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Performance Investigation of the Savonius Wind Turbine by Putting a Rotating Cylinder in the front of Advancing by Varying the Diameter and Stagger Angle

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***Abstract*— The wind energy is the one of the renewable energy to produce the power using turbine. The Savonius turbine have lower performance compared to the other. In this work, the method used is the experimental stu using the wind tunnel to flow air go to the Savonius turbine. The model used is a conventional Savonius wind turbine by adding cylinder installed in front of advancing area with a diameter of 0.4 m and a height of 0.4 m and ds/d of 0.1, 0.2, 0.3, and 0.4 with the rotation of 20 rpm at a stagger angle of 0°, 30°, 60°, and 90°. The experiment is kept constant at the velocity of 7 m/s. This work objective will determine the torque and power coefficient by varying the diameter and stagger angle. The results show that the biggest performance decreased was about 40% in the variation of ds/d of 0.3 with a stagger angle of 0°. The best results show that the wind turbine performance occurred the highest improvement in about 12% at the variation of ds/d = 0.4 with a stagger angle of 60°.**

Keywords—Savonius, circular cylinder, coefficient of torque, coefficient of power, stagger angle.

I. Introduction

Wind energy is a type of renewable energy that can be utilized. Therefore, wind energy can be used as a source of electrical energy generation. Utilization of wind energy can be used to rotate the wind turbine shaft which is transmitted to an electric generator.

Savonius wind turbines have low efficiency and performance. Therefore modifications have improved its performance such as the shape and variations of turbine blades, such as adding overlap ratios. The conclusion explains that the wind speeds will affect the performance. Wind velocities less than 4 m/s are suitable using the overlap of 0.15. A range of exceeds 4 m/s has a turbulent, the recommendation is in the overlap of 0.30 [1]. The Myring shape is performed to show the best performance at n = 1 [2]. The application myring is applied by varying overlap indicating the best overlap at 0.2 [3]. Myring study with the addition of cylinders can increase the Savonius performance by change the cylinder diameter indicating that the ds/D of 0.4 has the best Cp [4]. The myring for n = 1 also is performed by installing the cylinder and varying the stagger angle. The best stagger angle occurred at 60 degrees with Cp in about 0.4356 [5].

Additional circular cylinders can increase the Savonius performance [6] and it can also be varied by angle, diameter ratio, and distance of the cylinder installed in the returning or advancing blade area [7], [8]. The cylinder placed in front of the returning can increase the Savonius performance (Cp) by around 12.2% at S/D = 1.4 and a tip speed ratio or tsr = 0.65 [9]. The circular cylinder in front of the Savonius turbine shows an increase in performance by rotating the cylinder [10]. The obstacle placed in front of the Savonius turbine has been employed to enhance the performance from curtain 1 at $\theta = 60^o$ for the angles $\beta=15^o$ and $\alpha=45^o$ [11]. The deflectors have been tested experimentally and the best Cp increased by about 38.5% with the best curtain arrangement [12]. The best power coefficient, its corresponding Value of Ct, and TSR obtained in the wind tunnel differ from the water channel results and validation of measurements in the wind tunnel toward the power performance for hydrokinetic applications by adding the flow deflectors [13]. The performance of Cp increases by about 15% for $\lambda = 1.2$ [14]. The deflector placed in front of returning and the cylinder at the advancing side show that the best performance occurs at defector angle of 45 degrees [15].

Based on the research background, cylinder ratio and stagger angle in front of turbine will increase the performance. Effect of rotating cylinder and cylinder will increase the velocity on upper or lower side, which is affect interaction with advancing blade influencing the the performance.

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In this work, an experimental study was carried out on a 2-blade Savonius wind turbine with an additional circular cylinder placed in front of the advancing blade with stagger angle variations of 0º, 30º, 60º, and 90º at variation of ds/d = 0.1, 0.2, 0.3, 0.4. The experiment is carried out using the wind tunnel to flow the air. The experiment was performed to investigate the performance of Savonius wind turbine in torque and power coefficient.

II. METHOD

The methods used are experimentally tested in a wind tunnel having the dimension a turbine diameter of 0.4 m, height of 0.4 m, and cylinder diameter ratio (ds/d) of 0.1, 0..2, 0.3, and 0.4 by varying the stagger angle of 0º, 30º, 60º, and 90º. The methods uses experiment to obtain the performance of the Savonius turbine. The turbine used is the conventional Savonius turbine disturbed by a cylinder as passive control to enhance the turbine performance. The cylinder will be placed in front of the advancing blade as displayed in Figure 1.

