Parameters of Savonius Type Hydrokinetic Turbine to Enhance Efficiency

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Abstract. Increasing energy requirements accompanied by high fossil fuel emissions will lead to energy crises and the greenhouse effect in the future. These factors encourage the development of renewable energy. Hydropower can be one alternative energy to meet the energy demand. Hydrokinetic turbine is one of the latest technologies that utilize energy from water flowing in rivers, waterways, drainage in buildings, etc. This paper presents a review of hydrokinetic theory as an energy conversion system from flowing water with reference to the wind energy system. The most discussed type of turbine is a hydrokinetic savonius turbine with a description of the benefits, weaknesses, strengths, and conditions according to the application. Hydrokinetic savonius turbine is the most discussed turbine because of the ability of this turbine to work at low fluid flow rates in rivers and waterways. But the weakness of Savonius turbine is that it has low efficiency. Several experimental studies and numerical calculations by varying the design and parameters of the turbine have been carried out to improve its efficiency. The following parameters have been explained which affect the performance of hydrokinetic savonius turbines which are expected to be useful for future research to improve turbine efficiency.

1. Introduction
Energy is one of the important factors that influence a country's economic and social growth. Along with the increasing rate of urbanization and industrialization in developed and developing countries, the level of energy consumption will increase [21]. The use of fossil fuel resources has an impact on environmental pollution and global climate change. The combustion results from fossil fuels also have an impact on increasing concentrations of greenhouse gases such as carbon dioxide in the atmosphere [25].

Various impacts of the use of fossil fuels encourage the use of renewable energy sources [24]. Renewable energy is a topic of interest to be investigated along with the current increase in energy needs followed by policies to reduce fossil fuel resources and strict laws on the environment and global warming [12]. The use of non-renewable energy will continuously lead to energy crises in the future. The government has conducted various programs to anticipate the energy crisis, one of them is the Green Building program.

The Green Building Program implements the use of energy resources that are efficient, saving resources during the life cycle of a building, and also providing a comfortable living environment for its inhabitants [16], [43]. Green building programs have recently been recognized as a legacy of sustainable development with the responsibility of meeting and offsetting social, economic and environmental sustainability [26]. Building water drains that are channeled through vertical pipes are...
part of the building life cycle that has the potential to be utilized as a pico / nano scale power plant [30]. One method of utilizing energy from drains is to use a hydrokinetic energy conversion system that does not cause pollution [22], [8]. Using this system, [14] has made use of rainwater in buildings using a turbine that generates power of 26.6 W of electricity from 1.8% of the water reservoir flow. Hydrokinetic savonius turbines have enormous potential to produce electricity from water that flows at low speed and with a low head [42]. Compared to Savonius wind turbines, Savonius water turbines have advantages in a simple design that is easy to make. So, it is very very easy to be installed in streams, sewage in buildings, and rainwater utilization [27]. Payambarpour and Najafi [28] conducted research on the development of savonius turbines applied to water pipes. Based on the research that has been done, it can be concluded that Savonius turbine has big potential for water turbine application. On the other hand Sarma, et al. [38] has also conducted research on conventional Savonius wind turbines that are driven by low water flow at speeds from 0.3 m / s to 0.9 m / s in open waterways. The results showed that the performance of hydrokinetic savonius turbines was superior to wind turbines. The maximum power produced increases 61.32% from wind turbines with the same input power.

