Mekanika: Majalah Ilmiah Mekanika

Initial Rotation Characteristic Investigation of a Hybrid Savonius – Darrieus Wind Turbine using 6 DOF Computational Fluid Dynamics

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Abstract
The inconsistency of the wind flow considered as one of the factors which tend to decrease the performance of the wind turbine. This paper proposes a further analysis of the initial rotation characteristic of a hybrid Savonius-Darrieus wind turbine. The addition of the Darrieus blade intends to increase the aerodynamic stability of the overlapping Savonius turbine. This study implements 2D Computational Fluid Dynamics (CFD) transient analysis using the six Degrees of Freedom (DOF) methods in 0°, 30°, 60°, and 90° Darrieus blade position along with 2, 4, and 6 m/s wind speed variations. The results of the aerodynamic analysis show that the location of the Darrieus 30° turbine provides the greatest initial repulsion, especially when the turbine rotation is above 90°, the position of the Darrieus blade can provide additional impulse force when the Savonius turbine tends to be passive. This effect occurs more significant at higher wind speeds. Savonius with 3-blade modification has a more stable level of force distribution than the 2-blade modification, although the value is smaller. This shows that the 3-blade Savonius provide a higher stability of angular velocity development.

1 Introduction

Savonius wind turbine is simple but effective to be applied in a relatively low wind speed and inconstant direction. The performance of Savonius type wind turbines decreases in relatively high wind speed. This is caused by the presence of turbulence in the airflow shortly after passing the blades on Savonius wind turbines [1]. The highest average efficiency in Savonius turbines is 16% [2]. This value is so small that certain innovations are needed to improve turbine efficiency. The presence of wind collisions in the inactive blades results in obstacles to the turbine rotation.

The effect of the number of blades on conventional Savonius turbines shows that turbines with a number of two blades have a slightly higher rotor rotation value than turbines with three blades [3]. Another study shows that using four Savonius turbine blades has an efficiency value of up to 10%. The efficiency value is also greatly influenced by the ratio of the gearbox used [4]. The selection of Darrieus blade types using the National Advisory Committee for Aeronautics (NACA) 2412 model has a maximum generated power of 16.38 W at a wind speed of 6 m/s and the number of turbine blades of four units.

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However, the minimum power produced by the turbine is 0.45 W at wind speed is 6 m/s and the number of turbine blades is three units [5]. There is a tendency that the increasing wind speed and the number of blades used will increase the power generated by the Darrieus turbine [6]. Natural composite materials show good strength and flexural properties along with good damping properties designed for wind turbine blades [7]. With the low efficiency of wind turbines for both Savonius and Darrieus models, further research is needed. This paper proposes the development of hybrid turbine models using a combination of Savonius and Darrieus models that are expected to take the advantage of each type of wind turbine to overcome the low efficiency of current wind turbines.

This research aims to reduce the effects of these obstacles by adding a Darrieus blade to the inactive side of the Savonius blade. So that aerodynamic effects that occur more effectively and can improve the performance of the turbine.

2 Materials and Method

The hybrid turbine composed of Savonius and Darrieus turbines. The Savonius turbine used in this study was the half barrel with two blades and three blades. The effective diameter of both the Savonius Turbine was 500 mm. The Darrieus turbine was built based on NACA 2412 (see Figure 1) [8] with a 100 mm chord length. Two Darrieus blades connected using a movable arm that can be set for the Darrieus angle position. The Darrieus blades located about 373 mm from the center of Savonius turbines (see Figures 2 and 3).