The turbine has height of 0.4 m and a diameter of 0.4 m installed the cylinder with rotation of 20 rpm. The cylinder has a variation of ds/d = 0.1, 0.2, 0.3, and 0.4. The cylinder will join motor drive by pulley to rotate the cylinder around 20 rpm. The cylinder will be placed in front of the advancing blade by varying stagger angles of 0º, 30º, 60º, and 90º as shown in Figure. 2. Every stagger will be measured by varying the diameter (ds/d) of 0.1, 0.2, 0.3, and 0.4.

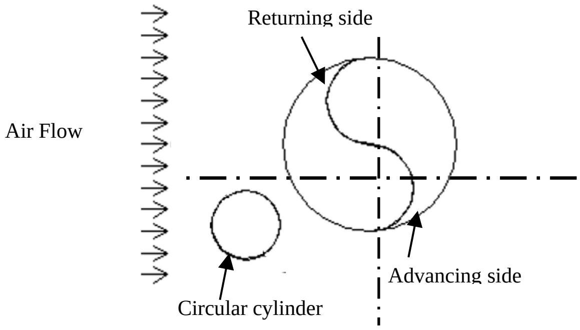

Figure. 1. Cylinder arrangement toward Savonius turbine

A. Experimental Setup

The experimental study will be performed at the exit of wind turbine over the honeycomb to keep the uniform flow. The cylinder rotation is kept constant at 20 rpm. Turbine rotation is measured by using a tachometer. Turbine rotation is used to calculate the tip speed ratio as shown in equation (1). The experimental study uses the spring balance and weighing pan to get the total weight taken by the Savonius turbine in kg until the turbine stops. The weighing pan is placed at the side of the returning blade which is mentioned m_1 and the spring balance is placed at the side of the advancing blade which is called m_2.

The spring balance and weighing pan in kg is used to measure the total weight used to calculate torque as shown in equation (2) and then the torque coefficient will be obtained using equation (3). The turbine rotation will be measured using the tachometer in rpm. The rotation of the turbine in rpm will be used to calculate the power as the turbine performance and then the power coefficient can be obtained. The experimental setup will be shown in Figure. 2. The equation of tip speed ratio, torque, torque coefficient, power, and power coefficient is represented in equation (1) up to (4), respectively.

$$\mathrm{TSR} = \frac{2.\omega}{d} \quad (1)$$

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

$$\mathrm{Ct} = \frac{4.\mathrm{T}}{\rho.A_s.d.U^2} \quad (3)$$

$$\mathrm{Cp} = \mathrm{Ct}.\mathrm{TSR} \quad (4)$$

The TSR is tip speed ratio, T is torque in N.m, ω is rotation of turbine in rad/s, d is diameter of Savonius turbine in m, m_1 is the big load in kg, m_2 is the small load in kg, g is gravitational acceleration in m/s^2, dp is diameter of pulley in m, d_n is nylon diameter in m, ρ is fluid density, A_s is area in m^2, U is linear velocity in m/s, and, Cp is power coefficient.

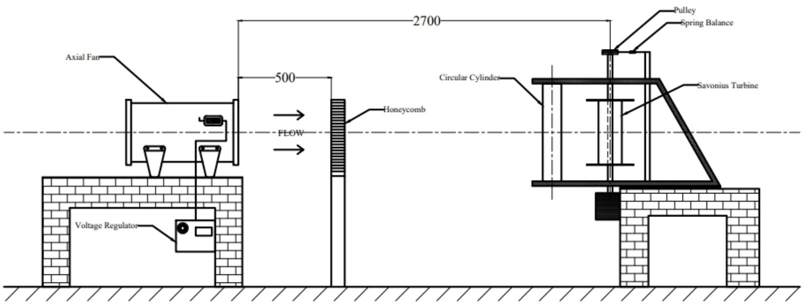

Figure. 2. Experimental Set-u

III. RESULTS AND DISCUSSION

The experimental results will be obtained data like the mass of loading in kg, and turbine rotation in rpm. Torque can be calculated from the mass of loading in kg and the radius of the pulley in meters. The rotation of the turbine will be used to calculate the power. The results will be represented in graphic torque and power coefficient.

