CFD Letters

Journal homepage:
https://semarakilmu.com.my/journals/index.php/CFD_Letters/index
ISSN: 2180-1363

Savonius-Magnus Hybrid Turbine Design Performance Based on Computational Fluid Dynamics

Rr. Heni Hendaryati[1], Achmad Fauzan Hery Soegiharto[1,*], Dolly Salwansyah[1], Andinusa Rahmandika[1], Bahrul Jalaali[2]

[1] Department of Mechanical Engineering, Faculty of Engineering, University of Muhammadiyah Malang, Indonesia
[2] Department of Mechanical Engineering, Osaka University, Japan

ARTICLE INFO

Article history:
Received 20 September 2023
Received in revised form 19 October 2023
Accepted 23 November 2023
Available online 31 May 2024

Keywords:
CFD Ansys Fluent; Wind Turbine; 3D Simulations; Wind Energy

ABSTRACT

Savonius turbine is a vertical-axis wind turbine (VAWT), which has the advantage of being able to capture wind from different directions. This turbine is suitable for high turbulent wind areas. The blade on the Savonius turbine used in this study is equipped with a Magnus rotor with dimensions of 120 mm in diameter and 720 mm in height. The main purpose of this study is to determine the torque and pressure generated by turbines with three and four blades. The design was then tested numerically with variations in wind velocity. The simulation model was created using computer-aided design software, namely Autodesk Inventor 2023, and then inputted into computational fluid dynamics (CFD) software, namely Ansys Workbench 2022 R2. Wind velocities were varied by 3, 5, 7, 9, and 11 m/s and simulated using transient time with constant wind velocity. The result of this study is that the largest pressure is generated by a hybrid turbine with four blades at a wind velocity of 11 m/s. The results show that the torque and wind pressure that occurs in three- and four-blade hybrid turbines tend to rise; the faster the wind, the higher the torque and pressure of both hybrid turbines.

1. Introduction

Energy is necessary for everyone's life, and its role is also vital. Energy is required in large quantities and is expected at minimum cost. Industrialized countries account for 77% of the world's energy production. Based on current estimates, the world's population will continue to increase 1.26 times to reach 9.7 billion by 2050. However, the majority of the world's population, covering 90% of population growth, is in developing countries. Many developing countries plan to build renewable energy facilities that do not use fossil fuels as they currently do.

Electricity consumption continues to increase every year in every country. Meanwhile, many electricity suppliers in each country still use fossil energy. Fossil energy use will increase by 27% over 20 years. Excessive use of fossil energy has a negative impact, resulting in global warming and increasing environmental pollution [1]. In addition, human activities are also polluting the atmosphere due to the emission of greenhouse gases, including carbon dioxide and other pollutants

---

[*] *Corresponding author.*
E-mail address: achmadfauzan@umm.ac.id (Achmad Fauzan Hery Soegiharto)

https://doi.org/10.37934/cfdl.16.10.4353

[2, 3]. Therefore, there is a need for other alternative energy to replace fossil energy, which is still widely used. Some countries have begun implementing new and renewable energy sources, replacing conventional fossil fuels. Renewable energy is a term that is often used to refer to energy that comes from nature and can be regenerated and used freely. This energy is also considered more environmentally friendly, able to be used continuously, and unlimited in number. Renewable energy consists of several types, including wind, hydro, and geothermal [4]. Using new renewable energy is able to absorb resources and investments where the benefits can be felt, one of which is minimizing the effects of global warming [5]. Wind energy can be an alternative to fossil fuels. The infinite nature of wind energy and its wide and abundant distribution make this energy suitable for use as alternative energy [6]. Every country also certainly has a fairly good wind energy potential. Wind power has been used extensively over the past few decades [7]. New renewable energy is easier to utilize as technology develops. Many countries consistently raise the ambition of renewable energy targets for several reasons [8]. Wind utilization technology requires a set of tools to be able to work, for example, wind turbines [9]. Wind turbines are the main element of a wind power plant. Wind turbines utilize the velocity of the wind to rotate blades, which are later channeled to the generator. The generator here has a function as a tool that converts mechanical energy into electrical energy.

Wind turbines themselves are generally divided into two types based on their rotating axis, namely horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT) [10-13]. The advantage of HAWT is that they can produce greater electricity. On an industrial scale, turbines of this type are more widely used. The disadvantages of HAWT turbines are heavy mass and poor performance in turbulent wind conditions. VAWT is known as a wind turbine that can work in minimum wind conditions. VAWT is classified into several types, such as Savonius, Darrius, and hybrid, as shown in Figure 1 [14]. VAWT-type turbines are widely used in remote areas. In contrast to HAWT, VAWT can work well in turbulent wind conditions.

