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# Estimation of Potential Energy Generated From Tidal Stream in Different Depth Layer at East Flores Waters Measured by ADCP

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**Abstract.** Tidal works on the currents occur in each layer with significant variations. Variations of types of tidal media are very appropriate to the phase of the tides. Measurement of currents in each layer is necessary to assess the potential that can be used in determining and studying the placement of energy sources as a source of energy to support renewable energy in East Flores. A 15 day measurement with the Acoustic Doppler Current Profile (ADCP) instrument can record the speed profile in the study area which has tidal current variabilities and power density variations in the vertical current profiles. The analysis showed that there were two layers of depth with very optimum potential energy: at  $-3.5 - -5.5$  meters with the highest speed of tidal current  $3.69\text{m/s}$  and  $-7.5 - -9.5$  meters with the highest speed of tidal current  $3.68\text{m/s}$  from the Lowest Astronomical Tide (LAT). Each layer has different character, the upper layer has a maximum-high kinetic power density of  $25.71\text{ kW/m}^2$  at layer 10 and  $25.43\text{ kW/m}^2$  at layer 9 and the bottom layer had an average kinetic power density of  $11.64\text{ kW/m}^2$ . This bottom layer had the potential with a lower capacity, it shows that this site is also applicable for seabed mounted tidal turbines.

## 1. Introduction

Renewable energy has become the reasonable option to succeed the human dependence on the fossil energy since fossil energy has a negative impact on the human environment. Electricity from non-conventional resources are of global importance as a strategy to mitigate the effects of climate change caused fossil energy impact and to ensure energy security that sustainable in the coming century. Exploration of new energy resources utilization is required to fix the energy needs and problem. For example optimizing, the Indonesia government through the Presidential Decree No 79 has set a target of 23% renewable energy utilization by 2020, and 31% by 2050 [1], and then according to the decree Indonesia's commitment to increase use of renewable energy resources set a target of 31% by 2050 [1]. From this regulation, the new energy resources come from ocean, such as ocean wave, ocean current and tidal energy. As the archipelagic morphology with area consists of approximately 70%



waters, energy resources from the ocean such as current, tidal, wave and ocean thermal is an appealing option, besides that ocean is one of the most promising energy resources in Indonesia area. Tidal stream energy is the most favorable ocean renewable energy source according to the physical oceanography characteristics in Indonesia waters. Tidal works on the currents in each layer with significant variations [2]. Variations of types of tidal media are very appropriate to the phase of the tides, this is also commonly referred to as vertical velocity profile. Tidal current profile at different layers are made up of a complex interaction cause lateral friction of different layer of stream, wind-driven surface wave, the bottom boundary layer and turbulent eddies, operating over varying time and length scales. Estimation of potential tidal-stream energy at different depth layer need to be characterised so that resilient, and improving efficiency turbines works.

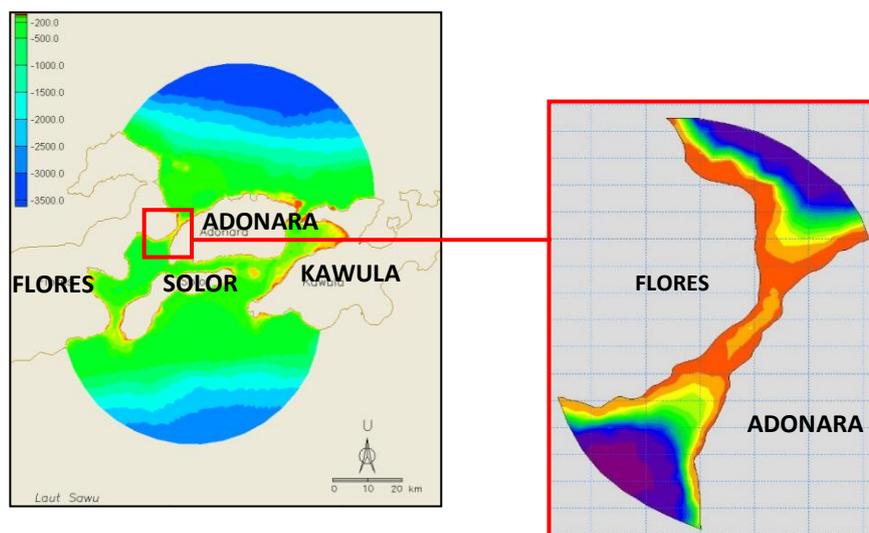
To be more efficient and more optimizing, tidal stream turbine is being positioned in right depth layer place. The incorrect placement of tidal turbine devices due to no calculation of the vertical current profile will result in a non-optimal power density. As we know, friction from the results in reducing tidal velocity near to the seabed. Surface waves can have significant mean velocity profile in waters [3]. Therefore, characterizing the velocity profile [4] and calculating the estimation of power density produced at each layer of depth in the waters affected by tides [5] are essential.

