Design, prototyping, and experiment of the ocean current power generation system using Bach Savonius rotor

Yusiran1, Erwin1, Lazuardi1
1Department of Physic, Faculty of Mathematical and Science, Riau University, Pekanbaru, Indonesia
E-mail: yusiran123@gmail.com

Abstract. Design, prototyping, and experiment of ocean current power generation system have been carried out using the Bach Savonius rotor. The introduced ocean current power generation prototype is validated on real measurement obtained in the Rupat Strait, Indonesia. In this research, the influence of the velocity of ocean currents, the number of turbine blades, and the blade arc angle of the generator output power are studied. The results showed that the turbine output power is strongly influenced by the velocity of ocean currents where the velocity values of ocean currents varied in the range 0.63-1.98 m/sec. The maximum electrical power of the turbine occurs at a current velocity of 1.98 m/sec of 26.88 Watts. The number of turbine blades has a significant effect on turbine output power. The turbine reaches maximum power is found in the rotor with a number of 3 blades with a power coefficient of 0.1176 on the tip speed ratio of 0.359. The blade arc angle is varied at angles of 90˚, 135˚ and 165˚. The blade arc angle 135˚ gives the best performance with a power coefficient of 0.102 on the tip speed ratio of 0.298.

1. Introduction
Ocean current energy is one of the interesting renewable energy resources to develop because it has several advantages, which are predictable, scalable and have no visual impact [1]. Ocean’s current exploration near the coast is not a new idea. The application of ocean current energy resources has been started since 1966 in France [2]. The process of converting the kinetic energy of ocean currents into electrical energy can be done using vertical axis ocean current turbines and horizontal axis ocean current turbines. Although the energy source of ocean currents is more promising, the problem that arises in the process of applying ocean current power generation technology is the high cost of making and installing tools. The cause of the increase in the cost of making and installing tools is limited accessibility and underwater work. To solve these problems, researchers have proposed a variety of concepts. Gorlov designed a helical turbine that was able to harness ocean current energy at low velocity without dam construction. This concept is offered in order to reduce environmental damage due to dam construction which damages ecosystems in the region and reduces the cost of power plants [3]. Another type of turbine developed by Marine Current Turbine Ltd is a kobold turbine mounted under afloat [4]. The research mentioned above is some practical effort to reduce investment costs for ocean currents. However, the cost constraints have not been completed with the development of both types of gorlov and kobold turbines, the reason being that the turbine manufacturing process is

1Corresponding author : yusiran123@gmail.com
complicated and still costs quite a lot. There is one type of turbine that is easy to make, cheaper and can work at low fluid flow speeds, called the Savonius turbine. Savonius turbine are usually composed of two curved blades with a flow passage around the center. In the original design, each blade shows a semicircular shape [5]. Savonius turbine still has a disadvantage, the turbine efficiency is still very low. The researchers sought to correct this weakness by optimizing turbine parameters. Only a few researchers have used a type of conventional Savonius turbine to be applied as a water flow turbine. Hassanzadeh conducted an experimental study to create a new configuration of ocean current turbines using conventional Savonius turbines [6].

To obtain a significant performance improvement, the author worked to design and conduct an experimental study of Savonius turbine power generation using the Bach Savonius rotor and study the influence number of turbine blades and blade arc angle of power generation system performance. The experiment was designed to allow measurements of ocean current velocity and operational variables to determine the electrical power output, coefficients of performance and dynamic torque.

2. Theory

2.1. Rotor Geometry
Bach is one of the second common profiles used in the Savonius rotor which was submitted by Bach six years after the conventional profile. Bach replaces a semicircular profile with a Bach profile consisting of a straight line and an arc. Figure 1 shows the geometry of the Savonius Bach rotor.

2.2. Mathematical Formulation
The power generated by ocean currents is calculated using equation 1 [7];

\[ P_T = \frac{1}{2} \rho A V_T^3 \]  

\( P_T \) is the power produced by ocean currents, \( \rho \) is the density of seawater (1.025 kg/m\(^3\)), \( A \) is sweep area and \( V_T \) is the velocity of ocean currents (m/sec).

The power extracted by the Savonius turbine from the free flow of the seawater can be calculated by using equation 2 [8];

\[ P_M = T \cdot \omega \]  

(2)
Where \( T \) is torque (N-m) generated by the turbine and \( \omega \) is the rotational speed (rad/sec) of the turbine. In order to evaluate how much energy is used by the turbine from the free stream flow, the term TSR is defined. It relates free stream velocity with the speed at the blade tip and is expressed as [10]

\[
TSR = \frac{\omega R}{V_T} \tag{3}
\]

The performance of the turbine is expressed non-dimensionally by using the term coefficient of power \( Cp \). It is defined as the ratio of power extracted by the turbine, \( P_M \) (W) with respect to the maximum energy, \( P_T \) (W) of the free stream flow and is expressed as [11];

\[
Cp = \frac{P_M}{P_T} \tag{4}
\]

3. Experimental Methodology

An experimental study was conducted to test real ocean current power system models under real operating conditions. The purpose of the experimental approach is to determine the performance of Bach-rotor.

3.1. Design Concept of the Model

The model of ocean current power generation system using the Bach Savonius turbine is shown in figure 2. As shown in figure 3 the ocean current power system is equipped with a float, gearbox, rotor, gearbox, bearing and shaft. The specification of the prototype showns in table 1.