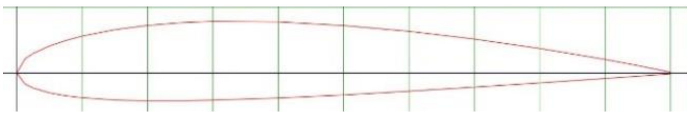

Figure 1. NACA 2412 base model

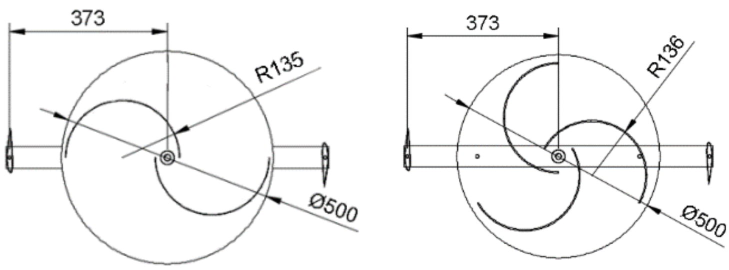

Figure 2. Configuration of hybrid turbines

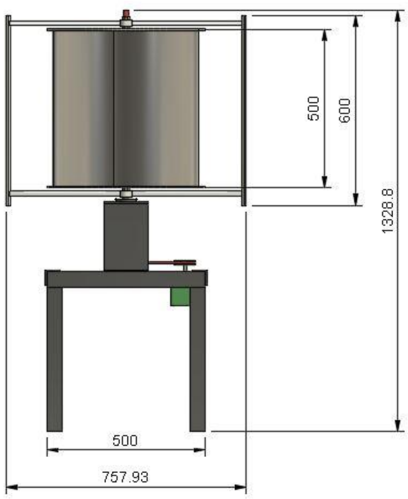

Figure 3. Full assembly of hybrid wind turbine

The turbine blade materials using an aluminum plate with 0.5 mm thickness. The base of Savonius blades and arms of Darrieus blades is using the composite materials to reduce energy inefficiency [9]. The static aluminum shaft used in this study. Some complex components produced using 3D printing due to its requirements to be easily assembled. Figure 4 describes the research domain in 2D.

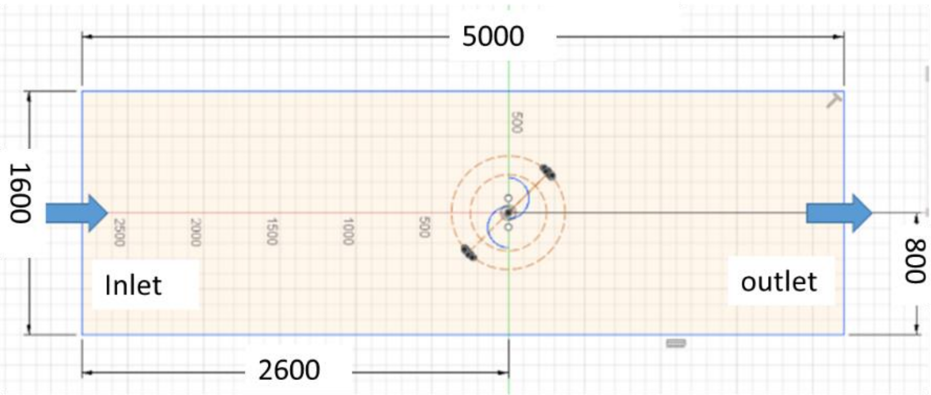

Figure 4. The domain of 2D aerodynamics analysis

In order to analyze the initial rotation characteristic, the six degrees of freedom transient analysis was used in this study [10]. Figure 5 describes the setup of the 2D simulation study. The Darrieus rotor position is modified in four different locations to determine the most effective location.

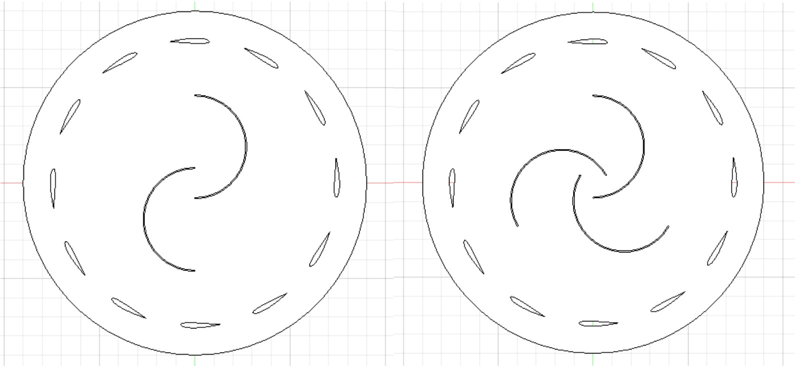

Figure 5. Darrieus rotor position in 0º, 30º, 60º, and 90º: (a) two blades Savonius model, and (b) three blades Savonius model

The flow calculation model used in this study is a segregated flow with a k-epsilon realizable turbulence model. Another parameter that needs to be considered is the use of implicit unsteady parameters with the second-order upwind discretization scheme. In addition, the time step discretization used is the second order.

$$\omega = \frac{2\pi n}{60} \tag{1}$$

The results of numerical data collected of the rotation at 0 to 120 s. The rotation value can be converted to an angular velocity value using Equation 1 [11] with ω is angular velocity rad/s, and n is Revolution Per Minute (RPM). The 60 constants used to convert revolution per minute into revolution per second.

