Effect of Geometry Modification on Turbine Performance: Mini-Review of Savonius Rotor

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***Abstract*—The rotor is a critical component in converting kinetic energy into electrical energy in the turbine. There are many types of turbines, one of which is the Savonius Turbine, a kind of cross-flow turbine. In recent years, research on improving the performance of the Savonius turbine has continued to develop. Several factors that affect the performance of the Savonius turbine are external factors, geometry, and materials. One of the Savonius turbine performances is influenced by the rotor geometry. Several studies have shown that modification of the geometry of the Savonius rotor can improve turbine performance. Some of the changes made are variations in aspect ratio, overlap ratio, the shape of a blade, number of blades, and multi-stage. This research is a mini-review of the geometry modifications that influence the performance of the Savonius turbine. This study aims to show the geometric factors that influence the performance of Savonius and compare the magnitude of these factors' Influence in increasing the Savonius turbine's performance. Reviews show that the Aspect Ratio is directly proportional to performance. Overlap variation of 0 to 0.3 has resulted in the best performance on the Savonius turbine, but other factors also influence this factor. The modified shape of the blade provides an increase of 8% - 25%. Multi-Stage on the Savonius can be a combination factor with other factors to maximize the performance of the Savonius rotor. The number of blades that have resulted in the best performance and stability against other factors is two-blades and three-blades.**

***Index Terms*—Savonius, turbine, geometry factor, coefficient of power**

I. INTRODUCTION

Research on renewable energy in Indonesia has increased yearly, both experimental studies [1] and simulations using software [2]. One renewable energy that has excellent development is power generation, especially Hydro-power. The turbine is one of the Machines used to utilize the Power System. Many research development of the turbine geometry design to improve the turbine's performance. The rotor is the main component that converts mechanical energy into electricity utilizing transmission systems [3].

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Fig. 1 shows the turbine classification. The turbine is divided into two types based on the flow, namely axial flow and cross-flow. Axial flow turbines have a similar working mechanism to propeller blades and rely on generating lift [3]. Cross-flow turbines can generate power at moderate flow rates but experience high torque fluctuations [3].

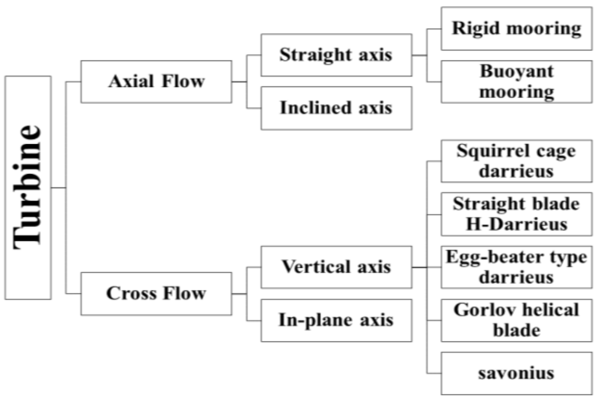

Figure 1. Classification of turbines [3].

In recent years, the Savonius rotor is one type of cross-flow turbine that has experienced many developments. Research to improve the performance of Savonius is mainly done by modifying the rotor geometry. The geometry of the Savonius continues to develop, such as the use of shaft [4], blade shape [4], aspect ratio [5], overlap ratio [6], number of blades [7], and multi-stage [8]. Blade profile changes have been carried out in the study of Zain Ullah Khan et al. [9]. Changes in the blade profile resulted in an increase in the maximum power coefficient against the conventional design from 0.128 to 0.38 [9].

This research shows that geometry has an essential role in increasing turbine performance. Many changes to the main rotor parameters have been made. The main parameters in question are many factors such as the number of blades, aspect ratio, and overlap ratio. Tests on the number of blades were carried out with various variations, namely two, three, four, and five. Several studies have shown that blade two has the best

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performance compared to other numbers. This is because the net drag that affects the rotor on two blades is higher than the number of other blades [7].

In contrast, other studies have shown that number blade four has better performance [10]. Tests on the aspect and overlap ratios have been carried out consecutively at 1.8 and 0.10 to 0.15. The tests show that the aspect ratio has a more significant influence than the overlap ratio [5]. Overlap studies have also been carried out at 0.12 to 0.21, showing that the optimal overlap is at 0.16 [11].