Various variations have been studied to get maximum results from Savonius turbine performance. One variation that can have a large effect on turbine performance is the installation of a deflector. The use of a deflector in a hydrokinetic savonius turbine confronted with a source of water flow is better than a savonius wind turbine with an unpredictable source of wind direction [6], [3]. Deflector works with the principle of reducing negative torque on the convex turbine surface and increasing positive torque on the concave surface of the turbine [35]. Turbine without a deflector produces an output power of only 9.77 Watt while adding a deflector at an angle of 30 degrees can increase the output power by 18.04 Watt [30]. The different deflector angles installed provide a significant difference to the power produced [31], [1], [36]. Other research was also conducted by Agus Setiawan, et al. [2] who examined the effect of the addition of a round cylinder on the performance of savonius water turbines. The results showed that turbine performance increased by 41.18% compared to conventional Savonius turbines. Another study conducted by Setiawan, et al. [39] which varies the position of the stagger's angle on the addition of the savonius water turbine round cylinder. The results showed that the maximum power coefficient increased by 29.84% at TSR 0.9 and 60 degrees stagger angle.

In addition to the addition of deflectors, the model and number of blades in savonius wind turbines greatly affect its performance [32], [40]. Therefore, various studies related to the modification of the model and the number of blades have been carried out such as the research of Sanditya, et al. [37] who have investigated the effect of blade angle curvature. The best results are at a curvature angle of 120 degrees with a maximum discharge of 714 lbm producing power of 39.15 Watt, a power coefficient (Cp) of 0.23 and a TSR ratio of 1.075. Angular curvature of the blade maximizes the flow of water captured by the blade [35]. Efforts to improve the efficiency of savonius turbines have been made by adding blades that serve to increase the speed of wind flow around the turbine and reduce the drag force of the turbine. This turbine is called savonius tandem blade (STB) [1]. Other studies on blade modification have been carried out by Ridwan, I. and Setiyono [32] namely by adding fins to the turbine blade. The study was conducted in a simulation using Solidworks (Flow Simulation) software. The simulation results show that the pressure distribution and wind flow velocity at each blade are higher and more evenly distributed at the blade with two fins than the blade without the addition of fins. More blade modification is done by numerical and experimental methods. Such research has been carried out by Al-Ghriybah, et al. [5], concerning the effect of adding inner blades with varying angles and mounting positions. The calculation results show the maximum Cp to 0.1885 at TSR equals 0.5. Based on the literature that has been studied, it is a challenge for researchers to improve the efficiency of hydrokinetic turbines. The following parameters have been explained which affect the performance of hydrokinetic savonius turbine.
2. The Savonius Turbine Concept
The Savonius turbine was developed and patented first by Sigurd J. Savonius, engineer from Finland in 1925. The design of the turbine is based on modification of the "S" rotor. Therefore, its appearance resembles the letter "S" when viewed from above (Figure 1) [41]. This turbine design initially consisted of two semicircular blades which were placed so that the concave part of one blade faced the other blade with a slight overlap in the middle. As a simple turbine, Savonius turbine works because of the difference in force applied to each blades where the concave part of the turbine will catch wind flow and force the blades to rotate on its axis while the convex portion will bend the wind flow sideways away from the shaft [32]. Al-Bahadly [4] states that Savonius turbines produce mechanical power due to different drag forces acting on the concave and convex sides. The drag force produced by the wind flow will induce turbine rotation. Savonius turbines have simple construction, low maintenance costs, and low noise. Savonius turbines have the ability to receive fluids from all directions with torque at a good initial rotation [18]. The main advantages of savonius wind turbines are that they can work in balanced air turbulence, can transmit vibrations to a minimum, and low pressure on walls or roofs [17].

![Figure 1. Schematic savonius vertical axis turbine. (d : blade diameter, D : turbine diameter, Do : end plate diameter, E : overlap distance, and H : turbine height).](image)

Various Savonius wind turbine (SWT) and Savonius hydrokinetic turbine (SHT) models have been tested experimentally and numerically by researchers for different design configurations and by using different augmentation techniques to achieve increased performance efficiency. [41]. Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented.