Acoustic Doppler Current Profiler (ADCP) is the instrument using eulerian method and acoustic for measurement velocity profile of current. In addition it is more efficient instrument for tidal stream characterization and energy resource quantification [5]. In the recent studies, [4] velocity profiles were recorded at Larantuka Strait to collect potential tidal stream which is used to calculate vertical velocity profiles characteristics. The velocity profile characteristics collected by ADCP were analysed for all depth layer of potential tidal stream energy. Our results showed an improved understanding for the optimal kinetic energy resources in different depth layer, and to take optimal depth tidal stream energy converter.

## 2. Research Methods

### 2.1. Study Location

Larantuka Strait is located in East Flores, East Nusa Tenggara, see figure 1. The condition of the strait in geomorphology is quite interesting, because this area has two large water masses. Northern part is the Flores Sea waters and in the southern part of the area of Flores Strait. Larantuka Strait is about 8 km in length, and 900 meters in smallest of width. The north and south inlets of Larantuka Strait are both around 4.5 km wide [6]. Meanwhile, at the narrowest part, the depth is 20 m – 40 m [7].



**Figure 1.** Location of the Flores Sea. Study area East Flores, Larantuka Strait (red square). ADCP location (black triangle). Contour of the bathymetry interval 0 meters - -41 meters.

Larantuka Strait, see figure 1 has one of the highest velocities in Indonesian waters [8]. The movement of water in and out past Larantuka Strait influenced by the dominance of tides makes the resulting flow has optimal speed to be used and its direction can be predicted [4]. Ref [9] and ref [10] also consider this as a potential area with current velocity exceeding  $3\text{ m/s}$ . The Indonesia government plan to build a tidal bridge connecting Adonara and Flores Island, this bridge integrated by tidal turbin as converter tidal stream to power density.

## 2.2. Scope

The objectives of this study are to calculate the potential energy generated from tidal stream in different depth layer focus on optimal layer, and lead to an improved understanding for the optimal potential energy at depth layer, and for take optimal site tidal stream energy convertor.

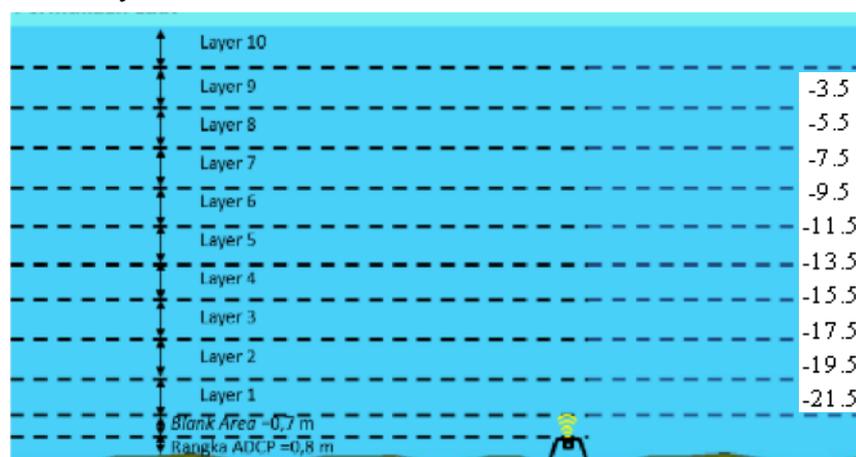
This study contains several calculations performed at optimal layer on the tidal stream profile, divided into several conditions to facilitate understanding the relationship between tidal current velocity and power density at each depth.

## 2.3. Methodology and application

A methodology of estimating the power density at each layer of velocity profile as measured by ADCP. The calculation of the power density estimation will be close to the kinetic equation generated from the tidal stream. The tidal stream studied has conditions that are affected by tides, including spring, daily spring, neap and daily neap.

## 2.4. ADCP Observation

A 750 kHz upward-looking Sontek Argonaut XR ADCP was deployed in the East Flores Waters, focus on Larantuka Strait at the site 51,E 502571 N 9080955 (UTM Projection) shown figure 1 during 15 days, from October 30<sup>th</sup> to November 13<sup>rd</sup>, 2017; during neap and spring phase. ADCP observations collected at one potential tidal stream locations at site were used to calculate vertical velocity profiles characteristics. Velocities were recorded every 2 meters layer (~10 depth layer), layer 10 is located nearest to the water's surface meanwhile, layer 1 is directly above the ADCP. shown figure 2, from 3.5 m to 21.5 m above the bottom. The deployment depth was 25 m and recorded every 600s. Given the strength of tidal currents in the Larantuka Strait, East Flores Waters, *in situ* data acquisition is very difficult and hazardous.