Other research related to the rotor geometry factor is about the shape of the blade. There have been many designs of blade shapes that show an increase in turbine performance. Changes to the blade in the form of blade shape [4, 9], twisted/helical blade [12, 13], or the addition of components to the blade [14]. This research is a mini-review of the geometry change factor in the Savonius turbine. This study aimed to show the geometry that influenced the performance of Savonius and compare the magnitude of the Influence of these factors in improving performance. Several studies show a significant increase in performance to be used to reference the following research design.

II. Savonius Turbine

Savonius published his rotor design in 1920, in which the rotor was operated on water and wind. This study shows that the rotor can perform well with water and wind. Savonius rotor can operate at low velocity. The rotor operates at a water velocity of 0.6 m/s, similar to a wind velocity of 5.5 m/s [1]. Rotor Savonius is an adaptation of the rotor system at the Flettner Principle.

Fig. 2 shows the flow pattern on the Savonius rotor. The work of the Savonius rotor is to use a different resistance coefficient between two blades in the turbine. Savonius work's principle is based on the torque produced or the drag force between the rotor blades' concave and convax parts when rotating around a shaft. At the same time, some fluid flows to arrive at a convex underwater surface through a fluid tunnel that produces torque [1].

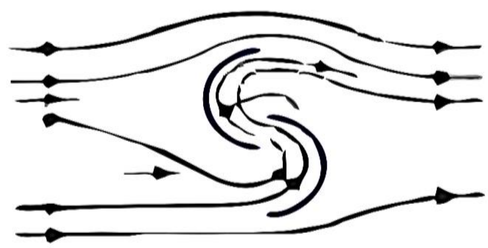

Figure 2. Fluid flow in the Savonius rotor [15].

In general, the Savonius structure is shown in Fig. 3. Savonius consists of 3 parts: endplate, blade, and shaft [8]. The Savonius rotor has several advantages and disadvantages. The benefits of Savonius are that it has a simple structure, is easy to manufacture, and is easy to maintain. Savonius has a high starting torque and can operate at low velocities. The Savonius rotor has the disadvantage of low efficiency in its conventional design [16]. Fig. 4 shows a comparison of the performance of the Savonius turbine with other types of turbines, where it can be seen that the Savonius turbine is the turbine that has the lowest Cp [15]. Table I shows the difference between the savonius turbine and the Darrieus turbine in general.

TABLE I. Comparison of the Savonius Rotor with the Darrieus Rotor.

Savonius	Darrieus
has an ability to self-start	do not have a self-start ability
has the Lower efficiency	has the highest efficiency
high starting torque	low starting torque
Lower Noise	Lower Noise
drag type turbine	lift type turbine

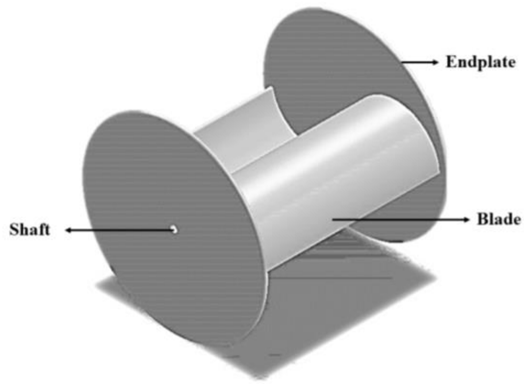

Figure 3. Savonius structure [8].

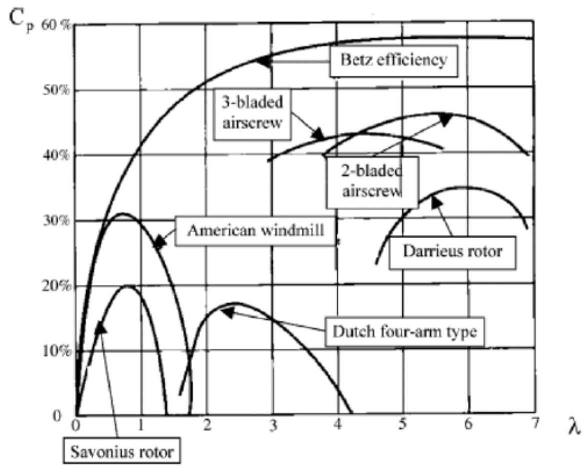

Figure 4. Rotor Turbine performance [15].

