Engineering Innovations
ISSN: 2813-1002, Vol. 11, pp 75-82
doi:10.4028/p-SfjZn0

Submitted: 2024-01-04
Revised: 2024-01-07
Accepted: 2024-01-08
Online: 2024-06-26

The Effect of Deflector Angle on the Performance of Turbine Combination Darrieus-Savonius

Irfin Rizki[1,a], Satworo Adiwidodo[1,b*], Eko Yudiyanto[1,c], Bagus Wahyudi[1,d], Fauzan Baananto[1,e]

[1]State Polytechnic of Malang, Indonesia

[a]irfinrizki9@gmail.com, [b*]satworo.adiwidodo@polinema.ac.id, [c]eko.yudiyanto@polinema.ac.id, [d]bagus.wahyudi@polinema.ac.id, [e]fauzan.baananto@polinema.ac.id

Keywords: vertical axis turbine, Darrieus-Savonius combination, deflector, pitch angle, CFD simulation.

Abstract. The Savonius and Darrieus are vertical-axis wind turbines. This turbine has resistance on one side of the blade that makes it difficult for the shaft to rotate resulting in reduced efficiency. However, the vertical shaft turbine type provides the advantage of being able to accept wind speeds from any direction without an additional tail. Savonius and Darrieus turbines show different characteristics in terms of their performances. Savonius turbine has a high power coefficient (CP) in the range of low tip speed ratio (TSR), when its TSR increases the CP will fall. In contrast to Darrieus, high CP is achieved if the TSR is also high but the CP achievement will fall at a low TSR. If it is compared to Savonius, Darrieus has higher power efficiency although it is difficult to self-start. In contrast to Savonius, Darrieus has a better self-starting ability but a lower efficiency.
This study aims to improve the performance of vertical shaft wind turbines by creating a new design combination of Darrieus and Savonius turbines with deflectors to produce CP achievement on a wide TSR. The combination of the Darrieus-Savonius turbine is to improve efficiency to make self-start easier. The research method uses numerical simulation by employing CFD Ansys software. On the airfoil with a deflector angle of 70 deg, it shows that there is an increase in speed in several parts of the Darrieus blade airfoil. The increase in speed causes the decrease of static pressure in the area. The pressure difference between the sides of the airfoil surface causes a force. The direction of the force causes the turbine shaft to rotate. The deflector acts as a directional headwind, increasing the local flow velocity to counter the resistance on one side of the rotor blades The average torque produced at an angle of 70 deg is 0.5 Nm. Whereas, at an angle of 90 deg, the average torque generated is lower by around 0.15 Nm.

Introduction

In a country's economic development, electricity plays a critical function as an energy system. Particularly at this time, new issues and dimensions that mankind is confronting due to population increase and aspects of daily life that must be addressed through an ever-increasing supply of power are arising. As the welfare of the population increases, various attempts are being made to provide electricity in isolated villages because there is a great need for it in both urban and rural areas [1,2,3]. One of the VAWTs that is most frequently employed in rural regions is the Savonius turbine. The Savonius turbine's simplicity of construction is a benefit, but it has low efficiency because of poor aerodynamics [4,5].
The problems that occur in the vertical axis wind turbine (VAWT) performance are less efficient than the horizontal axis wind turbine, even though this type of turbine has the advantage of being able to receive fluid flow from all directions. The wind received by the vertical axis turbine (VAWT) is divided into two parts, namely on the left and right sides of the axis (shaft), so that the flow leading to the left side will rotate the rotor to drive the blade, while the flow leading to the right side will be opposite to the blade movement and become an obstacle to the turbine rotation movement. As a result, the researchers previously pioneered ways to counteract negative torque, such as by inserting deflector plates on the vertical shafts of turbines [6,7,8]. Compare the startup torque values of