**Figure 2.** ADCP depth layer profile. Velocities were recorded every 2 m layer (~10 layer depth), layer 10 is located nearest to the water's surface, meanwhile layer 1 (-21.5 m) is directly above the ADCP.

## 2.5. Tidal Stream Analysis

Current strength characterization involves an assessment of the maximum, time averaged velocity, and also asymmetry of the tidal flow for each depth layer. The mean velocity is the average of current velocity magnitudes over a long period (15 days) including values around neap phase, daily neap phase, spring phase, daily spring phase and slack water. In addition, the maximum sustained velocity represents the maximum current observed. This establishes optimal layer to convert tidal stream velocity to power density. Besides, tidal stream asymmetry describes the difference between minimum and maximum of velocity magnitude. An imbalance between the strength of flood and ebb current speeds can exist, generating a considerably more power production during a specific stage of the tide. Other analysis methods, such as harmonic, spectral, and statistical analysis, were applied. Variable velocity currents ( $V$ ) are directly proportional to power density as we see in equation (1), which is used to convert power density. It is applied to make the optimal layer decision obtained from figure 4 and table 1. Optimal layer at maximum condition is layer 10 (-3.5 meters), 3.68 m/s maximum condition and 1.79m/s averaged condition, other condition layer 9 has a high value on average condition, with 3.67m/s at maximum condition and 1.79m/s at averaged condition. Water depth works on this current layer is -3.5 meters - -5.5 meters below LAT (Lowest Astronomical Tidal). Then the potential energy estimation, then will be carried out for these both optimal layers by comparing the profile bottom layer [11].

### 2.6. Power Density Analysis

Power density was estimated each depth layer, to know the power density of tidal stream and analysis optimal layer for turbine devices placement and efficiency. Kinetic power densities at the different depth layer have been estimated as follows:

$$P = \frac{1}{2} \rho A V^3 \quad (1)$$

Equation (1) shows where  $P$  is tidal stream power per unit area of flow,  $A$  are the efficiency and the area in direction of flow of the turbine, respectively, and  $\rho$  is water density which varies from  $1020 \text{ kg/m}^3$  to  $1029 \text{ kg/m}^3$  let  $\rho = 1025 \text{ kg/m}^3$ , in this case we just focused tidal stream value for estimation a power density as potential energy.  $V$  is the absolute current speed of the flow. Since the efficiency and the area in direction of flow of the turbine are usually constant, the power depends only on the absolute current speed [2]. In tidal stream analysis and power density analysis applied a time series analysis technique to velocity to identify probability of presence of optimal current velocity and power density [11].

## 3. Results and Discussion

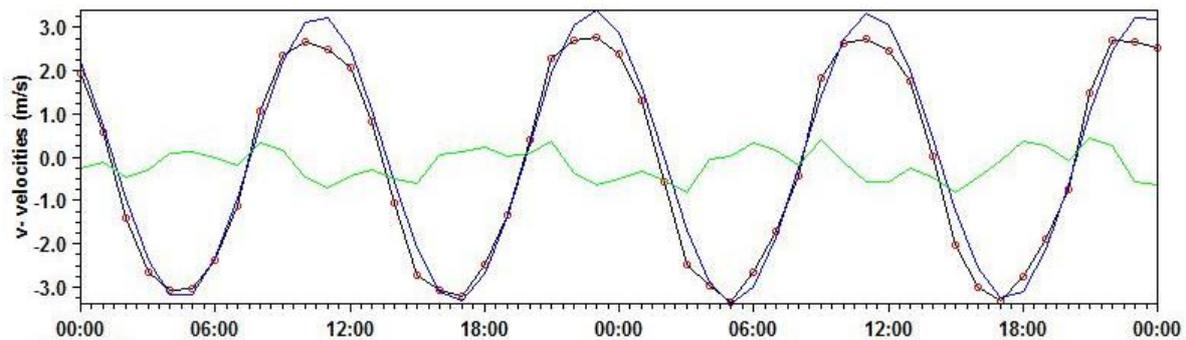
### 3.1. Tidal Stream Velocity and Velocity Distributions Each Depth Layer

ADCP measurement of ocean currents is brought close to harmonic analysis to be able to separate the receding currents with residual currents, the analysis is applied to the components of current  $v$ -velocity (north-south component). This is applied to ensure that the flow of the measurement results is dominated by tides as the main generator. The result are summarized in figure 3. Current curve represent 15 days measured by ADCP at averaged depth layer, current pattern for spring tide period.

