

CFD Analysis of The Stage-Ratio Factor on Savonius Wind Turbine Performance to Optimize Clean-Energy Conversion

Dandun Mahesa Prabowoputra^{1*}, Maria Krisnawati¹, Akhlis Rahman Sari Nurhidayat¹, Mohammad Khosyi¹, Ryan Febrian Nur Halim¹, and Haidar Zumara¹

¹Department of Industrial Engineering, Universitas Jenderal Soedirman, Purbalingga, Indonesia

Abstract. In Indonesia, 50% of electrical energy is supplied by coal via electric steam power plants, with the remaining 14% supplied by new renewable energy sources. This phenomena demonstrates a significant divergence in the utilization of fossil energy sources against new renewable energy sources. The impact of fossil energy sources is the occurrence of global warming and non-renewable energy sources, a transition process to clean energy produced from renewable energy is required. Hydro, wind, and bioenergy are all possible renewable energy sources in Indonesia. The potential for converting wind energy into electrical energy in Indonesia is relatively large, at 159 GW. The rotor in the wind turbine is one of the primary components that plays a part in reversing the kinetic energy of the fluid into electrical power. Savonius is a simple rotor that can be used to generate power from wind on a small scale. Savonius' merits are its basic structure and ability to function at low wind speeds. This study was carried out on a Stage-ratio variation on a two-stage Savonius rotor with a Phase Shift-Angle of 30°. The boundary condition is steady-state, and the turbulence type employed in modeling is SST. The goal of this research is to provide an optimal design for the Savonius Wind turbine as a design consideration in local-scale wind energy management, as well as to contribute to the attainment of the SDGs by 2030 through clean energy. Optimal design for Savonius with a PSA of 30° was produced C_{pmax} 0.29 with Stage-ratio 2:1.

1 Introduction

The United Nations aims to achieve 17 Sustainable Development Goals by 2030. Clean energy and affordability are among the SDGs, seeking access to clean energy and affordable to support climate improvement. Clean energy is essential as a source of everyday energy use in today's world. The effects of fossil fuels are increasingly being felt on Earth, such as serious climate change and declining fossil fuel supplies. The availability of fossil fuels continues to decrease every year. In Indonesia, oil has decreased by an average of 29% in the last five years, and natural gas has decreased by 17.12%, as shown in Figure 1 [1]. This phenomenon indicates that acceleration is urgently needed to realize clean energy to realize the SDGs in 2030.

Electrical energy consumption has risen by 4.7% year on year [2]. This consumption will continue to grow, and it is even possible that there will be a significant increase. The availability of electrical energy must be of particular concern, given the Indonesian government's regulations regarding converting electric stoves and electric vehicles. 80% of the composition of the national electricity supply in Indonesia comes from non-renewable energy, so optimization of the use of renewable energy needs to be done [2]. Accelerating the increase in the renewable energy mix in the national electricity supply is necessary. Clean energy sources

that can be used for electrical energy include wind power, hydropower, and solar. Indonesia has a pretty good potential for renewable energy sources, where the availability of this energy is shown in Figure 02 [1].

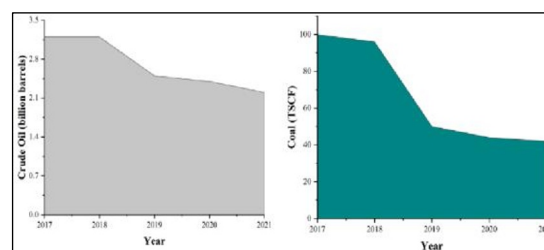


Fig. 1. Decreased availability of fossil energy [1].

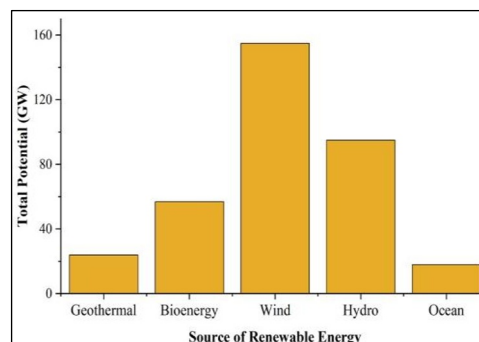


Fig. 2. Renewable energi potential availability in Indonesia [1].