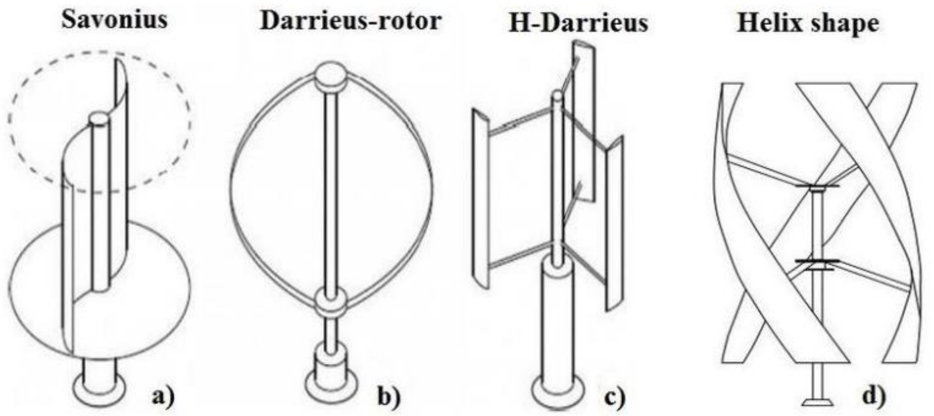


Fig. 1. Classification of VAWT

Innovation in the manufacture of wind turbine designs continues to grow from year to year, leading to wind turbine designs that are more powerful, efficient, and cost-effective. However, due to many parameters and various conditions, the efforts to improve the performance of wind turbines are still continuing. These include changing the rotor design, such as adding counter-rotating to the blades or adding more blades. Moreover, the majority of research on wind turbines uses computational and experimental methods.

Magnus rotor is a device that utilizes rotation to change the direction of wind motion. The Magnus rotor uses a dynamic phenomenon known as the Magnus effect. The Magnus phenomenon was first discovered in 1922 by the German Magnus [15]. The Magnus effect produces lift on a cylinder rotating in a flow perpendicular to the axis of rotation. Related to its development, the Magnus effect is used by scientists as a novelty in wind turbine design [16]. According to Bernoulli's theorem, an increase in the velocity of fluid (air) causes the pressure to drop. The pressure difference in the opposite part of the cylinder causes a lifting force that acts in the direction from the high-pressure area to the low pressure. The friction that occurs on the surface of the cylinder pushes the air movement of the top of the cylinder to move faster and bend the air more towards the top. Meanwhile, friction will slow the movement of air under the cylinder, producing higher static pressure. In addition, the smooth surface on the surface of the cylinder will produce less turbulence so that there is less drag [17, 18]. Large Savonius turbines will find it difficult to start rotation at low wind velocities [19]. Savonius hybrids with turbine lines are an option to reduce the weakness of Savonius turbines [17, 19-21]. Therefore, it is combined with the Magnus rotor as self-starting support. At low wind velocities, the Magnus rotor is rotated using an electric motor, resulting in the auxiliary force of the initial rotation of Savonius [15, 18, 22, 23].

The Savonius turbine may be constructed with two to five blades [17, 24]. The Savonius-Magnus hybrid can be adjusted according to the number of blades; increasing the number of blades is intended to enhance the wind-catching area, thus increasing power. However, having too many blades can disrupt the airflow and lead to a decrease in power. The relationship between Magnus and its Savonius counterpart needs to be investigated to understand the phenomenon. Therefore, in hybrid design, the number of blades should be tested to determine the optimal configuration.

2. Methods

2.1 Hybrid Turbine Model

In this study, the hybrid turbine model of the Savonius turbine was created using the commercial CAD software of Autodesk Inventor Professional 2023 version. The main components of the hybrid turbine are the main shaft, blades, and Magnus rotor (Figure 2). The number of blades was varied by 3 and 4, whereby the detailed design is depicted in Figure 3. Both turbines have height and outer diameter of 0.8m and 1.23m respectively, while a 120mm Magnus rotor was added in each turbine's blades. The specification of the hybrid turbine is described in Table 1.