Savonius rotors in the center with traditional H-Darrieus rotors on either side of the hybrid VAWTS. The findings demonstrate that hybrid turbines may start up at any azimuth angle and that the Reynolds number exceeds that of H-Darrieus. Several simulation studies to obtain results close to experiments have been carried out [9,10,11]. The simulation demonstrates that the deflector can modify the direction of flow towards the concave side of Savonius and impede the flow towards the opposite side [12,13,14]. The deflector can generate a region of low pressure on the upstream (convex) surface of the blade, resulting in a decrease in blade resistance. The dual action mechanism demonstrates exceptional performance in generating maximum torque [15]. Throughout its development, the Vertical Axis Wind Turbine (VAWT) has undergone modifications aimed at enhancing its power efficiency. One of them is the Savonius turbine, the many modifications made to connect the two ends of the cylindrical blades in reverse pairs to resemble the letter s perfectly [16,17]. In Savonious turbines without overlap or gap, this does not produce optimal coupling force pairs and can even cause a wider Vortex field in the concave part of the thrust Blade. The incorporation of tandem blades results in the creation of a constricted compartment that resembles a nozzle. This compartment facilitates the reversal of fluid flow direction and enhances the pressure differential required for blade propulsion [18]. The principle of cross-flow in the Savonius turbine can be developed by adding its corners to be double layered or called tandem blades. The incorporation of tandem blades results in the creation of a constricted compartment that resembles a nozzle. This compartment facilitates the reversal of fluid flow direction and enhances the pressure differential required for blade propulsion [18]. Sasongko [19] conducted research on impulse turbine blades by comparing blades with entry and exit angles of 90 degrees and 180 degrees, where it was found that the 180 angle produced a greater moment. Another type of vertical axis turbine that is often used is the Darrieus turbine. Compared to Savonius, Darrieus has higher power efficiency, but it is difficult to self-start, in contrast to Savonius, which has better self-starting ability but lower efficiency. The number of turbine blades has a significant impact on the self-starting wind speed. The impact of the pitch angle on the self-starting speed of wind is contingent upon the number of blades [20]. The enhancement in Savonius rotor performance is attributed to the presence of a passive deflector. The passive deflector exhibits a consequential impact on enhancing the performance of the Savonius rotor. The implementation of passive deflectors resulted in a 24.91% enhancement in rotor performance. Stable alignment can be adaptively achieved using passive deflectors in response to the wind direction. The enhancement of Savonius rotor performance can be achieved through the utilization of passive deflectors, which serve to mitigate the adverse torque exerted on the blades during their return phase. The presence of unstable aerodynamic forces results in a minor deviation in pitch angle between the stable position and the initial position of the passive deflector [21].

Material and Method

A 2D simulation of a Savonius-Darrieus combination turbine with a deflector was conducted using Ansys CFD. The selection of the computational domain size was made to ensure that it did not exert any influence on the final results. The computational domain for the simulation test of the Savonius-Darrieus combination turbine rotor with a deflector consists of two distinct regions: the stationary zone, characterized by a rectangular shape, and the rotary region, which is determined by the wind turbine and spans multiple diameters of the turbine.

The inclusion of a well-organized grid is a crucial aspect in the evaluation of models, as it serves to prevent issues such as non-convergence or instability, ultimately leading to the attainment of more precise simulation outcomes. The present portion commences by constructing a simulated environment in the shape of a mesh. In the process of wind turbine design, it is necessary to ensure that the arithmetic field is sufficiently large to prevent any interference from the field wall with the flow region, as depicted in Figure 3. Additionally, the size of the system should be such that computational resources are utilized optimally. The fundamental objective of ANSYS meshing technology simulation is to generate a mesh that is well-suited for comprehending the solution employed in the project, as it adheres to the requisite criteria. To construct an optimal network, the

attainment of precise flow modeling necessitates the utilization of a mesh that exhibits superior quality in terms of boundary layers and vortices.
Development and design of the Savonius-Darrieus turbine rotor with deflector is done using CAD Inventor software. Rotor Diameter rotor Diameter D = 300 mm and blade height H = 500 mm. The thickness of the Savonius turbine blades is t = 0.5 mm, and the deflector plates are modeled as wind-direction reversing plates with a thickness of 0.5 mm each. Fig. 1 and Fig. 2 apply the wind speed is 7 m/s for each case, while the pressure at the outlet of the domain is equivalent to atmospheric pressure.

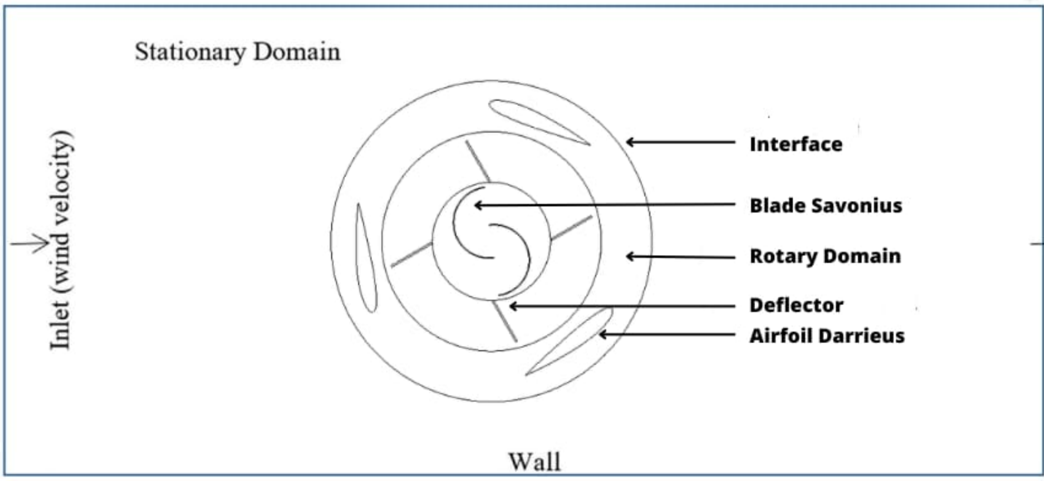

Fig. 1 Savonius-Darrieus combinatorial turbine computing domain with deflector angle 70°