* Corresponding author: dandun.mahesa@unsoed.ac.id

Wind Energy is a source of energy that has considerable potential in Indonesia. The potential for wind energy is 154.9 GW, and the installed installation is 0.1% [1]. The enormous potential of wind energy can provide a large supply of energy in wind power plants. Wind energy, considered one of the clean energy sources, is ideally suited to be turned into electrical energy, which is the type of energy that is typically utilized. The SDGs regarding clean energy and climate change can be realized with the creation of clean energy sourced from wind power.

A turbine is a tool used to convert kinetic energy into mechanical energy, which then turns into electrical power [3]. Based on the flow direction of the fluid, wind turbines are divided into vertical and horizontal turbines. Vertical wind turbines are called cross-flow turbines, where one type of rotor in a cross-flow turbine is the savonius rotor. The Savonius rotor is one of the rotors that can be used in increasing wind power installations. The Savonius rotor has a simple shape, making it easy to modify and easy to use or install [4]. A lot of research has been done on the Savonius rotor in wind turbines, which will make it easier to optimize the design to improve its aerodynamic performance. Optimization of the Savonius design is to modify the rotor geometry by involving the geometric factors that influence it. Several geometric factors that have an influence are Aspect ratio, Overlap ratio, number of blades, blade shape, and number of stages [5]. Savonius, with a multi-stage rotor, can improve turbine performance. Several studies have been conducted on modifying the savonius rotor to be multi-stage using wind and water fluids. The change to multi-stage increases performance up to C_{pmax} 0.197 on the Savonius water turbine [6]. In other studies that have been carried out on wind turbines, it shows an increase in performance up to C_{pmax} 0.261 with changes in the number of stages on the rotor [7].

This research has been carried out on a wind turbine with a multi-stage Savonius rotor. The Phase Shift-angle (PSA) used is 30° , following previous research, which shows that the Phase Shift-angle of 30° has the best performance [8]. The analysis has been carried out using the computational fluid dynamics method under steady-state conditions. This research aims to determine the Stage-ratio's effect on the Savonius rotor's aerodynamic performance, where information from research results can be used as a reference for design optimization for the Savonius rotor.

2 Literature Review

The Savonius rotor is a type of Vertical Axis Wind Turbines (VAWT). Where Savonius is a Drag-type VAWT, so it has the advantage of being able to operate at low speeds. The Savonius wind turbine converts the force on the wind to the torque generated on the rotating shaft. Figure 3 illustrates the fundamental operating principle of the Savonius, while Figure 4 shows the Savonius in its structural form [9]. Savonius has a simple geometry with just an endplate, a shaft, and a blade.

The turbine's coefficient power (C_p) is obtained through equation 1 [10], where the equation is the ratio between the energy produced and the power available. P is the generated power, ρ is the density of the fluid, U is the velocity of the fluid, and A is the projected area of the rotor.

$$C_p = \frac{P}{\frac{1}{2}\rho U^3 A} \quad (1)$$

Another aerodynamic parameter used is the Coefficient of torque. The torque coefficient is affected by the interaction between TSR and C_p . The Coefficient of torque (C_t) equation is shown by equation 2, and TSR is shown by equation 3 [11]. In equation 2, T is the torque, and R is the radius of the rotor. In equation 3, ω is the angular velocity of the rotor.

