Numerical study of Savonius wind turbine with additional fin blade using computational fluid dynamic

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Abstract. Savonius wind turbine is the wind energy conversion systems which has good potential for small-scale electrical energy source. However, standard design savonius rotor has a relatively low efficiency and rotation speed. The aim of this research is to study modification of wind turbine design of savonius type S by adding variation of fin in its turbine blades. It utilized computational fluid dynamic (CFD) using a commercial Finite Element (FEA) software. Savonius rotor employed in this research has a 1.1 m rotor diameter in 1.4 m height. The 3D model of savonius rotor was developed by a CAD Software, SolidWorks®. The wind speed utilized for simulation purpose were 3 to 5 m/s with k-epsilon turbulent model. Simulation was performed using ANSYS to generate mesh of the flow domain all of blade variant. Dynamic mesh model was used in this simulation, which then exported to FLUENT in evaluating the fluid flow for determining the aerodynamic coefficient such as drag, torque and power coefficient. This model simulated a fluid flow striking the blade and wind condition around the rotate blade. Results from this study is expected to provide an alternative evaluation of Savonius wind turbine performance in various conditions with different design parameters.

1. Introduction
Savonius wind turbines have good potential for small-scale energy resources. Potential applications of savonius turbine including: residential (lightning, air conditioning, and water pumping for irrigation. This wind turbine has an ability to operate at low wind speeds with good torque [1]. The savonius wind turbine can also receive wind from all directions and has good starting characteristics since it can spin at low wind speed. Considering its characteristic, the savonius wind turbine suitable to be implemented in Indonesia which relatively low wind speed, with the compact design and low construction cost. Savonius wind turbine has several advantages such as a compact design and low construction costs. However, savonius rotor have relatively low efficiency and rotation speed. Several studies were performed either experimentally or numerically to increase savonius rotor performance. Pamungkas and Hasan studied performance of savonius wind turbine with the addition of fin on its blade using experiment methods [2,3]. While Wijayanti studied the aerodynamic characteristic of savonius wind turbine with fin addition on its blade using numerical method [4]. The Computational of Fluid Dynamic method is used employed to estimate the aerodynamic forces acting on the rotor, torque, power absorbed by the rotor savonius. It also to analyze the influence of the variations of turbulence model [5]. Morshed, in his study numerically studied the effects of overlap ratio and Reynolds number on different type of turbine design with overlap ratio variation. It was suggested that the design without overlap ratios provide better aerodynamic coefficients at higher reynolds numbers [6].
& Petry [7] found that the moment coefficient and the wind power coefficient of the savonius rotor achieve the maximum value on the design with an overlap ratio close to 0.15. This numerical study uses a turbulence model k-\(\omega\) SST which is Reynold's simplest approach because it is considered to be in accordance with the phenomenon in this study. Another numerical study of overlap ratio was proposed by Rogowski & Maroński [5] which found that the 0.1 gap width produces higher power coefficient (Cp) compared with a gap width of 0.2. This research used two dimensional design of turbine geometry and adds variations with different turbulence models: SpalartAllmaras (SA), the k-\(\varepsilon\), the realizable k-\(\varepsilon\), the RNG k-\(\varepsilon\), and k-\(\omega\). This turbulence model SpalartAllmaras (SA) showed satisfactory results on modeling with 2 dimensional turbine geometry and the simulation results are similar with the experimental data.

In previous studies addition of fin to the Savonius S type wind turbine can increased electrical power resulted and power coefficient (Cp) [2]. Therefore this research aims to numerically study the aerodynamic behavior of savonius rotor with addition fin on its blade.

2. Method
This research utilized Computational Fluid Dynamic (CFD) method with commercial Finite Element Analysis (FEA) software ANSYS 16.2.

2.1. Geometry and computational domain

Table 1. The design of 3D savonius rotor was developed using CAD software of SolidWorks®.

| Specification         | Value          |
|-----------------------|----------------|
| Main shaft diameter   | 20 mm          |
| Rotor diameter        | 1100 mm        |
| Blade diameter        | 600 mm         |
| Blade Height          | 1400 mm        |
| Blade Overlap         | 50 mm          |
| Number of blade       | 2 blade        |
| Blade material        | 0.3 mm aluminium plate |

Figure 1. The geometry of savonius rotor.
The simulation domain composed of two parts separated by sliding interface. The stationary boundary represents wind tunnel test environments. The stationary domain was assumed with the box shape with
the dimension 4250 mm x 3600 mm x 7600 mm. The velocity inlet was set in 4.5 m/s with the TSR (Tip Speed Ratio) of 0.8 and angular velocity of rotating boundary is 6.5 rad/s. TSR of 0.8 was choose since it was experimentally found that it produces the highest electricity power. TSR value of savonius rotor is less than 1.0, it means that the savonius rotor is a drag type wind turbine.