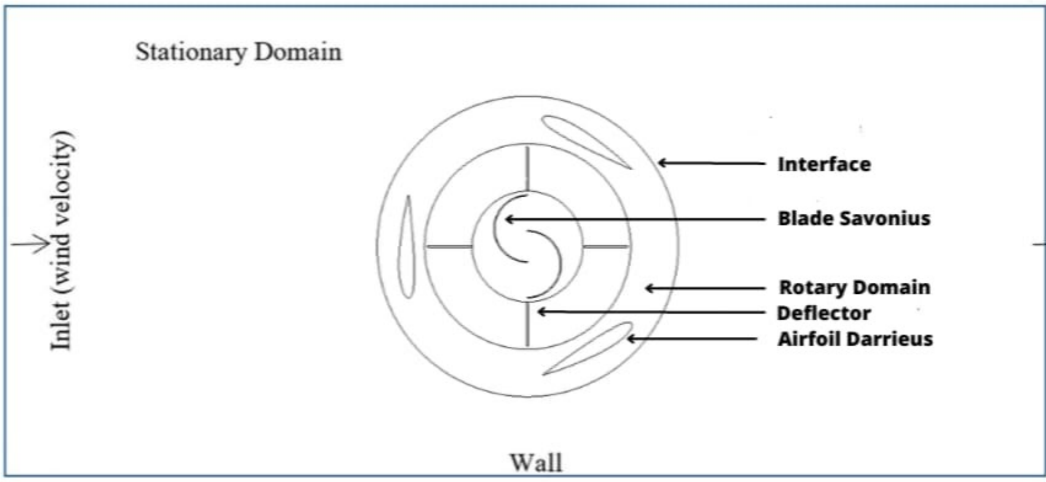

Fig. 2 Savonius-Darrieus combinatorial turbine computing domain with deflector angle 90°

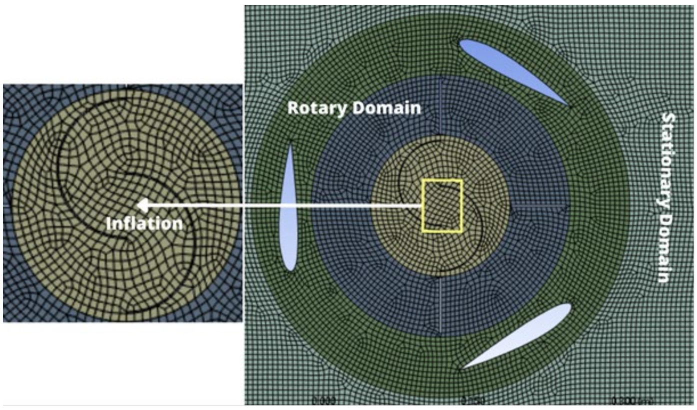

Fig.3 Meshing of modeling

The following boundary conditions have been used by the simulation program ANSYS. The stationary domain is moving freely. As beginning circumstances, hydrodynamic pressure conditions are used. The default boundary conditions in simulation software are Inlet and Outlet. Initial conditions call for a relative pressure on an outlet of 1.0132 x 10^3 [Pa] with an inlet velocity of 7 m/s. The turbine blade surface is regarded as a wall condition. Calculations of characteristics like surface force are possible under this circumstance.

The mesh report provides information on element 320666. The solver used in this study is pressure-based, transient, and two-dimensional. The viscous model employed in this study is the standard k-epsilon model. The material under consideration is air. Boundary conditions refer to the set of conditions that are imposed on a system or problem at its boundaries. The velocity magnitude at the inlet is 7 m/s, whereas the gauge pressure at the outlet is 0 Pascal. The wall remains stationary wall. The absence of slip characterizes the shear condition. The operating conditions are set at atmospheric pressure, specifically 1.0132 bar. The solution controls for pressure-velocity coupling set coupled with spatial discretization of fluids.

Result and Discussion

The pressure contour produced by the Savonius-Darrieus combination turbine with a deflector is depicted in Fig. 4. The flow velocity was 7 m/s, and the deflector angle was 70 degrees. As a result, the airfoil responsible for capturing flow energy experiences an increase in pressure, and it seems that the deflector can change the flow direction to the side of the Savonius turbine to increase local velocity and decrease negative torque. Outstanding double effect for maximum torque.

