An Experimental Study of Stagger Angle Effect Placed in front of Returning Side toward the Savonius Wind Performance Using Overlap Myring Blade for n = 1

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***Abstract*— The overlapping blade has increased the performance of the original turbine. This work investigated the performance of an overlap blade to enhance the turbine performance. This experimental study modified Savonius turbine with overlap blades utilizing Myring type for n of 1. The blade shape was made half-elliptical to decrease the drag force. The turbine had a diameter and height of 400 mm and an overlap of 0.3. The diameter ds/D was 0.4, and the distance (S/d) was 1.7. An experimental study varied the stagger angles of the cylinder located upstream of the returning for 45°, 50°, 55°, and 60°. The wind speed in the experiment was 5 m/s. The results showed that the biggest improvement occurred at a stagger angle of 60°. The improvement for Myring power coefficient was about 20.16% concerning the overlap myring n = 1 without cylinder.**

Keywords— Original Savonius turbine, Cylinder, Returning blade, Stagger angle, Power coefficient.

I. INTRODUCTION

The vertical Savonius wind turbine has several advantages, as it is simple to construct and can operate independently of any wind direction and work at low wind power. The Savonius turbine has a low efficiency value compared to others. The study was performed to enhance the performance of the Savonius wind turbine. The paper using the experimental study method comparing the number of blades of the Savonius 2-blade and 3-blade wind turbines with guide vanes obtained the highest Cp value at 2 blades with a wind speed of 3.5 m/s, it appears that the largest increase in the maximum Cp distribution price is at an angle of 15º or at the maximum Cp location, which is 1.1 x 10^{-1} based on this case it can be informed that the Savonius 2-blade turbine is more optimal than the Savonius 3-blade turbine in all speed variations and all angle variations [1].

Simulation was carried out to investigate the performance with ds/D=0.5. The bigger result occurred at a stagger angle of 60°[2]. In the case using the CFD numerical study method of Savonius wind turbine by modifying the blades using the myring equation with variations in the values of n = 0.5; 0.75; 1; 1.5; 2; 2.5; 3, the highest peak value of Cp was obtained at a value of n = 1 with a value of 0.257, there was a percentage increase in performance of 10.98% against the conventional Savonius turbine. So it can be concluded that shape n = 1 has better performance when compared to other n values [3]. The numerical simulation investigated the discretization effect along the blade surface for Myring shape n=1. The study show the number of layers 800 to time efficiency [4]. The Myring n=1 indicated the performance was bigger than the original, seeing the pressure drop in the attached area using the CFD approach [5] and the experimental study showed the same result [6].

An overlap blade increased the performance of Savonius turbine. The result displayed the best performance at an overlap of 3 [7]. The overlap used by Myring showed a higher performance than the overlap original Savonius [8].

The cylinder as passive control has increased the

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Savonius performance with variations y/D of 0, 0.25, 0.5, and 0.75. The study showed that the overlap increased the Savonius performance at y/D of 0.75 and improvement was about 22.267% [9].

Study with an experimental method on the Savonius wind turbine with overlap variations of 0.15, 0.20, 0.25, and 0.30 with speed variations (U) 1 m/s ≤ S/D ≤ 7 m/s. The study prove that at speed variations of 5 m/s to 7 m/s, it was found that overlap 0.3 had the highest RPM value, while for torque values at wind speeds from 1 to 4 m/s, it was found that overlap variation 0.3 had the highest torque value. The average value of the Coefficient of Power (Cp) from the minimum to maximum wind speed of the overlap variation of 0.3 showed the highest results [10]. The same results have shown that the overlap of 0.3 increased the performance [11].

The study used the CFD numerical study method with the addition of a disturbing cylinder upstream of the returning blade of the Savonius water turbine with a stagger angle variation of 0, 30°, 60°, and 90°, obtained the largest Cp produced at a stagger angle of 60° with a value of 0.276 at TSR 0.9, so that there was an increase of 29.84% over the conventional Savonius wind turbine. Based on the study, it can be informed that a cylinder with a stagger angle variation of 60° upstream of the returning blade gets the most optimal results [12].