3 Results and Discussion

The numerical simulation used to further analysis of the initial rotation aerodynamics characteristic. The analysis divided by the wind speed in each number of Savonius blades variation.

3.1 Initial rotation characteristic at 2 m/s wind speed

Based on Figure 6 it can be seen that the position of the Darrieus blade at 0° has the highest angular velocity value at each time change. The effective angular velocity value for this variation is 19.8 rad/s. While the lowest angular velocity value at each time change is obtained at a variation of the position of the Darrieus 90° blade. The effective angular velocity value for this variation is 16.7 rad/s.

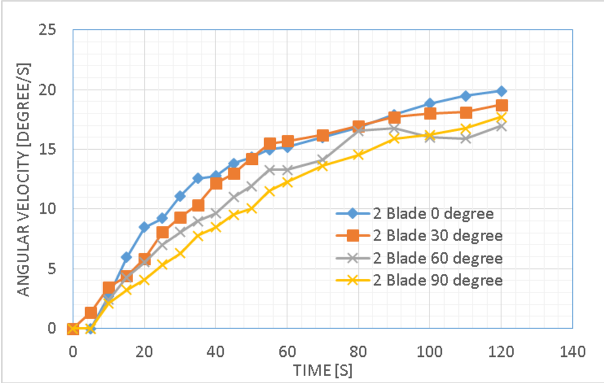

Figure 6. Turbine rotation development of three blades Savonius within 120 s at 2 m/s wind speed

More detailed observations were obtained from the results of the aerodynamic analysis. Figure 7. shows the variation of 2 Savonius blades at the time of 3 s it appears that the position of the Darrieus turbine determines the impulse of the fluid. Darrieus turbine location variation at point 0° receives more momentum from the fluid which causes the spin initiation conditions at this variation to run faster.

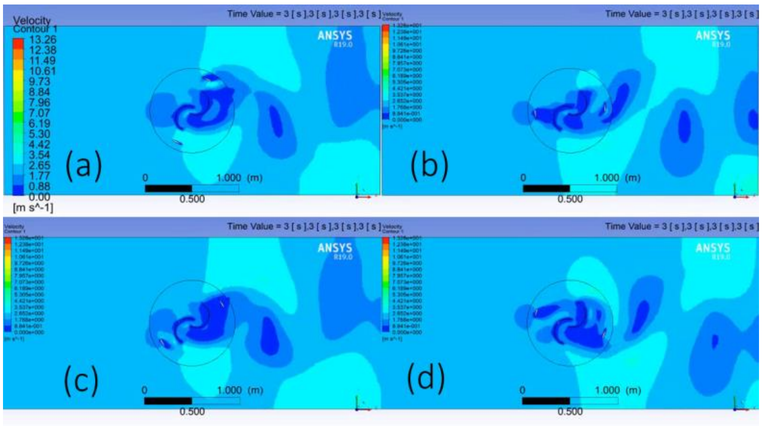

Figure 7. Velocity contour plot at 3 s: (a) 0° Darrieus position, (b) 60° Darrieus position, (c) 30° Darrieus position, and (d) 90° Darrieus position

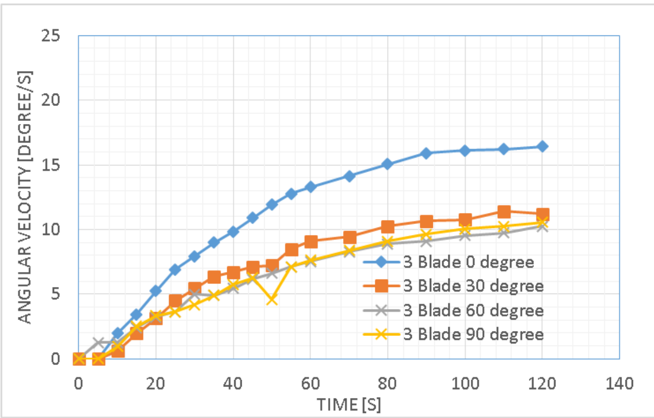

Figure 8. Turbine rotation development of 3 blades Savonius within 120s at 2 m/s wind speed

Figure 8 depicts the position of the Darrieus blade at 0° has the highest angular velocity value at each time change. The effective angular velocity value for this variation is 16.4 rad/s. While the lowest angular velocity value at each time change is obtained at a variation of Darrieus 60° blade position. The effective angular velocity value for this variation is 10.2 rad/s. Variation of Savonius three blades at the time of 5.9 seconds in Figure 9. shows that the variation of the Darrieus turbine location at point 0° receives more momentum from the fluid which causes the conditions of spin initiation at this variation to run faster. The position of the turbine blade at this point has a significant impact value for the initiation of the turbine rotation.

