Research Article

An Experimental Investigation of the Effect of Placing a Cylinder in Front of the Returning Side on Overlap Savonius Wind Turbine Performance

Dany Iman Santoso[a], Priyo Agus Setiawan[b*], Projek Priyonggo Sumangun Lukitadi[b], Emie Santoso[b], Budi Prasojo[b], Bambang Antoko[b], Anda Iviana Juniani[b], Adi Wirawan Husodo[b], Endang Pudji Purwanti[c]

[a] Faculty of Engineering, Universitas Negeri Surabaya, Kampus Unesa Ketintang, Jalan Ketintang, P. O. Box: 60231, Surabaya, East Java, Indonesia.
[b] Department of Marine Engineering, Politeknik Perkapalan Negeri Surabaya, Jalan Teknik Kimia Kampus ITS Keputih-Sukolilo, P. O. Box: 60111, Surabaya, East Java, Indonesia.
[c] Department of Shipbuilding Engineering, Politeknik Perkapalan Negeri Surabaya, Jalan Teknik Kimia Kampus ITS Keputih-Sukolilo, P. O. Box: 60111, Surabaya, East Java, Indonesia.

ABSTRACT

Wind is a renewable energy source and has potential for developing the Savonius wind turbine. However, the Savonius turbine typically exhibits low performance and requires further optimization. One approach to enhance its performance is through overlap modification, which improves turbine rotation efficiency. Additionally, adding a cylinder in front of the returning blade can further increase performance by reducing drag force. In this study, the turbine's performance was enhanced using both overlap modification and an additional disturbance cylinder. The experimental setup employed an original Savonius wind turbine with a diameter and height of 0.4 m, an overlap ratio of 0.3, and a cylinder with a diameter ratio of $d_s/d=0.4$. Various distance ratios (S/d) of 1.4, 1.7, 2.0, and 2.3 were tested under wind velocities of 5 m/s, 6 m/s, and 7 m/s. The resulting torque and power coefficients were measured. The best performance was achieved at a distance ratio of 1.7 and a wind velocity of 5 m/s, with the power coefficient (Cp) increasing by approximately 21.13% compared to the original Savonius turbine.

1. INTRODUCTION

Indonesia, as a tropical country, experiences low wind velocities ranging from 3 m/s to 6 m/s annually. The minimum velocity of approximately 5 m/s is sufficient to spin a wind turbine, indicating that the potential for wind energy is relatively low based on the mean annual wind speed, according to the IESR report (Puspitarini, 2021). In comparison, solar photovoltaic energy and wind power potential are 7,714.6 GW and 194 GW, respectively, for both offshore and onshore installations. Energy development to enhance turbine performance has been pursued in several Southeast Asian countries. Governments in Vietnam, Thailand, Malaysia, and Indonesia collectively account for approximately 84% of the region's total renewable energy capacity. Among these countries, the Philippines has the smallest capacity at 6.695 MW, followed by Malaysia (8.046 MW), Indonesia (9.861 MW), Thailand (11.860 MW), and Vietnam (24.519 MW) (Puspitarini, 2021). Several studies have focused on improving the performance of Savonius turbines, which generally exhibit lower efficiency compared to other turbine types. Enhancements include modifications to the turbine shape, number of blades, and the addition of deflectors or cylinders on the advancing or returning sides. Turbine shape significantly affects performance; for example, helical designs have shown improved efficiency compared to the original shape (Hassanzadeh et al., 2013). Using the Myring equation with n = 1 has also been shown to yield higher C_p compared to other values of n (Wenlong et al., 2014). When applied to the Savonius turbine, the Myring formulation with n=1 produced the best performance at an overlap ratio of 0.2 (Setiawan et al., 2021). The blade surface designed using the Myring equation with n = 1 improved performance through the addition of a cylinder, with the best performance, Cp, occurring at a cylinder-to-turbine diameter ratio of 0.4 (Setiawan et al., 2021). Turbine performance further increased when the cylinder was located on the advancing blade side for the Myring profile with n = 1. The best performance occurred at a cylinder-to-turbine diameter ratio of 0.4 (Setiawan et al., 2023). Cylinder rotation was also found to enhance the performance of the Savonius turbine across different diameter ratios. The highest performance, Cp, was achieved at a diameter ratio of 0.4, representing an improvement of approximately 66.193% compared to the configuration without a cylinder (Setiawan et al., 2023). The performance could be improved by varying the number of blades and by adding a cylinder and adjusting its position. Regarding the number of blades, Savonius turbines