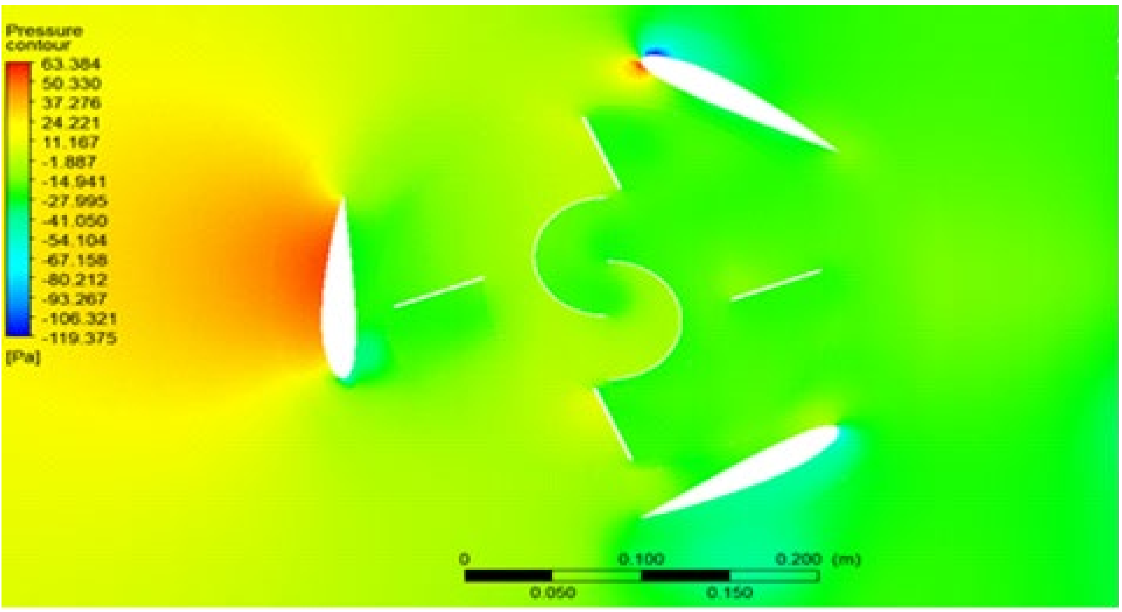

Fig. 4 Pressure contour of the savonius-darrieus combination turbine with deflector, α = 70°, U = 7 m/s.

The pressure contour at the flow speed is 7 m/s, and the deflector angle is 90 degrees produced by the Savonius-Darrieus combination turbine with deflector as shown in Fig. 5. The Savonius turbine can't rotate as efficiently as it should since the airfoil responsible for absorbing the flow energy looks to receive additional pressure, and it appears that the deflector can change the flow's direction so that it doesn't directly hit the turbine's side.

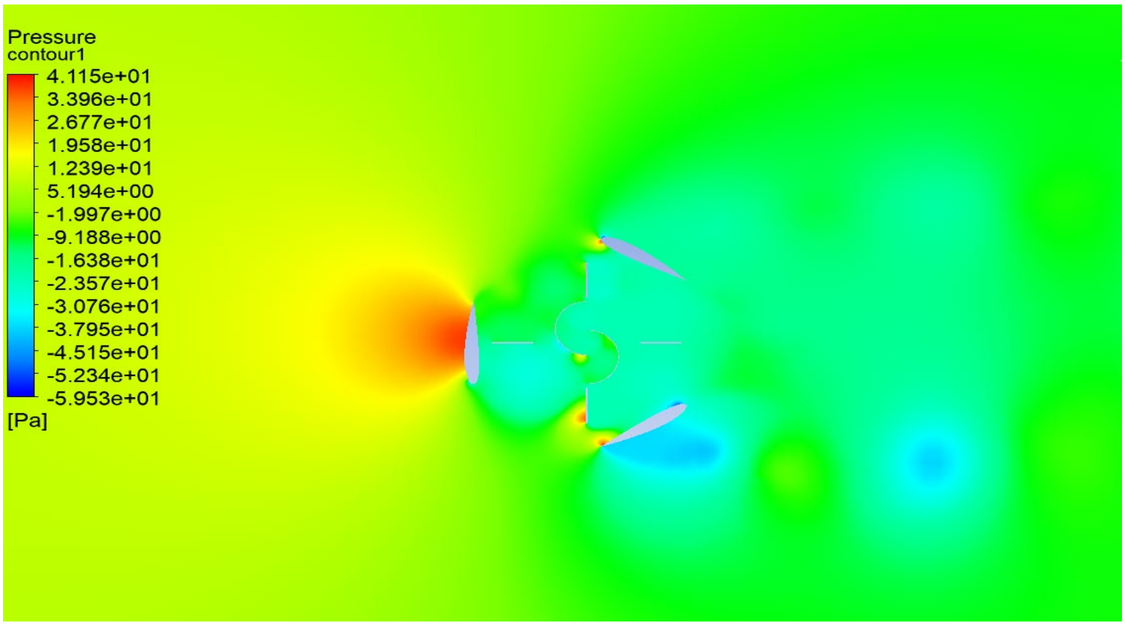

Fig. 5 Pressure contour of the Savonius-Darrieus combination turbine with deflector, α = 90°, U = 7 m/s

