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Development of Savonius Rotor Based on Bezier Curve for Vertical Axis Marine Current Turbine at Sunda Strait, Hindia Ocean

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Abstract. Due to its strategic location and ocean currents, the Sunda Strait has the potential to produce energy that might be used as a source of electricity. As a result, this strait area urgently needs a suitable turbine design. This strait's most significant sea current speed is 1 (one) m/s. The Savonius rotor is one of the rotor kinds of turbines that can operate in the slow sea current—modifying the rotor from semi-circular to use the Bezier curve for the shape to optimize the performance. This paper will discuss the design of the Savonius rotor using the Bezier curve, that have improved performance. The rotor with double stacking will also enhance the performance of the rotor. This design is a novelty for vertical marine current turbine applications in ocean renewable energy.

Introduction

With 17,805 islands and an estimated size of more than 5.4 million km2, Indonesia is an archipelagic nation with the second-longest coastline in the world, behind Canada, with a total length of 81,00 km. Naturally, given these circumstances, Indonesia is the nation with the largest potential for marine energy in the entire world.

Ocean energy is a source of power that is created using a variety of oceanic natural processes and methods and technologies that are constantly evolving. Because there are no CO2 emissions produced during the process of producing marine energy, it is a particularly eco-friendly and green energy source. Theoretically, the ocean has about 1.8 TW of energy, so given that the oceans cover 70% of the earth's surface, it becomes a significant enough source of energy. As a result, Indonesia has the biggest area of ocean, making it a country with a lot of marine energy.

Ocean currents known as tidal currents develop from tide movements brought on by the sun's and moon's gravitational pull. Ocean currents created by this movement have kinetic energy that can be utilised to turn the turbine's rotor. The generator is then linked to the turbine to allow it to produce power. This turbine can be built in a variety of locations and will be in the ocean.

Indonesia has a total potential of 61 GW, which includes tidal currents of 18 GW, sea waves of 2 GW, and OTEC of 41 GW, according to research findings from the Marine Geology Research and Development Center - Pusat Penelitian dan Pengembangan Geologi Kelautan (P3GL). The best opportunity to use these three energy sources is through ocean currents. This results from its predictable behavior, straightforward mechanical design, and offshore location, which insulates it from societal or population-related issues.

The energy of these tidal currents has been the subject of numerous studies on tides that have been carried out by various researchers. According to Orhan et al. (2016), the energy potential of the system at a present speed of 0.5 m/s is illustrated in Table 1 below. According to this table, the Alas Strait has 2.258 GW of electricity, whereas the Sunda Strait has 335 MW [1].

Introducing turbines in the Sunda Strait region will undoubtedly serve as a model for their use in other Indonesian straits. The Sunda Strait has the potential to concentrate on becoming a Vertical Axis Marine Current Turbine research pilot project because it is close to research facilities from the National Research and Innovation Agency - Badan Riset dan Inovasi Nasional (BRIN) or universities in Indonesia, as well as, of course, close to the center of government. The tide simulation for the Sunda Strait is depicted in Figure 1. According to this number, the marine currents' speed ranged from 0.4 to 1 m/s, indicating a low marine current situation [2].

Table 1. Tidal current energy map in the waters surrounding Indonesian territory [1]

Strait	Density Energy	Power Plant Energy	Total Energy
Bali	14.75	1,459	1,045
Larantuka	10.20	1,25	299
Boling	3.49	430	736
Alas	3.07	396	2,258
Lombok	2.36	236	865
Sunda	1.56	165	335
Badung	1.52	161	551

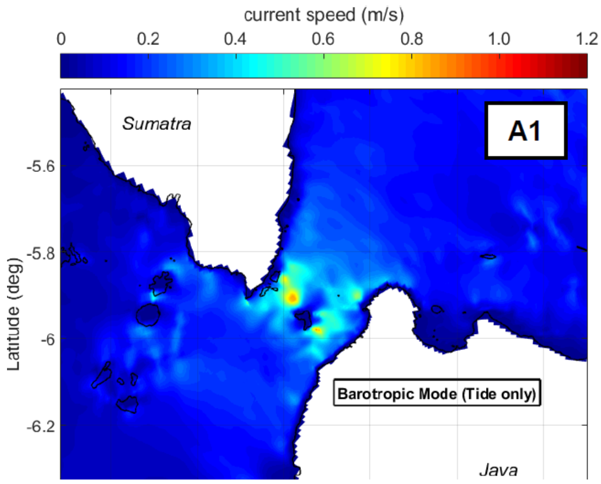

Fig. 1. Simulation Tidal current speed at Sunda Strait

Currently, the high potentioal to develope is Vertical Axis Marine Current Turbine (VAMCT). Suprayogi et al (2023) also briefly describes and classifies some of the most common VAMCTs being currently developed [3]. The type of VAMCT can run in low marine current is Savonius Turbine. This turbine have the rotor with Savonius type as wind energy power.

