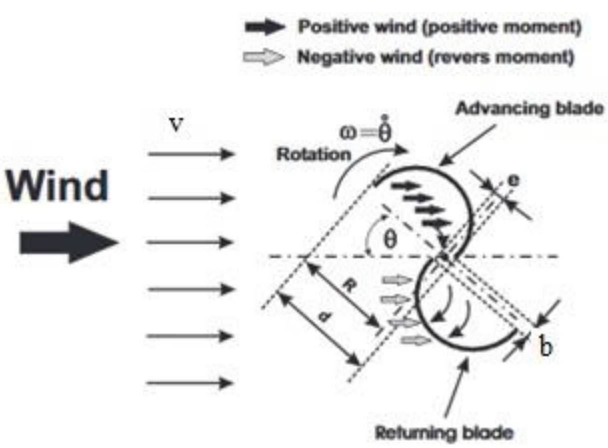

Fig. 1. Schematic description and main parameters on a Savonius rotor

Figure 1. The effect of two guiding plates (obstacle and deflector) for the standard Savonius geometry and internal distances between the blades b and e. The installation of an obstacleshielding the returning blade leads also to an increasein turbine performance and a better self-starting capability [3].

The turbine performance is highly dependent on the torque produced by wind pressure. The increase of moment arms at the concave side of the blade increase directly the positive moment of the rotor, such a case goes with the modified model, which increases the distance of energy catching point from the center of rotation.

The performance comparison between the modified model, the conventional model and the elliptical model developed on the Savonius Turbine is shown in Figure 2 [4].

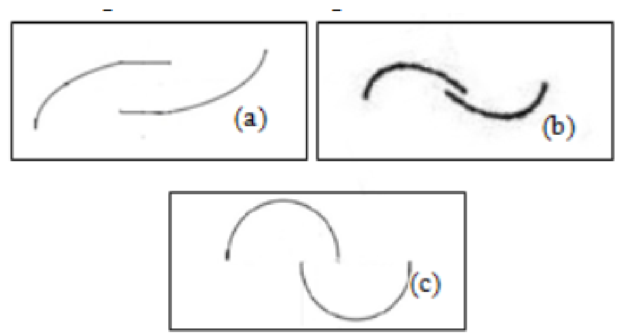

Fig. 2. Three geometries of savonius blades.

In Figure 2, three geometric shapes are shown on the Savonius blade:

(a) modified Savonius rotor
(b) elliptical Savonius rotor
(c) Conventional Savonius rotor

The variation of power coefficient against tip speed ratio for the three models. The performance of modified and elliptical blades show higher performance over the conventional blades. Moreover, the performance of the modified savonius blade investigated reveals a higher efficiency over the conventional and elliptical blade [1].

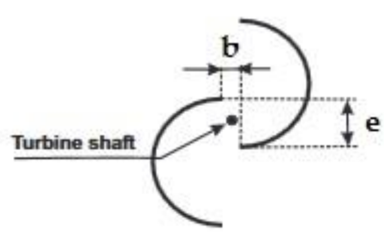

Fig. 3. Turbine Shaft

3 RESEARCH METHODS

3.1 First Stage

The first stage of research, field observation, learn some situations that are directly related to the circumstances at the test site. From the observation of some of the areas that are consid-

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ered good for testing, then the selected areas that have wind speeds capable of moving the Savonius turbine, namely beach Tegal and or in areas near the coast dost, on the campus of the University of PancasaktiTegal. Next is the study of literature to collect data from the following related reference data from previous studies, then made a comparison with analyzing formulas related to this research. Likewise, information retrieval via the Internet to support the data collection process of wind turbines.

3.2 Second Stage

In the second phase, research was conducted by using experimental research methods is to make observations to search for data in a process of cause and effect through the experiment in order to determine the effect of the blade gap distance of the wind turbine work Savonius axis.

3.3 Final Stage

Savonius turbine made according to figure 4, but the height of the turbine does not comply with the 2 x diameter of the turbine rotor, the height of the turbine should,
H = 2 x 3 r = 6 r.

