ASSESSEMENT OF TIDAL ENERGY RESOURCES IN BALI STRAIT

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Abstrak

The ocean possesses advantages as a sustainable and predictable source of energy, with tidal energy being one such marine-derived energy source. This study examines the analysis of ocean energy potential in the study location of the Bali Strait. The analysis of tidal energy potential follows the guidelines of the European Marine Energy Center (EMEC) and employs numerical modeling to identify current velocities using Delft3D. This study investigates the influence of water depth columns to determine the optimal depth for the placement of energy conversion technologies. It is found that the highest current velocities occur in the strait's narrowed section. Furthermore, from the analysis of tidal energy potential, it is determined that upper water depth columns (9 m, 19 m, and 26 m) can generate twice as much energy as the lower water depth columns (40 m and 45 m).

Keywords: Tidal current, renewable energy, resource assessment, Bali Strait, Indonesia.

INTRODUCTION

Indonesia is an archipelagic nation comprising scattered islands, posing a unique challenge for meeting electricity needs, particularly in remote small islands. It is hoped that marine energy, especially tidal currents, can serve as an alternative and renewable energy source for these small islands. Tidal currents possess both kinetic and potential energy that can be harnessed to rotate turbines. Kinetic energy is associated with the speed of the currents, while potential energy is linked to elevation and tidal fluctuations. To harness ocean current energy, thorough studies are necessary, for instance, research related to selecting the optimal location for siting ocean current turbines and the development of the ocean current turbines themselves [1].

Several researchers have conducted comprehensive studies regarding the potential of ocean current energy and its conversion technologies, employing both numerical and experimental approaches. Novico et al. [2] conducted an analysis of the ocean current energy potential in the Patinti Strait based on numerical simulations, but the energy assessment method used did not depict the detailed potential of the contained ocean current energy. Hwang et al. [3] performed an analysis of ocean current energy sources in Korea based on observational data and numerical simulations, yet the energy assessment followed wind energy assessment calculation methods, thereby lacking a detailed portrayal of ocean current energy characteristics. Hadju [4] conducted a study related to the analysis of ocean current energy potential in the Madura Strait based on historical data taken with a direct procedure converting current speed into power based on empirical formulas. However, this method lacks accuracy in analyzing ocean energy potential as the formula relies on specific technologies. Orhan et al. [5] conducted an analysis of ocean current energy potential in the Larantuka Strait using numerical modeling and subsequently illustrated the output in spatial form.

Drawing from the outlined background and preceding research, this study establishes a procedural framework for analyzing the potential of ocean current energy based on the guidelines of the European Marine Energy Center (EMEC) Assessment of Tidal Energy Resource module [6]. The study site chosen for this investigation is the Bali Strait. The modeling of ocean currents involves the utilization of Delft3D to identify locations characterized by maximum current velocities. Following the identification of these sites with potential ocean current energy, an in-depth study is conducted to ascertain the optimal seabed depth for the deployment of marine energy conversion technologies. This research approach adheres to the EMEC guidelines and contributes to a methodical examination of ocean current energy potential within the specific context of the Bali Strait.

RESEARCH METHODS

Case Study

This research is conducted in the Bali Strait, which connects the islands of Java and Bali. The strait has a width ranging from approximately 2.4 km at its narrowest point to 82 km at its widest location. Figure 1 illustrates the study area where the analysis will be carried out.