Savonius Turbine. The rotor of a Savonius turbine is rotated using the drag force principle. This particular model of wind turbine is quite well-known. This turbine was created in 1929 by S.J. Savonius, a Finnish engineer. It is a wind turbine powered by drag forces, and its two paddles are fixed in opposition to one another to its central shaft. By catching the wind and turning the shaft, each paddle propels the opposite paddle into the current. The shaft continues to rotate and completes a full rotation as this paddle then repeats the operation. The spinning shaft is used to drive a pump or a small generator throughout this operation, which continues as the wind blows. Despite the fact that typical maximum power coefficient values for other types of wind turbines range between 30% and 45%. The majority of researchers assert that the Savonius turbines are normally no greater than 25% [4].

Several types of Savonius rotors in the turbine have also been developed. First, the rotor used in the Pelton turbine or impulse turbine (not considering overlap ratio) and second, the type of Savonius with considering overlap ratio. The impulse turbine with Savonius rotor is quite interesting to develop; this rotor needs the inlet casing to increase the flow to be increased. Figure 2 shows the impulse turbine with the Savonius rotor. This type of turbine needs a casing to be suitable for the rivers (one direction) but is not appropriate for sea applications with many flow directions.

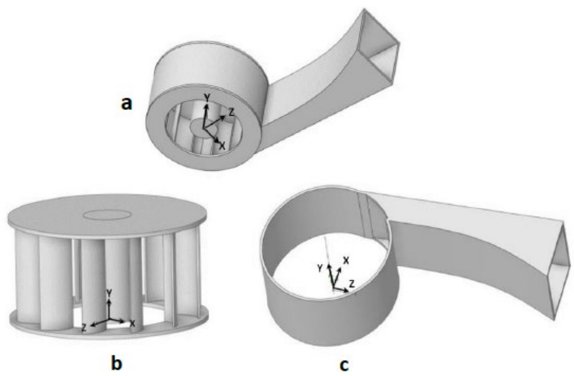

Fig. 2. The geometry of (a) turbine, (b) Savonius rotor, (c) casing [5]

Other type of the rotor, the Savonius with considering the overlap ratio, aspect ratio and also no need the casing. The ratio aspect of the rotor's height (H) to diameter (D) is a crucial factor in determining a Savonius rotor's aerodynamic performance. A high aspect ratio (α) number should significantly increase this effectiveness. For a typical Savonius rotor, coefficients of power about 4 tend to produce the greatest results [6]. Savonius rotor with single stacking is shown in Figure 3.

$$\alpha = \frac{H}{D}. \tag{1}$$

where:

α = Aspect ratio
H = Height of rotor
D = Diameter of rotor

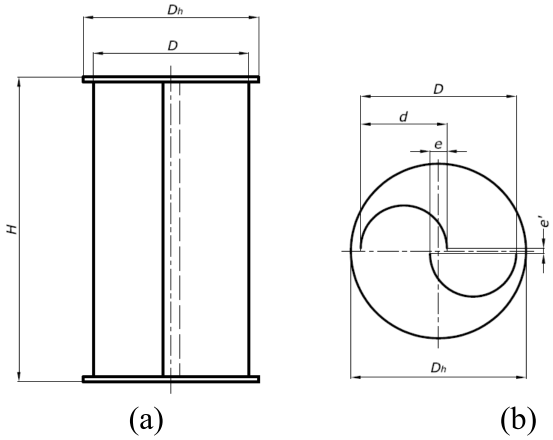

Fig. 3. Scheme of a single stacking Savonius rotor. (a) Front view; (b) Top view (conventional Savonius rotor : e'=0) [6]

Another parameter is overlap ratio β, which affects the overlap (e) and diameter of the paddle (d). Overlap ratio (β) is given by the following equation:

$$\beta = \frac{e}{d}. \tag{2}$$

Where:

β = Overlap ratio
e = Overlap between the paddle
d = Diameter of paddle

The best efficiencies were obtained for values of overlap ratio (β) between 0.20 and 0.30 [6]. Gupta [7] reported the maximum power coefficient in the overlap ratio of 0.20 – 0.25. In the previous design, the Savonius rotor use semi-circular that show in Figure 4.

