Numerical Study of a Circular Cylinder Effect on the Vertical Axis Savonius Water Turbine Performance at the Side of the Advancing Blade with Horizontal Distance Variations

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Received: 26.12.2019 Accepted:25.03.2019

Abstract- In this present study, a circular cylinder installation has been performed to increase the conventional savonius performance that has been simulated numerically. Placing a cylinder at the side of the advancing blade has been performed to increase the positive torque and numerical analysis has been performed without and with a circular cylinder. A numerical study has represented by using a 2D analysis of CFD simulation with moving mesh technique. The k-epsilon used is Realizable k-epsilon (RKE) by second-order upwind for the discretization method. The numerical simulation uses ANSYS 17.0 software. The first step, the validation is performed by comparing the experimental result with respect to torque coefficient using air fluid. The second step, The fluid has changed into the water fluid and installed a circular cylinder at Y/D of 0.7 kept constant. The parameter X/D has been varied from 0.0 to 2.0 with an increment of 0.5. The best results of the numerical study have been showed that the maximum power coefficient occurs at X/D = 0.5 and the best performance is in about 0.250, increase about 17.31% at a TSR of 0.9.

Keywords VASWT, circular cylinder, advancing blade, moving mesh, CFD, performance.

1. Introduction

Energy demand is growing and encouraging the Indonesian government for the blueprint implementation in which the energy composition by 2025 expected to attain 17%. [1]. Potential current in Indonesian island is measured by using ocean current speed in Berhala around 0.135 m/s, Anambas around 0.055 m/s, and Biawak around 0.272 m/s [2]. The current in Indonesian island has a low current speed that can be applied for operating of Savonius turbine.

The turbines are generally classified into the horizontal and vertical axis turbines. This present study uses the vertical axis turbine that generates power for all of the fluid flow direction [3] and uses the Savonius turbine type. The Savonius has lower the performance than others. The several studies have been carried out to improve the Savonius performance. Several improvements toward Savonius turbine have been conducted by installing obstacle in front of returning and advancing blade side. The experimental study of water turbine has been performed by Kailash et al. [4] using the modified turbine installing two plates of deflector on the advancing and returning blade tested in open water channel with Reynolds number Re = 1.32 x 10^5. The results have revealed the maximum power coefficient achieved 0.35 at TSR = 1.08. By adding circular cylinder, Setiawan et al [5] also have conducted a numerical study using a cylinder varied toward diameter (ds/D) from 0.1 to 0.9 with increment 0.2 placed on advancing blade side. The power coefficient has achieved maximum value at ds/D = 0.7 and TSR = 0.7. Setiawan et al [5] have continued numerical study by adding a cylinder installed on the advancing side. The changing of diameter (ds/D) of 0.1, 0.3 and 0.5 has been carried out by placing at each stagger angle of 0^o, 30^o, and 60^o. The highest performance is obtained at ds/D = 0.5 for $\gamma = 30^o$ and 60^o.

Sanusi et al [7] have performed experimental study toward blade change namely circle-shaped and concave elliptical model. The results of a study, the maximum performance has improved by around 11 % higher than the conventional blade at TSR = 0.79. Sheldahl et al. [8] have carried out an experimental study in wind tunnel using a Savonius blade tested at an air velocity of 7 m/s and 14 m/s. They used a Savonius turbine model having a Savonius diameter of 1 m with the bucket number 2 and 3 and the results show that the highest performance is obtained on the bucket number of 2. The experiment also has been carried out by varying overlap ratio from 0.0 to 2.0, and the maximum turbine performance has been obtained at the overlap ratio in the range 0.1 - 0.15. Kacprzak et al. [9] have performed a numerical study about turbine performance with two blade shapes namely conventional and elliptical blade. The elliptical blade has a higher performance than the conventional blade.

Freitas et al. [10] have carried out numerical study directed to avoid uncertainty numerical generating policy. Some policy has been so essential to improve accurate results in numerical simulation by using discretization of second order upwind, performed benchmark solution and comparison numerical simulation with respect to experimental data or simulated results until convergence with the transient simulation. The RKE is suitable for predicting flows such as separated flows and flows with complex secondary flow compared to other turbulence models [11]. Study about simulation using the 2D CFD for the turbine has revealed good analysis [12-18].

Satrio et al. [19] have simulated toward vertical axis tidal current turbine by using the CFD to see the influence of the time step. The numerical simulation results have shown that increment angle in time step size from 5^o up to 1^o will reduce power coefficient (Cp) error and the NTS about 6 rotation will reduce Cp error.