A. Graphic Ct and Cp to TSR at a Stagger of 0 Degrees

The graph of the torque and power coefficient against TSR at a stagger angle of 0 degrees can be seen as shown in Figure 3 and Figure 4, respectively. The graph of the torque coefficient will tend to decrease by increasing the TSR. The results show that the torque coefficient is inversely proportional to TSR. The data was taken by increasing the load gradually with attention to the rotation of the Savonius turbine until it approached a stop. This proves that the decreasing turbine rotation will have an impact on increasing the load on the spring balance and the torque will increase.

The diameter variations show that the torque coefficient value decreases below without the cylinder. This shows that the total flow from upstream is blocked by the cylinder so that the flow will be decelerated on the side behind the cylinder. A decreasing flow velocity will cause the drag force in the convex area to decrease so that the torque coefficient will also decrease in all variations compared to without the cylinder. The cylinder rotation does not influence the result of torque and power coefficient.

The biggest problem at ds/d = 0^o is that the flow from the upstream is completely blocked on the advancing side causing the flow over the Savonius turbine to decrease and reduce drag force on the concave surface side impacting on decreasing the turbine power coefficient (Cp).

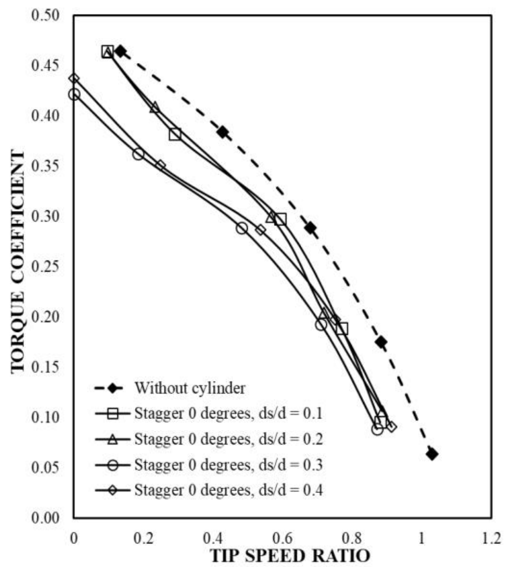

Figure. 3. Graphic of Ct to TSR at 0^o

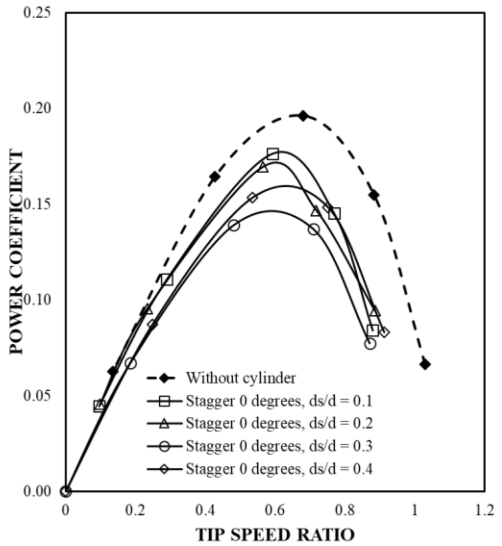

Figure. 4. Graphic of Cp to TSR at 0^o

B. Graphic Ct and Cp to TSR at Stagger of 30 Degrees

The torque and power coefficients as a function of TSR at a stagger angle of 30 degrees can be seen in Figure 5 and Figure 6, respectively. The torque coefficient at all variations has trend decreased by increasing the TSR. Variations do not show a significant increase in the torque coefficient. The torque coefficient at ds/d = 0.1 and 0.2 shows that the trend decreases compared the conventional. This shows that the flow from upstream is disturbed due to the formation of the wake behind the cylinder so the cylinder at ds/d = 0.1 and 0.2 does not effectively influence the torque coefficient of the Savonius turbine. The cylinder rotation is not significant to improve the torque coefficient. The analysis of ds/d = 0.3 and 0.4 shows that the Ct value has a trend of curve increase. The cylinder installed in the advancing blade will increase the torque coefficient. The cylinder can influence torque significantly and the flow across the convex advancing side increases the velocity and decreases the pressure. The total pressure drag at the side of the advancing blade will increase pressure in the concave surface causing the net pressure in the advancing increases. The increase of the pressure on the advancing surface will increase the total pressure however, the torque will increase and the results show that the torque coefficient will increase.

