The Influence of Zigzag Position on The Concave Surface of a Savonius Turbine on Its Performance

Ruzita Sumiati[1,2], Dendi Adi Saputra[1], Uyung Gatot S. Dinata[1*]
[1]Department of Mechanical Engineering, Universitas Andalas, Limau Manis Padang 25163, Indonesia
[2]Department of Mechanical Engineering, Politeknik Negeri Padang, Limau Manis Padang 25163, Indonesia
*Corresponding author: uyunggsdinata@eng.unand.ac.id

Abstract

One potential strategy for reducing carbon dioxide (CO_2) emissions from fossil fuel consumption is the adoption of renewable energy sources. One of these green sources is wind energy, which is captured by wind turbines. The Savonius wind turbine, a vertical-axis wind turbine, was designed for small-scale energy conversion and is especially right for Indonesia's low wind speeds. This study aims to investigate the influence of the zigzag position applied to the concave blade on the performance of the Savonius turbine. This objective was accomplished through the application of 3D computational fluid dynamics simulations, conducted at a tip-speed ratio of 0.6, a zigzag height of 2 mm, and velocity (U) of 5 meter per second. Based on the results of numerical analysis, the data obtained for turbines with the full zigzag model (model 1) and the zigzag at the blade tip model (model 2) show higher maximum moment data compared to the model with the zigzag in the middle of the blade (model 3), namely 0.06 Nm for model 1, 0.052 Nm for model 2, and 0.036 Nm for model 3. However, model 3 exhibits more stable rotation due to its smaller torque amplitude and lack of negative moment.

Keywords: - Simulation numeric, Savonius rotor, wind energy, zigzag

1. Introduction

A significant portion of the energy consumed by society is derived from fossil fuels, which have detrimental environmental impacts due to the emission of CO_2 (Cherni & Jouini, 2017). One alternative to the continued reliance on fossil fuels is the transition to renewable energy sources, such as wind energy. Wind energy has significant potential for electricity generation, and the choice of wind as an energy source is due to the fact that wind-generated electricity does not produce CO2 emissions, thereby not contributing to greenhouse gas formation (Boontome et al., 2017). Wind energy is harnessed using wind turbines, which are mechanical devices designed to convert the kinetic energy of the wind into mechanical power or electrical energy.

Indonesia is a region that has low wind speeds of approximately under 7 m/s (Pamungkas et al., 2018). In low wind speed areas, Savonius turbines are commonly used because they have good self-starting capabilities and high initial torque at low wind speeds, but they have low efficiency (Maldar et al., 2020). The limited efficiency of the Savonius rotor can be enhanced through geometric optimization of its aerodynamic characteristics.

Experts have proposed various design modifications and enhancements to improve the performance of Savonius turbines. These modifications are based on examining the effects of different design characteristics, including changes to blade shape (Mohan & Saha, 2023; Nasr, 2023; Tartuferi et al., 2015; Tian et al., 2018) the investigation examined potential overlap ratios (Dewan et al., 2023; Hassanzadeh & Mohammadnejad, 2019); investigated the influence of the endplate (Al-quraishi et al., 2022; Premkumar et al., 2018) examined the impact of aspect ratio (AR) (Saad et al., 2022), number of stage rotors (Saad et al., 2022), and number of blade (Thiyagaraj et al., 2021a). The main objective of the research conducted previously by the previous researcher was to examine the effect of geometric parameters on the efficiency of the Savonius blade.

Based on research by Tania et al. (2018), the Savonius turbine achieves maximum efficiency at wind speeds below 4 m/s when the overlap ratio is adjusted to 0.15. Conversely, for wind speeds exceeding 4 m/s or in turbulent conditions, an overlap ratio of 0.3 is required. Sumiati (2024a) and Thiyagaraj et al. (2021b) reported that overlab ratio value of 0.2 optimizes turbine power and reduces negative torque by effectively channeling wind power through the overlap area to the returning blade. The performance of a Savonius turbine is also influenced by the number of blades; adding more blades increases the convex area exposed to the wind

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at an angle. This increase in convex area decreases the torque differential between the concave and convex sides, thereby affecting the coefficient of performance (Al-Kayiem et al., 2016; Chaichana & Thongdee, 2019). The two-bladed Savonius turbine demonstrated the highest power coefficient in comparison to the 3, 4, 5, and 6 blade configurations (Thiyagaraj et al., 2021b).