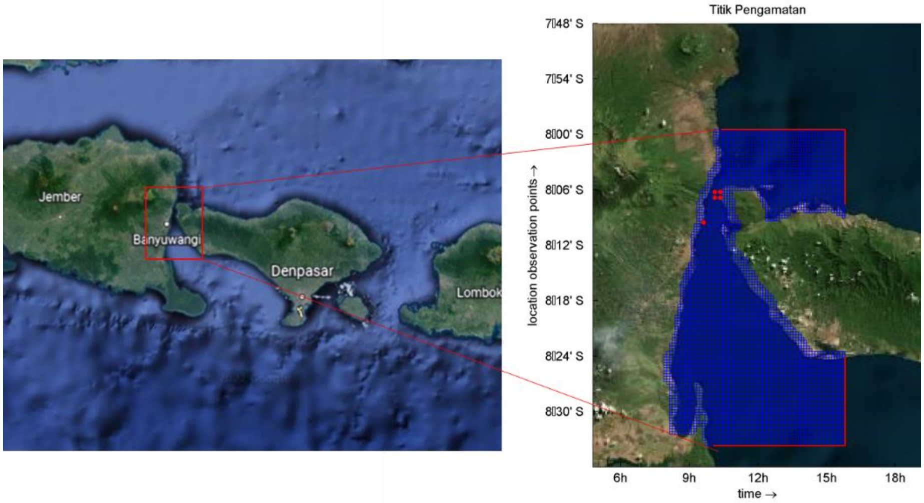


Figure 1. Study area, Bali Strait.

Bathymetric data were acquired from the GEBCO 30 arc-second global grid of elevations (GEBCO_2014 Grid), generated directly through the Delft Dashboard. The bathymetric details of the study area can be observed in Figure 2. Based on the available data, it is evident that the average elevation of the Bali Strait is approximately 50 meters.

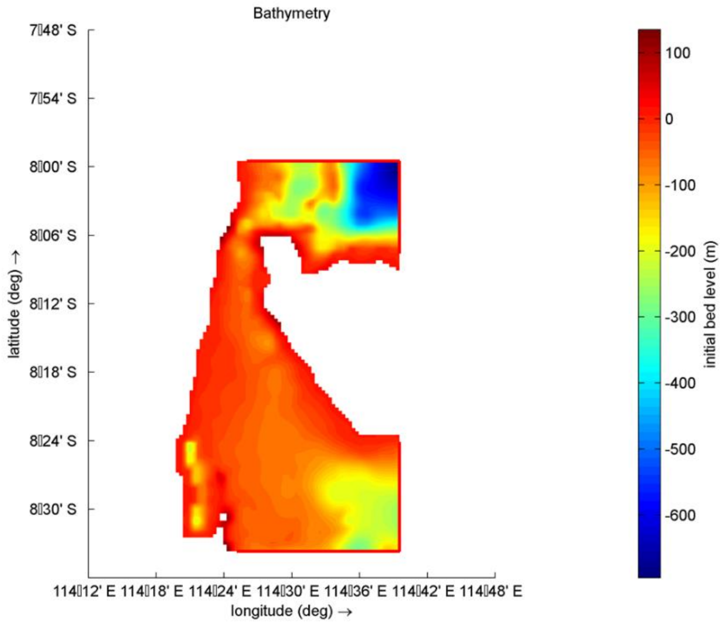


Figure 2. Bathymetry of the Bali Strait study location.

The simulation and modeling of tides and ocean currents were performed using the Delft3D software. The input parameters for the software included bathymetric data, and tidal astronomical data were obtained from the TPXO Indian Ocean Atlas (1/12° regional model) with 11 harmonic constituents (M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4, MN4), directly generated through the Delft3D dashboard. The research utilized a grid boundary of 300 meters, and the open boundary of the model was situated to the north, south, and east in the maritime region. Several observation points were strategically selected for the purpose of validation and the identification of current velocities. The grid, open boundary, and observation points are depicted in Figure 3.

For the validation of tidal data, the Ketapang Station data from the Badan Informasi Geospasial (BIG) database was utilized. The modeling was conducted over a duration of one month in September 2021. Observation point 1 was specifically designated as a representative for validation against BIG data. Meanwhile, observation points 2, 3, 4, and 5 were employed for the identification of potential ocean current velocities. Figure 4 illustrates the tidal elevation derived from the BIG tidal data, the modeling results, and the identification of spring tide and neap tide timings in the Bali Strait.