Based on the description above, the obstacle shape as a circular cylinder or deflectors improves the performance of the conventional blade. The present study has used circular cylinder installing besides of circular cylinder by varying horizontal distance (X/D). The use of a cylinder, the flow over the cylinder surface will be accelerated and maximum velocity occurs at the upper side. The velocity through the both of bluff body at a certain distance will cause flow interaction. Therefore, the study is expected to determine the best position of circular cylinder installing on advancing side with Savonius turbine with respect to horizontal distance (X/D) variations. The present study provides a remarkable finding on the Savonius performance like the torque coefficient, the power coefficient, the dynamic torque coefficient, and velocity pathline structure through both bluff bodies using ANSYS 17.0 software. The accurate numerical setup can overcome the drawbacks as turbulence model use Realizable k-ε, second order, the validation using the experimental data, the TSS use increment 1^o, and the minimum NTS use 10 rotations.

2. Performance Parameters

Performance parameter for this study is the power coefficient. The calculation in the transient or unsteady analysis for the rotating equipment uses the formula of TSS and NTS. Satrio et al [19] have represented NTS and TSS in equation (1) and (2). NTS is defined as the total time step needed to rotate the blade for 360^o. TSS is defined as the rotation time for each 1^o. The equation of the NTS and the TSS can be represented as in equation (1) and (2);

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

$$\mathrm{TSS} = \frac{\mathrm{N}}{(0.15915\ \omega) \times \mathrm{NTS}} \tag{2}$$

Where rotation number, N, time step rotation degree,θ, angular speed (rad/s), ω and 0.15915 is the conversion value, number of time step, NTS. The equation of Tip Speed Ratio (TSR), Torque Coefficient (Cm) and Power Coefficient (Cp) can be written as in equation (3) and (4) from Kailash et al [4];

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

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

Where angular speed, ω, the free stream velocity, U, the Savonius turbine diameter, D, power coefficient, Cp and moment coefficient from numerical simulation, Cm. Rotation for Savonius turbine can be seen in Fig. 1.

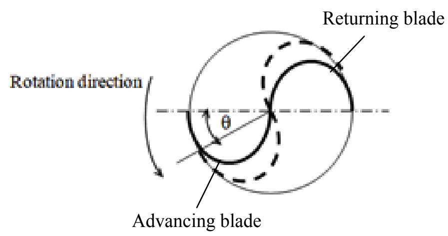

Fig. 1. Rotation for Savonius

3. Numerical Simulations

3.1. *Computational Domain*

Firstly, the numerical simulation has used conventional Savonius turbine with the following size of a model by sheldahl et al. [8] for verification. The verification towards the torque coefficient has used experimental data of Sheldahl et al. [8] with TSR = 1.078. The Savonius turbine has the diameter of 1 m and air velocity is 7 m/s kept constant, which the working fluid is air as presented at Table. 1. Secondly, the verification has attained, so the next numerical analysis using a circular cylinder with the d_s/D of 0.3 has installed Y/D = 0.7 kept constant, and the horizontal distance (X/D) has been varied from 0.0 to 2.0 with increment 0.5.

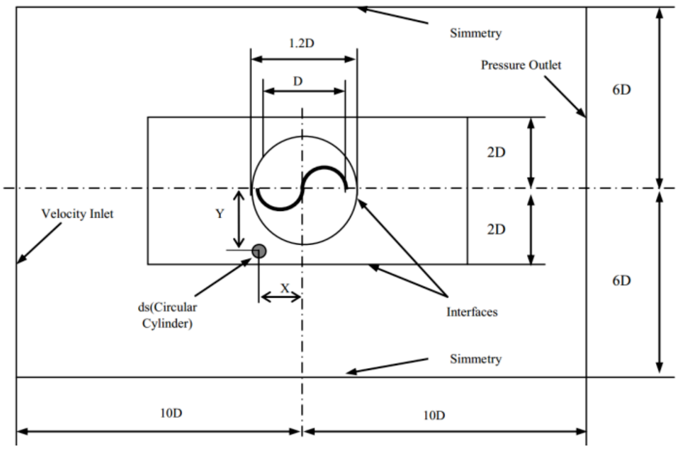

Fig. 2. Domain of computational.

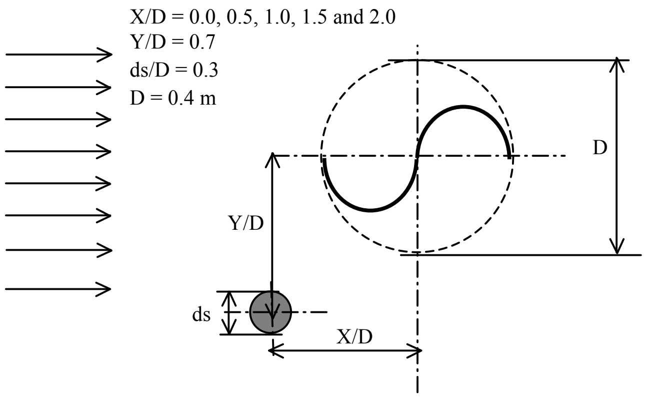

Fig. 3. Circular cylinder position with Savonius turbine.