Table 1
Specifications of the simulated hybrid wind turbine

Number of blades	Dimension	
	Diameter	Height
3	1.25 m	0.8 m
4	1.25 m	0.8 m

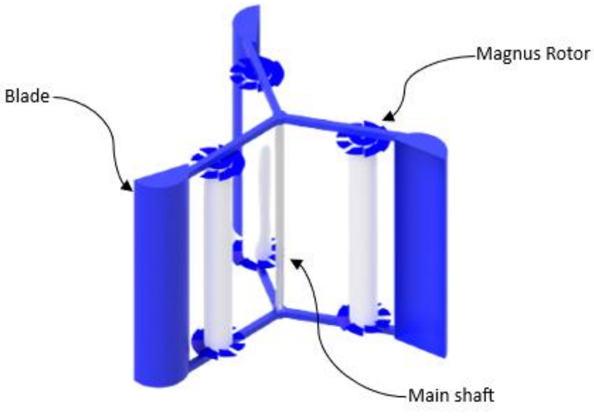


Fig. 2. Main components in hybrid wind turbine

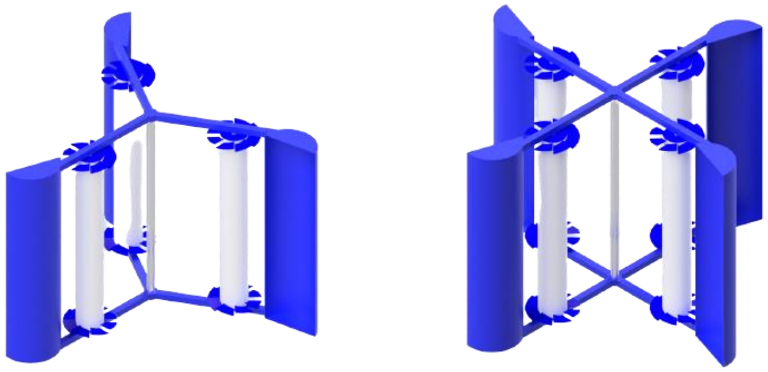
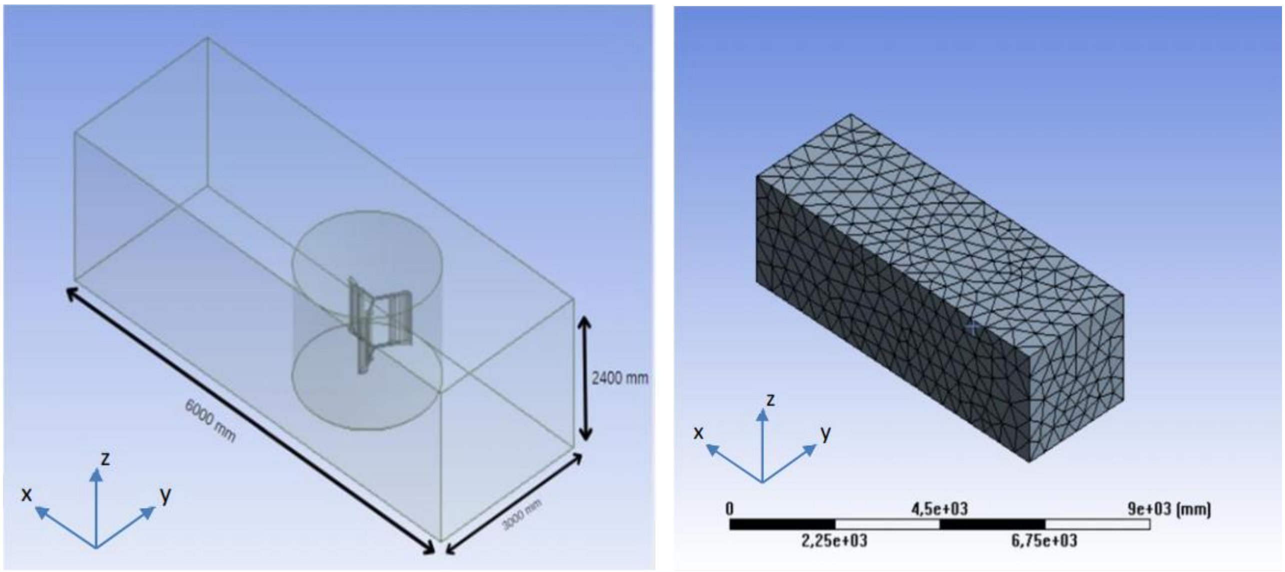

(a) (b)

Fig. 3. Design of the hybrid turbine (a) three blades (b) four blades

Magnus is driven by using a brushless motor placed at the bottom. Magnus works by rotating in the direction of the wind. Magnus rotor exerts thrust on turbine blades. The thrust helps the outer Savonius blades rotate at the start. Magnus is particularly useful if the implementation area of the turbine has relatively low wind. The wings on the lower and upper parts of the magnus serve as wind distribution.

2.2 Computational Domain and Meshing

A rectangular computational domain was used with the length of normal (y-axis), streamwise (x-axis), and spanwise (z-axis) component were set to 2.4m, 6.0m, and 3.0m, respectively. We build the 3D model from CAD which then embedded into Ansys solver with squared domain containing the turbines acted as model section. We carefully handled the meshing process using unstructured to incorporate the complex boundaries of the turbines. We believe that this process is very crucial as a poor result will be obtained due to the lack of convergence and discretization [25]. The meshes were modified using automatic tetrahedral type (see Figure 4). We utilized the resemblance of mech element for both turbines' model. The meshing size is described in Table 2.



(a) (b)

Fig. 4. A representative meshing (a) Simulation domain (b) Meshing

Table 2
Meshing specifications

Turbine model	Dimension of turbine	Meshing specifications Number of nodes	Number of elements
Three blades	450 mm	38,425	210,613
Four blades		44,438	247,271

2.3 Governing Equation

The mathematical approximation of the fluid analysis is carried out by obeying the governing equations of mass and transport based on Navier-Stokes. The continuity and momentum equations are denoted in Eq. (1) and Eq. (2). u_i, p, and Re_τ denotes the velocities, pressure, and frictional Reynolds number, steady and incompressible [25]. To solve the governing equation, we utilized the finite volume method on Fluent solver. In accordance with that, we consider the Reynolds-Averaged Navier-Stokes (RANS) model to predict the eddy viscosity and its dissipation on the occurred vortices. The prevalent phenomena of turbulent can be modelled using RANS as it is more computationally efficient and has been widely used by neglecting the accuracy. We used the $k - \epsilon$ approach to calculate eddy viscosity [26].