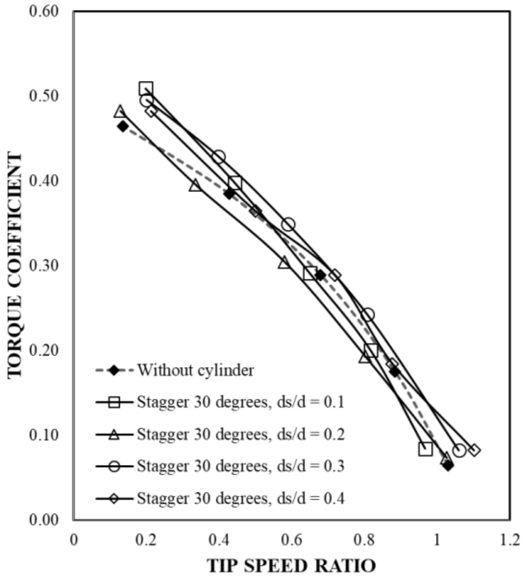

Figure. 5. Graphic of Ct to TSR at 30º

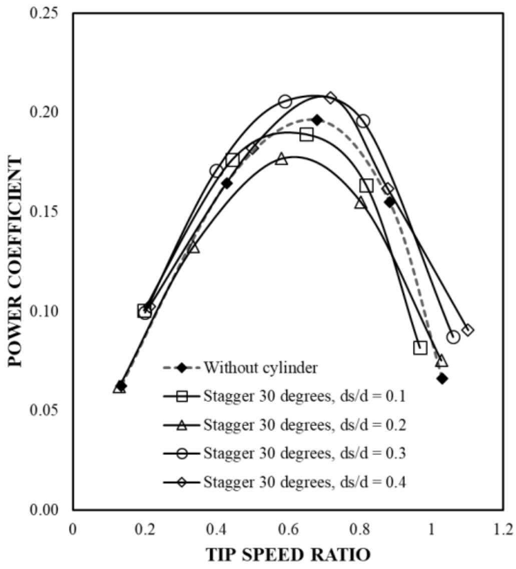

Figure. 6. Graphic of Cp to TSR at 30º

The power coefficient graph shows the peak performance of the Savonius turbine in each variation. The variation of ds/d = 0.1 and ds/d = 0.2, shows a decrease in the performance below the graph of without cylinders. This shows that a stagger angle of 30 degrees is not effective in increasing the performance of the wind turbine, even though the cylinder is rotated. This shows that the rotating cylinder has not significantly increasing the net drag force on the Savonius turbine and the power coefficient value of the Savonius turbine has decreased compared to without the cylinder. However, at ds/d = 0.3 and 0.4, the rotating cylinder is very effective in increase the performance of the Savonius wind turbine with peak performance values exceeding the Savonius turbine without the cylinder. This shows that the rotating cylinder can increase the net drag force so that the rotating cylinder can increase the power coefficient of the Savonius turbine.

C. Graphic Ct and Cp to TSR at Stagger of 60 Degrees

The torque and power coefficients as a function of TSR at a stagger angle of 60 degrees can be seen in Figure 7 and Figure 8, respectively. The graphs for all variations show that the torque coefficient value increases compared to turbines without cylinders. This shows that the torque coefficient at a stagger angle of 60 degrees is very significant in increasing the net drag force on the Savonius turbine which causes an increase in the torque coefficient of the Savonius turbine. Likewise, variations in diameter show that the power coefficient increases compared to turbines without cylinders. This shows that a stagger angle of 60 degrees can increase the net drag force of the Savonius turbine which causes an increase in the power coefficient of the Savonius turbine. This is because the advancing side of the blade experiences acceleration on the concave side, thereby increasing the drag force on the advancing side and the net drag force will increase, causing an increase in the power coefficient in the Savonius turbine.