with two blades exhibited the highest performance, with an optimal overlap ratio ranging from 0.1 to 0.15 (Sheldahl et al., 1978). Experimental studies on blade geometry were conducted to determine the optimal operating parameters by varying the number of blades from two to four. The results showed that the two-blade configuration had the highest performance compared to the three- and four-blade configurations. The use of end plates resulted in higher performance compared to turbines without end plates. In addition, double-stage rotors demonstrated better performance than single-stage rotors (Mahmoud et al., 2012). The overlap ratio can enhance performance by adding a drag force in the direction of turbine rotation on the returning side. A numerical study was conducted on the Savonius turbine with variations in overlap ratio, showing that the overlap ratio reduced negative torque and increased net torque. The results indicated that the best Cp occurred at an overlap ratio of 0.2 (Patel et al., 2013). Experimental validation of the overlap ratio effect on turbine blades was performed using CFD. Optimization of turbine performance can be achieved through three-dimensional simulations to obtain the best agreement with experimental validation (Yaakob et al., 2012). The experimental study has confirmed that numerical simulations show that the best overlap ratio occurs in the range 0.20 – 0.25 (Yaakob et al., 2013). A cylinder located in front of the advancing blade with varying stagger angles was investigated, and the best result occurred at a stagger angle of 60 degrees, with a Cp value of 0.4356 (Rohman et al., 2024). The addition of a cylinder with varying cylinder diameter, stagger angle, and cylinder distance was performed by locating the cylinder in the advancing region. The results showed that the highest performance was achieved at a cylinder-to-turbine diameter ratio of 0.4. Increasing the cylinder diameter increased the local velocity of the attached flow near the blade, which increased the velocity and reduced the pressure near the advancing blade, thereby increasing the positive torque. The effect of stagger angle also improved turbine performance, as a larger attached flow area near the cylinder reduced the pressure and increased the positive torque. The optimal stagger angle was observed at 60 degrees (Setiawan et al., 2019a). On the other hand, the use of a deflector relative to the turbine can also enhance Savonius turbine performance. A curtain-type deflector design located in front of the turbine has been implemented to increase Cp, with the best result obtained for curtain 1 at θ = 60° and angles β = 15° and α = 45° (Altan et al., 2008), (Altan et al., 2010). An experimental study on the use of deflectors showed that the highest Cp increased by approximately 38.5% when the optimal curtain arrangement was applied (Fatahian et al., 2022). Experimental investigations of Cp have also been conducted in wind tunnels and water channels using deflectors (Salleh et al., 2021). The Cp value improved by approximately 15% at a tip speed ratio, λ, of 1.2 (Kerikous et al., 2019).

Wind flow characteristics can significantly influence turbine performance, as changes in wind velocity affect turbine operation. At wind velocities lower than 4 m/s, the best performance was observed at an overlap ratio of 0.15, whereas at wind velocities greater than 4 m/s, turbulent flow conditions were present, with an optimal overlap ratio of 0.30 being recommended (Tania et al., 2018). Experimental studies on cylinder cuts showed an improvement in Cp of approximately 12.2% at an S/D ratio of 1.4 and a tip speed ratio, λ, of 0.65 (Yuwono et al., 2020). The effect of a circular cylinder with varying stagger angles was also investigated, and the highest performance was obtained at a stagger angle of 60 degrees, with

a performance increase of approximately 29.84% at a λ value of 0.9 (Setiawan et al., 2019b). The results further showed that a cylinder can enhance turbine performance, with the highest improvement of approximately 22.267% occurring at y/D = 0.75 (Setiawan et al., 2022). A cylinder located in front of the returning blade may either increase or reduce the performance of a Savonius turbine. This behavior is influenced by the wake released from the cylinder surface, which can cover the advancing blade area. The present work employs a two-blade Savonius turbine with a circular cylinder located in the front region of the returning side at various distance ratios, S/d, of 1.4, 1.7, 2.0, and 2.3, under wind velocities of 5 m/s, 6 m/s, and 7 m/s, representing Indonesian wind conditions. The objective of this study is to evaluate the torque coefficient, CT, and the power coefficient, Cp.