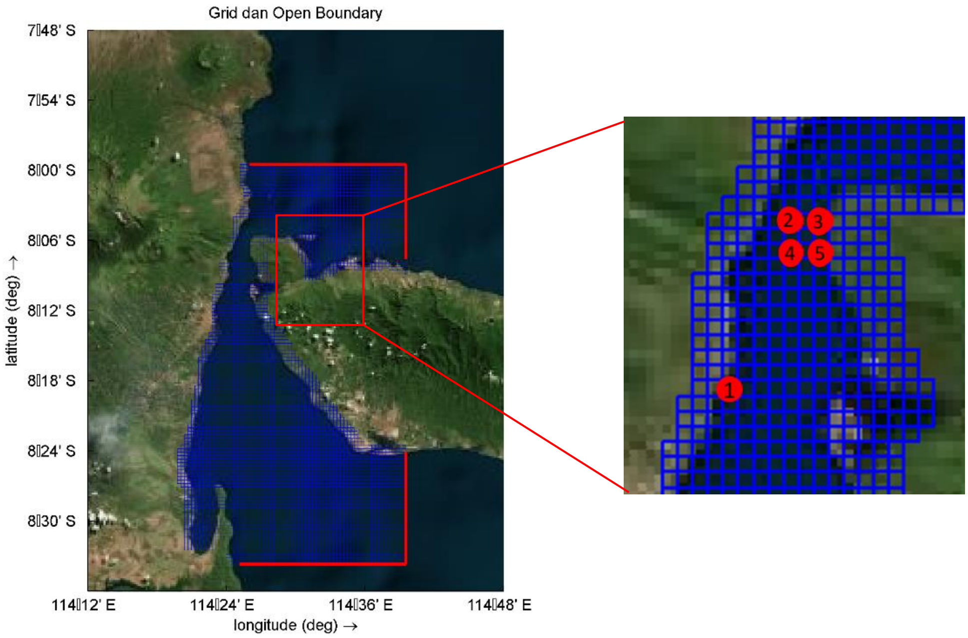


Figure 3. Grid, open boundary, and observation point model of the Bali Strait.

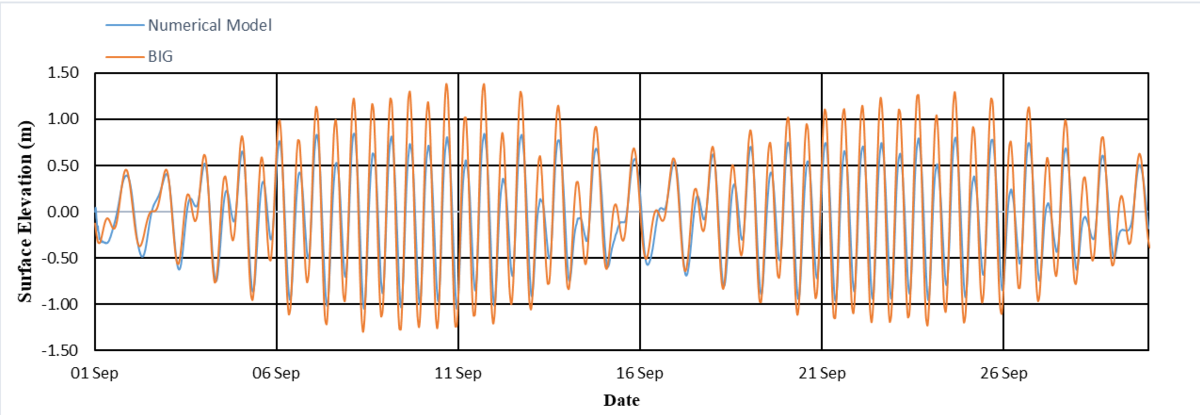


Figure 4. Water level comparison between BIG and model simulation results

From Figure 4, the type and state of the tide in the Bali Strait can be determined to identify the times when the current velocity reaches its maximum, both during spring tide and neap tide. The tidal pattern in the Bali Strait is identified as semi-diurnal tide. The times of spring tide in September 2021 were observed on the 9th-11th and 24th-25th, while neap tide occurred on the 16th-18th.