Figure 3 shows the  $v$ -velocity components, indicated that the movement is dominated by north-south currents. Morphology of the Larantuka strait cross section is a semi-close boundaries with waters in the north and south are shown by the figure 1, hence the formation of canals affects the direction of flow. The curve tidal stream that is very dominating in the measurement current by ADCP, the dominant of tidal currents of 81.7 % of  $v$ -velocity and other generators (residual current) is shows in green curve.

Results for the measurement of the current in at ADCP site has a maximum velocity value on 3.68m/s at top layer, in addition layer 10 have 0.01 m/s as minimum value and 1.78 m/s as averaged value. Bottom layer profile shown figure 4 has lowest value of current velocity, 2.83 m/s at maximum condition, 0.01 m/s minimum condition, 1.17m/s averaged condition. The current profile of each depth

layer to show the flow in the layer near the LAT (Lowest Astronomic Tidal) has a speed greater than the bottom layer profile. It is shown in the Table 1 and figure 4. The figure 4 that is for layer 10 to the bottom layer, the current velocity gradually decreases with increasing depth. The reduction of speed at each layer of water to the bottom layer due to the frictional forces between the layers [4]. It work indifferent direction vector deflection at each depth layer and at the bottom layer the bed roughness coefficient has given a negative value to the current vector [5].

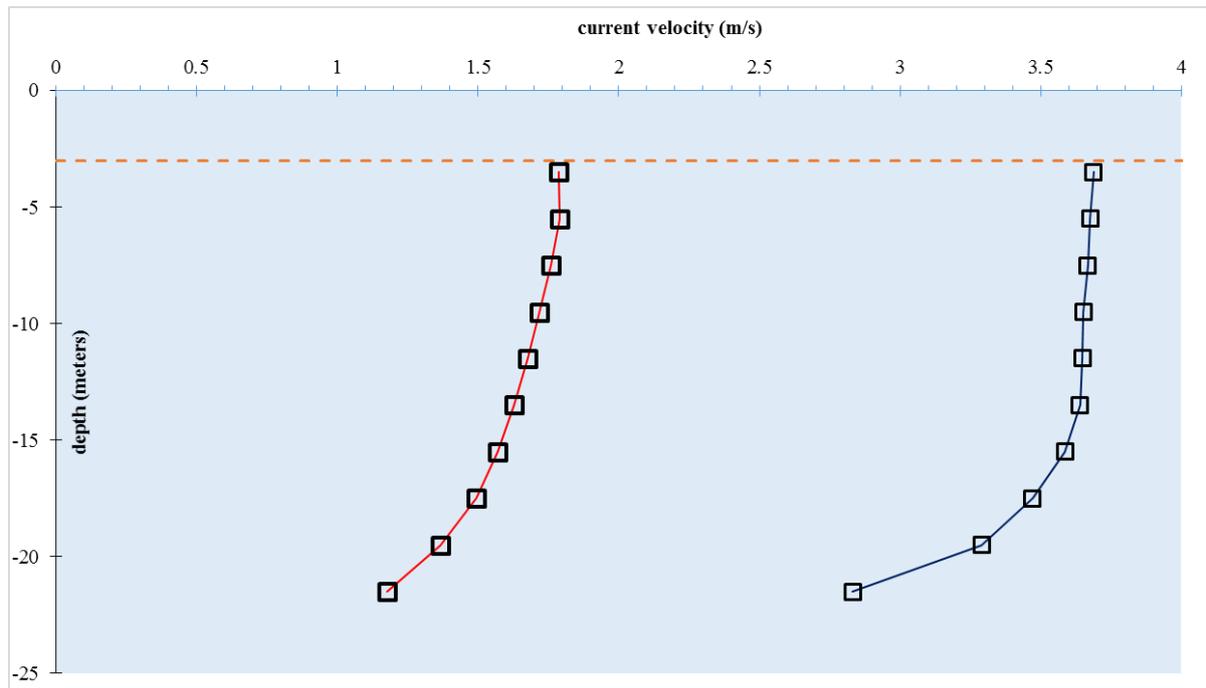


**Figure 3.** Tidal current analysis is applied to component *v-velocity* at spring phase to see the dominance of the tidal generator against the observation current results for 15 days. Red line shows tidal current, green line shows residual current and blue line shows observational current.

Variable velocity currents ( $V$ ) are directly proportional to power density as we see in equation (1), which is used to convert power density. It is applied to make the optimal layer decision obtained from figure 4 and table 1. Optimal layer at maximum condition is layer 10,  $3.68\text{ m/s}$  maximum condition and  $1.79\text{ m/s}$  averaged condition, other condition layer 9 has a high value on average condition, with  $3.68\text{ m/s}$  at maximum condition and  $1.79\text{ m/s}$  at averaged condition. Water depth works on this current layer is  $-3.5\text{ meters} - -5.5\text{ meters}$  below LAT (Lowest Astronomical Tidal). Then the potential energy estimation, then will be carried out for these both optimal layers by comparing the profile bottom layer.