3. Hydrokinetic savonius turbine
According to Kumar and Saini [21] hydrokinetic is kinetic energy that is produced due to the mass movement of water. The amount of hydrokinetic energy contained in the mass of water depends on the speed of the water. There are two types of hydrokinetic energy that are supported by the movement of water, namely from waves and currents that can be found in streams, artificial waterways, irrigation channels, dam heads, and others. Theoretically, hydrokinetic power can be expressed as:

\[
P_{\text{THEORY}} = \frac{1}{2} \rho AU^3
\]

Hydrokinetic turbines according to Güney and Kaygusuz [13] are turbines that convert the kinetic energy of flowing water into mechanical power. This turbine is also known as water current turbine (WCT), ultra-low head hydro turbine, free flow turbine, and zero head hydro turbine. According to Kumar and Saini [21] the kinetic energy that can be captured is only a small part of the
kinetic energy in which passes through the turbine cross section. This fraction is known as the power coefficient, CP. The hydrokinetic energy captured by the turbine can be expressed as:

$$P_{TURBINE} = C_P \frac{1}{2} \rho A U^3$$  \hspace{1cm} (2)

Similar to a wind turbine, the power coefficient of a hydrokinetic turbine depends on the speed of the tip ratio (TSR) i.e. the speed of the blade at its tip to the speed of flowing water. Can be stated as:

$$\lambda = \frac{\omega R}{U}$$  \hspace{1cm} (3)

4. Design parameters of hydrokinetic savonius turbine

4.1. The effect of aspect ratio Style and spacing
Zhao, et al. [45] has conducted numerical analysis on helical savonius turbines to improve efficiency. It was concluded that the helical savonius turbine with an aspect ratio of 6.0 showed higher performance than the rotors with an aspect ratio of 1.0, 3.0, 5.0 and 7.0.

Kamoji, et al. [19] have also investigated Savonius helical turbines to determine the effect of aspect ratios ranging from 0.88 to 1.17 on the Reynolds number 120,000. The overlap ratio is kept constant at zero to study the effect of the aspect ratio. Based on experimental studies it was concluded that the Savonius helical turbine which has a lower aspect ratio of 0.88 has better performance than the aspect ratio of 0.93 and 1.17. Savonius turbines with a higher aspect ratio produce better performance because of the low level of kinetic energy loss. However, most savonius turbines are installed with a low aspect ratio also due to turbine structure reasons. Adding an end plate to the turbine can also increase the performance of turbines that have a low aspect ratio [21], [9].

Payambarpour, et al. [29] examined the effects of adding deflectors on experimental water savonius turbines and numerical calculations. To get the results of the aspect ratio effect on turbine performance, the turbine aspect ratio is changed from 0.4 to 0.9 without changing the deflector geometry. The results show that increasing aspect ratio reduces turbine leakage and can increase pressure on the turbine blades so that efficiency increases. Mahmoud, et al. [23] examined the variation of geometry savonius wind turbines experimentally to find the most effective operational parameters. The results showed that the power coefficient increased with the increase in aspect ratio with zero overlap ratio.

4.2. The effect of end plates
Alom, et al. [7] conducted research on the effect of turbine shafts and end plates on vertical turbine savonius in the form of elliptical blades. The study was conducted using an experimental method with wind tunnel. The test results obtained that the blades with shafts and with end plates showed an increase in the power coefficient of 26.31% than blades without rotor and without end plates.

Jeon, et al. [15] has examined the performance of savonius helical wind turbines (twist angle 180°). The research was carried out by manipulating different end plate ratios (end plate ratio 0 to 1) as shown in Figure 2. The results of the study stated that the end plate with a ratio of 1 has maximum power and torque coefficient. The use of upper and lower end plates can significantly increase the power coefficient by 36% compared to without the end plate.
Figure 2. Helical savonius turbine with various shape and size of end plate.

Saad, et al. [34] has conducted research on the effects of various design parameters on savonius wind turbines. The effect of the end plates (Do / D) parameters with variations without end plates, 0.5, 1, 1.1, 1.2 have been investigated. The results showed that Savonius turbine rotor with single 45° twist, with zero overlap ratio value, and end plates ratio 1.1 could reach the highest output power compared to others.