2. EXPERIMENTAL METHOD

2.1 Savonius Arrangement

This work will be carried out as an experimental study using a Savonius model with a diameter and height of 400 mm each. The Savonius model will be tested at the exit of a wind tunnel with a cross-sectional area of 300 mm × 300 mm. The parameters used to determine turbine performance, as shown in Figure 1, include the distance, S, the turbine diameter, d, and the small cylinder diameter, ds. The turbine diameter, d, is 400 mm, while the distances S are 560 mm, 680 mm, 800 mm, and 920 mm, corresponding to dimensionless distance ratios, S/d, of 1.4, 1.7, 2.0, and 2.3. The ratio of the cylinder diameter to the turbine diameter is a dimensionless parameter denoted as ds/d. The cylinder diameter, ds, is 160 mm, resulting in a ds/d value of 0.4. The experimental study will evaluate turbine performance in terms of the power coefficient. This study employs the original Savonius turbine, with the cylinder acting as a passive control device to enhance turbine performance. The cylinder arrangement is located in front of the returning blade region, corresponding to the upstream flow, as illustrated in Figure 1. The Savonius turbine used in the experiment has two blades with a height of 0.4 m and a diameter of 0.4 m, and a rotating cylinder operating at 20 rpm is positioned in the front region of the returning blade. The parameters include a fixed cylinder-to-turbine diameter ratio of ds/d = 0.4. The gap at the center of the turbine relative to the turbine diameter is defined as the overlap, e. The overlap gap of the Savonius turbine is 120 mm, resulting in an overlap ratio of approximately 0.3.
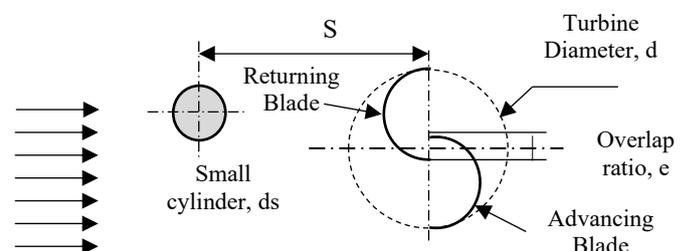

Figure 1. Cylinder arrangement in front of returning

2.2 Experimental Study

The experimental model will be installed downstream of the wind tunnel with a honeycomb to position the Savonius model. Subsequently, the airflow will pass through the honeycomb to produce a uniform flow, and the cylinder will rotate at a constant speed of approximately 20 rpm. The rotation measurement is performed using a tachometer, as shown in

Figure 2. Turbine rotation can be determined using a digital tachometer with a measuring range from 0.05 to 7.6 m, and an accuracy of 0.01% or ±1 digit. The tip speed ratio, or λ, will be determined by turbine rotation.

Figure 2. Tachometer

The calculation of λ uses the turbine rotational speed as presented in equation (1). The experiment is conducted by adding mass to a weighing pan (kg) until the turbine rotation approaches cessation. The weighing pan is installed on the returning side of the turbine and is denoted as m1, while the spring balance is denoted as m2, and the variables m1 and m2 are shown in Figure 3. The weighing pan mass, in kg, and the spring balance reading, in kg, are used to determine the net weight, from which the torque is obtained as expressed in equation (2). Subsequently, the torque coefficient is determined using equation (3). The tachometer is used to measure the turbine rotational speed in rpm, and this value is then employed to calculate the power coefficient as an indicator of turbine performance. Figure 4 illustrates the experimental setup, which includes the blower, the wind tunnel, and the honeycomb. The equations for λ, torque, power, C_T, and C_p are calculated using Equation (1) to (4), respectively. The parameters m_1, m_2, and dp are used to calculate the torque (T) and torque coefficient (C_T). The power coefficient (C_p) is calculated by multiplying the torque coefficient (C_T) by the tip speed ratio (λ).
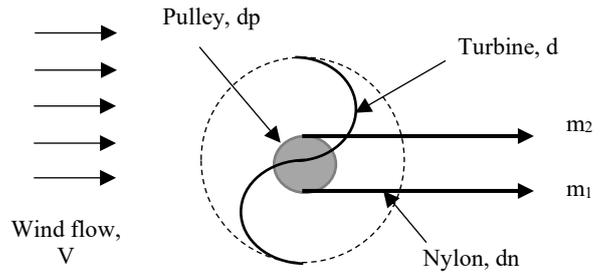