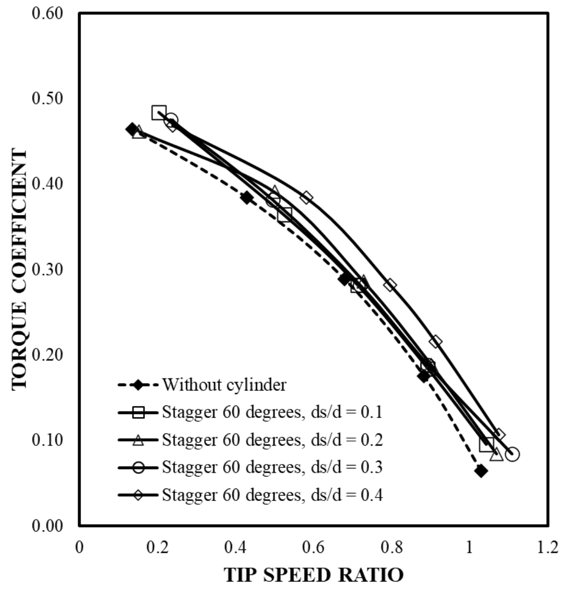

Figure. 7. Graphic of Ct and Cp to TSR at 60º

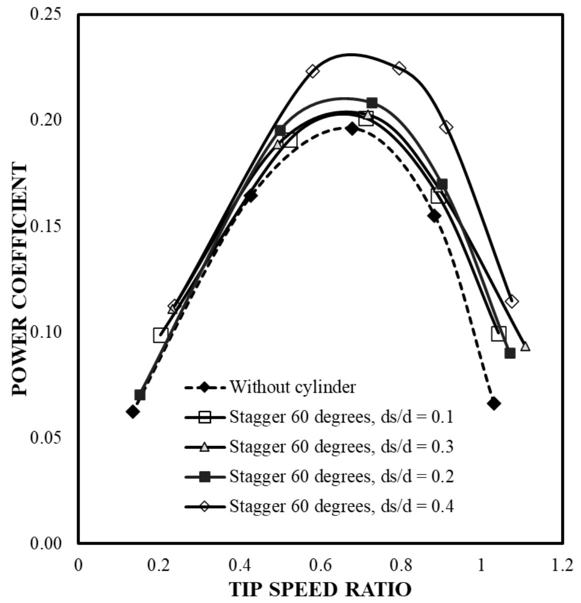

Figure. 8. Graphic of Ct and Cp to TSR at 60º

D. Graphic Ct and Cp to TSR at Stagger of 90 Degrees

The torque and power coefficients as a function of TSR at a stagger angle of 90 degrees can be seen in Figure 9 and Figure 10, respectively. The interaction between the turbine and the cylinder will influence the flow characteristics across the turbine in the advancing blade tip area. The nozzle effect will accelerate the flow on the blade surface, thereby reducing the pressure on the convex side.

All variations show that the torque coefficient value increases compared to turbines without cylinders. This shows that the torque coefficient at a stagger angle of 90 degrees is very significant in increasing the net drag force on the Savonius turbine which causes an increase in the torque coefficient of the Savonius turbine. Likewise, variations in diameter show that the power coefficient increases compared to turbines without cylinders. This shows that a stagger angle of 90 degrees can increase the net drag force of the Savonius turbine which causes an increase in the power coefficient of the Savonius turbine. This is because th advancing side of the blade experiences acceleration on the convex side, thereby increase the drag force on the advancing side and the net drag force will increase, causing an increase in the power coefficient in the Savonius turbine.