The boundary condition in domain simulation as displayed in Fig. 2, an inlet is velocity-inlet with U of 0.22 m/s, an outlet is pressure-outlet, the upper and lower side is symmetry, the blade of Savonius is wall and rotation, the area between the rotating zone with wake domain is interface 1, the area between wake domain and stationary domain is interface 2. The distance between the inlet and center of Savonius turbine is 10D, Distance between outlet and center of Savonius turbine is 10D, D is defined as the Savonius diameter. The upper and lower side domain are taken 6D from the Savonius center. In this study, the structured grids are for all grid in the rotor at the first layer. The changing of the circular cylinder position towards Savonius turbine is illustrated in Fig. 3 at X/D of 0, 0.5, 1.0, 1.5 and 2.0.

3.2. Mesh Generation

The domain simulation consists of three (3) domains for this simulation, namely the fixed, the wake, and the rotating domain as shown in Fig. 4. Simulation is supported by software ANSYS 17.0, 2D simulation using quadrilateral elements shape. It has high accuracy as presented in Fig. 4. The first grid in the surface of Savonius blade is made a layer using the y+ value setting between 30 and 100 [17]. The y+ is defined as a non-dimensional distance.

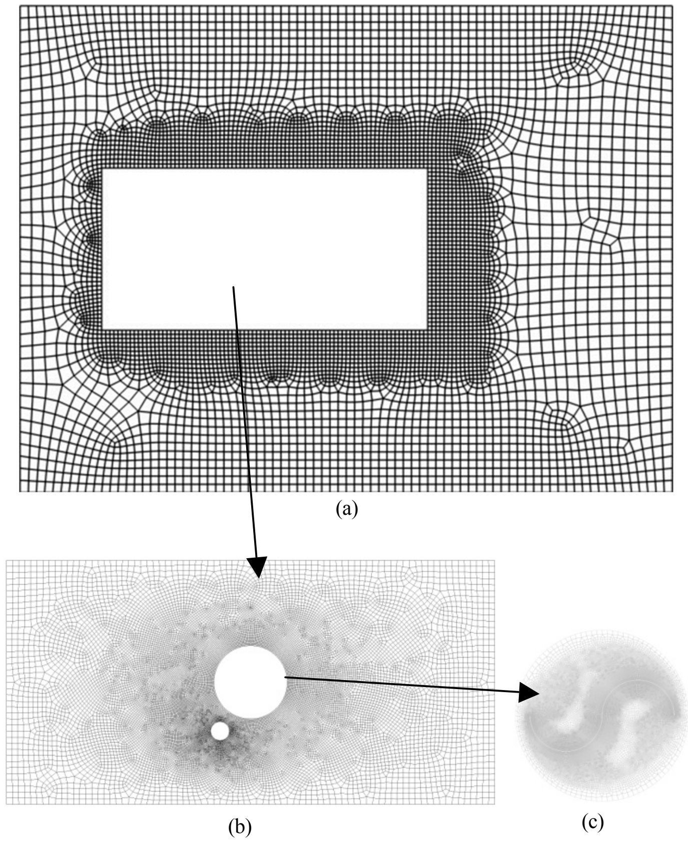

Fig. 4. The generation of grid

3.3. Solver Setup

The numerical simulation use 2D CFD performed by ANSYS 17.0 and solved the incompressible U-RANS equation by approaching transient analysis using moving mesh for the Savonius turbine case. In this simulation, increment angle or time step rotation degree has been determined 1^o from Satrio et al., 2018 [19]. This simulation uses the maximum iteration up to 150 iterations, which the turbine performance at each 1^o will be calculated until 150 iterations or the process will stop when the iteration has attained convergence criteria by setting 10^{-5} for continuity. The TSR has been chosen 0.3, 0.5, 0.7, 0.9, 1.1 and 1.3. The result of post-processing is torque coefficient parameter and the power coefficient is multiplication torque coefficient and Tip Speed Ratio. The verification step use TSR = 1.078 and air velocity = 7 m/s from Sheldahl et al., 1978 [8] given ω of 15.095 rad/s and N of 144.087 RPM. It is obtained time step size (TSS) of 0.0011627 and number of the time step (NTS) of 51871 presented in table 1.