Figure 3. Torque measurement of a top view

$$\lambda = \frac{U}{V} = \frac{\omega \, D}{2.V} \tag{1}$$

$$T = (m_1 - m_2).g.\frac{(d_p + d_n)}{2} \tag{2}$$

$$C_T = \frac{4,T}{\rho, A_s, d, U^2} \tag{3}$$

$$C_p = C_T, \lambda \tag{4}$$

The tip speed ratio is denoted by λ, the torque is represented by T in N.m, the turbine rotation is ω in rad/s, and the Savonius turbine diameter is d in m. The high load is denoted by m_1 in kg, and the low load by m_2 in kg. The gravitational acceleration, g, is 9.81 m/s². The pulley diameter, dp, is 0.032 m, and the nylon diameter, dn, is 0.0015 m.

The fluid density (ρ) is 1.225 kg/m³, the projected area for the turbine (A_s) is 0.16 m², power coefficient is C_p, and linear velocity is U in m/s.

Experimental studies were conducted by collecting data in the laboratory, and the quality of the experimental data was assessed by evaluating the associated uncertainty values.

The uncertainty calculations included parameters used in data collection during laboratory testing, such as density, angular velocity, torque, area, diameter, and the power coefficient. The uncertainty value of the power coefficient is 2.106%, and the results of the uncertainty analysis are presented in Table 1.
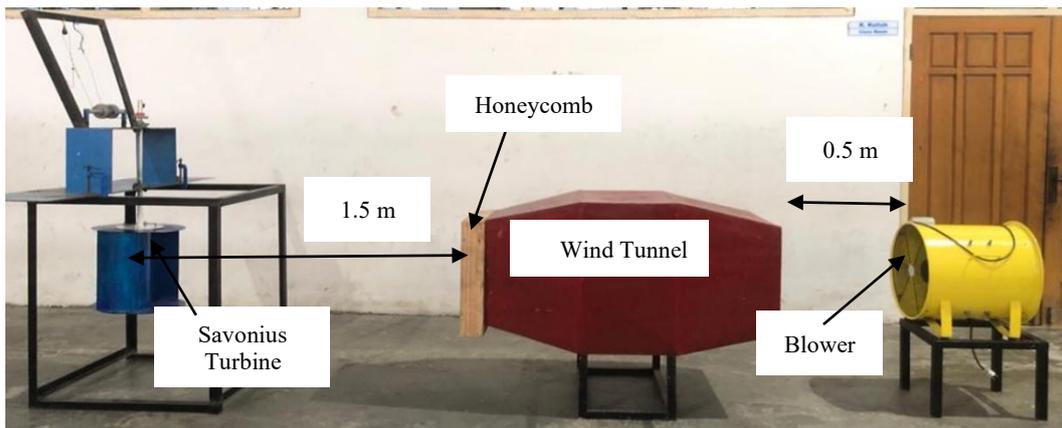
Figure 4. Experimental Set-up

Tabel 1. Uncertainty analysis

Variables	Symbol	Uncertainty Value (%)
Density	ρ	0.0151
Angular velocity	ω	0.71
Torque	T	0.5006
Area	A	0.35
Turbine Diameter	d	0.25
Power coefficient	Cp	2.106

The uncertainty calculations included parameters used in data collection during laboratory testing, such as density, angular velocity, torque, area, diameter, and the power coefficient. The uncertainty value of the power coefficient is 2.106%, and the results of the uncertainty analysis are presented in Table 1. Based on the uncertainty analysis, the power coefficient uncertainty of 2.106% indicates that the measurement certainty is 97.89%.

3. RESULTS AND DISCUSSION

The experimental study shows that the turbine performance, expressed by Cp, has a value of 0.18 at a wind velocity of 7 m/s. This result indicates that the performance approaches validation with other turbines, which typically exhibit Cp values in the range of 0.15–0.3 for the original wind turbine.