The simulation results are displayed as contour velocity in Fig. 6. The Darrieus airfoil has several areas on the blade where the speed increases. Simulation of Savonius-Darrieus combination turbine with deflector simulation shows that deflector can change the direction of flow towards the concave side of Savonius and block the flow to the other side. The static pressure in the area decreases as speed increases. The airfoil surface pressure differential generates a force (F), the direction of which drives the spinning of the turbine shaft. To overcome the resistance of one side of the blade, the deflector changes the wind's direction and raises the local flow velocity. A decrease in static pressure results from an increase in the local flow velocity as shown on the Blade Darrius's back. The Darrieus turbine blades experience a suction effect as a result of the pressure drop, which aids in the blades' rotation and continues to the turbine shaft.

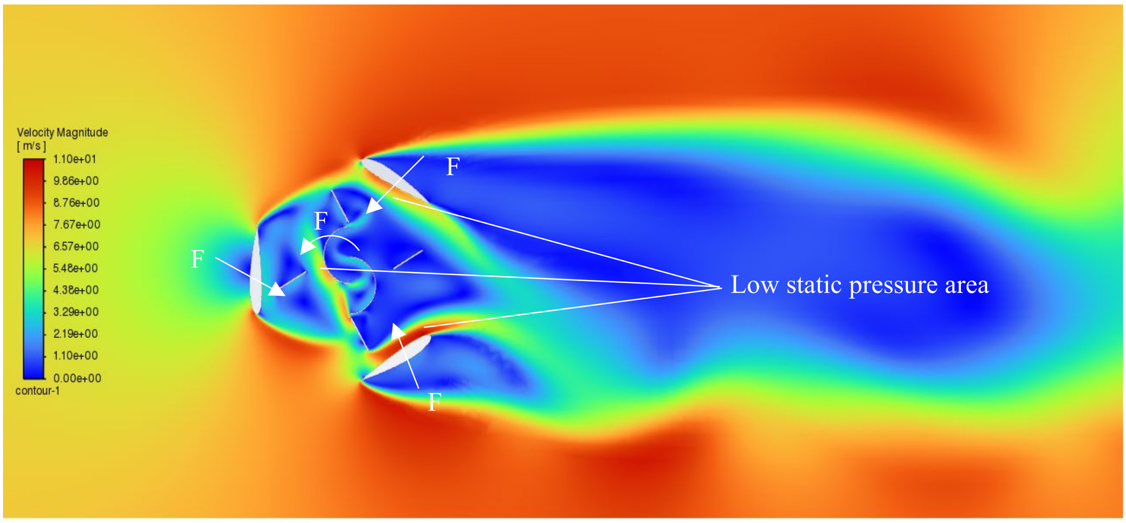

Fig. 6 Velocity contour of the savonius-darrieus combination turbine with deflector, α = 70°, U = 7 m/s.

Fig. 7 shows the simulation results in the form of the contour velocity of the Savonius-Darrieus combination turbine with a deflector at the flow speed is 7 m/s, and a deflector angle is 90 degrees. The Savonius turbine cannot rotate as efficiently as a 70 degree deflector because the airfoil which is responsible for absorbing the flow energy appears to be under additional pressure. To prevent the flow from immediately striking the side of the turbine, the deflector alters the flow directionless.