Table 1. NTS and TSS for validation

TSR	V (m/s)	D (m)	N (RPM)	ω (rad/s)	NTS (s)	TSS (ms)
1.078	7	1	144.087	15.095	51871	1.1627

Table 2. NTS and TSS for using air fluid

TSR	V (m/s)	D (m)	N (RPM)	ω (rad/s)	NTS (s)	TSS (ms)
0.3	7	1	40.091	4.200	14433	4.15567
0.5	7	1	66.818	7.000	24055	2.49340
0.7	7	1	93.545	9.800	33676	1.78100
0.9	7	1	120.273	12.600	43298	1.38522
1.1	7	1	147.000	15.400	52,920	1.13337
1.3	7	1	173.727	18.200	62542	0.95900

Table 3. NTS and TSS for using water fluid

TSR	V (m/s)	D (m)	N (RPM)	ω (rad/s)	NTS (s)	TSS (ms)
0.3	0.22	0.4	3.150	0.330	1134	52.89041
0.5	0.22	0.4	5.250	0.550	1890	31.73424
0.7	0.22	0.4	7.350	0.770	2646	22.66732
0.9	0.22	0.4	9.450	0.990	3402	17.63014
1.1	0.22	0.4	11.550	1.210	4158	14.42466
1.3	0.22	0.4	13.650	1.430	4914	12.20548

The verification has been attained, the next numerical step will be compared to experimental data from Sheldahl et al., 1978 [7] at TSR of 0.3, 0.5, 0.7, 0.9, 1.1 and 1.3 as shown in Table 2.

3.4. *Verification of Numerical Study*

The results of post-processing in the transient simulation are grid convergence to see the influence of the grid on calculating of dynamic torque coefficient per rotation of the Savonius with three grid size, which are approximately 17,006, 61,105 and 120,000 nodes. Simulations have been performed on a conventional Savonius turbine at a TSR of 1.078 following the value in table 1 and the results of verification as depicted in Fig. 5.

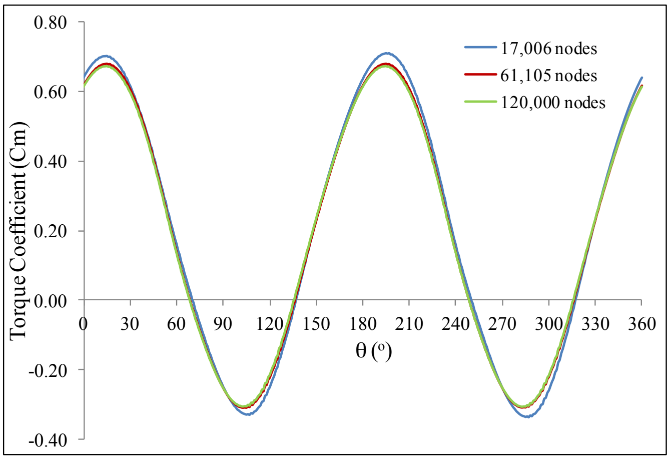

Fig. 5. Verification for nodes variations

The nodes have been controlled by the different size of elements near the blade shows that 61,105 and 120,000 nodes have given the same trend results. The grid with 61,105 nodes will be chosen for the validation step due to the time efficiency for the next simulation.

3.5. *Numerical Validation*

The experimental data [8] is used as the validation of numerical results. The post-processing results have been presented in Fig. 5 and will be taken average torque coefficient (Cm). The average torque coefficient (Cm) for the validation has been presented in Table 4. The data simulation will be taken the average torque coefficient (Cm) value by varying TSR of 0.5, 0.7, 0.9, 1.1 and 1.3 that can be seen in Table 4 and presented in Fig. 6. The graph illustrates validity with numerical in Fig. 6 and can be used in the real case by adding a cylinder based on setting numerical simulation as presented in Fig. 3. The next numerical analysis will be performed by means of water fluid as the input data of simulation as shown in Table 3.

Table 4. Average torque coefficient for 61,105 nodes using air fluid

TSR	Cm Numerical	Cm Experimental	Error (%)
0.5	0.3691	0.3772	2.15
0.7	0.3027	0.3303	8.36
0.9	0.2368	0.2493	5.01
1.1	0.1686	0.1749	3.60
1.3	0.1012	0.1088	6.99

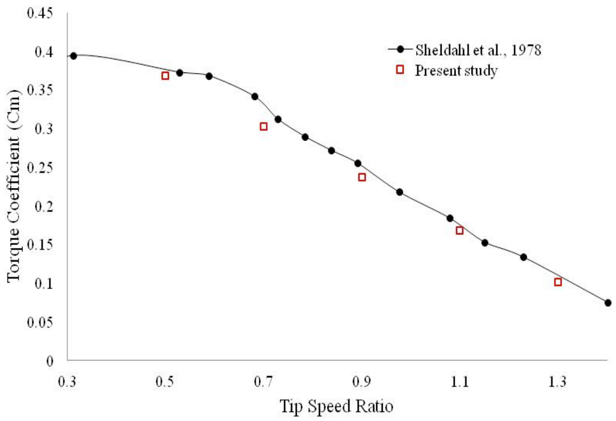

Fig. 6. Validation of the dynamic torque coefficient (Cm)

4. Results and Discussion

4.1. *Torque and Power Coefficient*

The wind will be changed to water turbine after validation has been attained. This present study, in which simulations have been applied to vertical axis Savonius water turbine. In this case, the characteristic of water fluid is similar to air fluid refer to [20]. The Numerical has been performed at the air velocity at 0.22 m/s kept constant and the Savonius diameter D = 0.4 m. When validation has been attained, so the next simulations in this problem has been performed by installing a cylinder at beside of the advancing blade, where ratio the cylinder diameter to the Savonius diameter (ds/D) is 0.3 kept constant. The vertical position of the circular cylinder relative to the rotor diameter (Y/D) is 0.7 kept constant, Meanwhile, the ratio the horizontal position to the Savonius diameter (X/D) has been varied from 0 to 2.0. Under those conditions, the simulation is carried out for TSR from 0.3 to 1.3 with using data from Table 4.