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{1}{Re_\tau}\frac{\partial^2 u_i}{\partial x_j x_j} \tag{2}$$

2.4 Boundary Conditions

This simulation applied inlet, outlet, and wall boundary conditions as shown in Figure 5. The constant wind velocities entered the inlet section. We adjust the velocities in range of 3-11 /s. The pressure outlet boundary was set to the outlet plane whereas we put a cylinder shape enclosure on the turbines acted as a rotating zone. The rotating zone was in the normal direction.

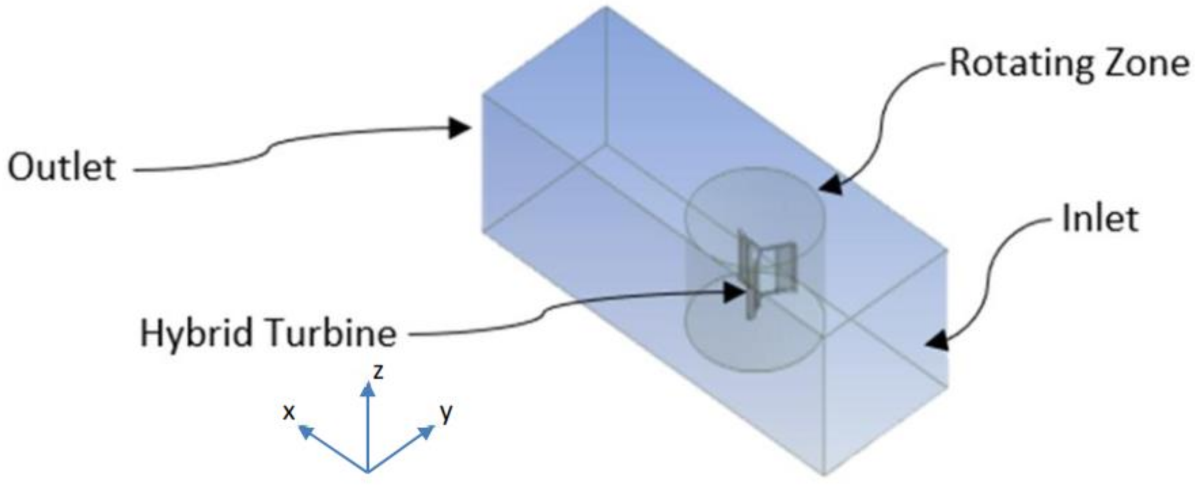


Fig. 5. Boundary conditions

3. Result and Discuss

3.1 Weight of Turbine Hybrid

Table 3 shows the hybrid turbine weight specifications

Tabel 3
Hybrid turbine weight specifications

No	Items	Specification	
		Material	Weight (kg)
1	Magnus	Aluminum 6061	15,697
2	Frame three blades		11,317
3	Frame four blades		14,884

The type of Magnus used is the Magnus with a cylinder model and has eight wing blades at the top and bottom (Figure 6). Figure 7 & Figure 8 show Analysis of the force acting on the Magnus rotor, and Forces acting on the Magnus, respectively.