The Savonius rotor generates torque by exploiting the drag difference between its two blades. Fig. 1 depicts the straightforward geometry of a Savonius rotor. To achieve optimal efficiency, the drag force on the concave blade surface should be greater than that on the convex blade (Sumiati, 2024a). Wavy or rough surfaces significantly influence boundary layer growth, which in turn affects surface drag, momentum transfer and heat transfer (Al-Ghriybah et.al, 2023).

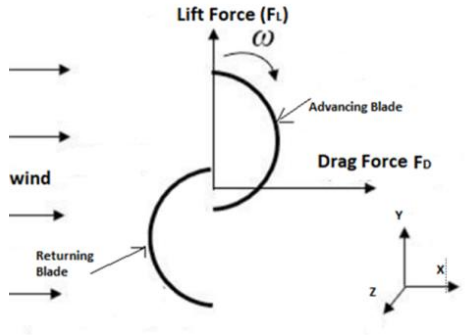


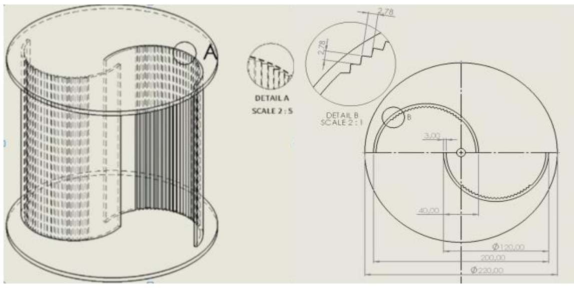
Fig. 1. Simple geometry of a Savonius rotor

Several studies have been conducted to see the effect of surface roughness with a zigzag pattern on the Savonius turbine including research conducted by (Sumiati et al., 2024b) on the roughness of the tiered-height zigzag pattern at the centre of the Savonius turbine surface can increase efficiency by 16%. The zigzag given to the centre of the Savonius can increase the efficiency of the turbine which was tested at a wind speed of 6 m/s in 3D numerical simulation (Sumiati et al., 2024b).

Previous research had not examined the impact of the position of zigzag patterns on concave surfaces on the performance of Savonius turbines. It is understood that the positioning of the zigzag pattern affects the flow dynamics, which in turn influences the overall efficiency of the Savonius turbine. The objective of this study is to investigate the impact of zigzag positioning on the concave blade surface on the performance of Savonius turbines.

2. Methodology

The objective of the research was to investigate the performance of a Savonius turbine with a zigzag pattern design on the surface of the concave blade. The study focused on variations in the zigzag placement positions: the middle, the tip of the blade, and a full zigzag. A conventional Savonius turbine was used for comparison, with a zigzag height of 2 mm. The Savonius turbine design is shown in Fig. 2. The geometric parameters of the model investigated are: blade diameter of 200 mm, overlap ratio (OR) of 0.2, aspect ratio (AR) of 1, blade height of 200 mm, endplate diameter of 220 mm, zigzag height (t) of 2 mm, two blades, and one stage. The variations in the zigzag position are shown in Fig. 3.



(a) (b)