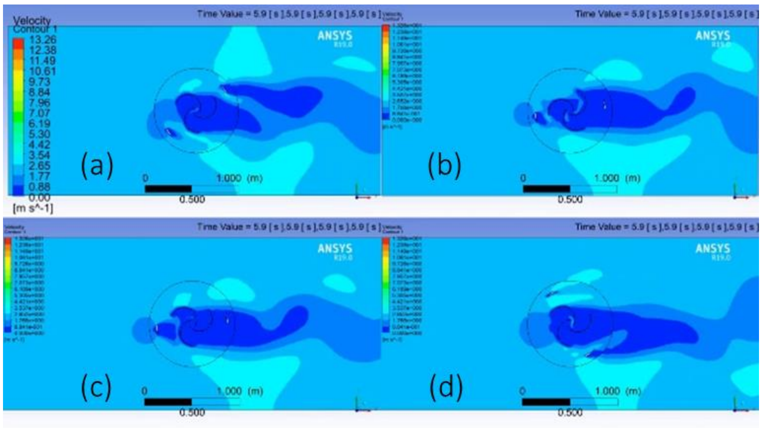

Figure 9. Velocity contour plot at 5.9 s: (a) 0° Darrieus position, (b) 60° Darrieus position, (c) 30° Darrieus position, and (d) 90° Darrieus position

In both number of Savonius blade variations, it is seen in that the variation of two Savonius blades has a higher angular velocity value. In both variations, the position of the Darrieus turbine addition at the location of 0° has the highest angular velocity.

3.2 Initial rotation characteristic at 4 m/s wind speed

Figure 10 shows that the position of the Darrieus blade at 30° has the highest angular velocity value at each time change. The effective angular velocity value for this variation is 46.4 rad/s. While the lowest angular velocity value at each time change is obtained at a variation of Darrieus 60° blade position. The effective angular velocity value for this variation is 33.3 rad/s.

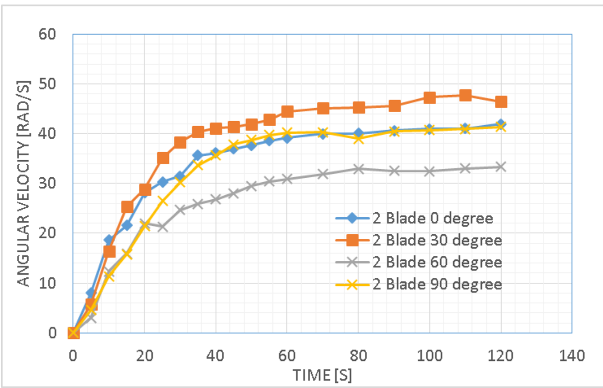

Figure 10. Turbine rotation development of two blades Savonius within 120 s at 4 m/s wind speed

Figure 11 showed significant impact values occur at 2.8 s where the Darrieus 30° angle variation has the best momentum position, resulting in faster spin initiation. This is because the Darrieus turbine is able to accept fluid repulsion when the Savonius turbine is passive. Due to the balanced force in Savonius blade which always occurs in 90° angle [12].

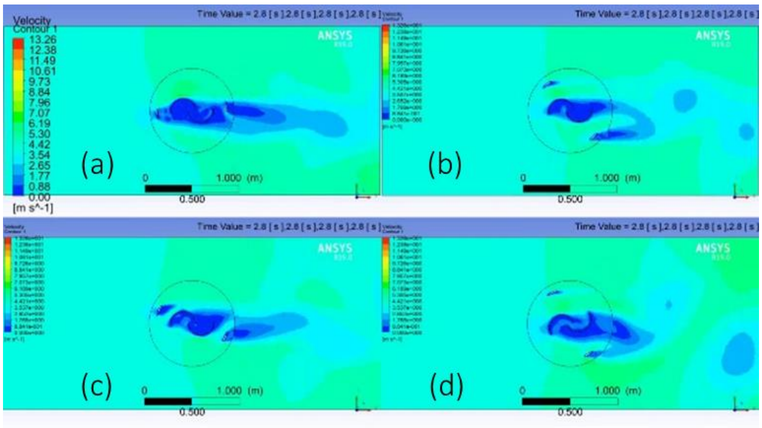

Figure 11. Velocity contour plot at 2.8 s: (a) 0° Darrieus position, (b) 60° Darrieus position, (c) 30° Darrieus position, and (d) 90° Darrieus position