**Table 1.** Current velocity profiles measured by ADCP in three velocity conditions (minimum, average and maximum velocity) and ten depth layer profile in Larantuka Strait represent 15 days.

ADCP Layer profile no.	Water Depth (meters)	Current minimum (m/s)	Current averaged (m/s)	Current maximum (m/s)
10	-3.5	0.01	1.79	3.69
9	-5.5	0.01	1.79	3.67
8	-7.5	0.01	1.76	3.67
7	-9.5	0.01	1.72	3.65
6	-11.5	0.01	1.68	3.65
5	-13.5	0.0	1.63	3.64
4	-15.5	0.01	1.57	3.59
3	-17.5	0.01	1.49	3.47
2	-19.5	0.0	1.37	3.29
1	-21.5	0.01	1.17	2.83



**Figure 4.** Current velocity profile derived from ADCP in the Larantuka Strait, East Flores Waters. Red line curve with cross represents averaged current, blue line curve with cross represent maximum current at each depth layer, and orange dot represent Lowest Astronomic Tidal (LAT) condition.

### 3.2. Power Density Distributions Each Depth Layer

The hydrokinetic resource varies with the tide phase [12] [5]. There is also a big difference in power generation during spring and neap tide and, to a lower extent, during daily spring and daily neap flow. Representative example tidal phase daily average kinetic power densities are shown in figure 5 and data table on table 2. Huge variability on the daily tidal phase depth scale is evident.

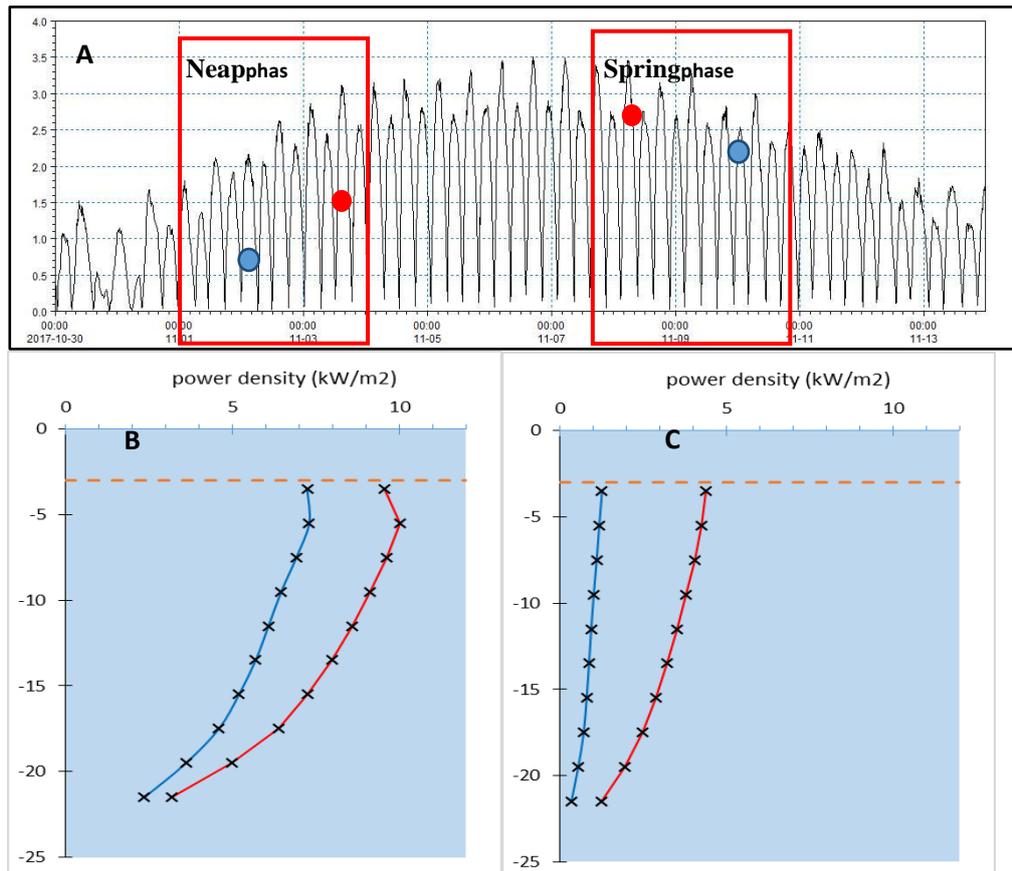
**Table 2.** Power density estimation ( $kW/m^2$ ) in depth layer (optimal layer, bottom layer, depth average) (Equation. (1)) for different stage of the probability (maximum and averaged) and tidal cycle phase condition (spring, daily spring, neap, and daily neap) measured by ADCP East Flores Waters, Larantuka Strait.

