Performance Investigation of the Savonius Horizontal Water Turbine Accounting for Stage Rotor Design

Dandun Mahesa Prabowoputra
Graduate School of Mechanical Engineering, Universitas Sebelas Maret, Surakarta, Indonesia
Email: dandunmahesa@student.uns.ac.id

Syamsul Hadi* and Aditya Rio Prabowo
Department of Mechanical Engineering, Universitas Sebelas Maret, Surakarta, Indonesia
Email: *syamsulhadi@ft.uns.ac.id, aditya@ft.uns.ac.id

Jung Min Sohn
Department of Naval Architecture and Marine System Engineering, Pukyong National University, Busan, South Korea
Email: jminz@pknu.ac.kr

Abstract— **Hydropower is one of the best renewable energy sources in Indonesia because they (hydro and micro-hydro) have large potential resources and suitable with water zone topology of a country with many rivers and similar water source. However, the percentage of installations Hydropower in Indonesia is 11.95% which is quite large considering the overall value of the investment. To optimize the water resources, development is needed in terms of hydro-electric power, which one of the well alternatives is the development of the water turbine rotor design. This study aims to determine the effect of adding stages on the performance of the savonius water turbine on the horizontal axis. The research subject will use a one-stage rotor that will be modified into two-stage. Variations in the shift angle are applied at an angle of 90° and the speed of water is 0.8 m/s and at TSR interval of 0.4-0.9. Simulation using Transient Blade Row type analysis. The calculation of the research was carried out using the computational fluid dynamic technique of the ANSYS codes in which the interacting fluid flow and turbine structure are explicitly modeled. Results data present torque distribution, velocity streamline, and coefficient of power (Cp). The tendency indicated that Cp was achieved in Savonius with the modified double-stage rotors. This configuration is suitable for an urban water source, such as sewage water pipes, which is capable to optimally utilize the flow of wastewater as a new energy resource. Furthermore, the emissions level due to machine combustion using fossil resources can be reduced.**

Index Terms— **renewable energy, Savonius rotor, two-stage rotor, hydropower, coefficient of power, CFD**

I. Introduction

The availability of fossil fuels as an energy source has decreased every year due to the increment of public and industry consumptions, as well as its characteristic as a non-renewable resource. The facts show that electricity demand has been growing at 6.0% per year since 2016 and is expected until 2050. The National Power Plant is supplied by coal power plants of 54%, new renewable energy-based power plants of 12%, and 34% of gas-fired plants [1]. So that new and renewable energy sources need to be developed. New renewable energy sources in Indonesia include geothermal, hydro and mini-hydro, solar and wind energy. Based on Table I, the types of water energy (hydro and micro-hydro) have large potential resources, but the percentage of installations is still small. Where this is a great opportunity for the development of hydro energy.

TABLE I. New and Renewable Energy Resource [1]

No	Energy type	Resources (MW)	Installed capacity (MW)
1	Geothermal	29,544	1,438.5
2	Hydro	75,091	8,671
3	Mini-micro hydro	19,385	2,600
4	Wind Energy	970	1.96

The development of the water turbine is one of the energy sources Development of water, one of them with a water turbine Savonius. Savonius water turbine type has the advantage of being easily developed because it has a simple structure and can be applied at low Velocity.

Many studies have been carried out on changes in rotor geometry in the savonius turbine. The geometry changes in the rotor shape of the blade become twisted blades. Where the angle of twist is done at 0° angle variations; 12.5°; and 25°. The optimal C_p value is generated at a twisted blades variation of 12.5° [2]. Research on the addition of tandem blades to the savonius rotor has been carried out. The study was conducted using three varieties