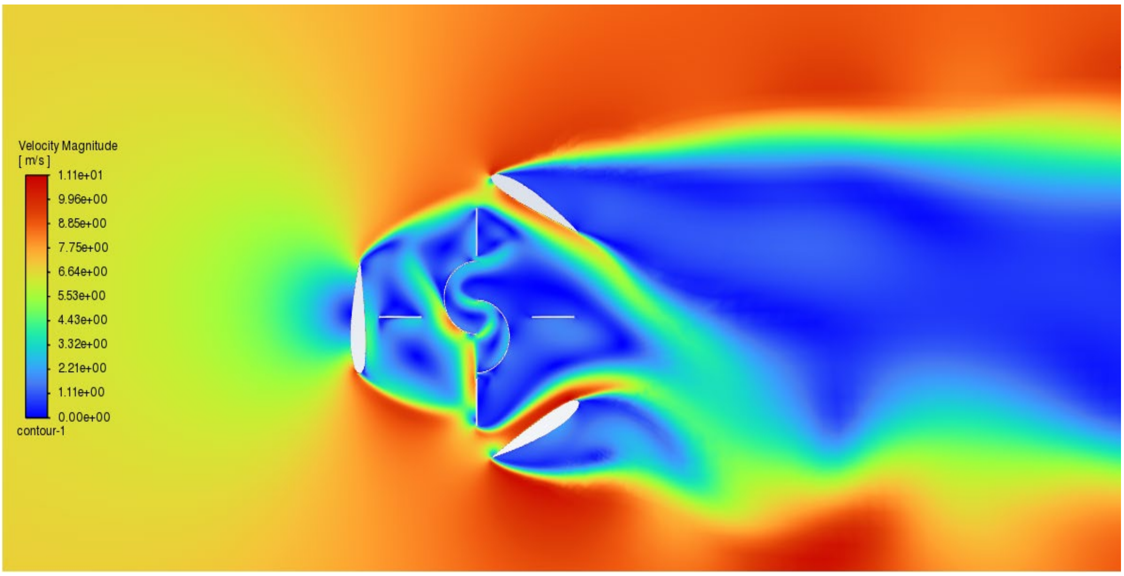

Fig. 7 Velocity contour of the Savonius-Darrieus combination turbine with deflector, α = 90°, U = 7 m/s

The correlation between flow time and torque is depicted in Fig. 8 and Fig. 9. The angle in the image is 70 degrees, and the max torque is almost 0.5 Nm. When the object is positioned at a 90-degree angle, the generated torque falls by a max of 0.15 Nm.

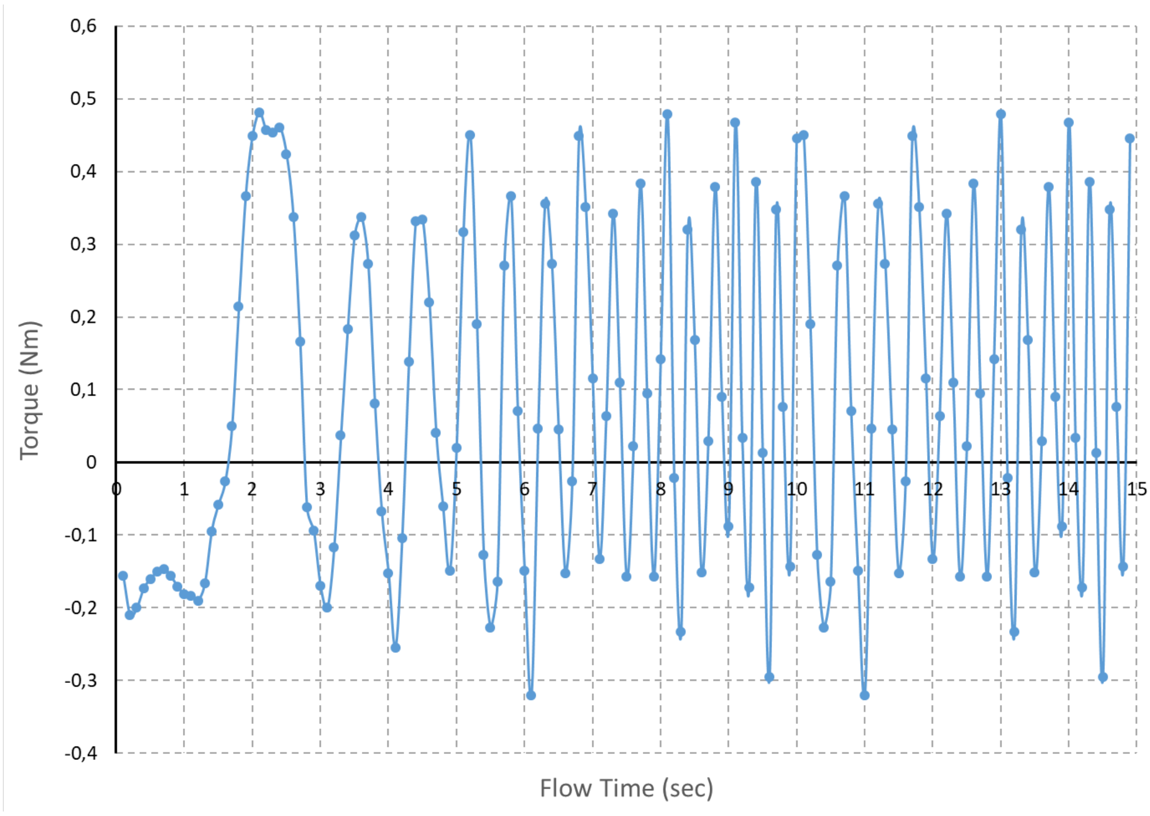

Fig. 8 Torque with deflector α = 70°

The decrease in torque observed in a combined turbine with a deflector angle of 90 degrees, as opposed to a deflector angle of 70 degrees, can be attributed to the higher pressure difference between the bottom and upper surfaces of the Darrius blade in the 70-degree deflector configuration. The pressure gradient generates a substantial change in force, resulting in a higher torque.