III. Performance of the Savonius Rotor

Savonius turbine performance is shown from the coefficient of power produced. In addition to the coefficient of power, another parameter is the Coefficient of Torque. Equations 1-4 Shown of these performance parameters are:

Tip Speed Ratio (TSR):

$$TSR = \frac{\omega D}{2V} \tag{1}$$

Power (P):

$$P = T\omega \tag{2}$$

Coefficient of Power (Cp):

$$Cp = \frac{2P}{\rho DHV^3} \tag{3}$$

Coefficient of Torque (Ct):

$$Ct = \frac{4T}{\rho D^2 V^2 H} \tag{4}$$

Where ω is Angular velocity, V is fluid inlet velocity, D is rotor diameter, H is rotor height, T is torque, and ρ is fluid density [17].

IV. Geometry Factor

Turbine performance with a Savonius rotor can be influenced by several things, including variations in inlet speed [10], turbine material [18, 19], and geometric factors [20]. The Savonius geometry factor has an important role in improving the performance of the Savonius turbine. The geometric factors include aspect ratio [21], blade shape [22], overlap ratio [23], multi-stages [25] and number of blades [10].

A. Aspect Ratio

Aspect ratio is one of the geometric factors on the Savonius rotor that influences the performance of the Savonius turbine. Aspect ratio (*AR*) is the ratio between the height of the rotor (*H*) and the diameter of the rotor (*D*). Equation 5 shows the expression of the aspect ratio equation [6]:

$$AR = \frac{H}{D} \tag{5}$$

Sukanta Roy and Ujjwal K Saha have researched the effect of the Aspect ratio on the Savonius rotor's performance [21]. The type of blade used is a conventional blade type. The aspect ratios used in this study were 0.6, 0.7, 0.8, 0.9, and 1. The study was conducted experimentally using a wind tunnel. The research shows that the best performance value is obtained at an aspect ratio of 0.8, producing a Cp_{max} of 0.178. The lowest Cp_{max} was obtained at an Aspect ratio of 0.6 of 0.145. Aspect ratios of 0.7, 0.9, 1 resulted in a Cp_{max} of 0.157, 0.172, 0.165 [21].

Jaohindy researched the aspect ratio effect on Rotor's Performance [25]. Variations made are AR 0.7 and 1.1. The research was conducted using the CFD method with 3D simulation on a conventional Savonius blade. The results show that the best aspect ratio is 1.1. The resulting Cp_{max} on AR 1.1 is 0.21, and AR 0.7 produces 0.14 Cp_{max} [25]. Saat et al. investigated the effect of aspect Cp_{max} on the performance of Savonius with twisted blades, and the research was conducted in 3D unsteady using the CFD method [23]. The software used in this research is fluent Ansys. Aspect ratio variations used are 1, 2, 3, and 4. The resulting Cp_{max} is directly proportional to AR, where the higher the AR, the higher the Cp_{max}. The smallest Cp_{max} is generated in AR 1 with a value of 0.223. The highest Cp_{max} is generated by AR 4 with a value of 0.261 [23]. There are 5 types of aspect ratio variations used in the research of Mahmoud et al. The aspect ratios are 0.5, 1, 2, 4, and 5. This study uses an experimental method in a wind tunnel. The study results show that the higher the aspect ratio used, the higher the Cp_{max}. The highest Cp_{max} was obtained at Aspect ratio 5, which resulted in a Cp_{max} of 0.14 [7].

B. Shape of Blade

The shape of the blade influences Savonius performance. Research shows that phenomenon, using both experimental and simulation methods. The shape of the blade is one of the changes in geometry that has attracted research attention. The model structure changes the shape of the conventional blade to become flat, as shown in Fig. 4a [26]. The research was carried out numerically in 2D using Ansys Fluent software. The type of turbulence used is Shear-Stress Transport (SST) k-ω. They are changing the shape of the blade results in an increase of 17.85%, from Cp 0.5 to 0.59. In addition, the Pranta model shows a wider TSR interval than the conventional type [26].

Shouman et al. have added fins to the savonius blade with 3 variations of shape [27]. The variation that has been done is to add 1 to 3 fins for each variation of the blade. The results showed that the best increase was obtained from adding 1-fin for each blade variation. The resulting Cp_{max} is 0.156 by adding a 1-fin variation, the best Cp_{max} production of all variations. The resulting increase is 42% from the conventional rotor design [27].

Mustafa kamal and Saini changed the savonius rotor with helix blades using variations in angles of 22.5°, 45°, and 90° [13]. Research has been carried out using three variations of inlet velocity: 0.5 m/s, 1 m/s, 1.5 m/s, and 2 m/s. The research that has been done shows that a rotor produces the best Cp_{max} with a helix angle of 45°. The resulting increase is 4.7% [13].

