Numerical study on the wake characteristics of the Savonius turbine for shallow water application in Malaysia

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Abstract. Since Malaysia is a country surrounded by bodies of water, tidal energy is one of the prospects that can be explored for energy extraction potential. While there are several turbine designs and technologies that have been used for tidal energy extraction, information on the use of Vertical Axis Tidal Turbine (VATT) for shallow water applications is very limited, while the implementation of Horizontal Axis Tidal Turbine (HATT) is not suitable due to Malaysia’s ocean depth. Therefore, this paper attempts to address this gap by analyzing the flow characteristics of the VATT in the working environment of shallow water in Malaysia. The first analysis compared the wake characteristics of the Savonius turbine model against a hypothetical ‘actuator’ cylinder, which is a representation of VATT. Next, the second study analyzed the wake characteristics between static and dynamic simulations of a Savonius turbine model. The outputs from this study were validated against previous work in order to gain a better understanding of the wake characteristics of a Savonius turbine.

1.0 Introduction
Every year, the amount of electricity produced and consumed increases dramatically around the world [1], which is due to the population's rise and economic growth. Furthermore, conventional or non-renewable energy sources account for more than 80% of Malaysia's electricity [2]. Malaysia's energy requirements and demands are expected to rise from 82,000 GWh in 2005 to 190,000 GWh in 2020, according to a study by Y. S. Lim and S. L. Koh [3]. Therefore, renewable energy such as solar energy, wind energy, biomass and ocean energy need to be urgently introduced to solve this problem. Malaysia is one of the countries that is blessed with several forms of renewable energy resources, and the interest here is more towards the use of ocean energy as a part of the electricity generation mix. Marine energy has attracted growing interest, especially in European countries, which are currently at the forefront of the development and exploitation of ocean energy, specifically for tidal stream energy. Tidal energy can be extracted by using a tidal turbine, which is a device or machine that generates electricity from the changes in ocean tides [4]. Tidal forces created by the rotation of the earth and moon around the sun are responsible for producing tidal motions [5]. In Malaysia and abroad, different types of technologies have been used to produce electricity from ocean tides.

1.1 Tidal stream conversion device
The majority of current studies are focusing on the improvement of classic turbines’ design in order to increase their performance based on location. Apart from design, there are other parameters to consider while choosing the type of turbine to be deployed, such as device clearance, location depth, ocean current, as well as development and deployment costs, to name a few. When it comes to tidal devices, two primary types of turbines are used, namely the HATT and VATT.
1.2 Existing types of VATT and specification

On the market, there are a few well-known VATT designs. Each turbine design has its own capabilities and specifications. Table 1 shows the types of VATT turbines and their specifications.

| Type of VATT   | Current Speed | Efficiency | Power    | Dimension |
|---------------|---------------|------------|----------|-----------|
|               |               |            |          | Height    | Diameter  |
| Darrieus      | 1.1 m/s       | 20%        | 0.015 kW | 1.60 m    | 1.6 m     |
| Helical Savonius | 1.5 m/s      | 35%        | 0.500 kW | 0.85 m    | 1.0 m     |
| Kobold        | 1.8 m/s       | 23%        | 20.000 kW| 5.00 m    | 6.0 m     |
| Davis         | 2.5 m/s       | 30%        | 4.000 kW | 1.20 m    | 1.2 m     |

1.3 VATT design for application in Malaysia

The scope of this study is limited to 0.6 m/s of current velocity. According to a study by Yaakob Omar [6], Malaysia's average ocean current velocity is about 0.56 m/s, and the Savonius turbine has been suggested as the best device to be used. Hence, for this study, the Savonius turbine was chosen for the analysis, with the current flow set at 0.6 m/s.

2.0 Methodology

The geometry for the Savonius turbine was designed with CATIA software, while the domain, which represents the open channel, was created with ANSYS software [7]. The water clearance for the bottom and top of the device was set at 15 meter. There are a total of 12 designs, with overlap ratios of 0, 0.1, 0.2, and 0.3 for single, double, and triple stage turbines. The phase angle for each stack will be 90 degrees. Figure 1 shows the domain setup of the inlet, walls and outlet.

![Figure 1](image)

**Figure 1.** The domain for the inlet, walls and outlet.

2.1 Model parameters

The model parameters of the Savonius turbine used in this study are shown in Table 2.

| Model Parameters | Numerical |
|------------------|-----------|
| Height, $H$      | 5 m       |
| Diameter, $D_h$  | 2.5 m     |
| Bucket Thickness | 0.05 m    |
| End Plate Thickness | 0.1 m |
| Diameter of rotor, $d$ | 1.25 m |
Each stage of the turbine will have the same total height, diameter, bucket thickness, end plate thickness and diameter of the rotor. The height of the rotor for each stage will be the difference between each stage. Because the height of the rotor varies with stage, the aspect ratio for each stage will also be different. For the overlap ratio, it can be calculated by the overlap distance ($e$) over the diameter of one side rotor ($d$) [8]. Table 3 shows the overlap ratio of the overlap dimensions with a bucket diameter of 1.25 meter. The front and top views of a Savonius turbine are depicted in Figure 2.

