Performance Analysis of Savonius Turbine Disturbed by Cylinder in Front of Returning with Variation of Distance to Perpendicular Fluid Flow

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Abstract—**Flow analysis across Savonius turbine with the addition of the circular cylinder before the flow touch returning side of turbine is performed. This project investigates the effect of distance (y) of the cylinder position using CFD, where the displacement of the circular cylinder perpendicular to the direction of the incoming flow is called distance of y. Numerical study is carried out by using moving mesh with 2 zones namely the stationary and rotating zone with Reynolds number (Re) in about 1.1 x 10^{-5}. This research uses circular cylinder as disturbance to improve the Savonius performance by varying y/D of 0.0, 0.25, 0.5, and 0.75. The result reveals that a circular cylinder can increase the performance and the best result occur at y/D of 0.75. The performance increases in about 22.267%.**

Index Terms—**savonius turbine, returning, circular cylinder, coefficient of torque, coefficient of power**

I. Introduction

The fossil fuel decreases from year to year, however, the alternative energy is required to get the energy in the world like renewable energy. Water and wind are the best renewable energy to get electrical power by using a turbine as a power generator. The several ways had been carried out to increase of Cp value of Savonius turbine like overlap and bucket number variations. The performance of bucket number 2 was better than the other, and overlap ratio recommendation from 0.15 to 0.2 [1]. Overlap variations had been performed by using numerical simulation with the best overlap of 0.2 [2].

The other way to increase the performance had been deployed with blade shape variations [3]-[5], by adding deflector [6], [7], adding circular cylinder [8]-[11], using myring n of 1 [12], [13], and adding rotating cylinder [14]. The numerical study with an unsteady condition about Time Step Size (TSS) had been conducted toward Darrieus blade performance and the result indicates that the rotation has occurred 6 rotation to reach the stable curve condition [15]. The discretization of surface blade had been done with discretization 810 to get the best accuracy [16]. Numerical simulation had been carried out by using turbulence model variations with Realizable k-epsilon [17]. The experiment conducted to get information about the coefficient characteristic between wind and water turbine. The result concluded that the water turbine had the same characteristics of both [18].

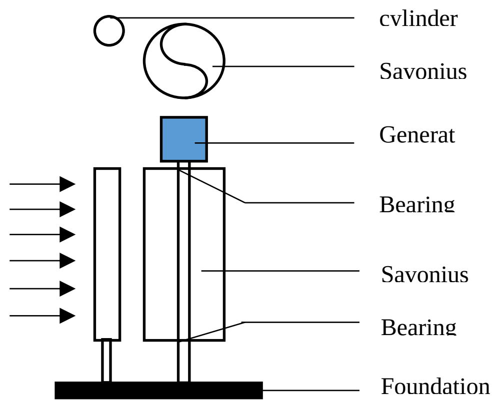

Figure 1. Application of research.

The combination obstacle between cylinder and plat in front of the turbine can increase turbine performance [19]. Flow visualization had been made by placing the cylinder in front of returning obtained the highest performance at a stagger angle of 60^o with the increase of pressure in front side and the reduction of the back of advancing blade using CFD approach. The stagger angle of 0^o in front of the turbine did not permitted because it can be blockage [20]. This study about cylinder as disturbance can be applied the potential water flow like the river and marine energy that have the constant fluid direction. The turbine feasibility

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depends on flow survey to support the turbine performance. The geometry arrangement of turbine is displayed as in Fig. 1.

This research investigates the distance effect of a circular cylinder placed in front of returning. Ratio vertical distance to turbine diameter (y/D) are 0, 0.25, 0.5, and 0.75 by calculating the coefficient of torque, power, velocity path line around the blade, and static pressure distribution on the blade surface. This study explores the performance analysis of savonius turbine disturbed by cylinder in front of returning from varying distance toward perpendicular fluid flow by means of the Gambit and than export to ANSYS. The above study was performed by placing the cylinder in advancing side to obtain the increase of turbine performance. This study will improve the turbine performance by placing the cyinder in front of returning side. The interaction between the cylinder and returning blade will be discussed in this study by taking parameters such as *TSR*, C_t, C_p and the flow visualization to see the phenomenon of flow across the turbine.