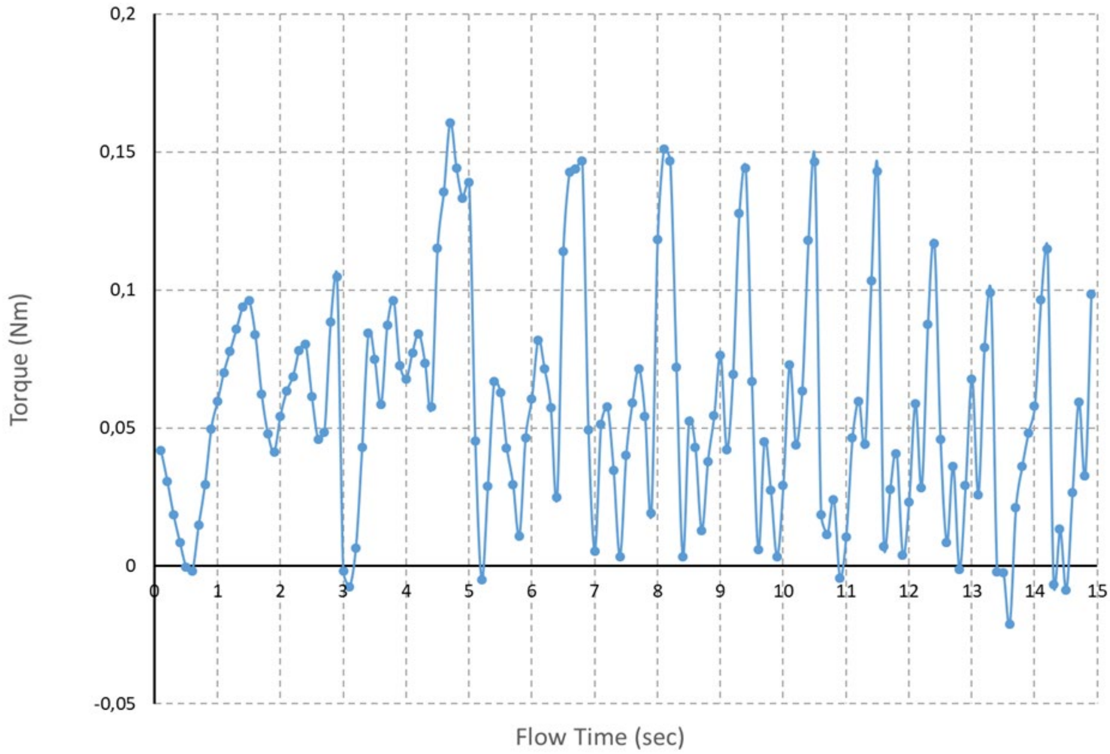

Fig. 9 Torque with deflector α = 90°

The reduction in torque at a 90-degree angle is also attributed to the ineffective positioning of the deflector plate, which fails to properly guide the wind flow to strike the Savonius blade at the desired angle. The Savonius turbine's contribution of torque is minimal and may even decrease due to the drag it generates. In general, this leads to impaired rotation of the tube shaft and a reduction in torque.

Conclusion

It may be inferred that an angle of 70 degrees has the potential to induce a wind direction reversal and enhance the local flow velocity to counteract resistance on one side of the blade thus producing high torque. At a bigger deflector angle in this case 90 degrees, the flow on the deflector is not aligned directly behind the Savonius turbine which can reduce torque.

References

[1] Hanni Wirawan, Yohanna M.L. Gultom, The effects of renewable energy-based village grid electrification on poverty reduction in remote areas: The case of Indonesia, Energy for Sustainable Development, 62 (2021), 186-194.

[2] G. Bedon, U. Schmidt Paulsen, H. Aagaard Madsen, F. Belloni, M. Raciti Castelli, E. Benini, Computational assessment of the DeepWind aerodynamic performance with different blade and airfoil configurations, Appl Energy, 185(2) 2017, 1100–1108.

[3] Qa Li, Y. Kamada, T. Maeda, J. Murata, Y. Okumura, Fundamental study on aerodynamic force of floating offshore wind turbine with cyclic pitch mechanism, Energy, 99 (2016), 20–31.