The Savonios development to get the performance of the Savonius wind turbine, research was done using an experimental method with a modification of the overlap ratio blade of 0.3 and variations in the cylinder stagger angle of 45°, 55°, 65°, 75° in front of the returning blade. The best torque and power coefficient values were found at a cylinder stagger angle of 55° at a wind velocity of 5 m/s. The coefficient of torque value obtained was 1.263 at a TSR value of 0.06705 with a performance increase of 84.71% from conventional turbines, while the power coefficient value was 0.389 at a tip speed ratio value of 0.804571 with a performance increase of 18.70% from conventional Savonius turbines [13].

Based on previous research, it can be seen that there are many ways to improve the performance of the Savonius turbine to make it more efficient. Overlap blade modification and the additional cylinder barriers can increase the performance of the Savonius wind turbine. In this work, an experimental study of the Savonius wind turbine was conducted with the modification of overlap blades utilizing the Myring equation n = 1 with an effort to reduce the drag force that works so that it can increase the performance of the Savonius wind turbine. The study utilize the diameter and height of the turbine 400 mm, an overlap of 0.3, and variations in the stagger angle of 45°, 50°, 55°, and 60°. The circular cylinder is put upstream of the returning area with a ratio of cylinder diameter to turbine diameter (ds/D) of 0.4, a ratio of the center distance of the cylinder to the center of the turbine diameter (S/d) of 1.7, and wind velocity of 5 m/s.

II. METHOD

A. Savonius Model

The workings of the Savonius turbine are when the turbine rotates, the concave surface or advancing blade catches the wind flow, while the convex surface or returning blade moves against the flow direction [6]. The advancing blade has a greater drag coefficient than the returning blade. Cylinder location at advancing side through which the wind flows will provide a greater drag force than the returning side so that the turbine rotates. This is an aerodynamic principle, where the Savonius Turbine utilizes the drag force [7].

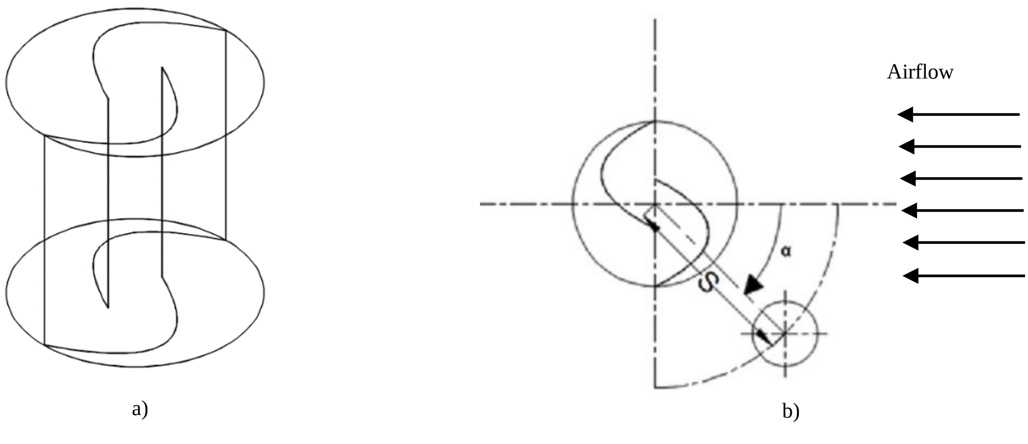

Figure. 1. a) Savonius Wind Turbine with overlap blade and Myring n=1, b) Arrangement of Savonius turbine and cylinder

B. Savonius Turbine Model Utilize Myring n=1

To optimize the performance of the Savonius blade, one of which is a change of bucket shape. The Myring for n of 1 will be implemented by changing the shape from the original shape to Savonius Myring n of 1 as displayed in Fig. 4 and turbine size in Table 1. The Savonius shape follows the equation Myring as shown in equation (1). The material utilizes aluminum with a thickness of 0.8 mm. The turbine installed shaft in the center of a turbine with a diameter of 15 mm. Two bearing positions install the shaft for the top and bottom turbine sides. The top shaft side will place a pulley measuring the load for torque calculation.