Assessment of Tidal Energy Resource

This research adheres to the guidelines of the European Marine Energy Center (EMEC) module on the Assessment of Tidal Energy Resources. EMEC provides a step-by-step explanation of the analysis of tidal energy potential, depending on the stage of energy assessment. In this study, the focus is limited to following stage 1 of the guidelines, which involves regional assessment. The objective is to screen locations for the potential of tidal energy, with the Bali Strait being the case study area.

The tidal energy conversion technology for the assessment has not been determined yet, so generic data from the European Marine Energy Centre (EMEC) guidelines is utilized. The rotor diameter chosen is 25 m. The consideration for selecting a diameter less than 14 m is neglected due to the cost-effectiveness ratio, where production costs are significantly higher compared to electricity generation. On the other hand, rotors with diameters exceeding 25 m require high lift forces due to the high mass flow and low velocity of water particles. This may lead to rotor blade bending, especially for rotors with larger blade diameters. With a rotor efficiency of 38% at the cut-in speed, increasing to 45% at the rated velocity, the rated velocity is set at 71% of the Vmsp. The cut-in velocity used for the technology to operate is 0.5 m/s [6].

In conducting the analysis of the potential energy of ocean currents, the calculation proceeds through the following stages. The available Average Power Density (APD) passing through the surface area where the conversion technology will be installed can be computed using Equation 1, where Nb represents the total number of bins, and i is the bin number.

$$APD = \frac{1}{2}\rho \sum_{i=1}^{Nb}\left(Ui^3 f(Ui)\right) = \frac{1}{2}\rho V_{rmc}{}^{3} \quad (kW/m^2) \tag{1}$$

Ui represents the midpoint value of the bin count, and Vrmc is the root mean cube velocity, which can be calculated using Equation 2.

$$V_{emc} = \sqrt[3]{\sum_{i=1}^{NB}\left(Ui^3 f(Ui)\right)} \quad \left({}^{m}/_{s}\right) \tag{2}$$

To obtain the electrical power for each velocity bin, it can be calculated using the following Equation 3 below.

$$P(Ui) = P_{Av}(i)\eta_R \quad (W) \tag{3}$$

With ηR representing the rotor efficiency and PAV being the available energy in the sea, which can be calculated using Equation 4 below.

$$P_{AV}(i) = 0.5\, \rho\, A\, U_i^{\,3} \quad (W) \tag{4}$$

To obtain the mean annual electrical power, it can be calculated using Equation 5 below, where f(Ui) represents the distribution of the occurrence rate for each velocity bin.

$$P_{mean} = \sum_{i=1}^{NB} P(Ui).f(Ui) \quad (W) \tag{5}$$

Lastly, to determine the Annual Energy Production (AEP), it can be calculated using Equation 6 as follows, where Av is the availability of extractable energy.

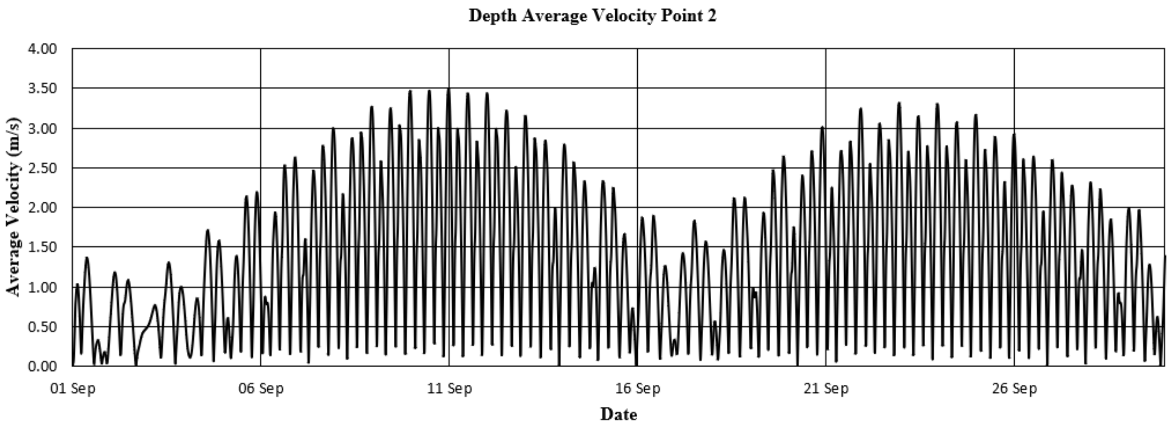
$$AEP = 8760.A_v.P_{mean} \quad (kWh) \tag{6}$$