The performance of the Savonius has included the value of the power coefficient (C_p). Graph of the torque and the power coefficient has illustrated in Fig. 7 and Fig. 8. By adding the cylinder as passive control placed at the advancing side has influenced the Savonius performance.

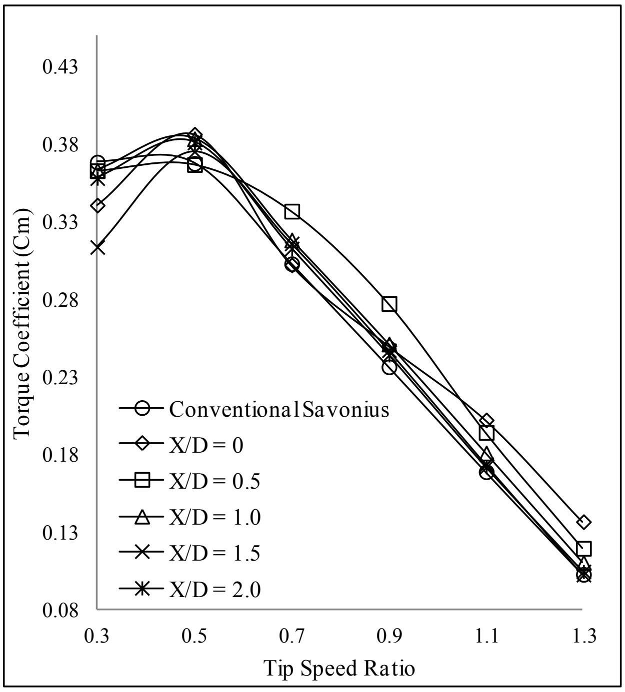

Fig. 7. The performance of the Savonius turbine for torque coefficient (Cm) with changing of horizontal distance (X/D) of 0.0, 0.5, 1.0, 1.5 and 2.0.

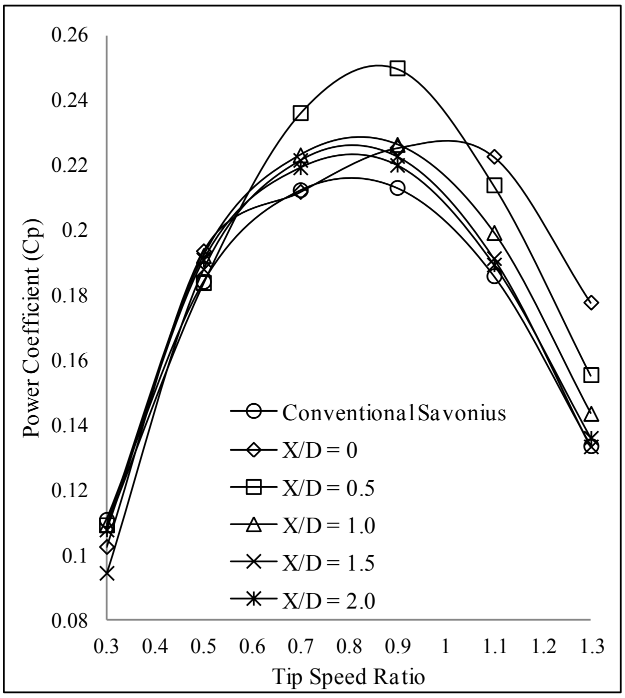

Fig. 8. The performance of the Savonius turbine for power coefficient (Cp) with changes of horizontal distance (X/D) of 0.0, 0.5, 1.0, 1.5 and 2.0.

Fig. 7 and Fig. 8 have reflected the performance of the Savonius turbine which includes the value of the torque coefficient (Cm) and the power coefficient (Cp) as the function of the tip speed ratio (TSR), respectively. It is clear that installing a circular cylinder beside the advancing blade will affect the performance of the turbine. For the fixed circular cylinder diameter at ds/D of 0.3 and for the vertical position of the circular cylinder has kept constant at Y/D of 0.7, the power coefficient (Cp) of the turbine tends to increase when the horizontal X/D position has increased until X/D of 0.5, and then Cp decreased at X/D more than 0.5. The results have revealed that the maximum power coefficient at X/D of 0.5 has increased by about 17.31 % at TSR of 0.9. When the circular cylinder positioned far away from Savonius turbine at X/D of 2.0 has shown that the performance of the turbine has decreased and the effect of the circular cylinder starts to decrease and the performance of the turbine will tend to return to conventional Savonius performance.