ADCP Layer No.	Depth (m)	Current		Power					
		Max (m/s)	average (m/s)	Max ( $kW/m$ )	average ( $kW/m^2$ )	spring ( $kW/m^2$ )	daily spring ( $kW/m^2$ )	neap ( $kW/m^2$ )	daily neap ( $kW/m^2$ )
10	-3.5	3.68	1.78	25.71	5.42	9.56	7.24	1.26	4.38
9	-5.5	3.67	1.79	25.43	5.47	10.02	7.30	1.12	4.26
1	-21.5	2.83	1.17	11.64	1.72	3.32	2.37	0.34	1.23
Depth Avg.		3.54	1.59	22.04	4.03	7.51	5.39	0.83	3.05

For the spring condition (figure 5B, bottom panel) the power density of depth is clearly apparent different for spring condition is  $7.51 kW/m^2$  (red dot figure 5, top panel) and  $5.39 kW/m^2$  for daily spring at depth average (blue dot figure 5, top panel). The result on layer 10 (table 2) at spring condition is  $9.56 kW/m^2$  peak spring and  $7.24 kW/m^2$  at daily spring. Layer 9 show the similar result trend with bigger value is  $10.02 kW/m^2$  at peak spring phase and  $7.30 kW/m^2$  at daily spring.

The tidal neap phase at depth averages (table 2) (figure 5C, bottom panel) shows  $0.83 kW/m^2$  (blue dot figure 5, top panel) and  $3.05 kW/m^2$  (red dot figure 5, top panel) at daily neap. The

result on layer 10 is  $1.26\text{ kW/m}^2$  and  $4.38\text{ kW/m}^2$  at daily neap. Layer 9 on tidal neap shows  $1.12\text{ kW/m}^2$  and  $4.26\text{ kW/m}^2$  at daily neap. Table 2 and figure 5 shows that, for layers 10, 9 to the bottom layer, the power density gradually decreased with respect to spring and neap tide. Our analysis indicates that the probability of large power density follows the tidal cycle pattern, this is because the tides are the dominant generator of the current measured by ADCP (figure 3), so the presence of optimal power density can be predicted. [2].

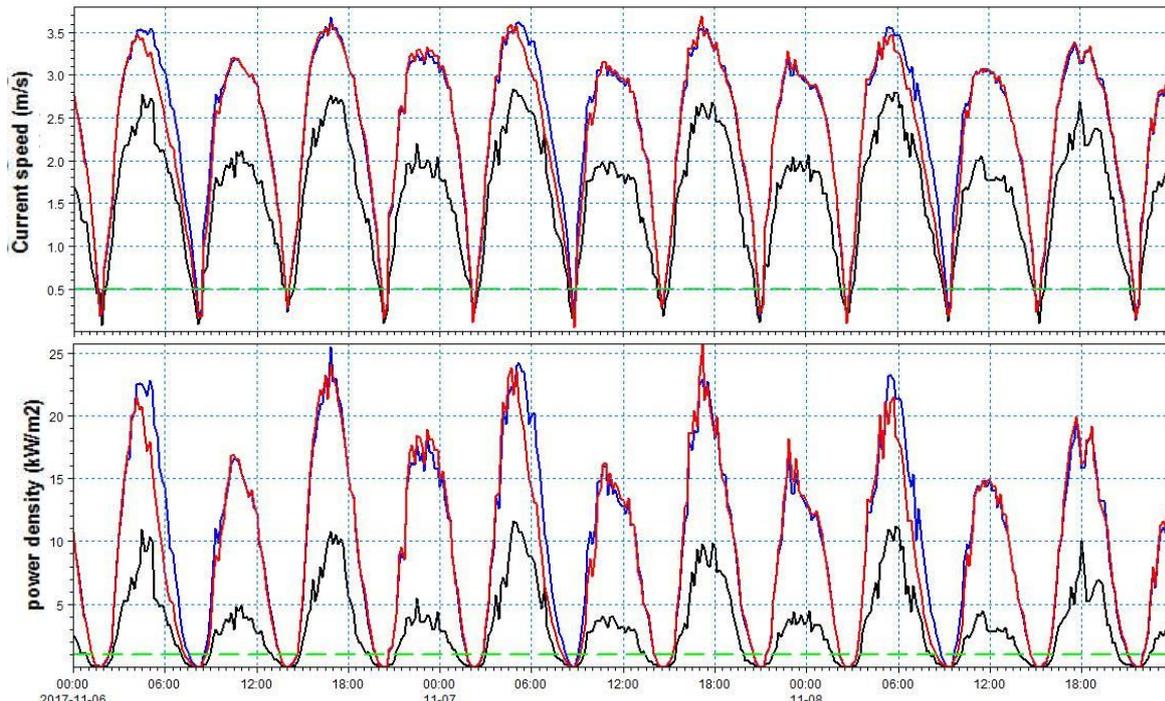


**Figure 5.** the depth-averaged velocity time series (top panel) to show tide condition phase. Two condition (B and C) of the power density profile are shown in bottom panels. Optimal result of power density (spring phase) on the left bottom panels and the neap phase right bottom panels, the daily spring/neap showed on blue line curve with cross and peak spring/neap red line curve with cross.