RESULTS AND DISCUSSION

Tidal Current

The tidal current data was obtained through modeling. The modeling was conducted for a duration of one month in September 2021 at the study location. Figure 5 illustrates the data of average current velocities for each observation point. It was observed that the highest current velocities at each point were attained during spring tide conditions.

Points 2 and 3 represent locations where the tidal current velocity reaches its highest point, reaching 3.5 m/s. The increase in current velocity is attributed to the narrowing of the sea cross-sectional area. Figure 6 provides a visualization of the tidal current velocities in the Bali Strait when reaching their peak speeds. Subsequently, an assessment of the potential marine current energy is conducted at observation point 2, which will be divided into several columns of sea depth to determine the depth with optimal tidal current velocities.



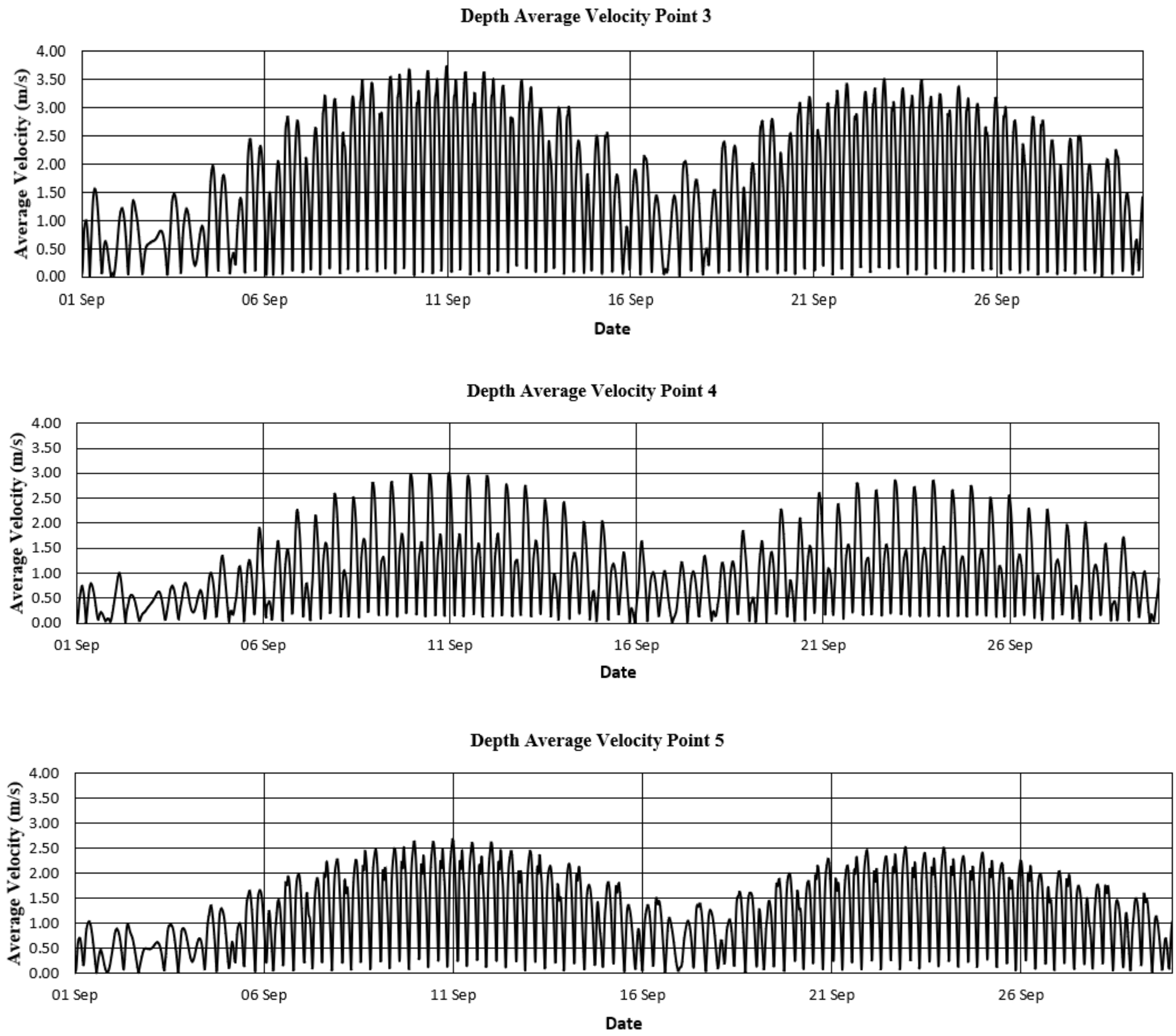