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of tandem blade geometry. The best performance based on the maximum difference in pressure upstream and downstream is Convergence Tandem Blade of Savonius [3]. Research on modification of the rotor geometry of Savonius has been carried out in this decade, both savonius wind turbine and savonius water turbine. This modification includes the design in the savonius rotor without the shaft between the endplate. The results of the study, it was found that removing the shaft on the rotor can increase the coefficient of Power (C_p) in the Savonius wind turbine [4]. In another study regarding the overlap ratio that has been carried out on horizontal axis water turbines, it shows that C_{pmax} is obtained in 0.3 overlaps. The C_{pmax} produced in the study was 0.19 at *TSR* 0.79 [5]. Modifications made are in the form of blade [3], a variation of helix angle [2,7,13], number of blades and Stage [8], overlap ratio and other modifications [10]. In these studies, geometric changes were associated with parameters that affected the performance of savonius turbines. The Performance Parameters used are Power Coefficient (C_p).

CFD is very helpful in this study. By using CFD, we can know the pressure distribution, streamlined velocity, and can be visualized in animation. These advantages make it easier for us to do analysis and support experimental studies. Simulation research has been carried out, preceded by an independent meshing test. Where the number of elements is changed to find an effective meshing to produce the right Cp value. The amount of meshing was added up to 4 times, then compared to the Cp results obtained [9]. In other studies doing the same is done by giving variations called refinement levels in 9 levels [10].

Savonius Rotor has a simple structure and easy to modify geometric designs. Also, the Savonius Rotor is easy to use on water turbines and wind turbines. The shape of the Rotor in Savonius can receive flow from all directions. Therefore, research on the rotor Savonius in turbines continues to develop, both experimental and simulation studies. Savonius wind turbine research is more developed compared to the savonius water turbine. So that research on the savonius water turbine still has many opportunities to develop. Research has been carried out using a numerical method to compare the performance of the savonius wind turbine with the savonius water turbine. At the same boundary conditions, the performance of the Savonius Water Turbine is better than the savonius wind turbine. Where the dimensions of the rotor, Power output and C_p are the same, wind turbines require wind speeds nine times greater than the speed of water flow [11].

Research has been conducted on the savonius turbine, especially on wind turbines on the Vertical axis. This study is different from previous studies because it made changes to the rotor geometry into two stages on the horizontal axis, while previous studies modified the shape of the blade [2-5, and 7]. Changes in the stage of the savonius water turbine show an influence on turbine performance.

II. Data Reduction

The results of the research that have been carried out through simulation, then processed using equations to calculate the performance parameters. These equations are:

Power :

$$P_{Available}=0,5 \times \rho \times A \times V^3 \quad (1)$$

$$\mathbf{P_{Rotor} = T \times \omega} \quad (2)$$

TSR (Tip Speed Ratio) :

$$TSR=\frac{\omega D}{2U} \quad (3)$$

Coefficient Power (C_p):

$$Cp = \frac{T\times\omega}{0,5 \times\rho \times A \times V^3} \quad (4)$$

where *V* is the free flow velocity, *ρ* for water density, *A* is the Area of the Rotor, *T* is Torque, *ω* represents the angular velocity, *Ct* for the torque coefficient, and *Cp* for the Power coefficient.

III. Method

CFD simulations have been performed using ANSYS 19 Software and CFX Solver. Comparison with Patel CR's research before simulation. The comparison shows a difference in the value of 3%. This shows that the scheme can be used [12]. The first step to do is to reproduce the 3D geometry of the rotor to be used as shown in Fig. 1. The ratio between the diameter and rotor height is 1:1. The selected diameter is 110 mm with a 2 mm thickness, and the rotor has a shaft with a diameter of 4 mm. The meshing of the rotating domain and the static domain using the ANSYS software is presented in Fig. 2-3. The setting boundary conditions using the CFX Solver, where the boundary conditions are shown in Table II, and Fig. 4 shows a complete flow domain of Savonius turbine.

Simulation is done with water fluid, using Transient Blade Row type analysis. The study was conducted with subsonic water flow at a speed of 0.8 m/s and a TSR interval of 0,4-0,9. Meshing is done on the workbench using the tetrahedron method.