Fig. 2. Geometry detail of the model under investigation

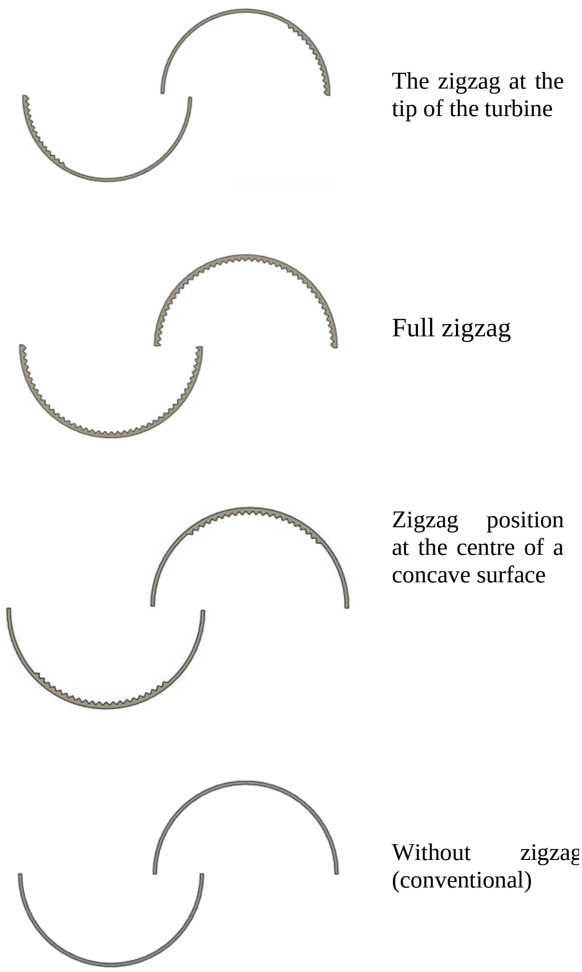


Fig. 3. Variation of the zigzag position

This study employs three-dimensional computational fluid dynamics (CFD) using unstructured triangular grids. The domain is segmented into two separate areas: one stationary region and one rotating region. The two components are separated by an interface. Fig. 4 illustrates the mesh of the rotating sub domain and the surface of the blade.

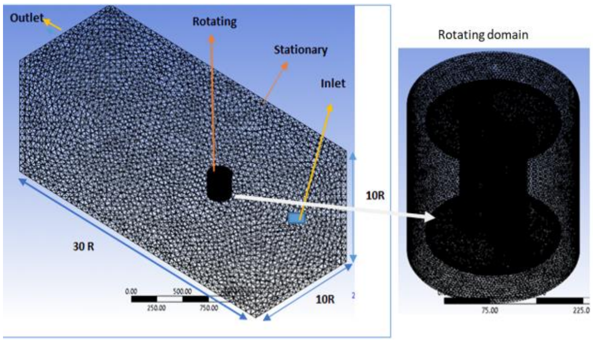


Fig. 4. Domain of computational

The academic version of Ansys Fluent was employed to model the flow field around the blade using the Unsteady Reynolds-Averaged Navier-Stokes (URANS) equations. The k-ω shear stress transfer (SST) model was applied to account for turbulent viscosity. Roy & Saha (2013) compared the SST k-ω model and the realizable k-ε model with experimental results, finding favorable attributes in the SST k-ω model. The cell zone condition utilized mesh motion within the rotating subdomain, with the Tip Speed Rasio varying. The sliding mesh technique can be employed to model the dynamic rotation of a turbine for the generation of electricity from an input stream. In order to enhance stability, a simple scheme is utilised for pressure-velocity coupling, and a least squares cell-based method is applied for the spatial discretisation gradient. Second-order upwind schemes are employed for the spatial discretisation of pressure and momentum. The boundary conditions consist of an inlet with velocity of 6 meters per second, a turbulence intensity of 5%, and an outlet pressure set to 0 Pa.

3. Result and Discussion

The numerical analysis conducted in this study employs the dynamic method. The model to be analyzed is placed in a sub domain designated as the rotating zone. The model and rotating zone are constrained by a stationary domain (tunnel) that serves as the boundary of the work being analyzed. The data obtained in this study comprise moments, pressure contour and velocity contour.

Based on the simulated variations in zigzag positioning on the concave surface of the Savonius rotor at a wind speed of 5 m/s, Tip Speed Rasio of 0.6, and a zigzag height of 2 mm, the configurations include full zigzag (model 1), zigzag at the blade tip (model 2), zigzag pattern positioned in the center of the concave surface (model 3), and conventional Savonius (model 4). The resulting moment data is shown in Fig. 5. The data collected represents the moment over flow time.