Figure 5. Average current velocities of the Bali Strait observation points 2, 3, 4, and 5.

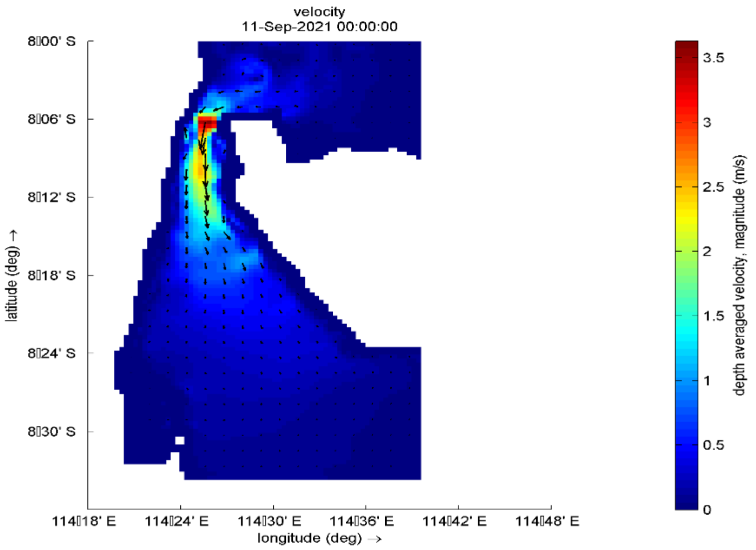


Figure 6. Visualization of the average current velocities of the Bali Strait.

Current Velocity Distribution

A histogram analysis was conducted using existing time intervals with a bin size of 0.1 m/s to obtain the percentage of time when the velocity falls within each bin. The percentage distribution of velocity data for each depth column is depicted in Figure 7.

Figure 7 illustrates the percentage distribution of tidal current velocity for several depth columns. Subsequently, data from depths of 9 meters and 45 meters will be utilized to depict the current velocity in the surface column and the column near the seabed. The maximum velocity obtained at a depth of 9 meters is 3.5 m/s, while at a depth of 45 meters, it is 2.9 m/s.

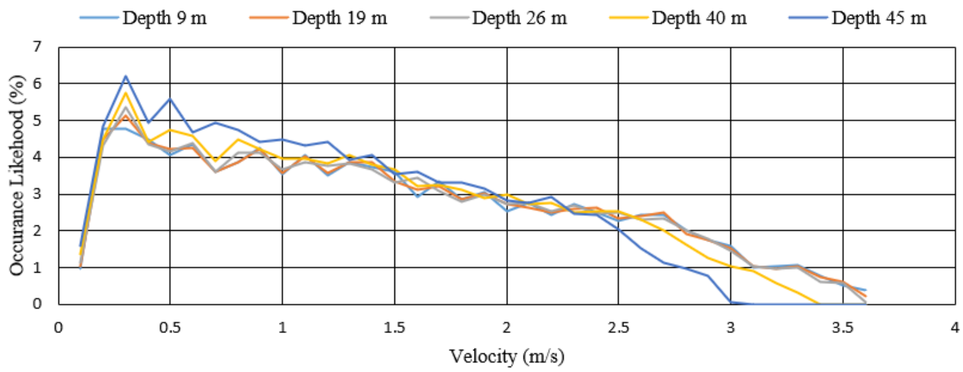


Figure 7. Velocity distribution curves for each depth column.