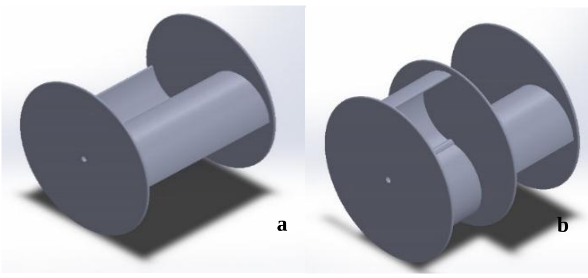

Figure 1. Rotor savonius: a) single-stage, and b) two-stage.

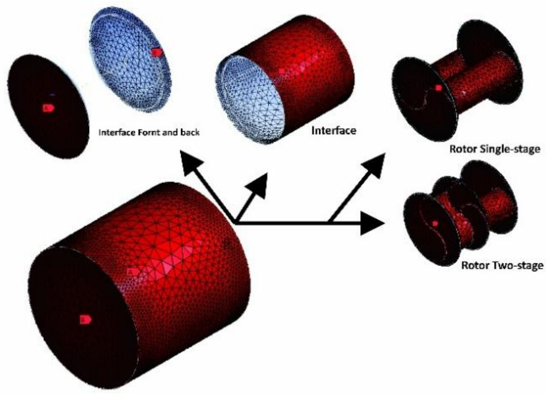

Figure 2. Meshing of the computational model rotating domain.

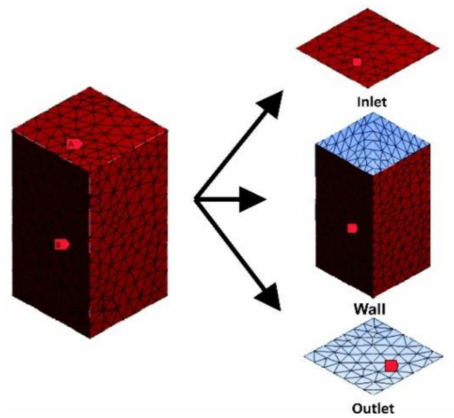

Figure 3. The meshing of the computational model static domain.

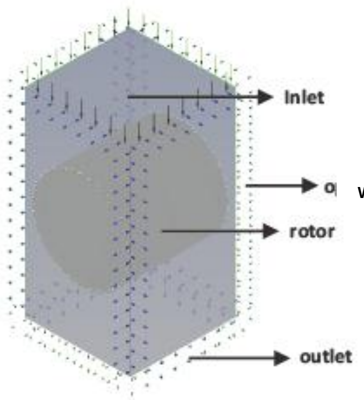

Figure 4. Computational fluid domain for the calculation.

TABLE II. BOUNDARY CONDITION FOR MODELS SIMULATIONS

No	PARAMETER	VALUE
1.	Fluid type	Water
2.	Density (kg/m^3)	1000
3.	Domain motion	Rotating
4.	Boundary condition inlet flow	Subsonic
5.	Water velocity (m/s)	0.8
6.	Outlet pressure (atm)	1
7	Turbulence model	K Epsilon

IV. RESULTS AND DISCUSSION

The performance of the Savonius hydrokinetic turbine having the variable number of stages on the rotor has been investigated numerically in open channel having the velocity of 0.8 m/s. TSR is carried out at intervals of 0,4 to 0,9. Through CFD, we can visualize pressure contours and velocity streamlines. From the simulation process, the pressure contours, Torque and velocity streamline of each design are obtained. Also, the torque value is obtained so that *Cp* can be obtained from each design. By investigating pressure contours around models with different numbers of the stage (Figs. 5 - 7), there is a slight difference in pressure distribution in the blade with the same position. Where pressure is seen around the upper blade, more rotors with more stages have higher pressure. This phenomenon occurred due to the area of the blade in multi-stage rotors smaller than the single-stage rotors. Fig. 8-12 shows the distribution of velocity streamlines at single-stage, two-stage and three-stage.