3.1 The power Coefficient for velocity velocity 5 m/s

The graph of Cp versus the tip speed ratio (λ) at a wind velocity of 5 m/s is shown in Figure 5. The Cp increases to reach a maximum at a certain λ, and then decreases as the value of λ continues to increase.

The original Savonius turbine has a Cp of approximately 0.328 at λ = 0.8 and is compared with configurations incorporating an overlap to improve performance. Wind turbines with overlap exhibit a Cp of 0.342 at λ = 0.654, representing an increase of approximately 4.27%. For the parameter S/d = 1.4, the Cp is around 0.265 at λ = 0.834, indicating a performance decrease of 19.18%. For S/d = 1.7, the Cp reaches approximately 0.397 at λ = 0.8, representing a performance increase of 21.13%. For S/d = 2.0,

the Cp is 0.237 at λ = 0.419, resulting in a performance decrease of 27.68%, while for S/d = 2.3, the Cp is 0.211 at λ = 0.49, decreasing performance by 35.56%. The best performance is achieved by the Savonius turbine with an overlap and an additional cylinder positioned in front of the returning area for S/d = 1.7.

This configuration outperforms both the original turbine and other overlap configurations. The improved performance at S/d = 1.7 is attributed to the cylinder effectively reducing the drag force on the returning blade. The difference in drag force between the advancing and returning blades is a key factor in optimizing turbine performance. When a small cylinder is positioned close to the returning blade, the wake formed by the cylinder interacts with the returning area, causing increased pressure and reducing the drag force difference between the advancing and returning blades, which decreases turbine performance.

If the cylinder is placed at a very short distance from the returning blade, the wake can disturb airflow to the advancing blade, reducing the positive torque contribution from the overlap gap. Conversely, increasing the S/d distance towards the returning side also reduces performance because the wake interaction on the returning blade is less effective in lowering drag force, resulting in higher returning pressure and a smaller drag force difference. At longer distances, the cylinder wake can still disturb airflow to the advancing blade, but this effect reduces positive torque and overall performance. The performance improvements for all S/d configurations at a wind velocity of 5 m/s are summarized in Table 2.
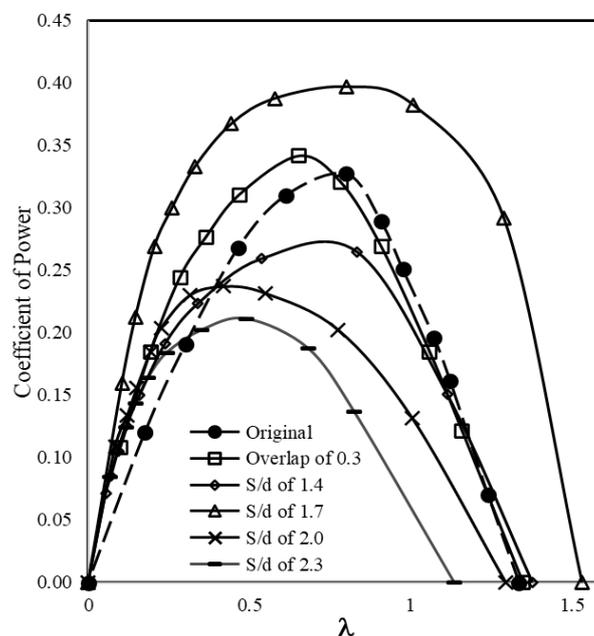

Figure 5. Coefficient of Power-λ for variation of distance S/d= 1.4, 1.7, 2.0 and 2.3 at wind velocity 5 m/s for ds/d = 0.4

Table 2. The Cp improvement at a wind velocity of 5 m/s

Parameters	N (RPM)	ω (rad/s)	λ	Cp	Improvement (%)	Results
Without cylinder	191	20.010	0.8	0.328	0	-
Overlap without cylinder	156	16.343	0.654	0.342	4.27	Increase
Overlap ratio for S/d= 1.4	199	20.848	0.834	0.265	-19.18	Decrease
Overlap ratio for S/d= 1.7	191	20.010	0.8	0.397	21.13	Increase
Overlap ratio for S/d= 2.0	100	10.476	0.419	0.237	-27.68	Decrease
Overlap ratio for S/d= 2.3	117	12.257	0.49	0.211	-35.56	Decrease

3.2 The power Coefficient for wind velocity 6 m/s

Figure 6 shows the graph of the power coefficient (Cp) versus the tip speed ratio (λ) at a wind velocity of 6 m/s. From the graph, Cp increases to reach a maximum value and then decreases as λ continues to increase. The original Savonius turbine has a Cp of 0.258 at λ = 0.657. When compared to the Savonius turbine with overlap, the performance increases slightly, with a Cp of 0.262 at λ = 0.74, representing an improvement of 1.49%. However, when the original turbine is compared to configurations with an overlap and an added cylinder, the Cp decreases.