Fig. 6. Magnus Type

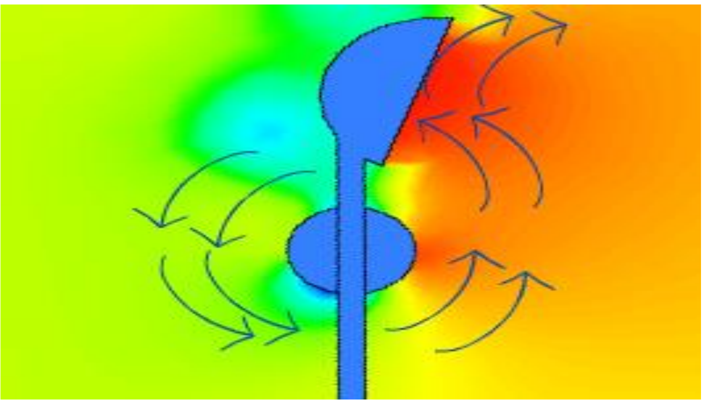


Fig. 7. Analysis of the force acting on the Magnus rotor

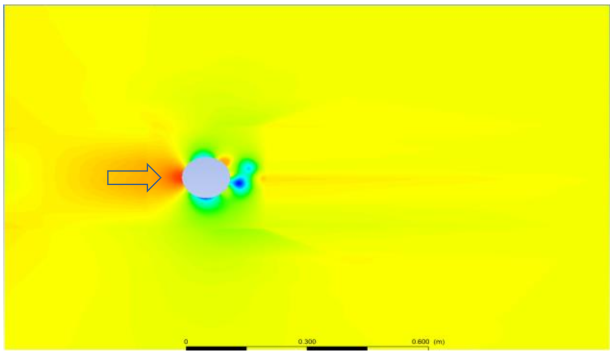
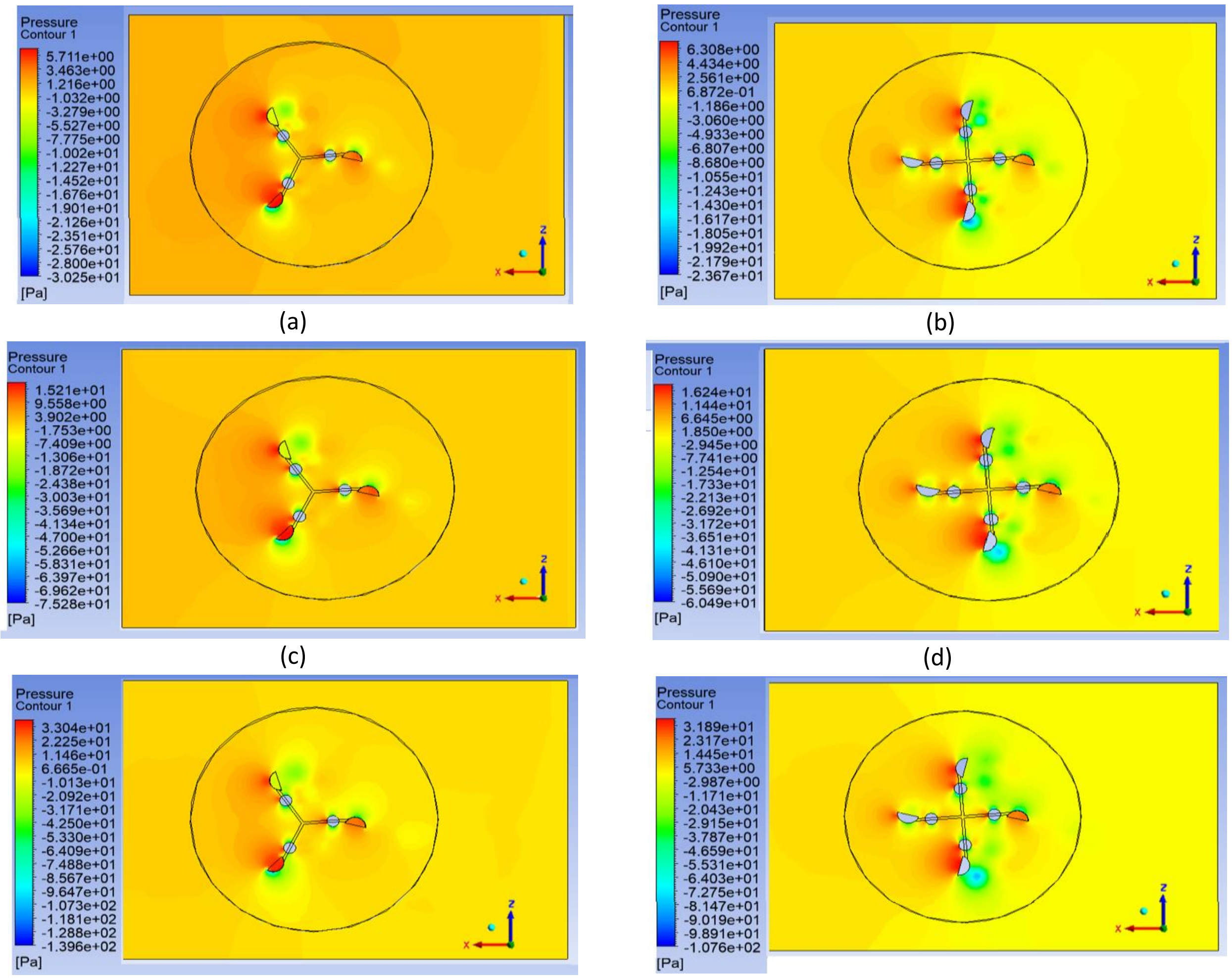


Fig. 8. Forces acting on the Magnus

3.2 Pressure Contour

The pressure contour of 3 blades and 4 blades on various wind velocities are mentined at Figure 9.



(a)

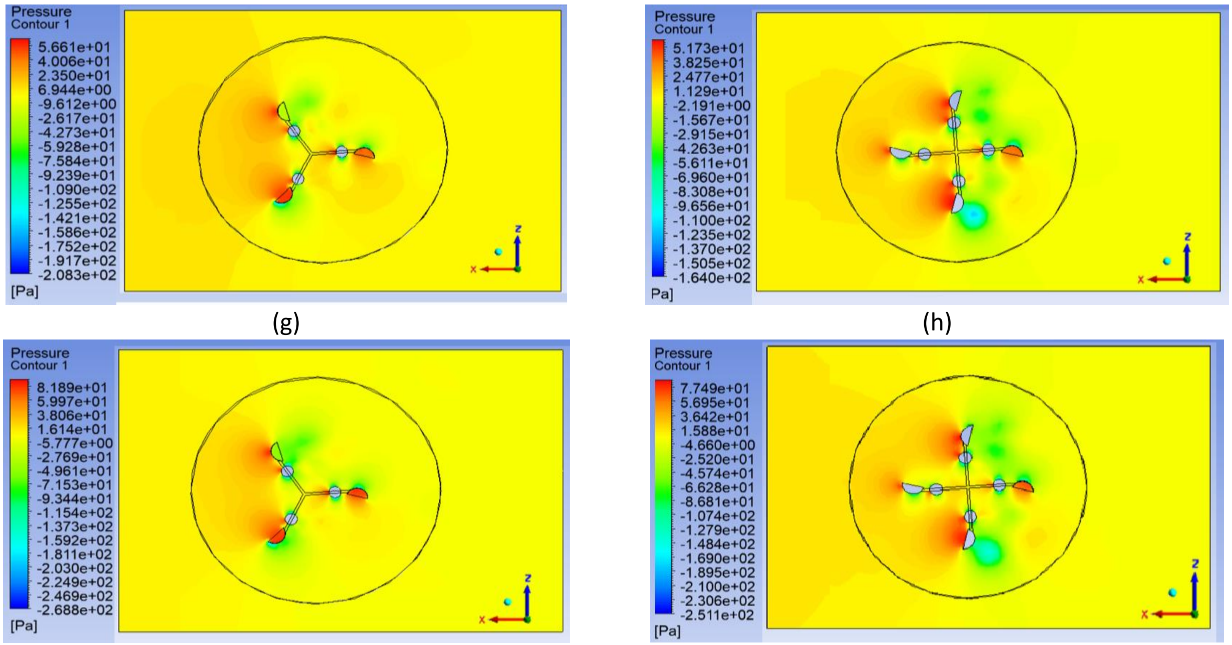
(b)