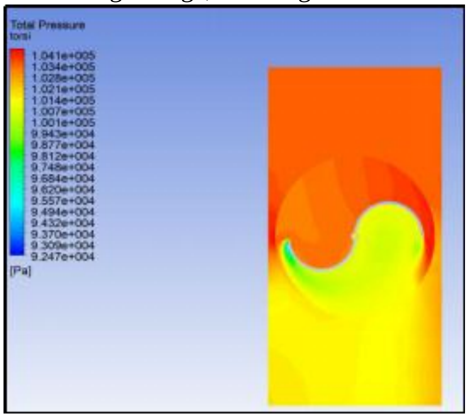

Figure 5. Distribution of pressure on single-stage.

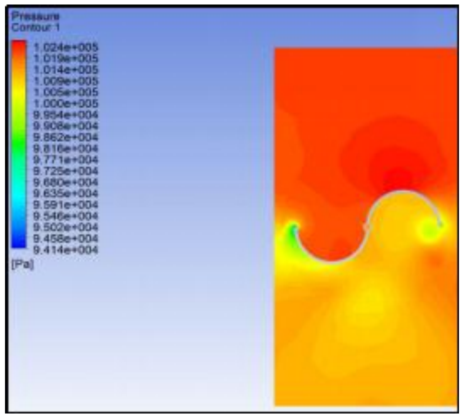

Figure 6. Distribution of pressure on two-stage (fist-stage).

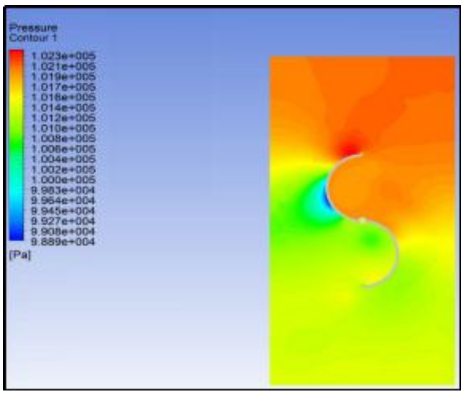

Figure 7. Distribution of pressure on two-stage (Second-stage).

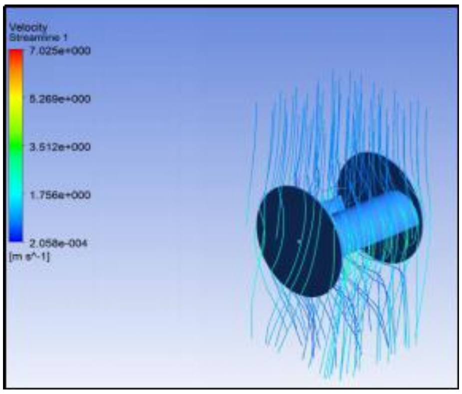

Figure 8. Distribution of velocity streamlines (3D) on the single-stage.

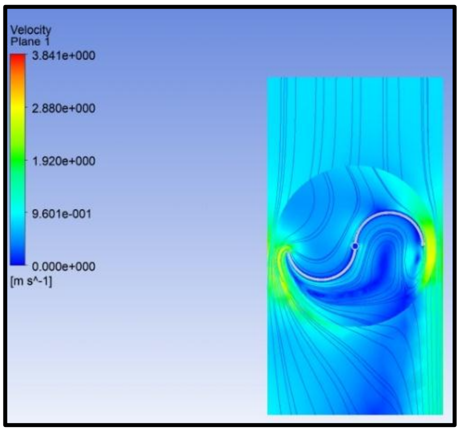

Figure 9. Distribution of velocity streamlines (2D) on the single-stage.