For S/d = 1.4, Cp is 0.158 at λ = 0.402, corresponding to a performance reduction of approximately 38.78%. For S/d = 1.7, Cp is around 0.186 at λ = 0.44, with a decrease in performance of 27.93%. For S/d = 2.0, Cp is approximately 0.126 at λ = 0.311, resulting in a performance decrease of 51.18%, and for S/d = 2.3, Cp is around 0.102 at λ = 0.339, corresponding to a decrease of 60.48%. The highest performance of the wind turbine is achieved with the overlap Savonius configuration.

The overlap Savonius turbine exhibits a higher Cp than the original bucket-type Savonius turbine. This improvement is attributed to the presence of the overlap rather than the central shaft, as the airflow entering the overlap enhances the drag force on the returning blade, increasing the effective torque and improving turbine rotation compared to the original design. The overlap Savonius also demonstrates a higher Cp than configurations with an added cylinder. The cylinder is not effective in reducing the drag force on the returning side; although the pressure at the returning side may increase, the drag force difference between the two blades is reduced, resulting in a lower Cp. Analysis indicates that wake formation from the cylinder in the downstream area at a wind velocity of 6 m/s disturbs the airflow to the advancing blade, and the overlap only increases the positive torque insignificantly.

Additionally, the advancing blade in the overlap configuration is smaller than that of the original turbine, which limits performance gains when a cylinder is added. All S/d variations of the cylinder result in a decrease in Cp compared to the overlap turbine.

When the cylinder is positioned near the returning blade, the wake interacts with the returning flow, increasing pressure on the returning side and reducing the net drag, which decreases turbine performance.

Furthermore, the cylinder wake near the returning side disturbs the airflow to the advancing blade, and the overlap is unable to significantly enhance the positive torque. When the cylinder is positioned farther from the returning blade, the performance is reduced because the downstream wake interacts with the returning surface and disrupts the airflow to the advancing side.
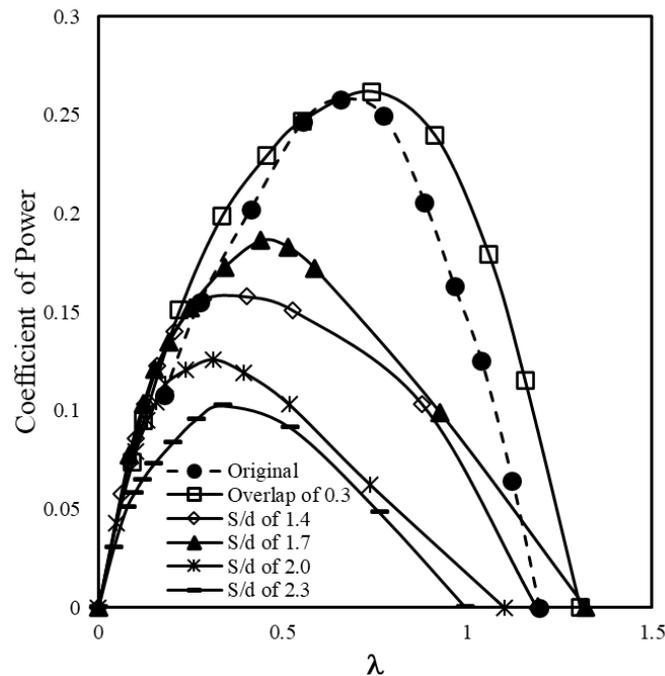

Figure 6. Coefficient of Power-λ for variation of distance S/d= 1.4, 1.7, 2.0 and 2.3 at a wind velocity of 6 m/s for ds/d = 0.4