![Figure 1. The model of ocean current power generation system.](image)

| Table 1 | Spesification of prototype ocean current power generation system using Bach-rotor. |
|---------|----------------------------------------------------------------------------------|
| Rated power | 65 Watt |
| Floating support dimensions | |
| Lenght | 2,2 m |
| Width | 1,2 m |
| High | 0,5 m |
| Generator rated power | 200 Watt |
3.2. Fabrication
The blades of the Bach rotor models were fabricated from 2 mm aluminum sheets due to good manufacturability. To bend the aluminum sheets to design profiles using a bending machine. The experiment was used Bach Savonius rotor with two, three and four-blades. The blade arc angle for investigating the performance of Bach-rotor with the various number of the blade is 135°. Bach Savonius rotor shown in figure 2 and Blade arc angle of the Bach-rotor shown in figure 3. The blade arc angle varied in angles 90°, 135° and 165° with the number of blades keeps in two blades.

| Gearbox ratio      | 1:12 |
|--------------------|------|
| Turbine Materials  | Alumunium |
| Thickness          | 2 mm |
| Diameters          | 0.6 m |
| High               | 0.5 m |
| Aspect Ratio       | 0.8  |

3.3. Experimental Set-Up
The experiment setup, as shown in figure 3, was used to test the ocean power generation system models. The free mainstream of ocean current velocity was measured using the current meter. The rotating speed of the rotors at specific ocean velocity was measured using a digital laser tachometer. A DC Generator was used for electrical power output and dynamic torque. To measure the electric current, a 20-ohm resistor was connected to the maximum output current. In this study, the Rupat Strait was chosen as a potential site for the turbine. The mean velocity of Rupat strait is 1.42 m/s.

Figure 2. Bach Savonius rotor
Figure 3. Blade arc angle at Bach Savonius rotor
Figure 4. Schematic setup for the experiment of ocean power generation using Bach-rotor in the sea current.

4. Result and Discussion
Figure 5 shows the prototype. The prototype was tested in Rupat Strait, Riau Province, Indonesia. The real values of ocean current velocity in the Rupat Strait shown in figure 6.

Figure 5. Prototype testing in Rupat Strait, Indonesia

Figure 6. Real data ocean current velocity in Rupat Strait
As shown in figure 6 it can be seen that ocean current velocity in Rupat Strait has a lunar semidiurnal tidal constituent. The maximum velocity of ocean current in the Strait is 2.02 m/s and the minimum velocity is 0.1 m/s. This appears to be rather a slow velocity, but it is sufficient for generating electricity because the density of water is 830 times higher than the density of air. The present work focuses on studying the electrical power output at various ocean current velocity, the number of blade and blade arc angle of Bach Savonius rotor.

4.1. Effect of Ocean Current Velocity

To investigate the efficiency of the turbine, three blades Bach rotor was chosen in this discussion. Figure 6 shows the electrical power.

![Figure 6. The electrical power output of Bach-rotor](image)

The power extracted by Bach-rotor increases with the increase of ocean current velocity. Turbine power is a function of the ocean current velocity, it is suitable with equation 1. In this study, the author was designed the rated electrical power approach at 65 Watts, but in the experiment result in only 26.88 Watts. The variations of turbine rotational speed versus ocean current velocity for three blades Bach- rotor presented in figure 7. As can be seen in figure 7, the rotational speed of the turbine increases with increases in ocean current velocity.

![Figure 7. Measured turbine rotational speed for three blades turbine](image)
4.2. Effect of Number of Blades

Figure 7 shows variation in electrical power with ocean current velocity for investigated rotors performance. The three blades gives high electrical output power compared to two and four blades rotors. The maximum can be reaches of three blades Bach-rotor is 26.88 Watt at ocean current velocity 1.98 m/s.

The number of blade has an impact on the hydrodinamic performance of the Bach-rotor, which can observed from Table 2. It shows that a low speed ratio, where ocean current velocity 1.42 m/s and the swept area 0.3 m², the three blade has good performance because the Cp on this turbine is higher than other. According to table 2, rotor with three blade have coefficient of performance 0.1176 on TSR0.359.

Table 2. The results of the calculation of dynamic torque, TSR, and the coefficient of turbine power with the variation in the number of blades.

| n  | Ocean Velocity (m/s) | $\omega$ (rad/s) | Torque (N-m) | TSR  | $C_p$  |
|----|----------------------|------------------|--------------|------|--------|
| 2  | 1.42                 | 1.421            | 33.25        | 0.325| 0.1073 |
| 3  | 1.42                 | 1.539            | 33.68        | 0.359| 0.1176 |
| 4  | 1.42                 | 1.331            | 29.43        | 0.281| 0.0668 |

4.3. Effect of Blade Arc Angle

Effect of blade arc angles is studied here for 90°, 135° and 165° angles. Figure 8 shows the relation between electrical power and ocean current velocity for 90°, 135° and 165° blade arc angles arrangement with the number of two blades. The electrical power for 135° is higher than electrical power obtained for 90° and 165° blade arc angles. This may be due to the 90° blade arc angle is much shorter and straighter created high negative torque in returning blades. The increase of blade arc angle up to 135° makes an effect of obstruction come into play. Thus the Bach-rotor design is optimized at 135° blade arc angles.
5. Conclusions
In the present study, the performance of the ocean current power generation system using Bach-rotor was evaluated experimentally. The performance of the ocean current power system was also experimentally compared to the Bach-rotor with a varied number of blade and blade arc angles. From the study, the following conclusions can be summarized; The electrical power and rotational speed of the turbine increase with increases ocean current velocity, which is maximum for velocity 1.98 m/s. Three blades of Bach Savonius turbine give the best performance with the coefficient of performance 0.11 at a tip speed ratio 0.359. Blade arc angle influences turbine performance. The angle of the arc blades giving the best performance is at a value of 135˚ which can reach a maximum power of 23.06 Watt and a maximum power coefficient value of 0.102 at a tip speed ratio value of 0.298.

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