4.2. The Dynamic Torque Coefficient

The dynamic torque coefficient as the function of the rotating blade for 360^o as shown in Fig. 9. Highest peak torque coefficient occurs at X/D = 0.5. The dynamic torque coefficient curve by varying X/D at the side of advancing by using the data of the TSR = 0.9 is shown in Fig. 9. The position X/D = 0.5 show highest peak torque coefficient and X/D = 1.0, 1.5 and 2.0 show the decreasing of the torque coefficient, respectively. The dynamic torque analysis shows the unique curve shape at the position cylinder X/D = 0.0 indicated the red color by moving the peak position the right side compared the other. The improvement of torque can be seen at the advancing zone in the range from 0^o to 90^o about the velocity pathline structure as shown in Fig. 10. The maximum torque will be determined by the value of the average torque coefficient for 360^o or one rotation.

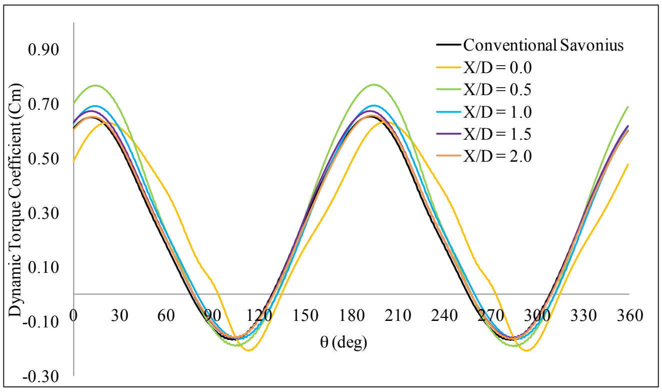

Fig. 9. The dynamic torque coefficient with X/D variations for 360^o at TSR = 0.9

4.3. Velocity Pathline Structure of the Savonius Turbine

Savonius turbine has been disturbed by a circular cylinder installation while the changing of the flow characteristics in the turbine. The flow characteristic has been qualitatively observed at the changing of horizontal distance by varying X/D = 0.0, 0.5, 1.0, 1.5 and 2.0. It has influenced the formation of velocity pathline as shown in Fig. 10. The contour of velocity pathline structure has been illustrated at TSR = 0.9 at a blade angle θ = 30^o as shown in Fig. 10.