II. Methode

A. Parameters

Power coefficient (Cp) is the one of performance parameter from Savonius turbine by calculating in the transient conditions using the formula of TSS and NTS. The NTS and TSS formula can be represented;

$$NTS = N\,\frac{360}{\theta} \tag{1}$$

$$TSS = \frac{N}{(0.15915\,\omega)x\;NTS} \tag{2}$$

Where *N* is defined as rotation, θ is defined in rotation degree, ω is defined angular speed in racd/s, and 0.15915 is defined the conversion (rad/s to rot/s). *NTS* is symbol of the number of the time step. The formulation of *TSR*, C_m, and C_p is written in equation (3) and (4);

$$TSR = \frac{\omega . D}{2\,.\,U} \tag{3}$$

$$C_p = TSR\;\;C_m \tag{4}$$

ω is defined as angular speed, *U* is as the free stream, *D* is as the Savonius turbine diameter, C_p is as power coefficient and C_m is as moment coefficient from simulation. Savonius turbine rotation is depicted in Fig. 2. The cylinder as passive control would be installed in front of returning blade perpendicular fluid flow as shown in Fig. 2.

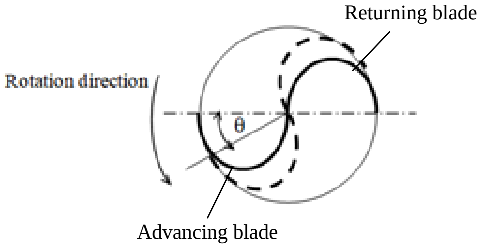


Figure 2. Turbine rotation.

The circular cylinder are varied the cylinder distance perpendicular to the fluid flow. The distance variations are varied at y/D of 0, 0.25D, 0.5D, and 0.75D. The bucket Savonius shape is illustrated in Fig. 3 and has the blade diameter of 400 mm. The TSR, torque coefficient (C_t), power coefficient (C_p) are obtained from the equation (2), (3), and (4), respectively. The boundary conditions in this case can be seen in Table I and Fig. 4.

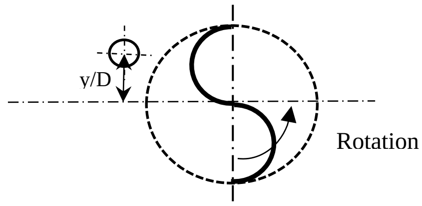


Figure 3. Schematic of blade with cylinder arrangement.

TABLE I. Boundary Conditions

No	Component	Boundary conditions
1	Upper side	Wall
2	Lower side	Wall
3	Inlet	Velocity inlet
4	Outlet	Pressure outlet
5	Savonius blade	Wall
6	Circular cylinder	Wall
7	Circle	Interface

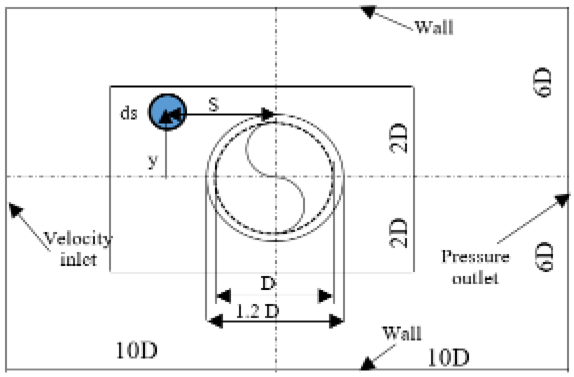


Figure 4. The boundary conditions.

Angular velocity (ω) is computed from TSR and various of TSR of 0.5, 0.7, 0.9, 1.1, and 1.3. TSS is calculated from TSR that can be displayed in Table II. The blade rotation can be calculated each 1° to get high accuracy.

TABLE II. Input Data for Unsteady Condition

TSR	RPM	TSS (s)
0.5	4.200	0.00249340
0.7	6.300	0.00178100
0.9	8.400	0.00138522
1.1	10.500	0.00115628
1.3	12.600	0.00095900

B. Validation

The validation uses experimental data of Sheldahl et al [1] and it compares the present study with Sheldahl data as displayed in Fig. 5. The post-processing is carried out by using transient at the TSR value of 0.5, 0.7, 0.9, 1.1, and 1.3.

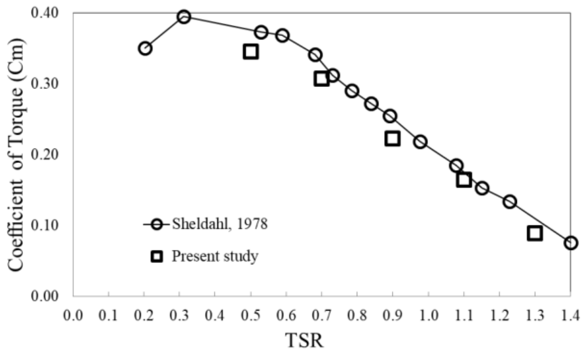


Figure 5. Validation of present study and experimental.