$$C_t = \frac{T}{0.5\rho A V^2 R} \quad (2)$$

$$TSR = \frac{R\omega}{V} \quad (3)$$

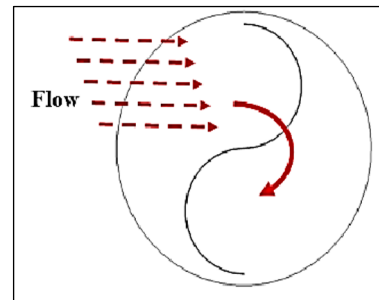


Fig. 3. Savonius working principle

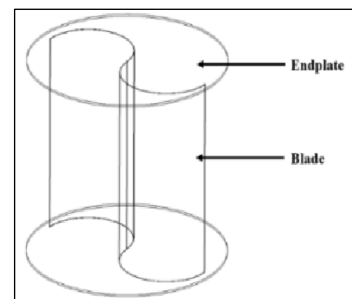


Fig. 4. Savonius structure

3 Design and numerical modeling

This research is a 3D model of a two-stages Savonius wind turbine. The Savonius design is shown in Figure 5. The Savonius rotor with a PSA of 30° was modified with changes to the stage ratio, namely 1:1, 1:2, and 2:1. The stage ratio is the ratio between the size of the first-stage and the second stage. Rotor dimensions are shown in Table 01, and information is in Figure 6. The Savonius rotor used is a rotor with an aspect ratio of 1.

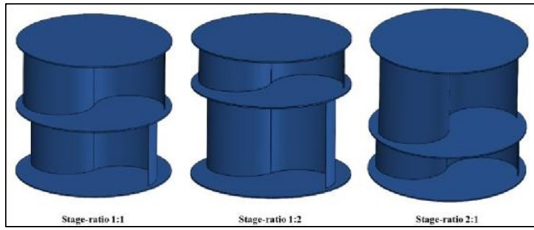


Fig. 5. Savonius rotor variants in 3D design

Table 1. Dimention of rotor's design

Symbol	Dimention
D	230 mm
d	210 mm
θ	30 °
H	210 mm
Stage-Ratio 1:1	
h1	102 mm
h2	102 mm
Stage-Ratio 1:2	
h1	68 mm
h2	136 mm
Stage-Ratio 2:1	
h1	136 mm
h2	68 mm

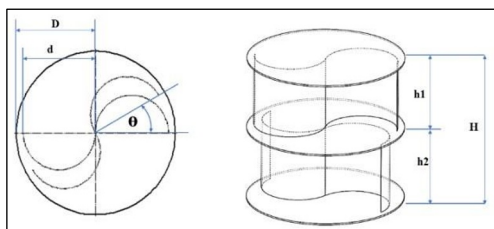


Fig. 6. Schematic of a savonius rotor

3D modeling of the Savonius rotor uses a finite difference approach and computational fluid dynamics. The modeling stages are carried out sequentially from domain design, Meshing, schematic modeling, Mesh Independent Study, Benchmarking, and running modeling. Modeling is done in steady-state conditions. Modeling is divided into two domains: the rotary and stationary domains [12-14]. The rotary domain is the rotating domain consisting of the rotor and the interface. A stationary domain is a static area in modeling where the boundary condition function is in this domain. Domain images are shown in Figure 7.

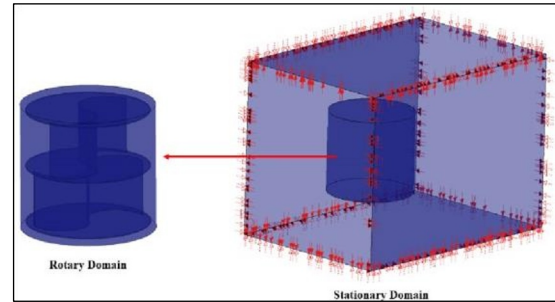


Fig. 7. The domain of modelling

Meshing has been done using the tetrahedral method [1517]. Maximum inflation of 5 layers is carried out in the rotary domain. The meshing results are shown in Figure 8, which shows the meshing results of the rotary domain and the stationary domain. Meshing is done with several settings to conduct a mesh independence study (MIS). MIS is performed to determine the optimal mesh size in a model [18]. This optimal mesh will affect the length of the modeling running process. Meshing is done by changing the mesh size in several settings [16]. The results of the MIS are shown in the graph in Figure 9. The MIS shows the optimal time found in the 4th mesh setting.