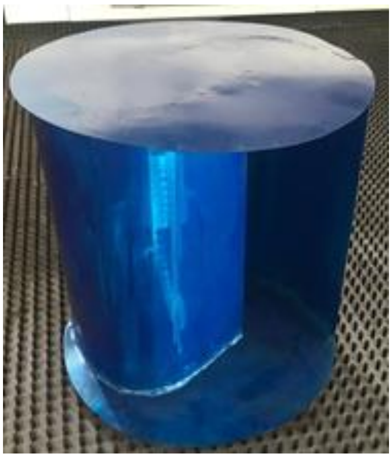

Figure. 2. Savonius Wind Turbine With Myring n of 1

TABLE 1.
SIZE OF SAVONIUS TURBINE

Symbol	Parameters	Value	Unit
D	Turbine Diameter	400	Mm
d	Blade Diameter	260	Mm
H	Turbine Height	400	Mm
e	Overlap blade	120	Mm
t	Blade thickness	1	Mm

C. Cylinder

To enhance the Savonius performance of the wind turbine in these cases, a cylinder would also be added which is located upstream of the returning side. The interfering cylinder used in this study has a diameter ratio 0.4 (16 cm) and a height of 40 cm. The cylinder material uses aluminum to reduce the friction on the cylinder surface and airflow. The cylinder position is varied for stagger angles of 45^o, 50^o, and 60^o. The cylinder can be displayed in Figure 3.

Figure. 3. Cylinder

D. Myring Equation

This equation is also to be applied to modify the blades on the Savonius turbine. If the drag force on the Savonius turbine can be reduced, then the turbine performance will increase [3]. The Myring equation can be written as equation (1).

$$y = b\left[1 - \left(\frac{x}{a}\right)^2\right]^{\frac{1}{n}} \quad (1)$$

Where y is heigh of the blade, x is the radius of the blade, n is the blade profile, and a = b is the radius of the turbine.

E. Tip Speed Ratio Parameter (TSR)
TSR is the ratio of the rotor speed to the fluid flow. The TSR would influence the rotor rotation speed. The Tip speed ratio is calculated using equation (2).

$$\mathrm{TSR} = \frac{\omega \times D}{2 \times U} \tag{2}$$

Where D is the diameter of Savonius in m, U is fluid flow in m/s and ω is angular velocity in rad/s.

F. Torque
Torque (T) can be calculated using equation (3).

$$\mathrm{T} = (\mathrm{M} - \mathrm{S})(\mathrm{R}_{\mathrm{Shaft}} + \mathrm{d}_{\mathrm{N}}).\,\mathrm{g} \tag{3}$$

Where M is load (kg), S is spring balance load (kg), R_{shaft} is radius of pulley (m), dr is nylon diameter (m), g is gravity (m/s²)

G. Torque Coefficient Paramter
The coefficient of torque is a calculation to determine the magnitude of the coefficient moment of force or torque produced by the turbine. The equation of the Coefficient of torque (Ct) can be calculated using the formula in equation (4).

$$C_t = \frac{T}{\frac{1}{4} \times \rho \times A_S \times D \times U^2} \tag{4}$$

H. Power Coefficient Parameter
The power coefficient (Cp) is the one parameter as the turbine performance. This is influenced by two factors namely, mechanical power and kinetic power. The power coefficient is defined the performance of the turbine. The power coefficient formula can be shown in equation (5) and (6).

$$C_P = \frac{P}{\frac{1}{4} \times \rho \times A_S \times U^2} \tag{5}$$

$$C_P = \mathrm{TSR} \times C_t \tag{6}$$

I. Experimental Setup
Experiments were carried out using an original Savonius turbine and a Savonius turbine using Myring n of 1. Myring is expected to produce better performance than original Savonius turbines. The cylinders are located at a distance ratio of S/d = 1.7 (34 cm), horizontal distance (X/s) = 1.7 (34 m), and distance ratio in the vertical axis (Y/d) = 0.5 (10 cm).