III. Result and Discussion

A. Torque and Power Coefficient

Coefficient of torque as the function of TSR has been shown in Fig. 6. Value of Ct has been decreased by the increase of TSR. The circular cylinder varying y/D has increased the torque coefficient of turbine. The distance variations (y/D) reveal that the distance was decrease compared the conventional blade at y/D of 0D and 0.25D. In this point, the fluid flow would be blocked by the cylinder and decrease the performance of turbine.

The drag force in front of advancing or concave blade decreased and the net total torque would decrease. The distance variations (y/D) indicate that the distance was increase compared to the conventional blade at y/D from 0.5D to 1D. Thus, the fluid flow would be directed by the cylinder to advancing blade and increase the performance of turbine. The drag force in front of advancing or concave blade increased and the net total torque would increase as displayed in Fig. 6.

The Cp can be represented by the performance of turbine that exposed in Fig. 7. The cylinder distance variations have the performance lower than the Savonius turbine without cylinder at y/D of 0 and 0.25. The increasing of the cylinder distance has increased the turbine performance. Henceforth, the increase of the cylinder distance becomes the blockage flow goes to advancing blade at y/D of 0.0 and 0.25. Placing a cylinder in front of the returning blade with varying distance (y/D) will increase the performance and the next is required phenomena of the flow around Savonius blade.

B. Improvement of Performance

The best Cp has been varied to y/D of 0, 0.25, 0.5, and 0.75 as seen in Fig. 6. The Cp results would be interpreted as Cp improvement in % compared with Savonius without cylinder as presented in Table III. Cylinder distance perpendicular freestream (y/D) has shown that y/D variations have low Cp results for y/D of 0.0 and 0.25 compared to Savonius without cylinder. The negative in % has indicated that the performance (Cp) decrease under performance of conventional Savonius occurred at y/D of 0.0 by decreasing in about -27.32%. The best performance occurred at y/D 0.75 by improving the performance in about 22.26%. The detailed analysis is discussed in velocity path line and static pressure to highlight the flow phenomena.

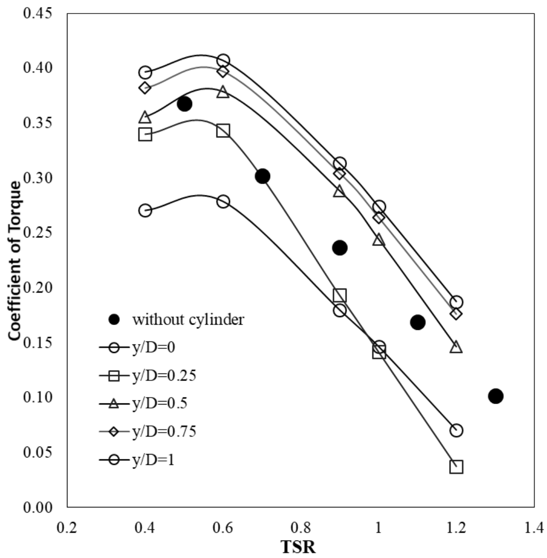


Figure 6. Coefficient of torque as the function of TSR.