Power Density

From the available data, the power density at the evaluated location is calculated. This power density is used to compute the total power contained within the cross-sectional area of the flow or power flux. The Average Power Density (APD) available across the surface area where the conversion technology will be installed can be calculated using Equations 1 and 2. Consequently, the APD at depths of 9 meters and 45 meters is determined, as presented in Table 1.

Table 1. Average Power Density (APD)

Depth (m)	V_{rmc} (m/s)	Density (kg/m^3)	APD (kW/m^2)
9	6.47	1025	139.07
45	3.67	1025	25.41

Power Curve

After estimating the velocity distribution at the selected location, the energy output can be calculated based on the power curve of the technology applied at the chosen site. The electrical power per bin can be computed using Equations 3 and 4. Table 2 summarizes the calculations of electrical power, P(Ui), for each velocity bin. From the modeling results, the maximum current velocities during spring tide, Vmsp, are 3.5 m/s at a depth of 9 meters and 2.9 m/s at a depth of 45 meters. Applying the explanation regarding the rated velocity for the Bali Strait, the rated velocity is determined to be 2.5 m/s at a depth of 9 meters and 2 m/s at a depth of 45 meters. Above these values, the electrical power remains constant. Following generic rotor diameter data used in this case (25 m), the swept area (A) is determined to be 491 m².

From Table 2, a curve depicting the relationship between energy and current velocity can be generated, illustrating the available marine energy potential and the corresponding output energy, as shown in Figure 8. From Figure 8, it is apparent that the output energy generated at a depth of 9 meters is greater than the output power at a depth of 45 meters. Additionally, the cut-out energy limit based on generic energy conversion technology data reaches 1769 kW at a depth of 9 meters and 906 kW at a depth of 45 meters.

Table 2. Electrical power per bin

Avrg Bin velocity	Available Power	Depth 9 m		Depth 45 m	
		Rotor Efficiency	Electrical Power per Bin	Rotor Efficiency	Electrical Power per Bin

Ui	$P_{av}(i)$	ηR	P(ui)	ηR	P(ui)
m/s	kW	%	kW	%	kW
0.1	0.25	0	0	0	0
0,2	2.01	0	0	0	0
0.3	6.79	0	0	0	0
0.4	16.10	0	0	0	0
0.5	31.44	38	12	38	12
….	…	…	…	…	…
3.2	8243.53	x	1769	x	906
3.3	9040.77	x	1769	x	906
3.4	9887.81	x	1769	x	906
3.5	10786.18	x	1769	x	906
3.6	11737.38	x	1769	x	906