Fig. 4. Design 1 ; Turbine Savonius H≠2D, D = 45 cm, H = 30 cm

Fig. 5. Design 2; turbine Savonius H≠2D, D = 45 cm, H = 30 cm

Design 1, Savounius turbine is made of ferrous metal plate and sheath half-circle made of zinc. Making this Savounius turbine with a diameter D = 45 cm, height H = 30 cm.
Design 2, Savounius turbine is made of ferrous metal plate and sheath half circle made of sheet aluminum. Making this Savonius turbine with a rotor diameter ofthe turbine, D = 52 cm and a height of 36 cm turbine.
Two turbines Savonius image 1 and image 2 are made to determine the effect of the blade gap distance on the vertical axis turbine Savonius. Effect on Savonius turbine height and a rotor diameter of a turbine in terms of the broad sweep of the turbine.

4 RESULTS AND ANALYSIS RESEARCH

The results of the Savonius 1 and 2 turbine designs, seen from the top cross-section are as follows:

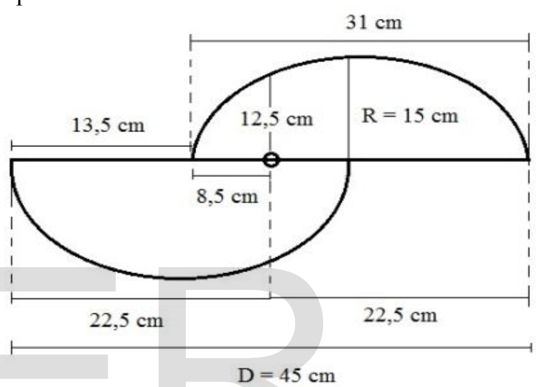

Fig.6. Top Cross-section of Savonius turbine design 1

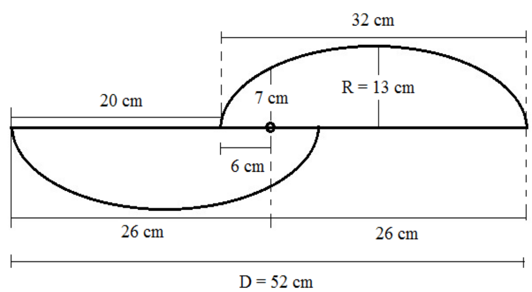

Fig. 7. Top Cross-section of Savonius turbine design 2

ρ = density of air = 1.225 kg/m^3.
Broad sweep of Savonius turbine:

$$A = D.H$$

Volume and mass of air in the turbine:

$$V_t = \pi\left(\frac{D}{2}\right)^2 H$$

$$M_t = \rho V_t$$

The volume of air entering the turbine gap is C/D of the total volume of turbine :

$$V_i = \frac{C}{D}\pi\left(\frac{D}{2}\right)^2 H = \tfrac{1}{4}\pi CDH$$

The mass of air entering turbine:

$$M_i = \rho V_i$$

Force of wind on the Savonius turbine :

$$P = F_t v = \tfrac{1}{2}\rho A v^3$$

$$F_t = \tfrac{1}{2}\rho A v^2$$

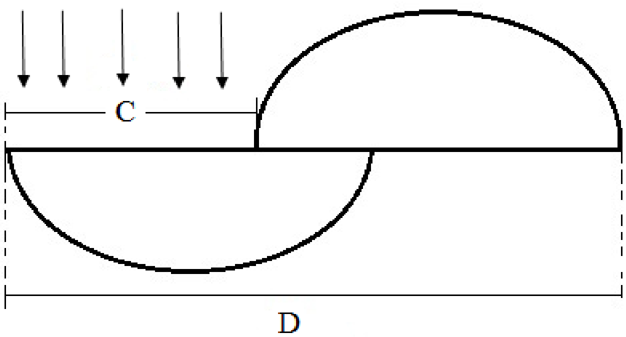

Fig. 8. The incoming airtoturbinegap

Thereare two possibilities for the transformation of wind power into kinetic power, namely the use of force barrier “drag force” and the “lift force”. Drag force rotors utilize F_W force generated by the wind on an area A at a certain angle:

$$F_w = c_w(\tfrac{1}{2}\rho A v^2)$$

Drag coefficient value “drag coefficient” c_w is an indication of the aerodynamic qualities of an object.