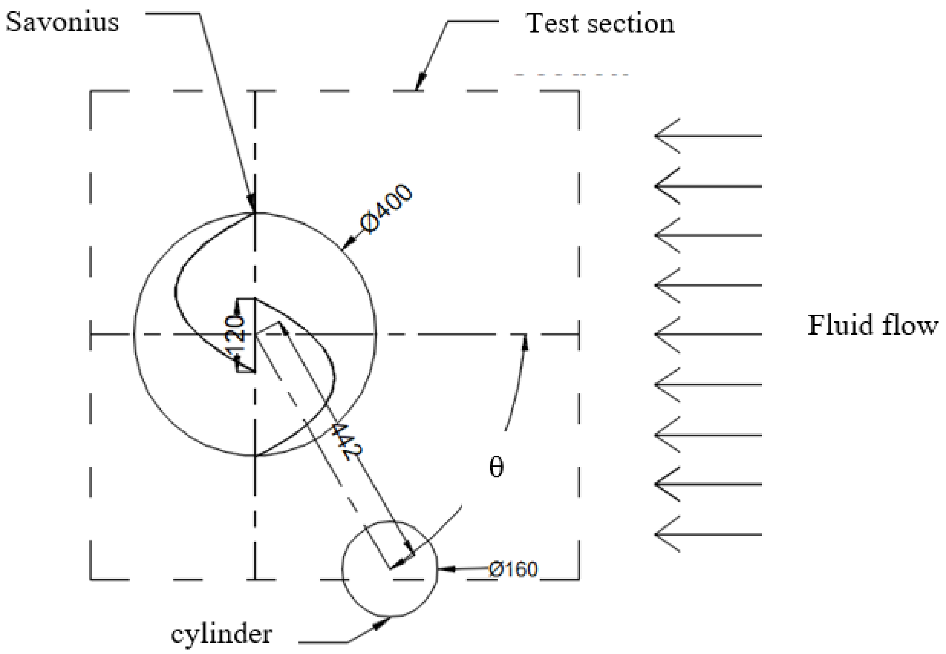

Figure. 4. The cylinder arrangement in front of the returning side

The data is obtained using a brake dynamometer to measure the load on the turbine. The tachometer measured the rotation of the turbine located upstream turbine. Wind speed was measured using an anemometer. The data will be taken in form of RPM, Mass of ballast (M), and scale load (S). The data is then processed to get the torque coefficient and power coefficient.

Specifications instrumentation for this experiment include a tachometer and anemometer can be seen in Figure 5. The tachometer used is the contact tachometer WIPRO series DT-2235A with an accuracy of 0.01% or ± 1 digit and the anemometer used is KRISBOW model: Kw 06-562.

a) b)

Figure. 5. Tachometer (a) and anemometer (b)