### 3.3. Power Density Site Selection for Optimal Depth Layer

Assumed that the ADCP derived velocity profile is representative for each depth layer (figure 4) around the Lantaka Strait, East Flores Waters, and figure 6. Representatif high velocity of tidal stream on optimal layer (surface to  $-5.5\text{ meters}$ ) compared with bottom layer velocity at spring condition. Only velocities exceeding  $0.5\text{ m/s}$  were used for power estimation. This value is taken to optimize the presence of current values that can be converted to power density with the Gorlov turbine model approach [13].

The power density ( $\text{kW/m}^2$ ) was estimated for different depth layer (Equation(1)) to optimize depth layer in the placement turbine installation. Velocity values were calculated to generate the power density on time series (15 days) in the layer 10 (surface to  $-3.5\text{ meters}$ ), layer 9 ( $-3.5\text{ meters}$  -  $-5.5\text{ meters}$ ), and bottom layer. Power density that is able to get once the time variation of velocity is known, the distribution of power densities can be readily calculated and averaged to find the mean daily power density [13].



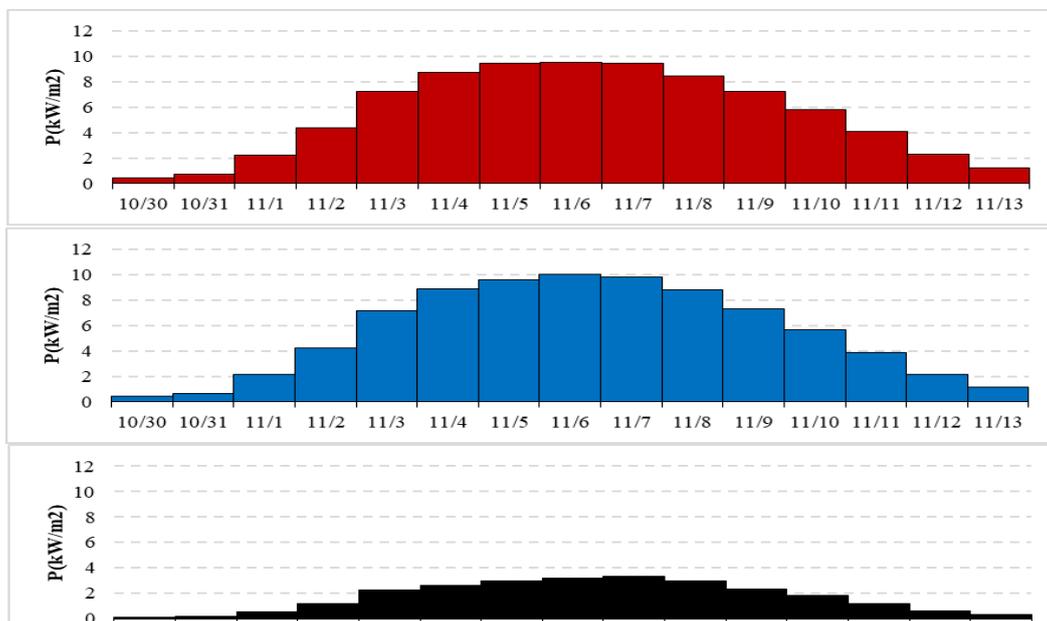
**Figure 6.** Time series of current velocity ( $m/s$ ) depth layer (A. top panel) and power density ( $kW/m^2$ ) at tidal spring phase condition, layer 10 (red line curve), layer 9 (blue line curve), bottom layer (black curve line), and green dash line each panel is cut in speed  $0.5 m/s$  and power density  $1kW/m^2$

The power density available around vertical profile ADCP measurement in the selective layer are presented in figure 6. The maximum power density at layer 10 is from  $0.5 kW/m^2$  to  $25.71 kW/m^2$  and from  $1kW/m^2$  to  $5.42 kW/m^2$  for the mean power density (table 2). Layer 9 shows similar profile with layer 10, the maximum power density is from  $0.5 kW/m^2$  to  $25.43 kW/m^2$  and from  $0.5 kW/m^2$  to  $5.47 kW/m^2$  for the mean power density. This condition is very relevant to the vertical curve profile (figure 4) of the tidal current measured by ADCP, [14] [15] power density is directly proportional to current velocity, as seen in equation 1, power density will increase sharply when compared to the vertical profile of tidal current velocity.