Table 1. Value of drag coefficient (c_w)

No	c_w	Body
1	1.11	Circular Plate
2	1.10	Square Plate
3	0.33	Closed Semi-Sphere
4	1.33	Open Semi-Sphere

Table 2. Savonius Turbine and Wind Speed

Design	M_t (kg)	D (m)	H (m)	A (m^2)	v_a (m/s)
1	3.29	0.45	0.3	0.135	4.2
2	2.32	0.52	0.36	0.1872	4.2

Table 3. Drag force rotor and frictional force

Design	C (m)	f (Hz)	V_t (m^3)	M_u (kg)	F_w (N)	f_g (N)
1	0.135	0.82	0.048	0.058	1.940	3.227
2	0.2	0.82	0.076	0.094	2.690	2.276

From the research, design 1 Savonius turbine can not rotate on wind speed range 1- 4 m/s. This can be analyzed by taking into account the turbine weight and friction coefficient (μ) between the shaft of the turbine weight. Frictional force against its axis turbine (f_g) can be calculated if $\mu = 0.1$, then

$f_g = mg\mu = 0.1x3.29x9.81 = 3.227N$

Drag force rotor

$F_W = 1.940$ N.

$F_w - f_g = 1.940 - 3.227 = -1.287$ N

$F_w - f_g < 0$

The forces acting on the turbine Savonius design 1 are smaller than-zero, so that the turbine does not move on the sample wind speed of 4.2 m/s. Thus Savonius turbine design one can not spin for speed range 1- 4 m/s.
From the research design 2, Savonius turbines can rotate.

$F_w - f_g > 0$

If $\mu = 0.1$ then $f_g = mg\mu = 0.1x2.32x9.81 = 2.276$ N and $F_w > f_g$. From the calculation results obtained $F_w = 2.690$ N and $f_g = 2.276$ N.Thus Savonius turbine design 2 can rotate to a certain speed range, which meets $F_w > mg\mu$.

With a Savonius wind turbine it does not matter from which direction the wind is blowing, since there will always be more force exerted on whichever cup has its open face into the wind, and this will push the rotor around. This makes this design of wind turbine ideal for areas with very turbulent wind.

The speed of the Savonius wind turbine can not rotate faster than the speed of the wind they are in and so they have a tip speed ratio (TSR) of 1 or below. This means that a Savonius type vertical axis wind turbines will turn slowly but generatehigh torque.

Table 4. Wind Speed at the Beach Tegal

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No	Time	wind speed (m/s)		
		Min	Max	$v_{average}$
1	11:00	1.08	2.33	1.71
2	11:30	1.20	2.67	1.94
3	12:00	2.18	3.58	2.88
4	12:30	2.31	3.00	2.66
5	13:00	2.24	3.21	2.73
6	13:30	2.05	3.25	2.65
7	14:00	2.01	2.59	2.30
8	14:30	1.93	2.88	2.41
9	15:00	1.91	2.83	2.37

Table 5. Shaft-Frequency

shaft-Frequency (rpm)			Frequency (Hz)
Min	Max	$f_{average}$	f
12.5	26.2	19.4	0.21
14.2	32.6	23.4	0.24
20.4	31.6	26.0	0.34
22.1	30.5	26.3	0.37
20.2	33.5	26.9	0.34
22.4	30.2	26.3	0.37
19.0	21.1	20.1	0.32
17.9	20.9	19.4	0.30
17.2	29.3	23.3	0.29

Table 6. Speed of Savonius Turbine

rotational speed (rad/s)	speed of turbine	TSR
ω	v = ω.r	
1.31	0.34	0.15
1.49	0.39	0.14
2.14	0.56	0.16
2.31	0.60	0.20
2.11	0.55	0.17
2.34	0.61	0.19
1.99	0.52	0.20
1.87	0.49	0.17
1.80	0.47	0.17

Therefore Savonius turbines are not ideal for electricity generation since turbine generators need to be turned at hundreds of RPM to generate high voltages and currents.

Table 7 Mechanical Power of Savonius Turbine

No	Time	v_{max} (m/s)	$P_m=0{,}5\rho A v^3$ (Watt)	f_{min} (rpm)	v = ω.r (m/s)
1	11:00	2.33	1.45	12.5	0.34
2	11:30	2.67	2.18	14.2	0.39
3	12:00	3.58	5.26	20.4	0.56
4	12:30	3.00	3.10	22.1	0.60
5	13:00	3.21	3.79	20.2	0.55
6	13:30	3.25	3.94	22.4	0.61
7	14:00	2.59	1.99	19.0	0.52
8	14:30	2.88	2.74	17.9	0.49
9	15:00	2.83	2.60	17.2	0.47

A gearbox can be used to reduce the torque and increase the RPM of the generator, but the blades of Savonius require a stronger wind to get spinning meaning it may not be able to self-start.