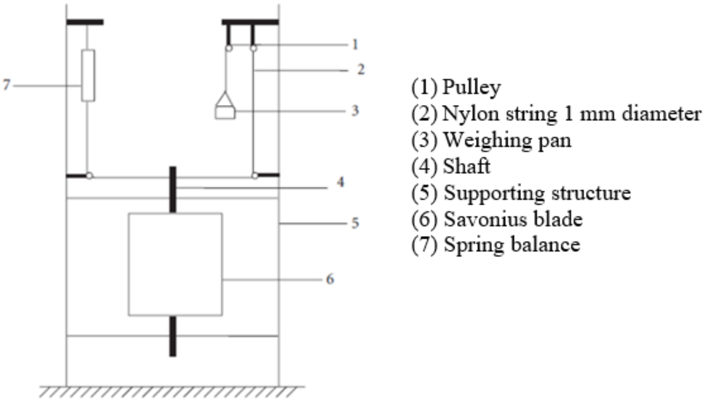

Figure. 6. Brake Dynamometer

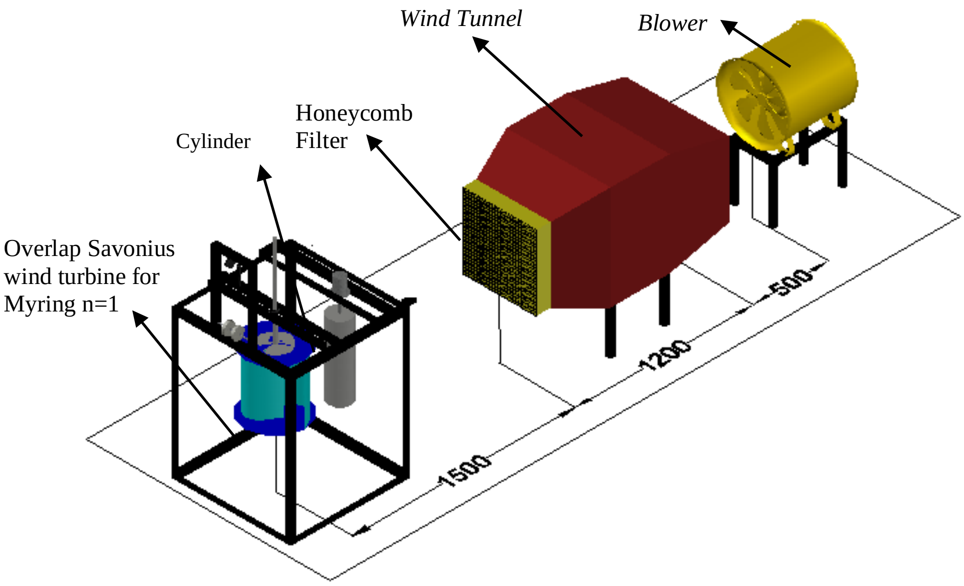

Figure. 7. Schematic experimental

The study results discuss the torque coefficient shown in Figure 7 and the power coefficient displayed in Figure 8 using Savonius overlap. The Savonius form uses the myring equation n = 1 by adding a circular cylinder. The stagger angle parameters were varied at angles of 45°, 50°, 55°, and 60° located upstream of the returning blade at a wind speed of 5 m / s.

Figure 7 shows that the smaller the value of the tip speed ratio. Parameters of the torque coefficient will increase and vice versa. All variations of the stagger angle experience the same condition. This is influenced by the loading factor on the turbine shaft which has an impact on the magnitude of the torque coefficient produced. The load received by the shaft impacted the results of the torque coefficient which would increase and the tip speed ratio value would decrease.

The trend of the torque coefficient curve tends to decrease against tsr. The studies show that the value of the torque coefficient is the largest at a stagger angle of 60° compared to without a cylinder. This shows that the cylinder increased the speed on the returning end side so that the convex returning pressure decreased. A cylinder affects decreasing on the pressure drag value, and the returning side torque value will also decrease at a stagger angle of 60°. The effect of decreasing the returning side torque value will increase the Savonius turbine torque.

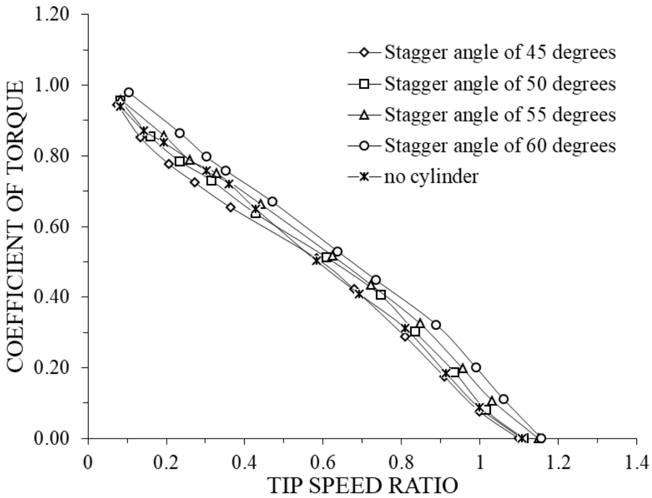

Figure. 8. Torque coefficient as the function of tsr

The power coefficient equation as a function of λ is shown in Figure 8. The smaller the tip speed ratio value, the higher the power coefficient value, the power coefficient value will reach a maximum a certain tip speed ratio value, and then the power coefficient value will decrease as shown in Figure 8. This is in line with the turbine rotation which decreases and approaches a stop due to the loading on the turbine shaft. The overlap-modified Savonius wind turbine has a bigger power coefficient value than the original Savonius wind turbine because the overlap-modified wind turbine does not have a shaft in the middle of the turbine so that the air captured on the concave advancing blade will be reflected to the convex surface at returning side, increasing the convex surface at the returning side torque so that the net Savonius torque increases. The overlap gap functions to reflect fluid from the advancing blade and the fluid will push the convex side of the returning blade so that the rotation and performance of the Savonius wind turbine increases.