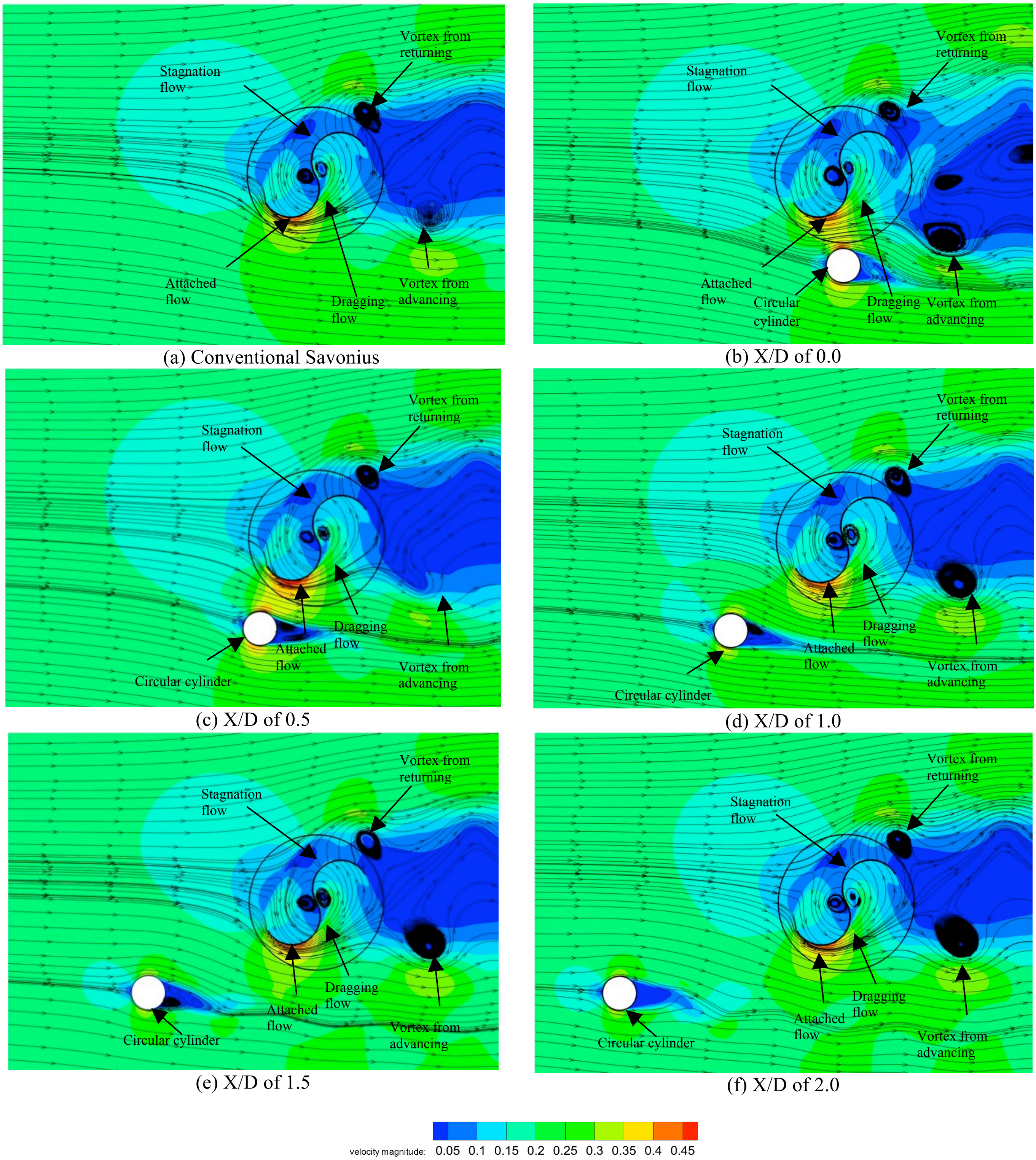

Fig. 10. The velocity pathline structure with horizontal distance variations (X/D) at θ=30°, TSR of 0.9 and TSR=0.9.

The gap between the circular cylinder and the Savonius turbine at advancing blade can increase the flow momentum or the water velocity through eventually both of bluff bodies. The contour of velocity pathline structure in conventional Savonius has shown the formation of the vortex at the edge of the advancing and returning blade. A circular cylinder installation near Savonius at the advancing side has increased the flow momentum and accelerated on both of the bluff bodies. The velocity in the attached flow zone will increase when the cylinder has been placed the advancing side. the analysis of the cylinder installation will increase the velocity in the attached flow zone however the pressure decrease at the convex of advancing. The net positive torque will increase and the power coefficient or performance will increase automatically. The stagnation flow occurs in front of the returning blade. A circular cylinder installed at X/D of

0.0 has shown that the vortex began to form three vortexes at the edge of the advancing, returning and between the vortex. Observation is performed at X/D of 0.5 has shown that the vortex phenomena forms one vortex at returning vortex but there is no vortex that formed at the advancing side influenced by the increase flow momentum both of the bluff body. On other hands, the velocity pathline prediction has shown that the maximum turbine performance occurs with installing a circular cylinder at X/D of 0.5. The analysis always includes the attached flow zone and in this position, it has the highest velocity or lowest pressure. In this case, the positive torque will increase and maximum performance occurs at X/D of 0.5. The analysis of the velocity pathline has been continued by installing a circular cylinder at X/D from 1.0 to 2.0. The vortex at the edge of the advancing blade has formed again like the velocity pathline of conventional Savonius. Therefore, the performance of Savonius turbine will decrease and be back to conventional Savonius when a circular cylinder has installed farther away from the Savonius turbine. The phenomena of the vortex can be seen in Fig. 10 and as a decision, the highest turbine performance has been predicted at X/D of 0.5. Thus, numerical analysis with velocity pathline qualitatively has obtained the same result with quantitative prediction as shown in Table. 4.

4.4. The Maximum Power Coefficient

Power coefficient or performance will be compared between high performance at each variation with respect to conventional Savonius as shown in Table 5, which the effect has shown that horizontal distance (X/D) variations have the maximum power coefficient in about 0.250 obtained at TSR of 0.9 and the value power coefficient or performance is 17.31% bigger than conventional Savonius.

Table 5. The maximum power coefficient at X/D variations for ds/D = 0.3

Distance variations	Maximum Cp	Relation of TSR	Gain Cp (%) toward conventional Savonius
Conventional savonius	0.213	0.9	0.00
X/D = 0	0.225	0.9	5.78
X/D = 0.5	0.250	0.9	17.31
X/D = 1.0	0.226	0.9	6.23
X/D = 1.5	0.223	0.9	4.54
X/D = 2.0	0.220	0.9	3.26

5. Conclusion

Based on the numerical result and analysis for changing of horizontal distance (X/D) of 0.0, 0.5, 1.0, 1.5 and 2.0, it has shown that conventional Savonius has improved the torque coefficient and the power coefficient. The maximum power coefficient has occurred at the horizontal distance (X/D) of 0.5. The power coefficient has increased by about 17.31 % at a tip speed ratio (TSR) of 0.9, compared to the conventional one. The circular cylinder as passive control that has been placed away from Savonius turbine until X/D of 2.0 will decrease the performance of Savonius turbine, and the vortex will be back to the formation of a vortex of conventional Savonius turbine.