(c)

(d)

(e)

(f)



(g) (h)

(i) (j)

Fig. 9. Pressure Contour of 3 blades and 4 blades, on various velocity (a) 3 blades on 3 m/s Wind velocity; (b) 4 blades on 3 m/s Wind velocity; (c) 3 blades on 5 m/s Wind velocity; (d) 4 blades on 5 m/s Wind velocity; (e) 3 blades on 7 m/s Wind velocity; (f) 4 blades on 7 m/s Wind velocity; (g) 3 blades on 9 m/s Wind velocity; (h) 4 blades on 9 m/s Wind velocity; (i) 3 blades on 11 m/s Wind velocity; (j) 4 blades on 11 m/s Wind velocity;

3.3 Streamline Flow Pattern

It is important to show the distribution of pressure around the blades of the rotor in order to study the nature of fluid flow during simulation. The pressure distribution is shown in Figure 9. Three and four blades have differences from the pressure contour. The pressure distribution at the front end of the blade looks quite high because the phenomenon of stagnation when the blade faces the wind is indicated by a red contour on the concave part of the outermost blade. In the pressure distribution drawing, there is no significant pressure difference resulting from the contour of the distribution. However, the average pressure along the blade walls varies. The rotation of the rotor causes the surrounding wind to rotate. This helps reduce the incoming wind velocity on the return blades, which affects rotor performance due to the resistance generated between the surface blades and the incoming air, as shown in Figure 10 and Figure 11.

Fig. 10. Flow patterns 4 blade

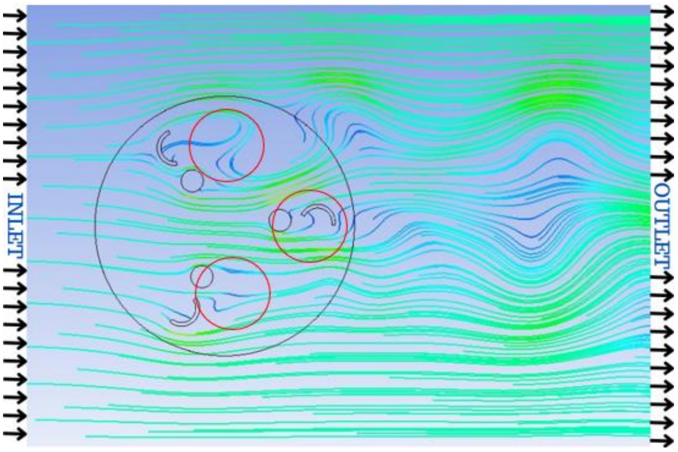


Fig. 11. Flow patterns 3 blade

Based on the results of the comparison between blade 3 and blade 4. Judging from the resulting pressure graph as shown on Figure 12. Hybrid turbines using Magnus rotors with three blades are superior at wind velocities of 7, 9, and 11 m/s compared to 4 blades. Supported by minimal wind flow distribution, turbulence occurs in blade 3. Where the pressure produced is directly proportional to the torque of the turbine, the greater the pressure, the greater the turbine torque. So, the design of a hybrid turbine with three blades was carried out. The dimensions applied correspond to what has been simulated.

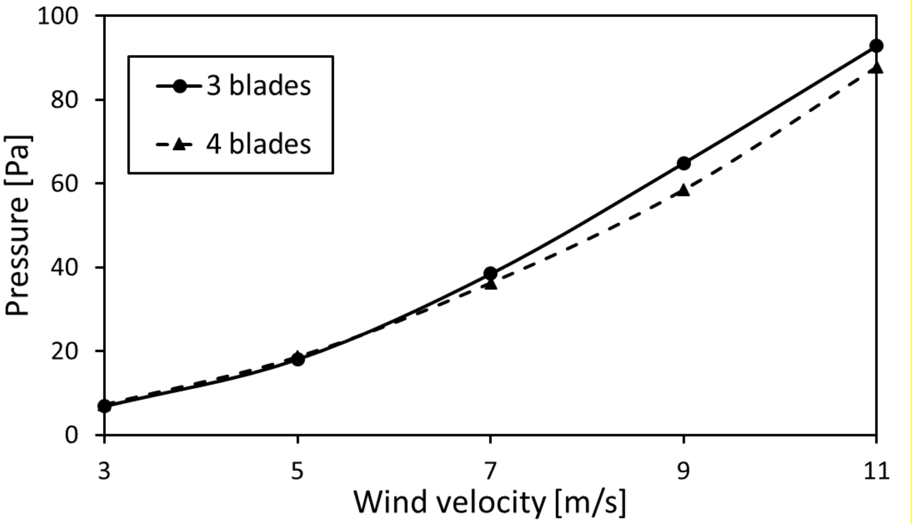


Fig. 12. The value pressure with respect to the wind velocities

4. Conclusion

Based on the observed numerical simulation result, the parametric analysis on the hybrid turbines has been carried out by varying the wind velocity. This study is beneficial as a first step consideration on designing and applying the wind turbine. We conclude the important finding as follows:

i. 3 blades turbine was considerably more superior that 4 blades type. The highest pressure was obtained on 3 blades turbine, peaked at about 92.85 Pa at 11m/s wind speed. Meanwhile, the 4 blades was merely 87.76 Pa at highest wind speed, meaning that 5% lower than that of 3 blades.
ii. We underlined that weight influenced the turbines performance of turbine. The gradually discrepancy of performance was showed in the wind velocty above 7m/s. The 3 blades was

produced more pressure, indicating that at high velocity the turbine’s weight highly affecting the preformance.

iii. On low wind velocity, both turbines has a similar performance so that either 3 or 4 blades can be effectively applied. On the other hand, on high velocity we suggest that 3 blades will more efficient in terms of performance. We noted that in terms of its applicaiton, further engineering investigation should be carried out as consideration apart from the performance itself.

Reference

[1] Aldhufairi, Mohammed, Mohd Khairul Hafiz Muda, Faizal Mustapha, Kamarul Arifin Ahmad, and Noorfaizal Yidris. "Design of Wind Nozzle for Nozzle Augmented Wind Turbine." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 95, no. 1 (2022): 36-43. https://doi.org/10.37934/arfmts.95.1.3643

[2] Loni, Reyhaneh, Gholamhassan Najafi, Rizalman Mamat, Mohd Fairusham Ghazali, and Nor Azwadi Che Sidik. "Nusselt Number Prediction for Oil and Water in Solar Tubular Cavity Receivers." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 97, no. 2 (2022): 157-174. https://doi.org/10.37934/arfmts.97.2.157174

[3] Elavarasan, Rajvikram Madurai, G. M. Shafiullah, Sanjeevikumar Padmanaban, Nallapaneni Manoj Kumar, Annapurna Annam, Ajayragavan Manavalanagar Vetrichelvan, Lucian Mihet-Popa, and Jens Bo Holm-Nielsen. "A comprehensive review on renewable energy development, challenges, and policies of leading Indian states with an international perspective." *Ieee Access* 8 (2020): 74432-74457. https://doi.org/10.1109/ACCESS.2020.2988011

[4] Adanta, Dendy, Mochammad Malik Ibrahim, Dewi Puspita Sari, Imam Syofii, and Muhammad Amsal Ade Saputra. "Application of the Grid Convergency Index Method and Courant Number Analysis for Propeller Turbine Simulation." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 96, no. 2 (2022): 33-41. https://doi.org/10.37934/arfmts.96.2.3341

[5] Bakar, Nurul Asyikin Abu, Nujjiya A. Mu’in, and Noorfazreena M. Kamaruddin. "Design and Development of Savonius Turbine for STEM Education." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 28, no. 2 (2022): 334-347. https://doi.org/10.37934/araset.28.2.334347

[6] Xu, Yang, Shu Zhou Fang, and Shuai Zhang. "Numerical Study on Aerodynamic Performance of Hypersonic Vehicle with Aerospikes." In *Aerospace Mechatronics and Control Technology: Selected Contributions from 2021 7th Asia Conference on Mechanical Engineering and Aerospace Engineering*, pp. 3-13. Singapore: Springer Nature Singapore, 2022. https://doi.org/10.1007/978-981-16-6640-7_1

[7] Singh, Upma, Mohammad Rizwan, Hasmat Malik, and Fausto Pedro García Márquez. "Wind energy scenario, success and initiatives towards renewable energy in India—A review." *Energies* 15, no. 6 (2022): 2291. https://doi.org/10.3390/en15062291

[8] Gielen, Dolf, Francisco Boshell, Deger Saygin, Morgan D. Bazilian, Nicholas Wagner, and Ricardo Gorini. "The role of renewable energy in the global energy transformation." *Energy strategy reviews* 24 (2019): 38-50. https://doi.org/10.1016/j.esr.2019.01.006

[9] Ariffin, N. I. B., and Mohammed Abdul Hannan. "Wingsail technology as a sustainable alternative to fossil fuel." In *IOP Conference Series: Materials Science and Engineering*, vol. 788, no. 1, p. 012062. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/788/1/012062

[10] Tahzib, Teeab, Mohammed Abdul Hannan, Yaseen Adnan Ahmed, and Iwan Zamil Mustaffa Kamal. "Performance analysis of H-Darrieus wind turbine with NACA0018 and S1046 aerofoils: impact of blade angle and TSR." *CFD Letters* 14, no. 2 (2022): 10-23. https://doi.org/10.37934/cfdl.14.2.1023