The blade shape using the Myring equation n = 1 has a little drag force on the convex side compared to the bucket blade. The decrease in drag on the convex side will increase the torque on the advancing side and decrease the torque on the returning side. This has an impact on improving the net torque of the Savonius wind turbine. In addition, accompanied by the use of overlap increased the torque again and will increase the performance of the Savonius turbine on the power coefficient. The performance of Savonius turbine with overlapping blades and Myring shape n = 1 at a wind speed of 5 m/s varying the stagger angle of the cylinder. The results show that the Savonius wind turbine with overlapping blades myring n = 1 with a cylinder upstream of the returning blade experiences an increase in performance from 45° to 60°.

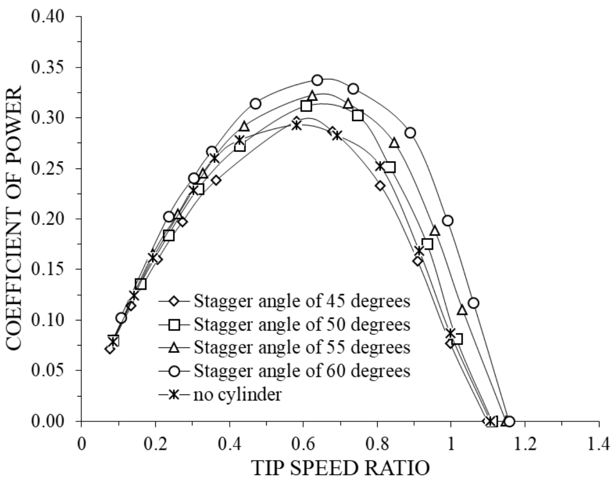

Figure. 9. Torque coefficient as the function of tsr

At a stagger angle of 45° has the lowest coefficient of power of 0.297 at a tip speed ratio of 0.582 this occurs because at a stagger angle of 45° the circular cylinder is less effective in covering the returning blade area and tends to interfere with the advancing blade. This causes the fluid flow that will pass through the advancing blade also to be blocked so that the flow that hits the advancing blade is not optimal this incident makes the difference in drag force on the advancing blade and the returning blade small which has an impact on the performance of the turbine decreasing.

The highest performance occurs at a stagger angle of 60° with the largest power coefficient of 0.337 at a tip speed ratio of 0.637 and an increase of 15.18% over the Savonius overlap myring turbine n = 1 without a cylinder. This is because the 60° cylinder stagger angle can block the fluid flow that hits the returning blade, resulting in a greater difference in drag force and making the turbine rotate faster. This is suitable to research conducted by Setiawan et al [12] where the best angle obtained was 60°. The following is a comparison table of the torque and power coefficient values for each variation at a wind velocity of 5 m/s.

TABLE 2.
VALUE OF CP EACH VARIATION AT SPEED 5 M/S

Variations	TSR	Cp	Improvement (%)	ket.
Overlap no cylinder	0.582476	0.293	0	
Stagger angle of 45°	0.582476	0.297	1.33	Increase
Stagger angle of 50°	0.607619	0.312	6.40	Increase
Stagger angle of 55°	0.624380	0.322	10.05	Increase
Stagger angle of 60°	0.63695	0.337	15.18	Increase

IV. CONCLUSION

The increase of Savonius turbine performance after overlap modification of blades with myring n = 1 profile and variation of stagger angle of circular cylinder located in upstream of returning blade obtained highest Cp at a stagger angle variation = 60° has the power coefficient of 0.337 at a tip speed ratio of 0.637 and an increase of 15.18% over the Savonius overlap myring turbine n = 1 without a cylinder.

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