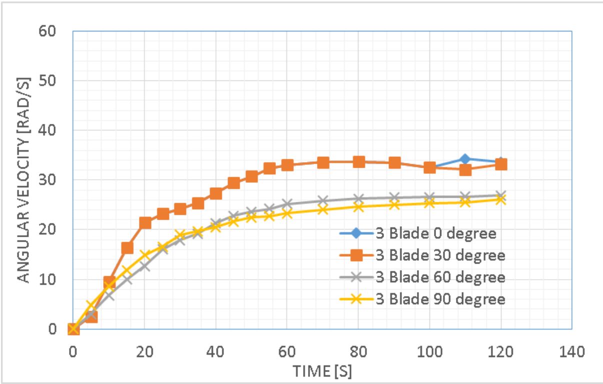

Figure 12. Turbine rotation development of three blades Savonius within 120 s at 4 m/s wind speed

Figure 12 can show that the position of the Darrieus blade at 30° has the highest angular velocity value at each time change. The effective angular velocity value for this variation is 33.1 rad/s. While the lowest angular velocity value at each time change is obtained at a variation of the position of the Darrieus 90° blade. The effective angular velocity value for this variation is 25.5 rad/s. Almost the same thing happened in Savonius three blades variation as seen in Figure 13. where the position of Darrieus 30° blades has the advantage in receiving turbine collisions when the rotation is above 90°. Therefore, the rotation value that can be generated in Darrieus 30° turbine blade variations has the highest rotation value compared to the others.

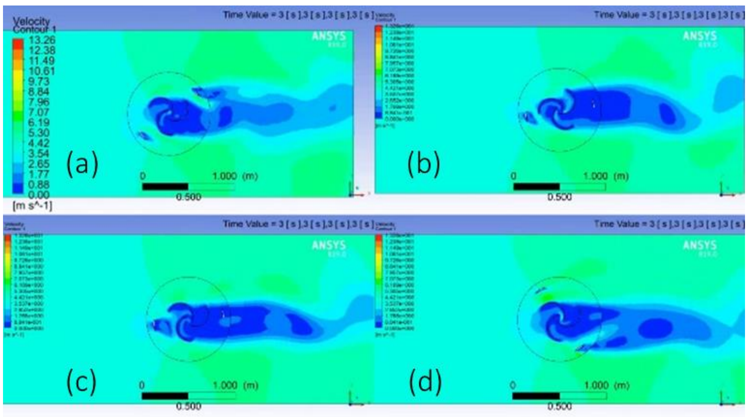

Figure 13. Velocity contour plot at 2.8 s: (a) 0° Darrieus position, (b) 60° Darrieus position, (c) 30° Darrieus position, and (d) 90° Darrieus position

3.3 Initial Rotation Characteristic at 6 m/s wind speed

Figure 14 shows that the position of the Darrieus blade at 30° has the highest angular velocity value at each time change. The effective angular velocity value for this variation is 50.1 rad/s while the lowest angular velocity value at each time change is obtained at a variation of the position of the Darrieus 90° blade. The effective angular velocity value for this variation is 45.3 rad/s. At high wind speeds, the effect of the position of the Darrieus turbine at position 30° has the highest impact value. Figure 15 showed the process of initiation of the spin is faster which occurs during the first 2.3 s.