Absi et al. conducted a study comparing the performance of a conventional Savonius blade with a modified blade [28]. The modifications made are shown in Fig. 4b, which gives a serrated surface on the blade. This research was conducted using two methods, namely experiment and simulation. The simulation was carried out in 2D unsteady conditions using ANSYS. At the same time, the experimental investigation was conducted using aspect ratio rotor 1 and research using a wind tunnel. In the simulation research, the classic blade produced the Cp_{max} obtained is 0.258 and produced 0.26 on an experiment. In the experimental study, the modification blade produced the Cp_{max} is 0.292. This study showed that the modification of the blade surface increased the Cp_{max} by 12.31% [28].

Figure 4. a) Pranata Blade [26] and b) Serrated Blade [28].

Research on the performance of Savonius with the CFD method has been carried out by Prabowoputra et al. [29]. Fig. 5a shows the L-Shape blade modifications that have been made. Simulations were carried out in 3D using Ansys software and CFX Solver. The turbulence model used in this study is k-epsilon. The aspect ratio used on the rotor is 1, and the overlap ratio 0. The increase in Cp_{max} resulting from the design modification is 10% [29].

Shashikumar et al. have researched modifying the blade with a v-shape model [30]. The V-shape model that has been used in this study consists of 5 types. Some improve performance, while some do not. The modifications made to the blade shape that has improved performance are shown in Fig. 5b. The research was conducted using experimental and simulation methods. However, the comparison with the conventional Savonius design was only carried out in simulation research. The resulting Cp_{max} is 0.22, and the increase obtained from the V-shape modification is 19.3% [30]. Fig. 5c shows a modified design of a tandem blade with an aspect ratio of 1. The research uses the CFD method in 3D and ANSYS CFX Slover. Blade design produces a Cp_{max} of 0.2266. Compared to the conventional Savonius type, this new design improves performance by 8.89% [31].

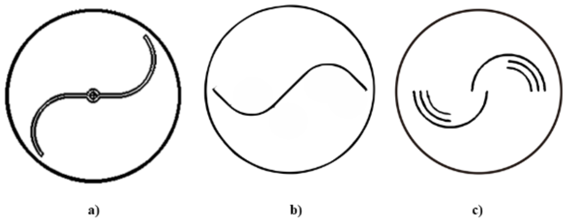

Figure 5. a) L-shape Blade [29], b) V-Shape Blade [30], and c) Tandem Blade [31].

The blade modification research that Nur Alom and Ujjwal K. Saha have done shows the effect on the performance of the Savonius turbine [32]. Modification is done with three variations: Benesh type, Elliptical type, and Modified batch type. Fig. 6 shows a visual of the variations in the blade shape modifications that have been made. This research was conducted using the CFD method in 2D unsteady conditions. The software used in this research is ANSYS Fluent. The results show that the three-blade modifications increased the performance of the Savonius turbine. The increase produced by the elliptical type is 25%, the benefit type is 15.64%, and the Modified batch type is 11.84% [32]. The shape of the batch profile on the rotor shows an increase in the cp max value. The increase in Cp_{max} was obtained by 36%, where the Cp_{max} in the conventional design was 0.195, and the batch profile was 0.2661 [33].

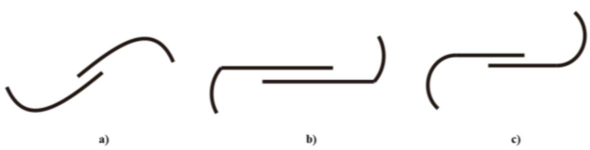

Figure 6. a) Elliptical Blade, b) Benesh Blade, and c) Modified Batch Blade [32].

Table II shows the increase in the performance of the Savonius turbine caused by the modification of the blade shape. This mini-review shows that the Sonu Sharma model has the smallest gain of 8.89% compared to several blade shape modifications on the Savonius rotor. The elliptical shape has the best increase, up to 25%. This review shows the effect of blade shape modification on the performance of the Savonius rotor in general. Fig. 7 shows a graph of the relationship between Cp and TSR for each rotor variation.

TABLE II. SAVONIUS PERFORMANCE IMPROVEMENT.