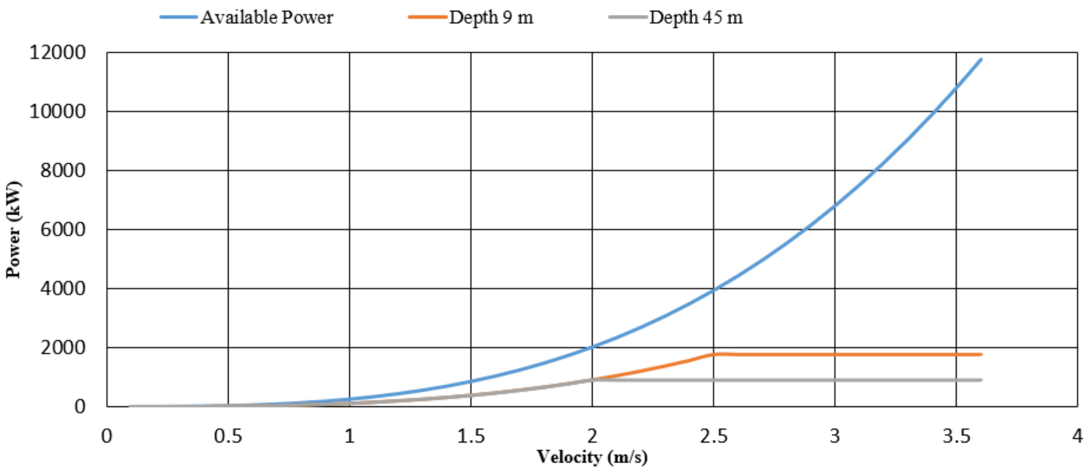


Figure 8. Electrical power curve

Mean Electrical Power

The mean electrical power (Pmean) is obtained by combining the velocity distribution f(Ui) with the average power absorbed for each velocity bin P(Ui). The mean electrical power can be calculated using Equation 5. Table 3 summarizes the calculations of mean electrical power, resulting in mean electrical power values of 488.35 kW and 204.98 kW for depth columns 9 m and 45 m, respectively.

Table 3. Mean electrical power

Avrg Bin velocity	Depth 9 m			Depeth 45 m		
	Velocity Occurance	Electrical Power per Bin	Mean annual electrical power per bin	Velocity Occurance	Electrical Power per Bin	Mean annual electrical power per bin
Ui m/s	f(Ui) %	P(ui) kW	f(Ui) x P(ui) kW	f(Ui) %	P(ui) kW	f(Ui) x P(ui) kW
0.1	0.96	0	0	1.60	0	0
0,2	4.77	0	0	4.84	0	0
0.3	4.77	0	0	6.20	0	0

0.4	4.50	0	0	4.93	0	0
0.5	4.07	12	0.48	5.58	12	0.66
….	…	…	…	…	…	…
3.2	1.03	1769	18.21	0	906	0
3.3	1.08	1769	19.06	0	906	0
3.4	0.79	1769	13.97	0	906	0
3.5	0.53	1769	9.31	0	906	0
3.6	0.38	1769	6.77	0	906	0
		Pmean	488.35 kW	Pmean		204.98 kW

Annual Energy Production

The Annual Energy Production (AEP) can be calculated by multiplying the previously calculated Pmean by the number of hours in one year, as shown in Equation 6. Assuming Av is 100%, the annual energy production for the two different depth columns is obtained as follows: AEP = 5,248,877.71 kWh for the 9 m depth column and AEP = 2,865,857.67 kWh for the 45 m depth column.

CONCLUSION

This study examines the theoretical potential of tidal energy with a case study in the Bali Strait. Several observation points were selected for analysis to identify potential locations for energy conversion technology placement. The assessment of energy potential was then carried out at the designated points, with analyses conducted at the upper water column represented at a depth of 9 m, and the lower water column represented at a depth of 45 m.

The maximum current velocity in the Bali Strait occurs at points 2 and 3, where the sea cross-section narrows, leading to an increase in current velocity, particularly during spring tide conditions. From the analysis of the histogram distribution of current velocity occurrence rates in the water columns at depths of 9 m, 19 m, and 26 m, a nearly identical distribution is observed. However, in the water columns at depths of 40 m and 45 m, the current velocity distribution is below average.

From the energy curve analysis, the cut-off values for energy with generic energy conversion technology data are determined to be 1769 kW at a depth of 9 m and 906 kW at a depth of 45 m. Subsequently, the annual energy production at a depth of 9 m is found to be twice as large as that at a depth of 45 m. Therefore, it is concluded that the optimal placement for tidal energy conversion technology at the study location is in the upper water column (9 m, 19 m, and 26 m).

In this study, energy conversion technology utilizes generic data based on guidelines from EMEC, emphasizing the need for a study related to specific energy conversion technology suitable for installation at the study location. Data, along with modeling over a longer time period, is also required to identify marine conditions more accurately.

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