Power density at the bottom layer (figure 5) is three time lower than top layer, at the maximum power density is from  $0.5 kW/m^2$  to  $11.64 kW/m^2$  and from  $0.5 kW/m^2$  to  $1.72 kW/m^2$  for the mean power density [5] [3]. The maximum potential turbine is above the seabed to calculate the current velocity because of the basic frictional coefficient that affects the current vector, assuming that it is  $5 m$  above the seabed.

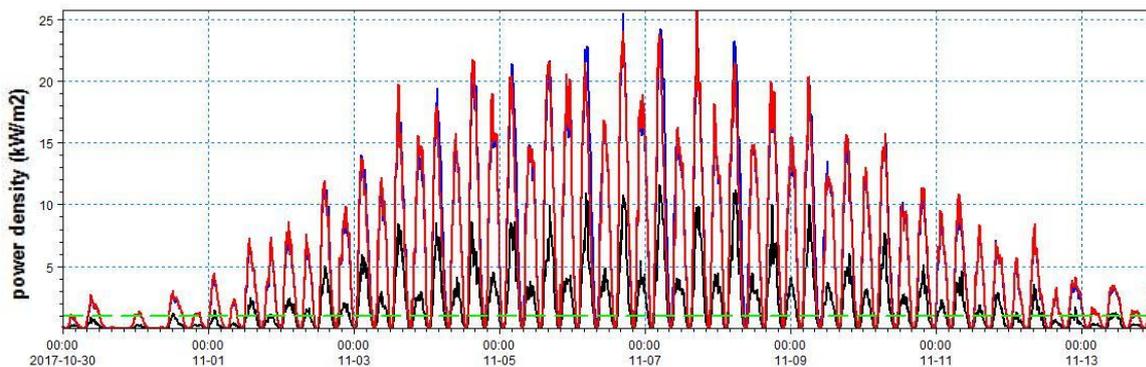
Representative daily average kinetic power densities (Equation (1)) are shown in figure 7. Variability on the daily time scale evident, for the daily average (figure 7), the semi-diurnal inequality is clearly apparent on either side of the strong tides which generates peak power densities at location of ADCP measurement. For 15 days period, ADCP observe neap-spring tidal cycles (figure 3, figure 5A), the power generation seems to be more balanced at 3 layers sample, can be seen figure 7 in the optimal layer (layer 9 and layer 10) shows the maximum power density that occurs during peak spring conditions on November 6<sup>th</sup> 2018, or the eighth day of measurement by ADCP is done.

Bottom layer power density has similar pattern, with high power density at spring condition with difference day (November 7<sup>th</sup>, 2018, ninth day measurement). Optimal power density has  $9.56 kW/m^2$  at layer 10 and  $10.02 kW/m^2$  at layer 9, In the bottom layer, the estimated power density probability is very different, bottom layer have  $3.32 kW/m^2$  on spring condition.



**Figure 7.** Variations in average power density on daily in location ADCP measurement in the layer 10 (-3.5 - -5.5m) (red), layer 9 (-5.5 - -7.5m) (blue), and bottom layer (black).

In order to assess the effect of velocity asymmetry on power production on optimal layer and bottom layer, is applied and compared power density time series (figure 8) from the current value measured by ADCP and the power density approach with equation (1) during the tide cycle. Layer 9 and layer 10 are dominant power density with high value (figure 8; red line and blue line). Placing a power density value at the time series aims to predict the presence of kinetic energy sources that can be optimized, and planned for energy backup during the tide in the slack phase.



**Figure 8.** Power density ( $kW/m^2$ ) variation during 15 days at layer 10 (red curve), layer 9 (blue curve), and bottom layer (black curve). Green dash indicates the power density value of  $1 kW/m^2$  [3]

#### 4. Conclusion

Our result indicate that the tidal stream *forv-component* velocity is dominate 81.1%, and *u-velocity* is 86.2%. Two depth layer with high energy potential, known as optimal layer: the layer 10 (surface to -3.5 meters) with 3.68 m/s and layer 9 (-3.5 - -5.5 meters) with 3.67 m/s current velocity. This bottom layer has the potential although lower capacity than other depth layer, it shows that this site is also applicable for seabed mounted tidal turbines.

The optimal layer of power density were estimated. Maximum probability condition layer 10 (surface to -3.5meters) have power density higher than layer 9 (-3.5 meters - -5.5meters), 25.7 kW/m<sup>2</sup>. However each depth layer has a maximum current velocity can be converted to power density to be optimized.

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