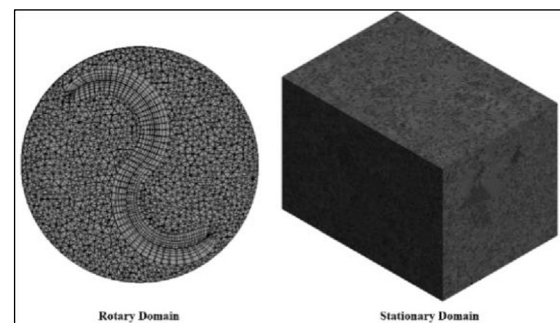


Fig. 8. The outcome of the domain meshing process

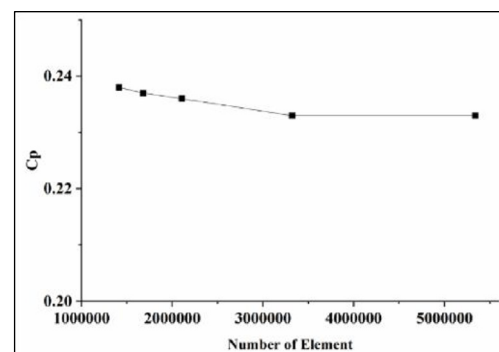


Fig. 9. Independent study mesh graph

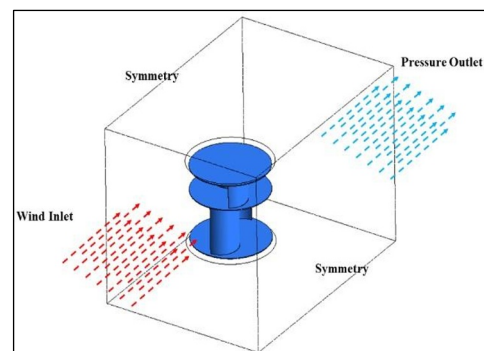


Fig. 10. Schematic of a modelling

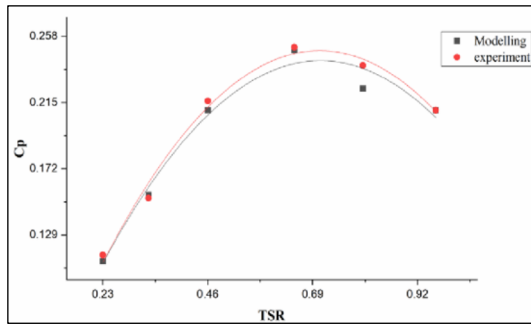


Fig. 11. Modeling performance on graph benchmarks through Saha's experiment [20].

Figure 10 shows the modeling schematic. Modeling has been carried out in steady-state conditions. The type of turbulence used is Shear Stress Transport (SST) [8, 17, 19]. The boundary conditions in the modeling consist of an inlet with a wind speed of 6m/s, a wall with a symmetry condition, and an output with a pressure of 1 atm. Compared to other studies, modeling results showed a difference of 3%. The graph of benchmarking results is shown in Figure 11. Running modeling is carried out at a TSR of 0.3 to 0.9.

4 Result and discussion

CFD modeling on the Savonius rotor produces several outputs, including torque values, pressure contours, and velocity contours. Torque values will be converted into aerodynamic performance using equations 1 and 2. The graph of the stage-ratio comparison of the Savonius performance is shown in Figure 12 and Figure 13. Figure 12 shows the Coefficient of Power (C_p) of all the stage-ratio variations on the Savonius rotor. The graph shows that the C_{pmax} of each rotor is achieved at a TSR of 0.7, then the performance decreases after that. The highest C_{pmax} is obtained in the 2:1 variation, where the rotor has a C_{pmax} of 0.29. In the second and third order, respectively, in variations of 1:1 and 1:2. Savonius, with a stage ratio of 1:1, produces a C_{pmax} of 0.285 and a stage-ratio of 1:2 produces a C_{pmax} of 0.28. Another aerodynamic performance is the coefficient of torque (C_t), where C_T is shown in Figure 13. In all variations of the stage ratio, C_T continued to decrease from TSR 0.3 to 0.9. Savonius produced the highest C_{Tmax} with a 2:1 stage ratio of 0.78. The Savonius rotor with a stage ratio of 1:1 has a C_{Tmax} of 0.70, and a stage ratio of 1:2 produces a C_{Tmax} of 0.65. The modeling results show that the modified stage ratio 2:1 can achieve maximum performance in a wind turbine with a Savonius rotor.