Acknowledgements

The authors would like to thank the Shipbuilding Institute of Polytechnic Surabaya which has given a chance to study in the Doctoral Program of Mechanical Engineering, at Sepuluh Nopember Institute of Technology.

References

[1] A. Yuningsih, E. H. Sudjono, B. Rachmat, and S. Lubis, ”Currents energy prospect”, ESDM. Report; 2010.

[2] N. P. Purba, J. Kelvin, M. Annisaa, D. Teliandi, K. G. Ghalib, I. P. Resti Ayu, and F. S. Damanik, ”Preliminary research of using ocean currents and wind energy to support lighthouse in small island, indonesia”, Energy Procedia , vol. 47, pp. 204-210, 2014.

[3] B. Yang, C. Lawn, “Fluid dynamic performance of a vertical axis turbine for tidal currents”, Renewable Energy, vol. 36, pp. 3355-3366, 2015.

[4] G. Kailash, T. I. Eldho, S. V. Prabhu, “Performance study of modified savonius water turbine with two deflector plates”, International Journal of Rotating Machinery, vol. 2012, pp. 1-12, 2012.

[5] P. A. Setiawan, T. Yuwono, W. A. Widodo, ”Numerical simulation on improvement of a Savonius vertical axis water turbine performance to advancing blade side with a circular cylinder diameter variations”, IOP Conf. Ser.: Earth Environ. Sci., vol. 200, pp. 012-029, 2018.

[6] P. A. Setiawan, T. Yuwono, W. A. Widodo, ” Effect of a circular cylinder in front of advancing blade on the Savonius water turbine by using transient simulation”, International Journal of Mechanical and Mechatronics, vol. 19, No. 01, pp. 151-159, 2019.

[7] A. Sanusi, S. Soeparman, S. Wahyudi, and L. Yuliati, ”Experimental study of combined blade savonius wind turbine”, International Journal Of Renewable Energy Research, vol. 6, pp. 614-619, 2016.

[8] R. E. Sheldahl, L. V. Feltz, B. F. Blackwell, “Wind tunnel performance data for two- and three-bucket savonius rotors”, Journal of Energy, vol. 2, pp. 160-164, 1978.

[9] K. Kacprzak, G. Liskiewicz, K. Sobczak, ”Numerical investigation of conventional and modified Savonius wind turbines”, Renewable Energy, vol. 60, pp. 578–585, 2013

[10] C. J. Freitas, “The ıssue of numerical uncertainty”, The 2nd International Conference on CFD in the Minerals and Process Industries, Melbourne: CSIRO, pp. 29-34, 1999.

[11] Ansys Inc.: Ansys fluent theory guide. Ansys Inc. publication, release 17.0.

[12] B. D. Altan, M. Atilgan, ”An experimental and numerical study on the improvement of the performance of Savonius wind rotor”, Energy Convers. Manag, vol. 49, pp. 3425–3432, 2008.

[13] L. Rosario, M. Stefano, M. Michele, "2D CFD modeling of H-Darrieus wind turbines using a transition turbulence model", Energy Procedia vol. 45, pp. 131–140, 2014.
[14] S. McTavish, D. Feszty, T. Sankar, "Steady and rotating computational fluid dynamics simulations of a novel vertical axis wind turbine for small-scale power generation", Renewable Energy, vol. 41, pp. 171–179, 2012.
[15] A. Benzerdjeb, M. K. Hamidou, B. Abed, M. Bordjane, H. Achache, A. M. Gorlov, "Numerical study on the performance of darrieus turbine by K-ε standard and K-ε EARSM turbulence models", IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), 2017.
[16] T. Wenlong, S. Baowei and M. Zhaoyang, "Numerical investigation of a Savonius wind turbine with elliptical blades", Proceedings of the CSEE, vol. 34, pp. 796-802, 2014.
[17] D. M. Ramos, C. D. Sauced, "CFD study of a vertical axis counter-rotating wind turbine", IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), 2017.
[18] A. Benzerdjeb, M. K. Hamidou, B. Abed, M. Bordjane ; H. Achache, A. M. Gorlov, "Numerical study on the performance of darrieus turbine by K-ε standard and K-ε EARSM turbulence models, IEEE 6th International Conference on Renewable", Energy Research and Applications (ICRERA), 2017.
[19] D. Satrio, I. K. A. P. Utama, Mukhtasor, "The influence of time step setting on the CFD simulation result of vertical axis tidal current turbine", Journal of Mechanical Engineering and Sciences, vol. 12, pp. 3399-3409, 2018.
[20] O. B. Yaakob, D.T. Suprayogi, M. P. Abdul Ghani, and K. B. Tawi, "Experimental studies on savonius-type vertical axis turbine for low marine current velocity," *IJE Transactions A*: Basics Vol. 26, No. 1, 91-98, 2013.