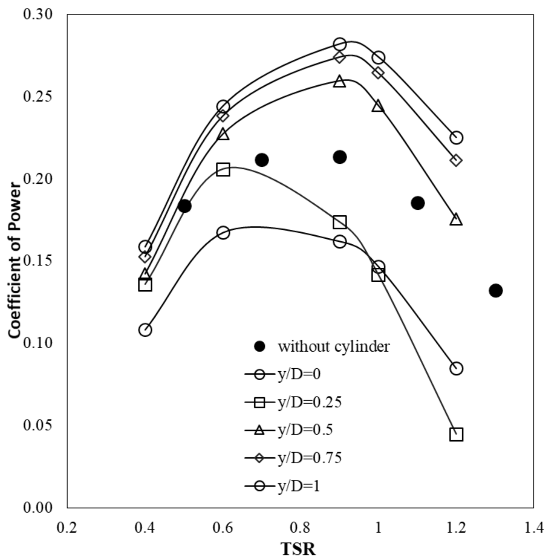


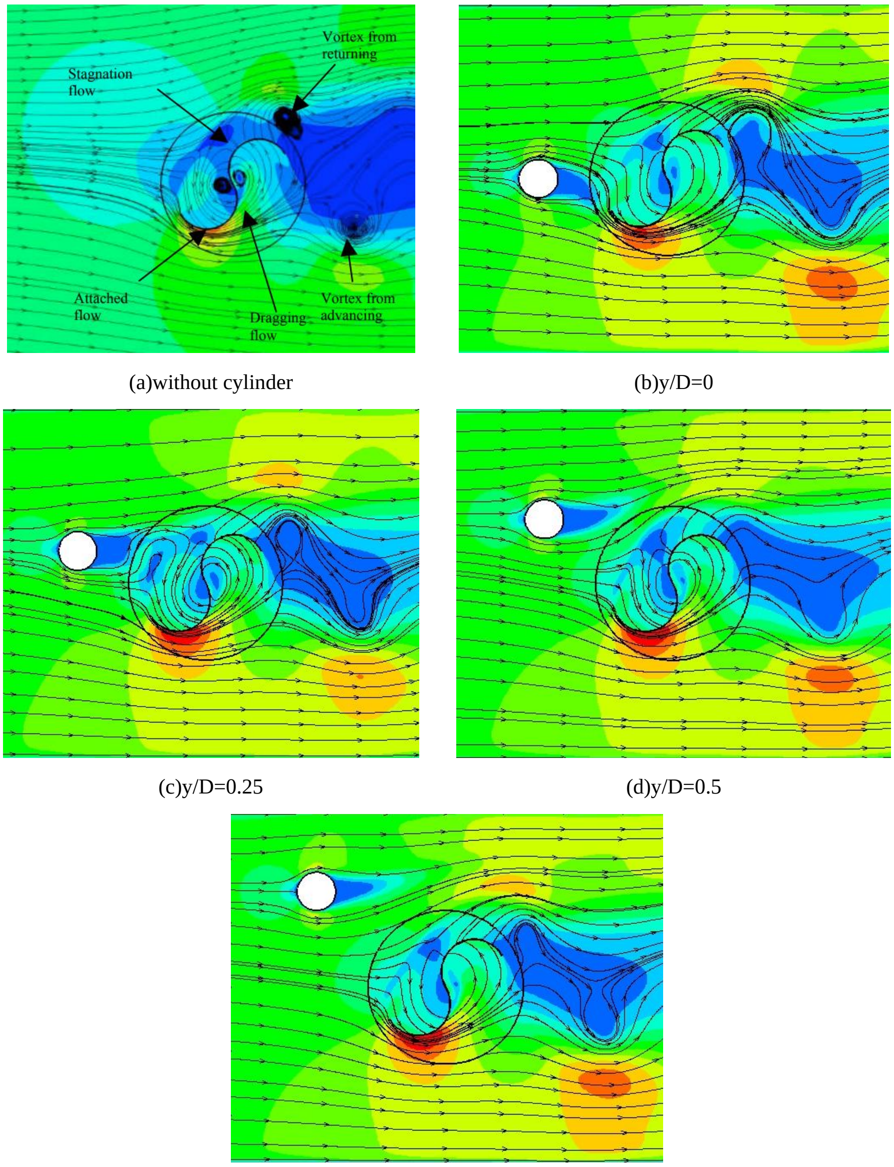
Figure 7. Coefficient of power as the function of TSR.

TABLE III. The Performance Improvement By Varying Y/D

Variation	Peak Cp	Corresponding TSR	Performance improvement (%)
Savonius wiyhout cylinder	0.213	0.9	0
y/D = 0.0	0.1673	0.6	-27.32
y/D = 0.25	0.206	0.6	-3.40
y/D = 0.5	0.2596	0.9	17.95
y/D = 0.75	0.274	0.9	22.26

C. Velocity Pathline

Visualization flow analysis in front of returning blade by using y/D of 0, 0.25, 0.5, and 0.75 is depicted in Fig. 8. There are five flow types occurred around Savonius blade without overlap ratio, namely stagnation flow, vortex from returning, vortex from advancing, dragging flow and attached flow illustrated in Fig. 8 (a). The flow over cylinder placed in front and center turbine indicated that the performance decreased by comparing the conventional or without cylinder. While the cylinder has blocked the flow from the free stream and the pressure drag on concave blade advancing blade decreased, however, the performance decreased for the distance y/D of 0 and 0.25.



(a)without cylinder (b)y/D=0

(c)y/D=0.25 (d)y/D=0.5

(e)y/D=0.75

Figure 8. Velocity pathline for y/D= 0.0, 0.25, 0.5, and 0.75.