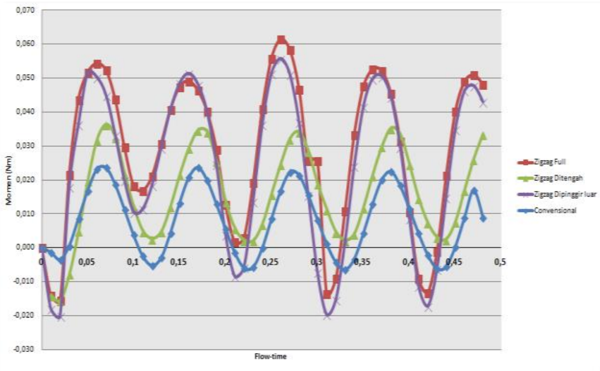


Fig. 5. Comparison of the moments of the four models

Based on the results of the numerical analysis, it was found that turbines with model 1 and model 2 exhibit higher maximum moment data compared to model 3, with 0.06 Nm for model 1 and 0.052 Nm for model 2. In contrast, model 3 has a moment of 0.036 Nm, and model 4 has 0.022 Nm. Models 1, 2, and 4 have negative minimum moments: model 1 = -0.013 Nm, model 2 = -0.02 Nm and model 4 = -0.005 Nm. Meanwhile, model 3 has a positive minimum moment of 0.0022 Nm. Thus, model 3 does not experience any counter-rotation moments. Regarding moment amplitude, models 1 and 2 have higher amplitudes compared to models 3 and 4. High moment amplitudes can cause strong vibrations during turbine operation. According to (Rahman et al., 2015), turbines with high amplitude moments experience vibrations that negatively impact turbine performance. Fig. 6 presents the pressure contours of the four Savonius turbine models.

Based on the pressure contours (see Fig. 6), it is observed that the model with a full zigzag pattern exhibits higher pressure compared to the other three models. Additionally, all blades with zigzags on the concave surface show higher pressure than the conventional model. This increased pressure is likely due to the rough surface causing an increase in drag force on the concave side, thereby increasing the moment value. As illustrated in the moment graph in Fig. 5, the maximum moment value for the blade with a zigzag pattern is higher than that of the conventional Savonius turbine.

Fig. 7 presents the velocity contours for the four models. The jet stream is more pronounced in the model with a zigzag pattern on the concave surface at the blade tip. This jet stream can enhance the power output of the Savonius turbine by providing additional force to the return blade from the flow passing through the overlap area. Conventional and full zigzag models have relatively small jet streams.