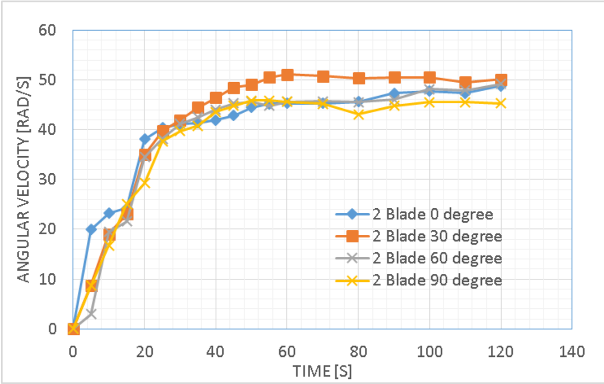

Figure 14. Turbine rotation development of three blades Savonius within 120 s at 6 m/s wind speed

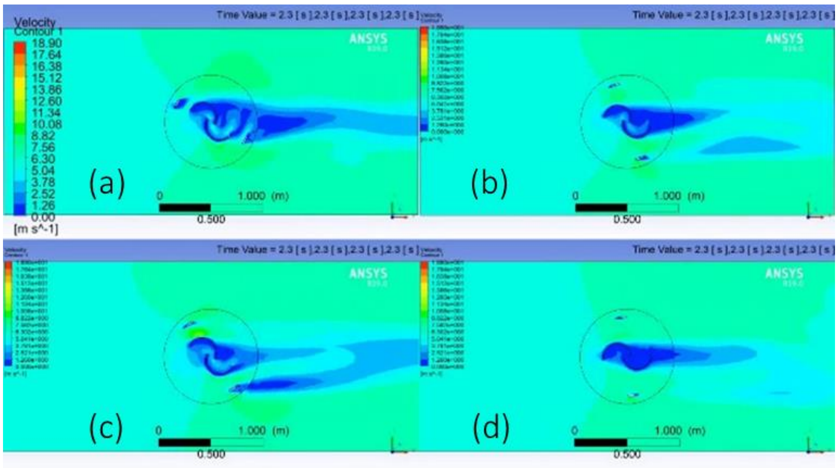

Figure 15. Velocity contour plot at 2.3 s: (a) 0° Darrieus position, (b) 60° Darrieus position, (c) 30° Darrieus position, and (d) 90° Darrieus position.

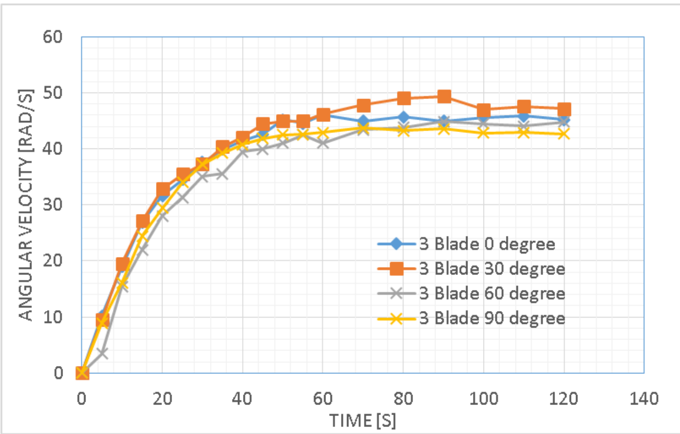

Figure 16. Turbine rotation development of three blades Savonius within 120 s at 6 m/s wind speed

Figure 16 shows that the position of the Darrieus blade at 30° has the highest angular velocity value at each time change. The effective angular velocity value for this variation is 47.2 rad/s. While the lowest angular velocity value at each time change is obtained at a variation of the position of the Darrieus 90° blade. The effective angular velocity value for this variation is 42.7 rad/s. In variation of three Savonius blades, Figure 17 shows that initiation of rotation occurs faster in the Darrieus 30° turbine variation. This is in line with experimental results which show that the variation has the highest rotation.

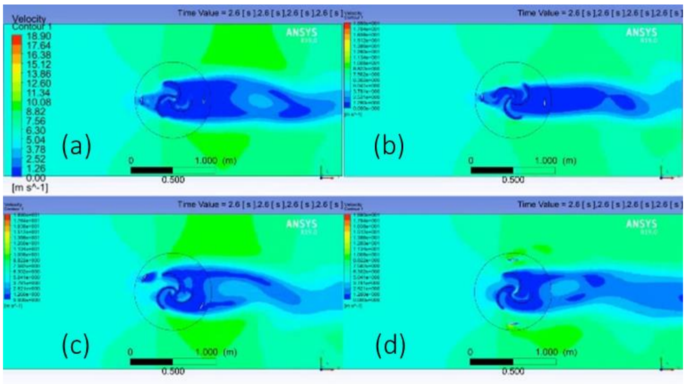

Figure 17. Velocity contour plot at 2.6 s: (a) 0° Darrieus position, (b) 60° Darrieus position, (c) 30° Darrieus position, and (d) 90° Darrieus position