Table 8. Wind Power

$a = \omega^2.r$ (m/s²)	F = m.a (N)	T = F.r (Nm)	$P_w = T\omega$ (Watt)	Cp
0.45	1.03	0.27	0.35	0.24
0.57	1.33	0.35	0.51	0.24
1.19	2.75	0.72	1.53	0.29
1.39	3.23	0.84	1.94	0.63
1.16	2.70	0.70	1.48	0.39
1.43	3.32	0.86	2.02	0.51
1.03	2.39	0.62	1.23	0.62
0.91	2.12	0.55	1.03	0.38
0.84	1.95	0.51	0.92	0.35

The ratio between the mechanical power extracted by the converter and that of the undisturbed air stream is called the "power coefficient" Cp:

$$C_P = \frac{P_m}{P_w}$$

The power coefficient is directly linked to the global efficiency of a wind machine.

Figure 9 gives the power coefficient Cp, ratio of the aerodynamic power of the turbine to the power of the incident wind, as a function of the speed ratio λ. This speed ratio λ is also called velocity coefficient and is equal to the ratio of the tip peripheral speed to the wind velocity. The power coefficient is directly linked to the global efficiency of a wind machine.

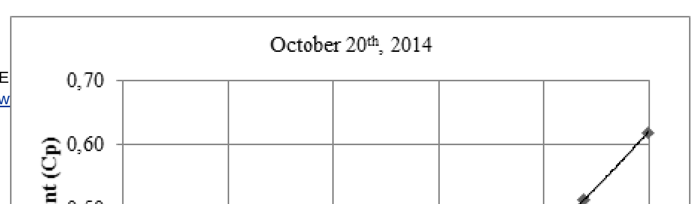

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Fig. 9. Power Coefficient vs Tip Speed Ratio

The curve in Fig. 9 shows that the fast running horizontal axis wind machines (two- or three-bladed air screw) have incontestably the best efficiencies. Consequently, theses machines are nowadays systematically chosen for the equipment of large-area wind sites. On the other hand, the Savonius rotor, which is a slow-running vertical axis wind machine ($\lambda \approx 1.0$) has a rather poor efficiency: Cp ≈ 0.15 to 0.2 at the best. Nevertheless, it can present some advantages for specific applications, in particular due its simplicity, and resulting robustness and low cost.

	Nomenclature
T	Mechanical torque (Nm)
ω	the angular speed(rad/s)
e, b	internal distances between the blades
P_m	mechanical power (W)
n	the shaft rotational speed (rpm)
r	the pulley radius; radius of turbine (m)
F	The force acting on the rotor shaft (N)
F_w	Drag force rotor (N)
c_w	Drag coefficient
m	the mass loaded on the pan (kg)
s	the spring balance reading in kg
g	the gravitational acceleration
a	Acceleration of wind (m/s^2)
c_p	The power coefficient
c_{ts}	static torque coefficient
ρ	air density (kg/m^3)
A	the projected area for the rotor (m^2)
v	the wind speed; speed of turbine (m/s)
V_t	the totalvolume of turbine (m^3)
H	rotor height (m)
D	rotor diameter (m)
α	the aspect ratio
λ	Tip speed ratio
μ	Friction coefficient
f	Shaft-frequency (Hz)
f_g	Frictional force (N)
M_t	The massof air entering turbine (kg)
P_m	Mechanical power (W)
P_w	Wind power (W)

4 Conclusion

1 The forces acting on the turbine Savonius design 1 are drag force rotor F_W = 1.940 N and Frictional force $f_g = mg\mu$ = 0.1x3.29x9.81 = 3.227 N. $F_w - f_g < 0$, so that the turbinedoes not move on the sample wind speed of 4.2 m/s.

2 The forces acting on the turbine Savonius design 2 are drag force rotor F_W = 2.690 N and Frictional force $f_g = mg\mu$ = 0.1x2.32x9.81=2.276 N. $F_w - f_g > 0$, so that the turbine can rotate on the sample wind speed of 4.2 m/s.

3 The speed of the Savonius wind turbine can not rotate faster than the speed of the wind they are in and so they have the values of tip speed ratio (TSR) on table 6, which are smaller than one.

4 The input mechanical power in this research is the shaft power in the generator that has 0,4 – 2 Watt.

5 By changing the broad sweep of the Savonius turbine, power generation will be higher in the power range of the generator can be obtained.

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