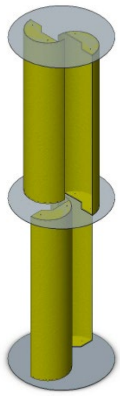

Fig. 4. Savonius rotor previous design

Discussion

The discussion will describe about the Bezier curve and also stacking rotor for Savonius turbine. Bezier curve is new trens shape of Savonius rotor that previously is used for wind energy application. This is will a novelty if use for Savonius rotor of marine current application (water) that have different with wind energy (air). The stacking of rotor also will be discussed to get improvement performance.

Bezier Curve. Future work could include developing a 3D Discrete Vortex Method solver, modeling airfoils using different curve methods like splines or Bezier curves, defining a boundary for airfoil coordinates optimization, using CFD as a solver to determine the power coefficient of a new wind turbine, and conducting experimental research on the ideal Savonius airfoil, among other things [8]. The blades are separated into two halves, and a novel technique for creating blade shapes is suggested in this paper [9]. Each blade is optimized independently using the six-control point method and a Bezier curve.

Savonius rotors are a type of vertical axis wind turbine that utilize drag forces to generate torque. Many studies have explored ways to improve the performance of these rotors. Putranto et al found that modifying the Savonius rotor to have an elliptic shape increased its static torque coefficient at low wind speeds [10]. Yoshida et al also found that modifying the Savonius rotor's blade shape, specifically giving it an elliptical curvature, improved its power coefficient [11].

Díaz et al computationally analyzed five different Savonius rotor designs and found the helical rotor to have the best power and torque coefficients, outperforming the traditional rotor by 20% [12]. Alit et al studied a multi-level Savonius rotor and found that its performance decreased as the angle between rotor levels increased. At an angle of 0°, the rotor reached a maximum rotation speed of 150.6 rpm at a wind speed of 5 m/s [13].

The modification of savonius rotor to improve the performance by use the Bezier curve. This application of this design for marine current vertical axis marine current turbine is a novelty that marine current is a regular phenomena of the sea. As well known that sea water have higher density compare with fresh water and air (wind turbine application).

Stacking of Savonius Rotor. Comparison between stacking of Savonius rotor also done by Suprayogi 2010 [14]. The reseach showed that the double stacking can generate higher average torque than single stacking. Beside that Nakajima (2008) showed that a "double-step" Savonius rotor with a more complex blade shape produced 10% higher power coefficient than a standard rotor [15]. Saha (2008) found that two- and three-stage rotors produced higher power output than single-stage rotors [16].

As above discussion, Bezier Curve is the method to make curve tahat can apply for Savonius rotor. The previous rotor of Savonius is semicircular that change using Bezier Curve. This curve can improve the performace of the Savonius rotor due to considering airfoil shape and also torque value higher that semi circular shape. The Bezier curve will have longer distance between the center of rotor and highest point of shape compare with semicircular shape. Thus, the torque will higher compare with semicircular shape.

Based on above discussion the Savonius rotor with two stacking will have higher performance that singgle stacking. With use the the Bezier curve on the paddle this will make improvement of the performance. Figure 5 show the Savonius rotor use Bezier curve on the paddle and two stacking to get improvement of the rotor for vertical marine current turbine.

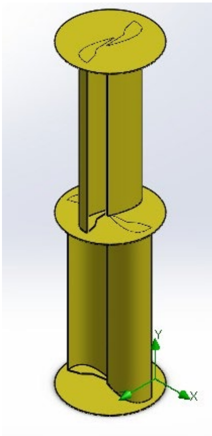

Fig. 5. Savonius rotor using Bezier curve with double stacking

Summary

As discussion above the Savonius rotor using Bezier curve and have double stacking have improvement performance compare with semi circular and single stacking. This rotor also can be used for marine current application that this is a new development for ocean renewable energy. In summary, optimizing the Savonius rotor through experimentation and computation has led to major performance improvements.

Acknowledgement

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