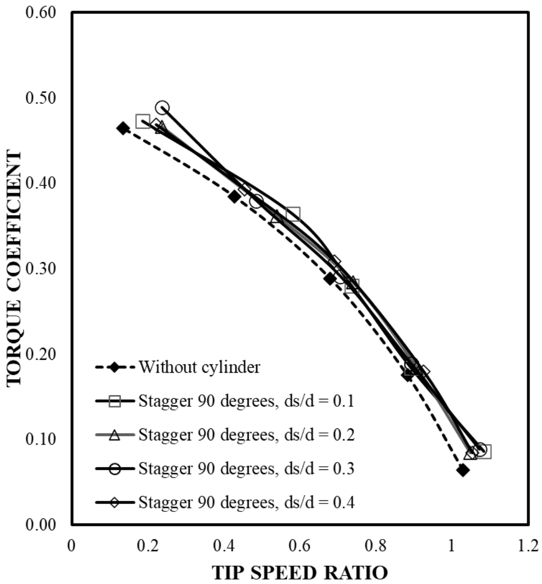

Figure. 9. Graphic of Ct and Cp with respect to TSR at 90º

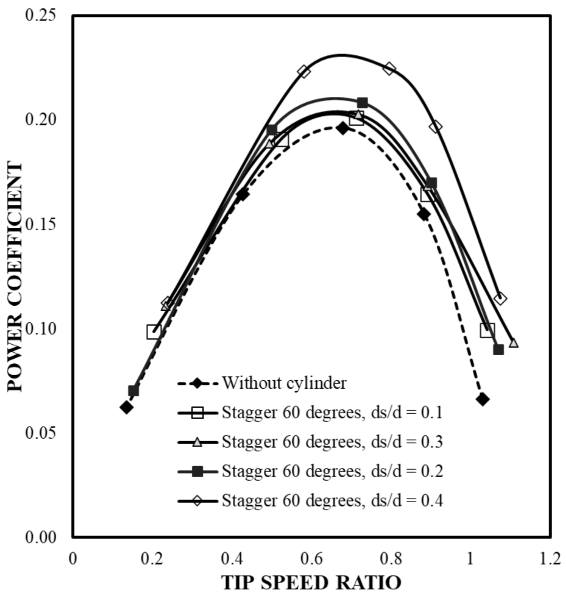

Figure. 10. Graphic of Ct and Cp with respect to TSR at 90º

E. The Improvement of Cp

The improvement of the power coefficient in % can be seen in Table. 1 for stagger angle 0 degrees. The power improvement will be calculated based on the turbine without the cylinder at various diameters at the stagger kept constant.

At a stagger angle of 0 degrees, it shows that all variations experience a decrease in performance which is marked with a negative sign. The influence of the cylinder in front of the advancing will cause the formation of a vortex. The vortex effect will increase the drag force on the advancing side which reduces the net drag force thereby reducing the torque coefficient and power of the Savonius turbine. The performance of the Savonius turbine decreased by 40 percent as can be represented in Table. 1.

A stagger angle of 30 degrees shows that the performance is still under the performance of the turbine without the cylinder. The performance at all diameter variations decreases by 10 percent as can be seen in Table. 2.

A stagger angle of 60 degrees shows that the performance is above the performance of turbine without the cylinder. The performance at all diameter variation increases by 12 percent as can be seen in Table. 3.

A stagger angle of 90 degrees shows that the performance is above the performance of the turbine without the cylinder. The performance at all diameter variation increases by 9 % as can be seen in Table. 4.

TABLE 1.
PEAK POWER COEFFICIENT AT STAGGER ANGLE 0 DEGREES

Variation	TSR	Cp	Improvement (%)
Without cylinder	0.630966	0.128921	--
stagger angle of 0º, ds/d of 0.1	0.525605	0.112237	-20%
stagger angle of 0º, ds/d of 0.2	0.500463	0.11043	-26%
stagger angle of 0º, ds/d of 0.3	0.449578	0.08418	-40%
stagger angle of 0º, ds/d of 0.4	0.489687	0.094493	-29%

TABLE 2.
PEAK POWER COEFFICIENT AT STAGGER ANGLE 30 DEGREES

Variation	TSR	Cp	Improvement (%)
Without cylinder	0.630966	0.128921	--
stagger angle of 30º, ds/d of 0.1	0.614803	0.142143	-3%
stagger angle of 30º, ds/d of 0.2	0.574694	0.120336	-10%
stagger angle of 30º, ds/d of 0.3	0.611211	0.151706	-3%
stagger angle of 30º, ds/d of 0.4	0.68185	0.148863	7%

TABLE 3.
PEAK POWER COEFFICIENT AT STAGGER ANGLE 60 DEGREES

Variation	TSR	Cp	Improvement (%)
Without cylinder	0.630966	0.128921	--
stagger angle of 60º, ds/d of 0.1	0.674667	0.150882	6%
stagger angle of 60º, ds/d of 0.2	0.669878	0.146959	6%
stagger angle of 60º, ds/d of 0.3	0.689034	0.152869	8%
stagger angle of 60º, ds/d of 0.4	0.720762	0.17428	12%

TABLE 4.
PEAK POWER COEFFICIENT AT STAGGER ANGLE 90 DEGREES

Variation	TSR	Cp	Improvement (%)
Without cylinder	0.630966	0.128921	--
stagger angle of 90º, ds/d of 0.1	0.695619	0.152774	9%
stagger angle of 90º, ds/d of 0.2	0.693823	0.15427	9%
stagger angle of 90º, ds/d of 0.3	0.678259	0.153808	7%
stagger angle of 90º, ds/d of 0.4	0.669279	0.150329	6%

IV. CONCLUSION

The effect of the stagger angle and the ratio of the diameter concluded that the biggest performance decreased was about 40% in the variation of ds/d of 0.3 with a stagger angle of 0°. The best results show that the wind turbine performance occurred the highest improvement in about 12% at the variation of ds/d = 0.4 with a stagger angle of 60°.

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