[11] Didane, Djamal Hissein, Muhammad Nur Arham Bajuri, Bukhari Manshoor, and Mahamat Issa Boukhari. "Performance Investigation of Vertical Axis Wind Turbine with Savonius Rotor using Computational Fluid Dynamics (CFD)." *CFD Letters* 14, no. 8 (2022): 116-124. https://doi.org/10.37934/cfdl.14.8.116124

[12] Shkara, Yasir, Martin Cardaun, Ralf Schelenz, and Georg Jacobs. "Aeroelastic response of a multi-megawatt upwind horizontal axis wind turbine (HAWT) based on fluid–structure interaction simulation." *Wind Energy Science* 5, no. 1 (2020): 141-154. https://doi.org/10.5194/wes-5-141-2020

[13] Leahy, Kevin, Colm Gallagher, Peter O’Donovan, and Dominic TJ O’Sullivan. "Issues with data quality for wind turbine condition monitoring and reliability analyses." *Energies* 12, no. 2 (2019): 201. https://doi.org/10.3390/en12020201

[14] Parakkal, Jabir Ubaid, Khadije El Kadi, Ameen El-Sinawi, Sherine Elagroudy, and Isam Janajreh. "Numerical analysis of VAWT wind turbines: Joukowski vs classical NACA rotor’s blades." *Energy Procedia* 158 (2019): 1194-1201. https://doi.org/10.1016/j.egypro.2019.01.306

[15] Lukin, Aleksandr, Galina L. Demidova, Dmitry V. Lukichev, Anton Rassõlkin, Ants Kallaste, Toomas Vaimann, and

Anouar Belahcen. "Experimental prototype of high-efficiency wind turbine based on magnus effect." In *2020 27th International Workshop on Electric Drives: MPEI Department of Electric Drives 90th Anniversary (IWED)*, pp. 1-6. IEEE, 2020. https://doi.org/10.1109/IWED48848.2020.9069565

[16] Nuttall, Peter, and John Kaitu'u. "The Magnus effect and the Flettner rotor: potential application for future oceanic shipping." *The Journal of Pacific Studies* 36, no. 2 (2016): 161-182. https://doi.org/10.33318/jpacs.2016.36(2)-9

[17] Didane, Djamal Hissein, Siti Masyafikah Maksud, Mohd Fadhli Zulkafli, Nurhayati Rosly, Syariful Syafiq Shamsudin, and Amir Khalid. "Performance investigation of a small Savonius-Darrius counter-rotating vertical-axis wind turbine." *International Journal of Energy Research* 44, no. 12 (2020): 9309-9316. https://doi.org/10.1002/er.4874

[18] Ishkhanyan, M. V., and L. A. Klimina. "Wind turbine of the Savonius–Magnus type with conical blades: Dynamics and control." *Journal of Computer and Systems Sciences International* 59 (2020): 630-638. https://doi.org/10.1134/S1064230720040085

[19] Meziane, Mohamed, Elhachmi Essadiqi, Mustapha Faqir, and Mohamad Fathi Ghanameh. "CFD study of unsteady flow through Savonius wind turbine clusters." *International Journal of Renewable Energy Research* 9, no. 2 (2019): 657-666..

[20] Siddiqui, Ali Shan, Syet Nadeem Mian, Muhammad Alam, Muhammad Saleem ul Haq, Abdul Hameed Memon, and Muhammad Shahzad Jamil Energy. "Experimental study to assess the performance of combined Savonius Darrieus vertical axis wind turbine at different arrangements." In *2018 IEEE 21st International Multi-Topic Conference (INMIC)*, pp. 1-8. IEEE, 2018. https://doi.org/10.1109/INMIC.2018.8595538

[21] Mari, Michele, Mauro Venturini, and Asfaw Beyene. "A novel geometry for vertical axis wind turbines based on the savonius concept." *Journal of Energy Resources Technology* 139, no. 6 (2017): 061202. https://doi.org/10.1115/1.4036964

[22] Seifert, Jost. "A review of the Magnus effect in aeronautics." *Progress in aerospace sciences* 55 (2012): 17-45. https://doi.org/10.1016/j.paerosci.2012.07.001

[23] Nasrallah, Siraj AM, and AS Mohd Rafie. "The Effect of Different Rotational Speeds of a Cylinder on Magnus Wind Turbine Performance." (2022). https://doi.org/10.15866/irease.v15i2.19719

[24] Liang, Xiaoting, Sauchung Fu, Baoxing Ou, Chili Wu, Christopher YH Chao, and Kaihong Pi. "A computational study of the effects of the radius ratio and attachment angle on the performance of a Darrieus-Savonius combined wind turbine." *Renewable energy* 113 (2017): 329-334. https://doi.org/10.1016/j.renene.2017.04.071

[25] Andersson, Bengt, Ronnie Andersson, Love Håkansson, Mikael Mortensen, Rahman Sudiyo, and Berend Van Wachem. *Computational fluid dynamics for engineers*. Cambridge university press, 2011. https://doi.org/10.1017/CBO9781139093590

[26] *Documentation, ANSYS Fluent. "ANSYS Fluent Theory Guide." ANSYS Help (2016).*