Nevertheless, the performance increased at the distance y/D of 0.5 and 0.75. The pressure drag on concave increased because the cylinder was not disturbed by the flow on the blade surface of the advancing blade. In this point, the performance improved by increasing the distance of the cylinder perpendicular fluid flow. Contour changes on the blade surface are not clear and hence the flow analysis requires a static pressure value on the blade surface. The wake formation behind cylinder at y/D of 0 follows the rotation of advancing blade disturbing the flow from upstream as displayed in Fig. 8 (b). The wake formation behind cylinder at y/D more than 0 does not interfere the flow from upstream as displayed in Fig. 8 (c), (d) and (e).

D. Static Pressure Along Blade Surface

Analysis of blade performance can be taken static pressure at the position of blade 30^o as represented in Fig. 9.

The static pressure demonstrates that the static pressure in front and rear of blade increases at the advancing blade. The pressure difference has been used to analyze the performance of Savonius. Pressure drag in front of advancing increase when ratio the distance perpendicular of cylinder to turbine diameter (y/D) increase. Blockage ratio increases the performance of Savonius turbine when the boundary conditions for the upper side and lower side use the wall. The curve area reflects the performance of the turbine. Turbine performance increases at concave side by observing the area of static pressure increases and decreases the area of returning side. This phenomena can be denoted in Fig. 9.

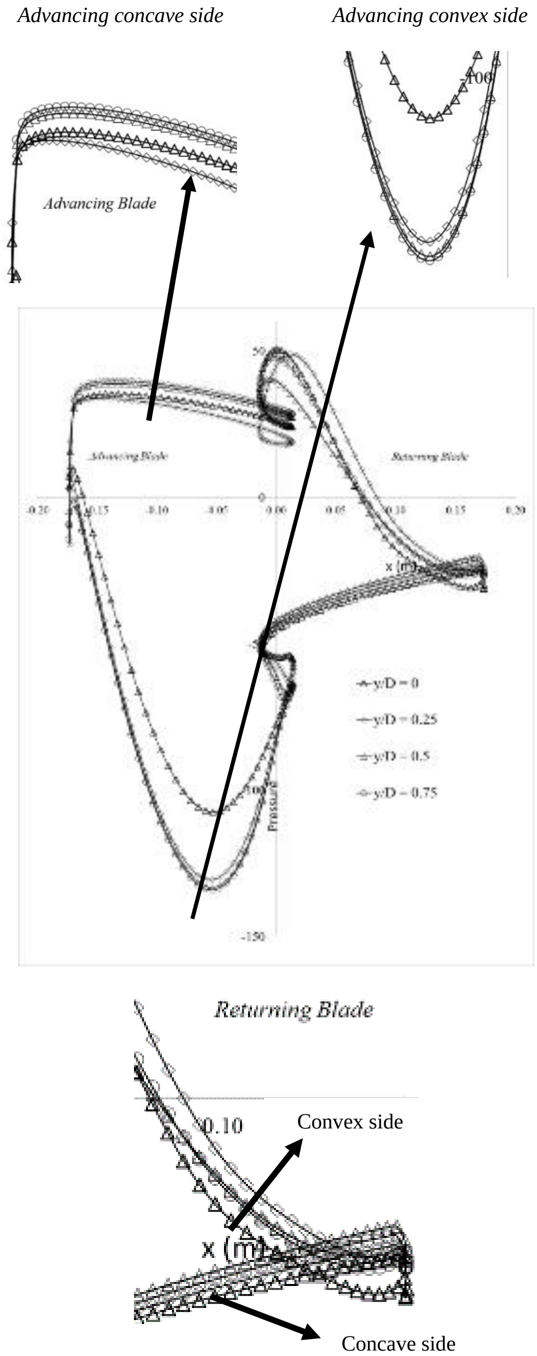


Figure 9. Static pressure.

IV. CONCLUSION

This work investigates the effect of a circular cylinder placed in front of returning by varying y/D to the performance of turbine. A circular cylinder in front of returning blade can increase performance of Savonius turbine and the best performance at y/D of 0.75. The performance has increased compared to the conventional without cylinder in about 22.26%.

CONFLICT OF INTEREST

The authors have declared that this article does not have potential conflict of interest.

AUTHOR CONTRIBUTIONS

Priyo Agus Setiawan performed the research by deliberately conducting numerical analysis. Triyogi Yuwono and Wawan Aries Widodo wrote the paper. Adi Wirawan Husodo carried out the numerical review from geometry in Gambit. Fais Hamzah helped to compile data at post processing.

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