Table 3. The Cp improvement at a wind velocity of 6 m/s

Parameters	N (RPM)	ω (rad/s)	λ	Cp	Improvement (%)	Results
Without cylinder	188	19.695	0.657	0.258	0	-
Overlap without cylinder	212	22.210	0.74	0.262	1.49	Increase
Overlap ratio for S/d= 1.4	115	12.048	0.402	0.158	-38.78	Decrease
Overlap ratio for S/d= 1.7	126	13.200	0.44	0.186	-27.93	Decrease
Overlap ratio for S/d= 2.0	89	9.324	0.311	0.126	-51.18	Decrease
Overlap ratio for S/d= 2.3	97	10.162	0.339	0.102	-60.48	Decrease

As a result, the overlap is unable to improve the Cp value. A comparison of the performance for all configurations at a wind velocity of 6 m/s is presented in Table 3.

3.3 The power coefficient for wind velocity 7 m/s

The Cp as a function of the tip speed ratio (λ) at a wind velocity of 7 m/s is shown in Figure 7. The graph indicates that Cp increases to reach a peak value and then decreases as λ continues to increase.

The original Savonius turbine has a Cp of approximately 0.188 at λ = 0.641. In comparison, the overlap Savonius turbine achieves a Cp of around 0.213 at λ = 0.805, representing a performance enhancement of 13.32%. For configurations with an added cylinder, performance decreases are observed. At S/d = 1.4, Cp is approximately 0.122 at λ = 0.688, corresponding to a reduction of 35.05%. For S/d = 1.7, Cp is 0.152 at λ = 0.835, with a decrease of 19.08%. At S/d = 2.0, Cp is 0.083 at λ = 0.449, resulting in a performance decrease of 55.81%. For S/d = 2.3, the Cp is approximately 0.071 at λ = 0.392, representing a performance decrease of 62.2%.

The highest performance is achieved by the overlap turbine, which exhibits a Cp higher than that of the original Savonius turbine. The overlap configuration lacks a central shaft, allowing it to generate additional positive torque on the returning blade.

3.4 The Power Coefficient Analysis for varying the wind velocity

All variations were analyzed for wind velocities from 5 m/s to 7 m/s. The analysis of velocity variations is presented in Figure 8, which shows that the best performance at each wind velocity occurs at a distance of S/d = 1.7, particularly at a wind velocity of 5 m/s.

The maximum Cp is observed at S/d = 1.7, with a value of approximately 0.397 at λ = 0.8. The results indicate that performance increases and reaches its optimum at S/d = 1.7, yielding a Cp higher than all other configurations. Furthermore, the performance analysis aligns with wind velocity data recorded in Indonesia (Puspitarini, 2021).