![Figure 2. Detail dimension of Savonius turbine model setup: (a) Front view (b) Top view [9].](image)

| Overlap Ratio | Overlap Distance, $e$ |
|---------------|----------------------|
| 0             | 0                    |
| 0.10          | 0.1250 m             |
| 0.20          | 0.2500 m             |
| 0.30          | 0.3750 m             |

3.0 Result and discussion

3.1 Overview

The main focus of this study is on the behavior of the flow as it passes by the device in the domain. Based on the velocity contour, we can identify how fast the velocity of the wake recovery is. The longer the wake region behind the turbine, the slower the velocity recovery of the device. In contrast, a shorter wake indicates a faster velocity recovery. Hence, it is essential to understand the influence of turbine design on wake generation in order to plan for device arrangement in an array to ensure optimal energy extraction.

3.2 Validation between cylindrical object and Savonius turbine model

The design geometry plays a major role which will impact the velocity contour along the domain. Bakri A. [10] previously investigated the velocity wake of a hypothetical ‘actuator’ cylinder representing a VATT with a diameter of 5 meter. However, a cylindrical shaped object is not an accurate representation of the actual design of a turbine. Hence, this study produces an actual design of a VATT, specifically a single stage Savonius turbine with an overlap ratio of 0.2, to compare against a hypothetical ‘actuator’ cylinder. The diameter of the Savonius turbine design used in this study is 2.5 meter, whereas the previous study by A. Bakri employed a cylinder with a diameter of 5 meter. To give an accurate overview, this study compares an ‘actuator’ cylinder with a 5 meter diameter as used...
by A. Bakri (Figure 3), an ‘actuator’ cylinder with a 2.5 meter (Figure 4) and an actual Savonius turbine design with a 2.5 meter diameter (Figure 5). The difference in the diameter is clearly highlighted in these figures.

Figure 3. Side view velocity wake simulation of ‘actuator’ cylinder with 5 m diameter by A. Bakri. [10]

Figure 4. Side view velocity wake simulation of the ‘actuator’ cylinder with 2.5 m diameter.

Figure 5. Side view velocity wake simulation of actual Savonius turbine design with the design of the single stage turbine with overlap ratio of 0.2.

The plots in Figure 6 show that velocity recovery for an ‘actuator’ cylinder with a diameter of 5 meter takes longer than for an ‘actuator’ cylinder of 2.5 meter in diameter. The vertical axis of the plot is represented as depth over the diameter and the horizontal axis of the plot represented as inlet velocity over the downstream velocity. Additionally, for the actual Savonius turbine design, the velocity wake also takes a slightly longer time than the ‘actuator’ cylinder with a 2.5 meter diameter, which is expected. Therefore, the smaller the diameter of the turbine, the faster the velocity recovery. This highlights the importance of the real turbine design geometry for the arrangement of the devices in an array.
3.3 Validation between static and dynamic simulation of single stage Savonius turbine with 0.2 overlap ratio

Two types of simulations have been performed - static simulations in which there is no rotation on the turbine, and dynamic simulations in which there is a rotation on the Savonius turbine with a rotational speed of 7.5 rad/s. In both cases, the current velocity was set at 0.6 m/s. The study was conducted to see the difference in the velocity contour generated for both simulations. Figure 7 and Figure 8 show the velocity contour for static and dynamic simulations, respectively. Based on these figures, the static simulation of the turbine shows a longer velocity wake than the dynamic simulation’s velocity wake, and this observation is supported by Figure 9, which displays the velocity deficit experienced by both models. Therefore, from the results presented, we can see that the velocity recovery for dynamic simulation is faster compared to static simulation. This observation can be attributed to the turbine’s rotation, which is responsible for the dynamic simulation’s quick velocity recovery.

Figure 6. Velocity wake difference between ‘actuator’ cylinder with 5 m diameter by A. Bakri, ‘actuator’ cylinder with 2.5 m diameter and actual Savonius turbine design with 2.5 m diameter. (a) 5D, (b) 7D & (c) 9D.

Figure 7. Side view velocity wake for static simulation of single stage Savonius turbine with 0.2 overlap ratio.

Figure 8. Side view velocity wake for dynamic simulation of single stage Savonius turbine with 0.2 overlap ratio.
4.0 Conclusion

Based on the analysis that was conducted using ANSYS Fluent to study the velocity wake difference, the following points can be concluded:

- In terms of velocity recovery, the 2.5 meter diameter ‘actuator’ cylinder shows quicker wake recovery than the 5 meter diameter ‘actuator’ cylinder, which is expected.
- Due to its geometrical design, the actual Savonius turbine has a larger velocity drop than the 2.5 meter ‘actuator’ cylinder.
- The dynamic simulation of a single stage Savonius turbine with a 0.2 overlap ratio shows a faster recovery rate than the static simulation due to the rotation of the Savonius turbine.

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