No	The shape of the blade type	Increment
1	Pranata Blade	17.85%
2	Serrated Blade	12.31%
3	V-shape Blade	19.3%
4	Tandem Blade	8.89%
5	L-shape Blade	10%
6	Elliptical Blade	25%
7	Benesh Blade	15.64%
8	Modified Batch	11.84%

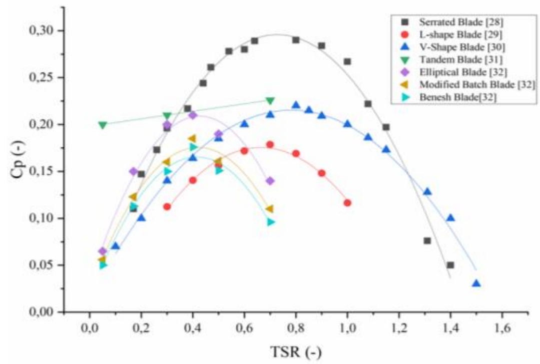

Figure 7. Graph of the relationship between Cp and TSR.

C. Overlap Ratio

The overlap ratio is one of the parameters related to the turbine diameter, which is the ratio of the overlap distance between the turbine blades (e) to the turbine diameter (D). The following equation 6 shows the equation of the overlap ratio [6].

$$OR = \frac{e}{D} \tag{6}$$

Akwa et al. conducted a study on the effect of overlap on the performance of the Savonius turbine [23]. The blade used in this study is the conventional Savonius. The research was conducted in 3D simulation using the CFD method. There are 5 types of overlap modifications, namely 0, 0.15, 0.3, 0.45, and 0.6. The results show that the overlap of 0.15 produces the best Cp_{max}, which is 0.3161. However, the position of Cp_{max} at overlap 0.15 is almost the same as that produced by overlap 0.3 [23]. Research on the effect of overlap on Savonius with an elliptical type blade shape has been carried out. The CFD method is used in this study, and the simulation uses 2D unsteady. The software used in this research is Ansys Fluent. The overlap ratio variations given are 0, 0.1, 0.15, 0.2, 0.25, and 0.3. The highest Cp_{max} of 0.34 was obtained at an overlap ratio of 0.15 [34]. Simulation research on the effect of overlap on the performance of Savonius has been carried out. The type of blade used is conventional Savonius, where this research was conducted using the CFD method with 2D simulation. The overlaps used in this study were 0, 0.075, 0.15, 0.225, and 0.3. The highest Cp_{max} is obtained at overlap 0, which is 0.19. At 0.15 overlap, Cp_{max} is close to overlap 0, which is 0.186 [35].

Another study was carried out using an experimental method on conventional Savonius turbines using variations of the overlap ratio [36]. The overlap ratio used is 0, 0.1, 0.2, and 0.3. The study was conducted using a tunnel in an experimental setup. The Cp_{max} produced by each overlap variation of 0, 0.1, 0.2, and 0.3 are 0.105, 0.138, 0.14, and 0.11. These results indicate that the overlap that produces the best performance is 0.2, Cp_{max} is 0.14 [36]. Absi et al. conducted a study on the effect of overlap on the new blade design on the performance of the Savonius turbine [28]. This research was conducted on a blade with a serrated shape on the blade surface. The method used in this study is the CFD method with 2D simulation. The overlap variations used are 0.1, 0.15, and 0.2. The highest Cp_{max} is obtained at overlap 0.2 with a value of 0.258. The overlap of 0.1 and 0.15 produces a Cp_{max} of 0.246 and 0.25 [28].

D. Multi-Stages

Prabowoputra et al. conducted a study on the performance of the Savonius turbine [37]. The research was conducted using an unsteady 3D simulation using the CFD method with the ANSYS CFX. The design used is shown in Fig. 8. The variation used is the number of stages, namely single-stage, two-stage, and three-stages. The type of blade used is conventional Savonius. The overlap used is 0, and the aspect ratio is 1. The kind of turbulence used is K-epsilon. The results show that the best performance is obtained on a three-stage rotor, resulting in a Cp_{max} of 0.197. A two-stage rotor produces a Cp_{max} of 0.178, and a single-stage produces a Cp_{max} of 0.1 [37].

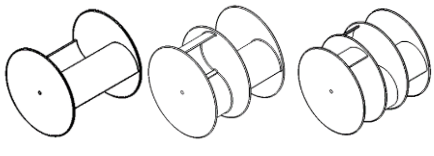

Figure 8. a) Single-stage, b) Two-stages, and c) Three-stages [37].