The pressure distribution in the wind fluid is depicted in Figure 14. The contours at each stage show the similarity of the contours with other variations. In the first stage, all variations show the same wake-zone area and are on the right side of the blade. The highest pressure is at the lower left end of the concave blade because this section is the highest point that hits the fluid flow. At the first-stage the most expansive highest pressure area is found in the 1:1 stage-ratio variation. The Second-Stage on the stage-ratio variation shows a different contour from the others, where this rotor has the smallest wake-zone area. There is also a difference in the location of the highest pressure point at the second

stage. In the 1:1 stage-ratio variation, the highest pressure point is in the middle of the concave blade, while in other variations, the highest pressure point is near the left end of the concave blade. According to the pressure distribution, the Stage-ratio determines the pressure contour in the second-stage area.

The velocity distribution in the fluid is shown in Figure 15. The velocity distribution shows similar contours for all variations at the first and second stages. There is a slight difference in the second-stage area, where the high-velocity area in the 2:1 rotor variation is larger than the other variations. However, the highest velocity location has the exact location, which is in the middle of the concave blade for all stages and all variations.

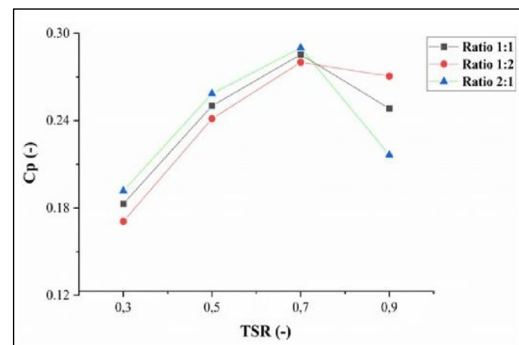


Fig. 12. Schematic of a modelling

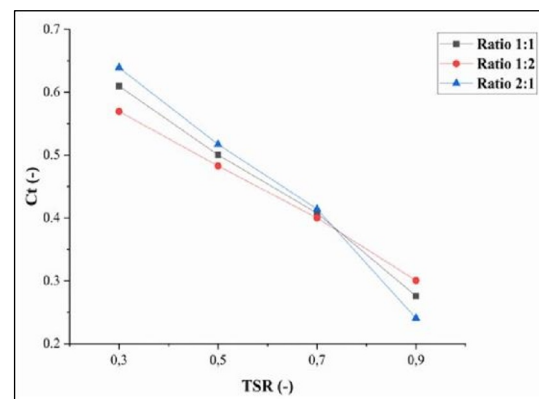


Fig. 13. Torque coefficient on a savonius rotor graph

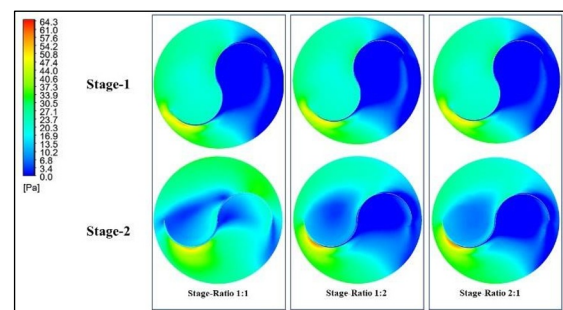


Fig. 14. Torque coefficient on a savonius rotor graph

5 Conclusion

The modeling was done on a wind turbine with a savonius rotor with a PSA of 30° shows that the stage ratio influences the aerodynamic performance of the turbine. The research that has been done shows that the 2:1 stage-ratio design produces the best performance compared to the 1:1 and 1:2 stage-ratio. The C_{pmax} produced by Rotor Savonius two-stages with a 2:1 stage ratio of 0.29. the 2:1 stage-ratio shape shows an optimal design for Savonius with a PSA of 30° , where the first stage influences performance optimization. The results of this study are expected to be added in optimizing the design of the Savonius rotor because it has shown that the Stage-ratio shows an effect on the performance of the Savonius wind turbine.

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