4 Conclusions

From the overall data collection, several conclusions can be obtained as follows. In both variations of the number of blades of Savonius turbine, the number of blades two has a higher mean rotation value than the number of blades three. The difference in rotation is higher in the variation of wind speed 2 m/s. While the difference is not too large at 6 m/s wind speed variations. This shows that the performance of two blades Savonius turbine is better than three blades, especially in low wind speed conditions. The addition of the Darrieus blade has a role as a driver of fluid flow which also acts as the driving force of the turbine. The results of aerodynamic analysis shows that the location of the Darrieus 30° turbine provides the greatest initial repulsion, especially when the turbine rotation is above 90°, the position of the Darrieus blade can provide additional impulse force when the Savonius turbine is passive. This effect is more significant when the wind speed is higher. Savonius 3-blade variation has a more stable level of force distribution than the 2-blade variation, although the value is smaller. This shows that the level of consistency of Savonius three blades is relatively constant in terms of the results of the force plot on the turbine.

References

1. N. Halsey, *Geometrically Modeling the Twisted Savonius Wind Turbine*, Portland: Saltire Software. Available in http://celloexpressions.com/ts/dynamic–documentation/intro/(Accessed in January 8, 2019).
2. M. Óskarsdóttir, *A General Description and Comparison of Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines*, Reykjavík: University of Iceland, 2014.
3. M. H. Ali, "Experimental Comparison Study for Savonius Wind Turbine of Two & Three Blades At Low Wind Speed." *Int. J. Mod. Eng. Res*., vol. 3, no. 5, pp. 2978-2986, 2013.
4. D. Ashwin, and V. Bankar, "Design, Analysis And Fabrication Of Savonius Vertical Axis Wind Turbine." *Int. Res. J. Eng. Tech.*, vol. 2, no. 3, pp. 2048-2054, 2015.
5. B. Purwono, A. Walid, and Maskuri. *Simulasi Pengaruh Kecepatan Angin, Putaran Poros dan Variasi Sudu terhadap Daya Listrik Model Pembangkit Listrik Tenaga Bayu (PLTB) Tipe Turbin Angin Vertikal dengan NACA 2412*, Malang: Politeknik Negeri Malang, 2015. (*in Indonesian*).
6. B. Purwono, Masroni, and A. Muqit, *Strategi Pemanfaatan Kincir Angin Sumbu Vertikal Tipe Naca 3412*, Jakarta: Politeknik Negeri Jakarta, 2017. (*in Indonesian*).

7. A. Murdani, S. Hadi, and U. S. Amrullah, "Flexural Properties and Vibration Behavior of Jute/Glass/Carbon Fiber Reinforced Unsaturated Polyester Hybrid Composites for Wind Turbine Blade", *Key Eng. Mater.*, vol. 748, pp. 62-68, 2017.
8. G. J. Herbert, S. Iniyan, E. Sreevalsan, and S. Rajapandian, “A review of wind energy technologies,” *Renew. Sustain. Energy Rev.*, vol. 11, no. 6, pp. 1117-1145, 2007.
9. K. Pope, I. Dincer, and G. Naterer, “Energy and exergy efficiency comparison of horizontal and vertical axis wind turbines,” *Renew. Energy*, vol. 35, no. 9, pp. 2102-2113, 2010.
10. X. Wang, X. Luo, B. Zhuang, W. Yu, and H. Xu, "6–DOF Numerical Simulation of the Vertical–Axis Water Turbine," in *ASME–JSME–KSME 2011 Joint Fluids Engineering Conference*, Hamamatsu, Japan, 2011.
11. F. Thönnißen, M. Marnett, B. Roidl, and W. Schröder, “A numerical analysis to evaluate Betz's Law for vertical axis wind turbines,” *J. Phys. Conf. Ser.*, vol. 753, article no. 022056, 2016.
12. K. Witono, M. Nasir, E. Faizal, H. Wicaksono, B. Pranoto. "Pengaruh Model Sudu Overlap dan Helix pada Proses Inisiasi Putaran Turbin Savonius," *Otopro: J. Mech. Eng. Appl.*, vol. 15, no. 1, pp. 27-31, 2019. (*in Indonesian*).