Saat et al. conducted a study on multi-stage [24]. This study aimed to determine changes in the performance of the Savonius turbine. This research was conducted on twisted blade form. The aspect ratio used is 1 for single-stage, 2 for two-stages, 3 for three-stages, and 4 for four-stages. The research uses the CFD method with 3D simulation. The results show that the higher the number of stages, the higher the Cp_{max}. A four-stage rotor produces the best performance with a Cp_{max} of 0.261. a single-stage produces the most negligible performance with a Cp_{max} value of 0.223 [24]. Kamoji et al. studied multi-stages with experimental methods [38]. Tests were carried out on single-stage, two-stage, and three-stage rotors, which conditions were set using Reynolds numbers 80,000 and 100,000. Both types reproduce the same performance pattern: the more stages, the smaller the Cp_{max} produced. The overall Cp_{max} results are shown in Table III [38].

Frikha et al. have researched variations in the number of stages in Savonius. The CFD method is used in this study with 3D simulation. The number of stages used in this study was two-stages, three-stages, four-stages, and five-stages. The blade used is a conventional blade without using an endplate. This study indicates that the best performance is obtained on a rotor with five stages producing a Cp_{max} of 0.132. The most negligible performance is obtained on a two-stage rotor with a Cp_{max} of 0.081[39].

TABLE III. Cp_{MAX} RESULTS IN THE STUDY OF KAMOJI ET AL. [38].

Type of Multi-stage	Cp_{max} at Re 80,000	Cp_{max} at Re 100,000
Single-Stage	0.17	0.18
Two-Stages	0.13	0.15
Three-stages	0.10	0.13

E. Number of Blades

Wenehenubun et al. conducted a study on the effect of the number of blades on the performance of the Savonius rotor [10]. The number of blades used in this study was 2, 3, and 4, and used was the conventional blade. The research method used in this research is an experimental and simulation method. The simulation used ANSYS, and the results show that Cp_{max} is obtained at the number of blades 4 [10].

Experimental research has been carried out on blades 2, 3, 4, 5, and 6 [36]. The blade used a conventional blade, with an aspect ratio of 2 and an overlap of 0. The results showed that the best performance was obtained at the number of blades two because the net drag force affected on the rotor is higher than on other blades. A rotor with two blades produces a Cp_{max} of 0.1 [36]. Research has been carried out on the effect of the number of blades on the performance of Savonius [15]. This research was conducted using the CFD method with unsteady 3D simulation. The software used is ANSYS CFX. The type of turbulence used in this study is k-epsilon. The blades used conventional and modified types, as shown in Fig. 8. Variations in the number of blades used are 2, 3, 4, and 5. Table IV shows the Cp_{max} results obtained. The largest Cp_{max} is obtained for both blades at the number of blades 3 [15].

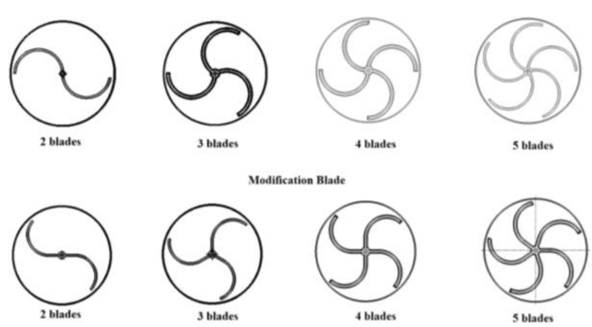

Figure 8. Savonius rotor [15].

TABLE IV. Cp_{MAX} RESULTS IN THE STUDY OF PRABOWOPUTRA ET AL. [15].

Type of Blade	Cp_{max}			
	Number of blades: 2	Number of blades: 3	Number of blades: 4	Number of blades: 5
Conventional	0.10	0.215	0.06	0.04
Modification	0.11	0.18	0.08	0.05

V. CONCLUSION

This mini-review shows several geometric factors that influence the performance of the Savonius turbine. These factors are aspect ratio, overlap ratio, shape of blade, multi-stages, and number of blades. The review shows that the higher the Aspect Ratio tends to increase the performance of the Savonius turbine. However, this factor needs to be considered in terms of the ergonomics of turbine construction. In this simple review, changes in performance caused by the shape of the blade can increase the performance of Savonius by 8% to 25%. The best performance is obtained on the rotor design with 0.15 overlap. Multi-Stage on the Savonius can be a combination factor with other factors to maximize the Savonius rotor performance. The best number of blades is generally achieved in numbers 2 and 3. For a number of blades > 4 has different results for each researcher.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Dandun Mahesa Prabowoputra: Conceptualization, methodology, software, formal analysis, data curation, and writing—Original draft preparation.

Aditya Rio Prabowo: Methodology, conceptualization, software, validation, resources, writing—Review and editing, supervision, supervision, project administration, and funding acquisition.

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