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

Priyo A. Setiawan, Adi W. Husodo, and Fais Hamzah
Shipbuilding Institute of Polytechnic Surabaya, Surabaya, Indonesia
Email: {priyo.as, adi_wirawan, fais.hamzah}@ppns.ac.id

Triyogi Yuwono and Wawan A. Widodo
Sepuluh Nopember Institute of Technology, Surabaya, Indonesia
Email: {triyogi, wawanaries}@me.its.ac.id

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 $1.1 \times 10^5$. 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.
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 cylinder 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, Ct, Cp 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:

\[
NTS = N \frac{360}{\theta}
\]

\[
TSS = \frac{N}{(0.15915 \omega)x NTS}
\]

Where \(N\) is defined as rotation, \(\theta\) is defined in rotation degree, \(\omega\) is defined angular speed in rad/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);

\[
TSR = \frac{\omega D}{2U}
\]

\[
C_p = TSR \ C_m
\]

\(\omega\) is defined as angular speed, \(U\) is as the free stream, \(D\) is as the Savonius turbine diameter, \(C_p\) as power coefficient and \(C_m\) 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.

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 (Ct), power coefficient (Cp) 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.](image3)

![Figure 4. The boundary conditions.](image4)

**TABLE I. BOUNDARY CONDITIONS**

<table>
<thead>
<tr>
<th>No</th>
<th>Component</th>
<th>Boundary conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Upper side</td>
<td>Wall</td>
</tr>
<tr>
<td>2</td>
<td>Lower side</td>
<td>Wall</td>
</tr>
<tr>
<td>3</td>
<td>Inlet</td>
<td>Velocity inlet</td>
</tr>
<tr>
<td>4</td>
<td>Outlet</td>
<td>Pressure outlet</td>
</tr>
<tr>
<td>5</td>
<td>Savonius blade</td>
<td>Wall</td>
</tr>
<tr>
<td>6</td>
<td>Circular cylinder</td>
<td>Wall</td>
</tr>
<tr>
<td>7</td>
<td>Circle</td>
<td>Interface</td>
</tr>
</tbody>
</table>

Angular velocity (\(\omega\)) 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**

<table>
<thead>
<tr>
<th>TSR</th>
<th>RPM</th>
<th>TSS (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>4.200</td>
<td>0.00249340</td>
</tr>
<tr>
<td>0.7</td>
<td>6.300</td>
<td>0.00178100</td>
</tr>
<tr>
<td>0.9</td>
<td>8.400</td>
<td>0.00138522</td>
</tr>
<tr>
<td>1.1</td>
<td>10.500</td>
<td>0.00115628</td>
</tr>
<tr>
<td>1.3</td>
<td>12.600</td>
<td>0.00095900</td>
</tr>
</tbody>
</table>

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.
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.

<table>
<thead>
<tr>
<th>Variation</th>
<th>Peak Cp</th>
<th>Corresponding TSR</th>
<th>Performance improvement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savonius without cylinder</td>
<td>0.213</td>
<td>0.9</td>
<td>0</td>
</tr>
<tr>
<td>y/D = 0.0</td>
<td>0.1673</td>
<td>0.6</td>
<td>-27.32</td>
</tr>
<tr>
<td>y/D = 0.25</td>
<td>0.206</td>
<td>0.6</td>
<td>-3.40</td>
</tr>
<tr>
<td>y/D = 0.5</td>
<td>0.2596</td>
<td>0.9</td>
<td>17.95</td>
</tr>
<tr>
<td>y/D = 0.75</td>
<td>0.274</td>
<td>0.9</td>
<td>22.26</td>
</tr>
</tbody>
</table>

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.

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).

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

D. Static Pressure Along Blade Surface

Analysis of blade performance can be taken static pressure at the position of blade $30^\circ$ 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
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.

**ACKNOWLEDGMENT**

This paper has been funded by Kemenristek-Dikti year 2020.

**REFERENCES**


Copyright © 2022 by the authors. This is an open access article distributed under the Creative Commons Attribution License (CC BY-NC-ND 4.0), which permits use, distribution and reproduction in any medium, provided that the article is properly cited, the use is non-commercial and no modifications or adaptations are made.

**Priyo A. Setiawan** is a Senior Lecturer in Marine Engineering Department, Shipbuilding Institute of Polytechnic Surabaya (Politeknik Perkapalan Negeri Surabaya) – Indonesia. He received the Master and Ph.D. degree in Mechanical Engineering from ITS (Institut Teknologi Sepuluh Nopember) Indonesia, in 2012 and 2020. He is actually member of Fluid Mechanics Laboratory at Marine Engineering Department of Shipbuilding Institute of Polytechnic Surabaya. His main research interests are fluid flow, wind and water turbine.

**Triyogi Yuwono** is a Professor in Mechanical Engineering Department, Faculty of Industrial Technology of ITS (Institut Teknologi Sepuluh Nopember) – Indonesia. He received the Master and Ph.D. degree in Mechanical Engineering from INPG (Institute National Polytechnique de Grenoble), France in 1990 and 1993. He is actually Head of Fluid Mechanics & Fluid Machineries at Mechanical Engineering Department of ITS. His main research interests are fluid flow, wind and water turbine.

**Wawan Aries Widodo** is a Associate Professor in Mechanical Engineering Department, Faculty of Industrial Technology of ITS (Institut Teknologi Sepuluh Nopember) – Indonesia. He received the Master and Ph.D. degree in Mechanical Engineering from ITS, in 2006 and 2010. He is actually member of Fluid Mechanics & Fluid Machineries at Mechanical Engineering Department of ITS. His main research interests are fluid flow and heat transfer.

**Adi W. Husudo** is a Senior Lecturer in Marine Engineering Department, Shipbuilding Institute of Polytechnic Surabaya (Politeknik Perkapalan Negeri Surabaya) – Indonesia. He gained the Master degree in Ocean Engineering, from the Faculty of Marine Technology, ITS (Institut Teknologi Sepuluh Nopember)–Indonesia in 2010. His research interest is in the area of the static and fluid dynamics.

**Fais Hamzah** is a Senior Lecturer in Marine Engineering Department, Shipbuilding Institute of Polytechnic Surabaya (Politeknik Perkapalan Negeri Surabaya). He gained the Master degree in Industrial Engineering, from the Faculty of Industrial Technology, ITS (Institut Teknologi Sepuluh Nopember)-Indonesia in 2010. His research interest is in the area of marine engineering.