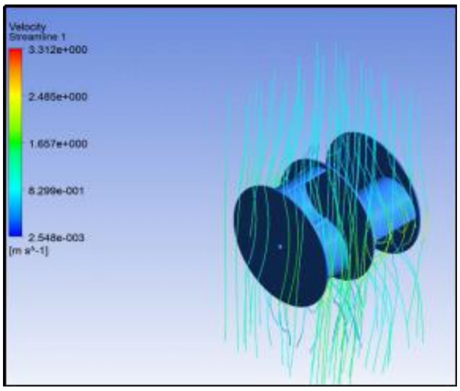

Figure 10. Distribution of velocity streamlines (3D) on the two-stage.

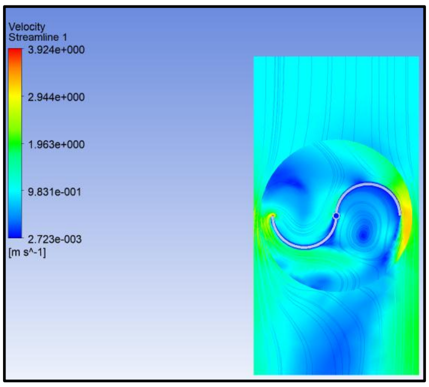

Figure 11. Distribution of velocity streamlines (2D) on the two-stage (first-stage).

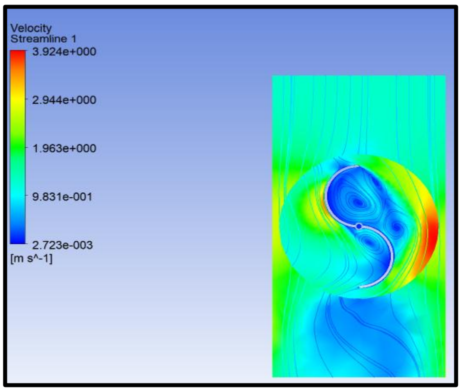

Figure 12. Distribution of velocity streamlines (2D) on the two-stage (second-stage).

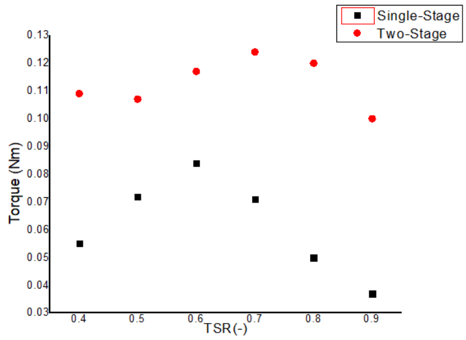

Figure 13. Comparison of calculation torque between two rotor types.

TABLE III. COMPARISON OF CALCULATION TORQUE

No	TSR	Torque	
		Single-Rotor	Two-Rotor
1.	0.4	0.055	0.109
2.	0.5	0.072	0.107
3.	0.6	0.084	0.117
4.	0.7	0.071	0.124
5.	0.8	0.050	0.120
6.	0.9	0.037	0.100

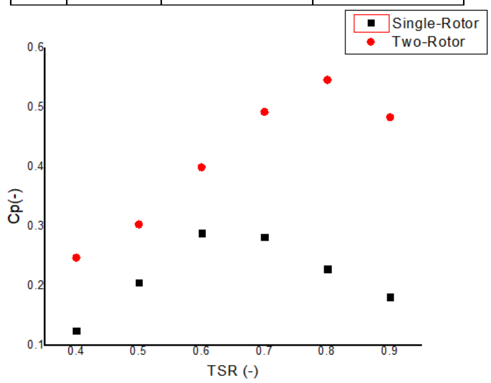

Figure 14. Comparison of calculation Cp between two rotor types.