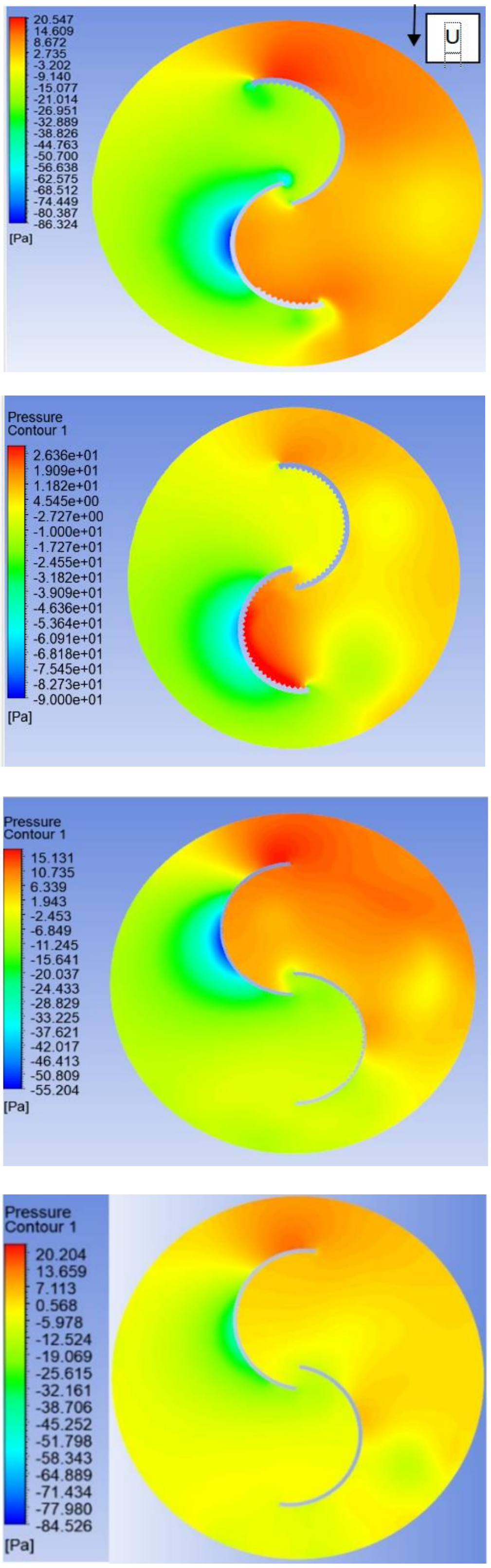


Fig. 6. Pressure contours

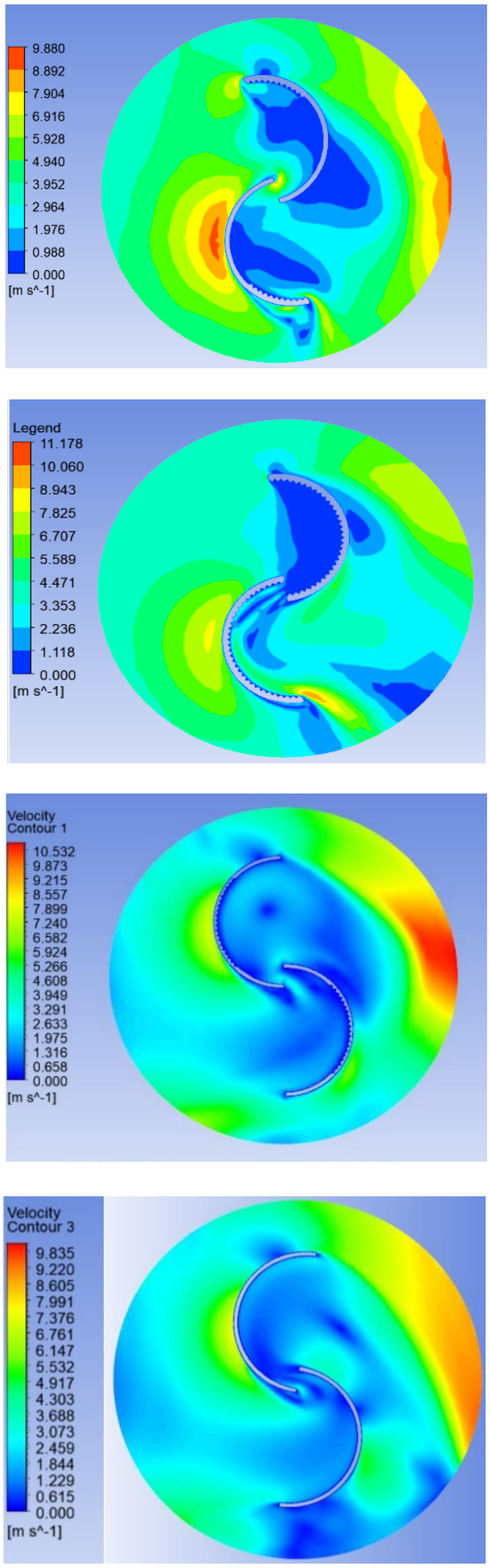


Fig. 7. Velocity contour

The numerical analysis indicates that the model with a zigzag pattern in the middle of the blade is more stable in rotation and has a smaller moment amplitude compared to the other three models. The largest moment was observed in turbines featuring a full zigzag pattern. The full zigzag model produces a large moment amplitude, leading to vibrations that negatively impact the efficiency of the Savonius turbine.

4. Conclusion

This study investigated the impact of a position of zigzag pattern on the concave surface of a Savonius rotor, focusing on moment and performance coefficient using 3D CFD methode. Based on the results of numerical analysis, the data obtained for turbines with full zigzag model (model 1) and zigzag at the blade tip model (model 2) show higher maximum moment data when compared to the model with zigzag in the middle blade (model 3), namely 0.06 Nm for model 1, 0.052 Nm for model 2 and 0.036 Nm for Model 3. However, for model 3 the rotation is more stable because the torque amplitude is smaller and does not have a negative moment.

This study is still limited to numerical studies of 3D simulations; it still needs to be researched more deeply. In future studies, investigations will be conducted to examine the impact of position the zigzag pattern on the concave surface of the blade through the use of experimental methods.

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