4.3. Effect of number of blades
Chaichana and Thongdee [10] have conducted research that aims to compare the work of savonius vertical axis turbines with the number of blades (4, 6, 8, 12, 16, and 18) and blade angles (-15°, -5°, 0°, 5°, and 15°). The results showed that the maximum power coefficient of the wind turbine was obtained at the number of blades 16 and the angle of the blades 5° with an increase in efficiency of 4.5% compared to the turbine basically.

Salleh, Kamaruddin, Mohamed-Kassim and Bakar [36] have investigated the effect of adding deflectors on conventional savonius turbines with two blades and three blades. The study was carried out experimentally in a wind tunnel at wind speeds of 10 m / s or equivalent to 0.57 m / s water velocity with the Reynolds number 90200. The experimental results showed that the maximum power coefficient of a turbine with two blades and three blades each 128, 36% and 604.62% can be combined with three blades producing a greater coefficient of power than a two blades turbine.

4.4. The effect of multi-staging
Rosmin, et al. [33] has conducted an experimental study of single stage two bladed and double stage two bladed savonius turbines using the RWH system. This research compares the test results from single stage and double stage turbines which are carried out with two testing methods, namely the volume of water flowed into the turbine from the tank when 30 liters in the first test and 60 liters for the second test. The results show that a single stage turbine produces more electricity than a double stage turbine.

Kamoji, et al. [20] have examined the two stage and three stage modified Savonius turbine blades. Multi-staging gives a positive value to the static torque coefficient in all slats. Tests using wind tunnels to determine the performance of savonius turbines two stages and three stages that are modified without the shaft between end-plates on the blade aspect ratio and different stage aspect.
ratios. The results showed that the power coefficient increased with increasing Reynolds numbers as well as the static torque coefficients for all types of two-stage and three-stage blades. However, the comparison of two stage and three stage blades shows the maximum power coefficient which decreases with increasing number of stages.

4.5. Effects of rotor profiles
Damak, et al. [11] has conducted research by comparing the use of helical rotors and helical rotors that are nominated with Bach rotors named Bach helical rotors. Bach rotor has a high power coefficient, but the static torque coefficient is negative. Conversely, the helical rotor has a low power coefficient, but the static torque coefficient is positive. The results showed that Bach's helical rotor has a greater power coefficient and static torque coefficient than helical rotors. Bach's helical rotor produces a power coefficient of 0.20 while the helical rotor produces a power coefficient of 0.18. Saad, El-Sharkawy, Ookawara and Ahmed [34] has conducted research on the performance produced on savonius turbines with helical blades. The results showed that the helical savonius turbine with a 45-degree girth produces a 0.231 power coefficient while a conventional savonius turbine is 0.174 on the same parameters.

Zakaria and Ibrahim [44] conducted a simulation study using CFD on four savonius turbine rotor designs with a comparison between conventional rotors, rotors with twist angle 0°, 90°, and 180°. The results showed that the helical savonius rotor with aspect ratio and overlap ratio showed variations in the low torque coefficient in the various turbine rotor designs studied. In fact, in conventional savonius rotors the negative static torque coefficient is almost zero. The best performance is the rotor with a 90° twist angle.

5. Conclusions
Much research has been done to improve the performance of Savonius turbines. Several studies have shown that savonius turbines can be applied to waterways as hydrokinetic turbines. In previous studies the accuracy of design parameters and flow parameters were prioritized by researchers to improve the efficiency of savonius turbines. Based on the review, several studies have been carried out to improve the performance of Savonius turbines by modifying aspect ratio, addition of end plates, overlap ratio, gap ratio, number of blades, blade stage, blade shape, and others. To form an energy source in an effort to increase electricity generation, hydrokinetic savonius turbines can be regulated in various ways. Negative interactions in savonius turbines can affect the power produced. Therefore, further research is needed to examine the effects of hydrokinetic savonius turbine interactions in different variations.

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