TABLE IV. COMPARISON OF CALCULATION CP

No	TSR	Cp	
		Single-Rotor	Two-Rotor
1.	0.4	0.124	0.247
2.	0.5	0.205	0.303
3.	0.6	0.288	0.399
4.	0.7	0.282	0.492
5.	0.8	0.228	0.546
6.	0.9	0.181	0.483

Fig. 10 shows the torque, and Fig. 11 shows the coefficient of power (C_p) value of each rotor. All torque values and power coefficients are shown in Tables III and IV. Based on the conducted simulation, the rotor with two-stage produces the largest torque and C_p. Torque is directly proportional to the power produced so that large torque produces large power. The simulation was performed on a water velocity of 0.8 m/s with intervals of TSR 0.5-0.9. As presented in Fig. 7b, the single-stage rotor reached C_p maximum of 0.28 on TSR 0.6. With torque 0.084 Nm. The Two-stage rotor reached maximum C_p at 0.54 on TSR 0.8 with torque value 0.12013 Nm. At the two-stage rotors, maximum C_p was not obtained at maximum torque. The maximum torque in the two-stage rotor is 0.124 Nm on TSR 0, 7.

V. Conclusions

The simulation of three different types of savonius rotors has been carried out by involving single-stage and two-stage. The results of this study conclude that the modification of the two-stage rotor has the highest coefficient of power maximum *(C_{pmax})* value compared to the single stage. Overall, on the same TSR, two-stage rotors have a higher coefficient of power (*C_p*) when compared to single-stage rotors. The *C_p* maximum two-stage rotor is reached at 0.54 and the single-stage *C_p* maximum is reached at 0.28. Therefore, the two-stage rotor is proofed as an alternative design which can improve the performance of water turbine savonius, especially utilize water resource to produce renewable energy. From this simulation research, we get a picture of the velocity and pressure distribution, that can be used as a reference for experimental studies and the development of the next rotor design.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dandun Mahesa Prabowoputra designing model, conducting benchmark and analysis; writing draft manuscript; approving the final version of the manuscript. Syamsul Hadi was providing research funding, supervising manuscript writing, checking analysis results, supporting the final version of the manuscript. Aditya Rio prabowo supervising manuscript writing; checking result data and presentation; approving the final version of the manuscript. Jung Min Sohn was providing calculation instruments, checking computational estimation, approving the final version of the manuscript.

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Dandun Mahesa Prabowoputra graduated in Mechanical Engineering from Sebelas Maret university. He is a Master Student in Graduate School of Mechanical Engineering, Sebelas Maret University, Surakarta, Indonesia and Lecturer in the Department of Mechanical Engineering in Perwira Purbalingga University, Indonesia. His research interests water turbine and CFD.

Syamsul Hadi graduated in Mechanical Engineering from Institut Teknologi Sepuluh Nopember. He has completed his Masters degree from Gajah Mada University and Doctor degree from Kyushu University. He is a professor and senior lecturer in the Department of Mechanical Engineering in Sebelas Maret University, Indonesia. His research interests water turbine, Fluid Dynamic, Sensor, and termoelectric.

Aditya Rio Prabowo graduated in Mechanical Engineering from Diponegoro University. He performed a series of numerical simulation based on an incident of ship collision, which also became main topic for his graduate thesis. After finishing double-degree program of a combined discipline, Naval Architecture and Marine Systems Engineering, and Mechanical Engineering, he continued to Marine Convergence Design, Pukyong National University,South Korea. He expanded his research to other engineering phenomena, such as grounding/stranding and arctic engineering. He is a Professor and Lecturer in the Department of Mechanical Engineering in Sebelas Maret University, Indonesia.

Jung Min Sohn is a Professor and Lecturer in the Department of NavalArchitecture and Marine Systems Engineering, South Korea. Her research focused on impact phenomena, especially blast mechanic, fluid-structure analysis and numerical estimation as published in reputable journals, such as Thin-Walled Structures, Ship and Offshore Structures, and Latin American Journal of Solids and Structures. Numbers of marine structure-related project had been handled, for instance structure strength, full-ship vibration, and collapse strength due to collision. She involves in various activities of Korean Naval Society, in the form of regulation meetings and bi-annual conferences.