\[
\text{TSR (} \lambda \text{)} = \frac{\alpha DN}{60V_{\text{max}}}
\]

\[
T = \frac{P_{\text{turbine}}}{\omega}
\]

\[
CP = \frac{T_{\text{turbine}}}{T_{\text{available}}} = \frac{T_{\text{turbine}}}{\frac{1}{2} \rho A V^2 R} = \frac{F X t_p}{\frac{1}{2} \rho A V^2 R}
\]

2.2. Meshing

This research employed mesh motion to analyses the rotating domain. Mesh sizing was set as fine relevance centre and high smoothing mesh. Residual criteria used is $10^{-5}$, means that when the value has below of the criteria the solution will be convergent. Turbulence model used is standard k-ε model which relatively simple and most widely used [8].
2.3. Solving
After the mesh readings, the parameters are then determined to calculate the conditions set in the pre-processing process, boundary condition, solver value of numerical error (residual), and calculation to reach convergence value. Solver used is pressure-based type and for velocity formulation is selected as absolute. The simulation was performed in a transient fluid flow state which changed by time.

3. Discussion
From the simulation found that the drag force that work in 1 fin addition is 21,0041 N. Meanwhile drag force that work in 2 fin variation is 21.0001 N. Torque from the 1 fin addition is 14,712 N. Meanwhile torque of the 2 fin addition is 14,6658. It means that the addition of fins on the rotor blade minimizes the drag force and torque.

![Figure 7](image1.png)  ![Figure 7](image2.png)

**Figure 7.** (a) Velocity distribution of 1 fin variation (b) Velocity distribution of 2 fin variation.

This simulation was set in a rotating condition or mesh motion, the velocity distribution show that variations with the addition of 2 fins make the wind speed around the turbine higher compared to 1 fin addition.

![Figure 8](image3.png)  ![Figure 8](image4.png)

**Figure 8.** (a) Velocity streamline of 1 fin variation (b) Velocity streamline of 2 fin variation.
From the velocity streamline, the addition of fins on the blade turbine directing the wind flow to fills the space in blade more quickly. The addition fin will causes the blade rotate at lower velocity than without fin. Pressure along the turbine will increased because of smaller area which formed by addition of fin. Pressure of the both side of turbine area will also increase. It means pressure difference of the two blade will decreased because of both turbine area are reached higher pressure. The smaller pressure difference will make positive drag force on the blade also smaller. Torque which produce by savonius rotor will also decreased because of lower angular velocity.

4. Conclusion
The conclusion is that the addition of fin can directing the incoming turbine flow on the turbine, but the addition of the fin can reduce the torque and the drag force from the turbine, the torque variation of the addition of 1 fin higher than the addition of 2 fin at wind speed 4.5 m/s. It means that the addition of 1 fin can reached the higher power coefficient. Because the greater drag force, and torque will increased the power coefficient value [4]. This means that the simulation results support to the experimental results performed by Pamungkas et al and Hasan et al, which say the highest power coefficient is achieved by the 1 fin variation [2].

References
[1] Kamal F M and Islam M Q 2009 Aerodynamic characteristics of a stationary five bladed vertical axis vane wind turbine Journal of Mechanical Engineering, 39(2)
[2] Pamungkas S F, Wijayanto D S, Saputro H and Widiastuti I 2018 Performance ‘S’ Type Savonius Wind Turbine with Variation of Fin Addition on Blade IOP Conference Series: Materials Science and Engineering, 288
[3] Hasan O D S, Hantoro R and Nugroho G 2013 Studi Eksperimental Vertical Axis Wind Turbine Tipe Savonius dengan Variasi Jumlah Fin pada Sudu, 2(2)
[4] Wijayanti W D H, Hantoro R, Nugroho G and Hakim J A R Studi Pengembangan Model Vertical Axis Wind Turbine (VAWT) Savonius Tipe U dengan Penambahan Fin pada Sudu Menggunakan Pendekatan CFD, 6
[5] Rogowski K and Maroński R 2015) CFD computation of the Savonius rotor Journal of Theoretical and Applied Mechanics, 37
[6] Morshed K N 2010 Experimental and Numerical Investigations on Aerodynamic Characteristics of Savonius Wind Turbine with Various Overlap Ratios Electronic Theses & Dissertations,
[7] Akwa J V, Alves S J G and Petry A P 2012 Discussion on the verification of the overlap ratio influence on performance coefficients of a Savonius wind rotor using computational fluid dynamics Renewable Energy, 38(1), 141–149
[8] Debnath B K, Biswas A and Gupta R 2009 Computational fluid dynamics analysis of a combined three-bucket Savonius and three-bladed Darrieus rotor at various overlap conditions Journal of Renewable and Sustainable Energy, 1(3)