[4] A. Kumar, R.P. Saini, Performance parameters of the hydrokinetic turbine savonius type-reviews, Energy of Revelation, 64 (2016), 289-310.

[5] D. Kumar, S. Sarkar, Numerical investigation of hydraulic loads and voltages induced in Savonius hydrokinetic turbines by the effects of augmentation techniques through fluid-structure interaction analysis, Energy, 116 (P1) 2016, 609-618.

[6] K. Golecha, T.I. Eldho, and S.V. Prabhu, Performance study of modified Savonius Water Turbine with two deflector plates, International Journal of Rotating Machinery (2012), Hindawi Pub. Co., 12 pages.

[7] A. Bianchini, F. Balduzzi, J.M. Rainbird, J. Peiro, J.M.R Graham, G. Ferrara, et al, An experimental and numerical assessment of airfoil polars for use in Darrieus wind turbines-part I: flow curvature effects, J Eng Gas Turbines Power 138 (2015), 032602.

[8] A. Bianchini, F. Balduzzi, G. Ferrara, L. Ferrari, Virtual incidence effect on rotating airfoils in Darrieus wind turbines, Energy Convers Manage, 111 (2016), 329–338.

[9] G. Ferrara, D. Federici, P. Schito, F. Inzoli, R. Mereu, Savonius wind turbine CFD study: 3D model validation and parametric analysis, Renewable Energy, 105 (2017), 722-734.

[10] F. Balduzzi, A. Bianchini, G. Ferrara, L. Ferrari, Dimensionless numbers for the assessment of mesh and timestep requirements in CFD simulations of Darrieus wind turbines, Energy, 97(2016), 246–261.

[11] K.M. Almohammadi, D.B. Ingham, L. Ma, M. Pourkashan, Computational fluid dynamics (CFD) mesh independency techniques for a straight blade vertical axis wind turbine, Energy 58 (2013), 483–493.

[12] S. Bhuyan, A. Biswas, Investigations on the self-starting and performance characteristics of H and hybrid H-Savonius vertical axis wind rotors are simple, Energy Converters Manage, 87 (2014), 859-867.

[13] Arian Hosseini, Navid Goudarz, Design and CFD study of a hybrid vertical-axis wind turbine by employing a combined Bach-type and H-Darrieus rotor systems, Energy Conversion and Management, 189 (2019), 49-59.

[14] R. Gupta, A. Biswas, CFD analysis of flow physics and aerodynamic performance of a combined three-bucket Savonius and three-bladed Darrieus turbine, Int J Green Energy, 8(2) 2011, 209–233.

[15] S. Adiwidodo, B. Wahyudi, E. Yudiyanto, Subagiyo, M. Hartono, and F. Baananto, Simulation study of Savonius tandem blade wind turbine using an adjustable deflector, In IOP Conference Series: Materials Science and Engineering, IOP Publishing Vol. 732 (2020), No. 1, 8(2) p. 012093.

[16] Kailash Golecha, T. I. Eldho, S. V. Prabhu, Study on the Interaction between two Hydrokinetic Savonius Turbines, International Journal of Rotating Machinery, vol. 2012, Article ID 581658, 10 pages.

[17] Salih Meri Al Absi, Abdullah Hasan Jabbar, Salim Oudah Mezan, Bakir Ahmed Al-Rawi, Salah Thajeel Al-Attabi, An experimental test of the performance enhancement of a Savonius turbine by modifying the inner surface of a blade, Materials Today: Proceedings, Volume 42(5) 2021, 2233-2240.

[18] B. Wahyudi, S. Soeparman, H.W.M. Hoeijmakers, Optimization Design of Savonius Nozzle-Diffuser Blade with Moving deflector for Hydrokinetics Cross Flow Turbine Rotor, Energy Procedia 2015, Energy Procedia, 68 (2015), 244-253.

[19] H. Sasongko, H. Mirmanto, G. Bangga, E.F Nugrahani, J.H Pasaribu, Numerical approach of the blade shape and number on the performance of multiple blade closed type impulse wind turbine, International Journal of Mechanical Engineering Technologies and Applications (MECHTA), 4 (2) 2023, 220 – 235

[20] S. Adiwidodo, E. Yudiyanto, B. Wahyudi, and S.H. Susilo, The role of the blades number and pitch angles to the capability of self-starting the Darrieus wind turbine, In IOP Conference Series: Materials Science and Engineering, IOP Publishing Vol. 1073 (2021), No. 1, p. 012074.

[21] Wenlong Tian, Jiaheng Bian, Guangyong Yang, Xiwen Ni, and Zhaoyong Mao, Influence of a passive upstream deflector on the performance of the Savonius wind turbine, Energy Reports, 8 (2022), 7488-7499.