An interesting phenomenon occurs in the performance of Savonius wind turbines at very high wind speeds. When rotating rapidly, the turbine blades can form a configuration resembling a solid cylinder for the upstream airflow. In this state, the Savonius turbine is unable to efficiently capture the wind's kinetic energy, and the blades partially obstruct the flow from upstream to downstream. This phenomenon increases turbulence and reduces overall efficiency.
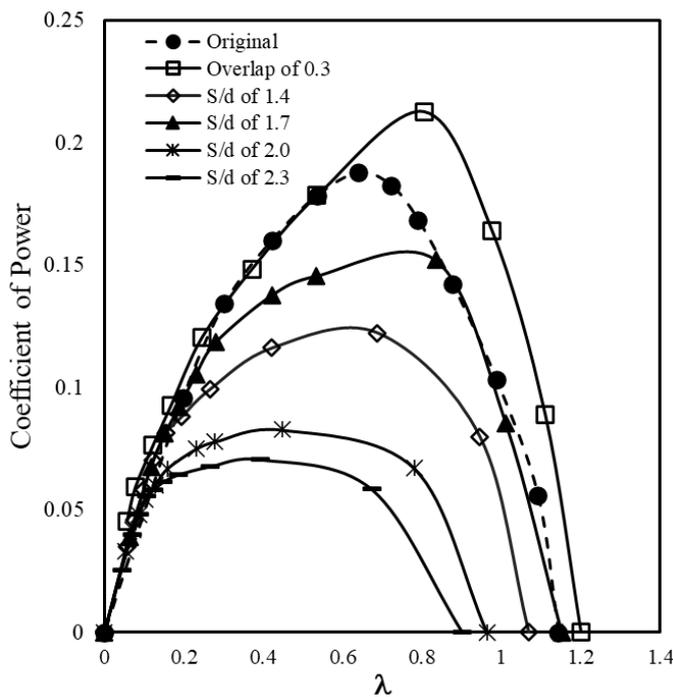
Figure 7. Coefficient of Power-λ for variation of distance S/d= 1.4, 1.7, 2.0 and 2.3 at wind velocity 7 m/s for ds/d = 0.4
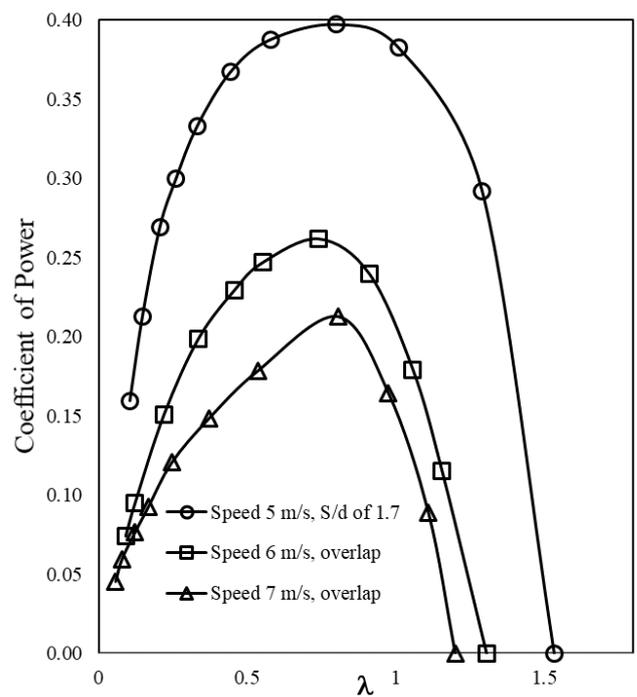
Figure 8. Coefficient of Power-λ for the best performance of each wind velocity

Table 4. The Cp improvement at the wind velocity of 7 m/s

Parameters	N (RPM)	ω (rad/s)	λ	Cp	Improvement (%)	Results
Without cylinder	214	22.419	0.641	0.188	0	-
Overlap without cylinder	269	28.181	0.805	0.213	13.32	Increase
Overlap ratio for S/d= 1.4	230	24.095	0.688	0.122	-35.05	Decrease
Overlap ratio for S/d= 1.7	279	29.229	0.835	0.152	-19.08	Decrease
Overlap ratio for S/d= 2.0	150	15.714	0.449	0.083	-55.82	Decrease
Overlap ratio for S/d= 2.3	131	13.723	0.392	0.071	-62.20	Decrease

4. CONCLUSIONS

Experiments were conducted on a Savonius wind turbine with an overlap, adding a small cylinder in front of the returning side at distance ratio variations of S/d = 1.4, 1.7, 2.0, and 2.3, across wind velocities of 5 m/s, 6 m/s, and 7 m/s. All variations demonstrate an improvement in the performance of the Savonius turbine, with the best performance observed at S/d = 1.7 and a wind velocity of 5 m/s. The maximum power coefficient (Cp) achieved is 0.397 at a tip speed ratio (λ) of 0.8, representing an increase of 21.13% compared to the original Savonius turbine. These results support the suitability of this turbine configuration for energy applications in Indonesia.

5. ACKNOWLEDGEMENT

NOMENCLATURE

Cp	Coefficient of power
λ	Tip Speed Ratio
ω	Angular velocity [rad/s]
d	Turbine diameter [m]
ds	Cylinder diameter [m]
S	Distance [m]
T	Torque [N.m]
m_1	Spring balance for advancing [kg]
m_2	Spring balance for returning [kg]
d_p	Pulley diameter [m]
d_n	Nylon diameter [m]
g	Gravity [m/s^2]
ρ	Density of air [kg/m^3]
As	Area of turbine [m^2]
U	Linear velocity of turbine [m/s]
S/d	Ratio distance to turbine diameter
ds/d	Ratio cylinder to turbine diameter

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