Potential of tidal power plants with least square method on Toaya Beach

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Abstract. The use of energy, especially electrical power, is needed by the wider community—lots of alternative energy from nature, especially in Indonesia that can be utilized to produce electricity. One of the newest alternative examples is the energy produced by tides. Tidal energy is a type of renewable energy that is relatively more predictable in number. One method that can process the waves is the Least Square Method. Where the results of data processing using this method can be known based on tidal observations for 15 days on Toaya Beach located in Donggala Regency, Central Sulawesi, the types of tidal types that occur based on the results of Formzahl's count is 0.357 that the tidal types that occur are varied types leaning to double daily, with a Root Mean Square Error (RMSE) of 0.028, which means that the difference between predictive results and observational data is accurate. Then also obtained the value of the design water level elevation that is the highest high water level (HHWL) is 2.7 meters, and the lowest low water level (LLWL) is -0.3 meters with a height difference is 3.0 meters. So with the high height difference, the total energy generated by two times a day with a sea area of 9 km² which is capable of producing energy movement from seawater can be calculated the potential energy generated from the waves of Toaya Beach, which is 5.53 MW.

Keywords: Tidal, Least Square method, formzahl, elevation, energy potential.

1. Introduction
Indonesia is a country that is developing towards changes towards the better for advancing the nation. However, in achieving these change goals, Indonesia is faced with various problems. One of the issues that occur is that along with the development of human civilization, Indonesia's population is increasing so that the need for energy is also growing. So far, most energy needs come from non-renewable energy, such as coal, oil and natural gas, which are usually used as fuel for electricity generation.

Therefore, the existence of ideas that can generate electrical energy is vital. In this case, the issue of tidal power generation will be discussed both from the generator, raw materials to facilitate the generation process and how the generator works so that it can generate sufficient electrical energy.

The use of tides for electricity generation is the right step to minimize the use of fossil fuels as fuel for conventional power plants. One method that can process the waves of seawater is the Least Square Method. This method is one of the ways that can be used to process tidal data with high data frequency accuracy. This method is often used after the invention of modern numerical calculators. This is because this method requires a matrix calculation process with large matrix dimensions (Gumelar, 2016).

Toaya is one of the villages in Sindue Subdistrict, Donggala Regency, which throughout the town is located on the coast of the open sea so that the authors chose this village as a reference that the beach will research Tidal Power Plants (TPP).
The purpose of this study is to determine the type of tides that occur at Toaya Beach based on the calculation of Formzahl numbers using the Least Square method, to obtain the water level elevation of the HHWL and LLWL plans on Toaya Beach, and to determine the potential generated by tidal power plants. Sea on Toaya Beach.

Based on the description above, the formulation of the problem of this study is how the type of tides that occur at Toaya Beach based on the calculation of Formzahl numbers using the Least Square Method, what is the elevation of the HHWL and LLWL design water levels on Toaya Beach, and whether there is potential for tidal power plants. Low tide at Toaya Beach.

2. Overview Of The Research Location
The research location is planned to be located in Toaya Village, Sindue District, Donggala Regency, Central Sulawesi Province, approximately 40 km from Palu City. With an area of 23,540 hectares, which consists of 5 hamlets. Coordinates 00 ° 36'7,1 / 119 ° 47'28,8', and the typology is coastal / fisherman. The height of the land above the sea level is 100 asl.

3. Literature Review
3.1 Tidal
Ocean tides are a phenomenon of the periodic up and down movement of sea levels caused by a combination of forces and attractive forces from astronomical objects, especially by the sun, earth and moon. The influence of other celestial bodies can be ignored because of their greater distance or smaller size (Dronkers, 1964).
### 3.2 Tidal Curve

Tidal conditions can be displayed visually in the form of tidal curves. The curve describes the sea level at a particular time. The x-axis shows the time, while the y-axis shows the sea level. Tide height is the vertical distance measured from the top of the highest water to the lowest water position. The tidal period is the time it takes from the highest (or lowest) water level to the next highest (or lowest) water level. The period when phenomena sea level moves up is called the Tide period, while the period when the sea level moves down is called the low tide period.

According to Nontji (1987), there are four types of ebb and flow based on their period and regularity. Within a month, the daily variation of the tidal range changes systematically with the lunar cycle. The tidal range also depends on the shape of the waters and the configuration of the ocean floor. Here below the tides of seawater in Indonesia are divided into four types, namely: Regular Double Daily, Mixed Semi-Diurnal Tides, Mixed Semi-Diurnal Tides, Regular Single Daily Tides.

![Figure 3. Types of Tides that occur in Indonesia (Triatmodjo, 1999)](image)

Apart from looking at the tide data plotted in the form of a tidal type graph, it can also be determined based on the Formzahl (F) number which is expressed in the form of the following equation:

\[
F = \frac{AK_1 + AO_1}{AM_2 + AS_2}
\]  

(3.1)

Where:
- \( F \): Formzahl or tidal constant
- \( AK_1 \): The amplitude of the single daily mean tidal wave chicks are affected by the declination of the moon and the sun
- \( AO_1 \): The amplitude of the mean available daily tidal wave children as affected by the declination of the sun
- \( AM_2 \): The amplitude of the sub-daily mean double tidal wave affected by the moon
- \( AS_2 \): Amplitude of the mean daily double tidal wave child affected by the sun

The tidal type classification can be seen in **Table 1**.

| Form Value | Type of Tide | Phenomenon |
|------------|--------------|------------|
| \( F \leq 0.25 \) | Semi Diurnal Tides | 2x pairs a day with the same relative height |
| \( 0.25 < F \leq 1.5 \) | Mixed Mainly Semidiurnal Tides | 2x pairs a day with different heights and different intervals |
1,50 < F ≤ 3,0

Mixed Mainly
Diurnal Tides

1x or 2x pairs a day
at different intervals

F > 3,0

Diurnal Tides

1x pair a day, when
Spring can occur 2x
pairs a day

(Source: Triatmojo, 2010)

3.3. Tidal Power Plant
Tidal Power Plants Seawater is a power plant that utilizes tidal energy in seawater to make energy in other forms, especially electricity, where tides can drive turbines to run a generator. Tidal power generation for seawater is renewable energy. There are two types of generator types, namely Tidal Dam (Barrage Tidal System) and Offshore Turbines (Onshore Turbines). The Sea Water Tidal Power Generation System is very suitable for use in Indonesia, especially in Central Sulawesi, because Indonesia is known for its ocean waves.

3.4. The advantages of TPP
1. Once built, tidal energy can be obtained free of charge.
2. Does not produce greenhouse gases or other waste.
3. Does not require fuel
4. Low operating costs.
5. The tides are predictable.
6. Offshore turbines have low installation costs and do not cause a massive environmental impact

3.5. Disadvantages of TPP
1. Depends on the characteristics of the Tides.
2. Need a precise location.
3. The tools must be sturdy so they can withstand any weather conditions.
4. A dam that covers a river mouth is costly to build and covers a vast area so that it changes the environmental ecosystem both upstream and downstream for many kilometres.
5. Can only supply energy for approximately 10 hours per day, when the waves move in or out.

3.6. Tidal Power Plant (TPP) Type Onshore Turbines
This tidal power plant uses an offshore turbine method which is more like an underwater version of a wind power plant. The shape of the tidal turbine is as varied as the wind turbine.

This system does not require a dam but is directly installed in the open seas; the thrust is generated from the movement of the kinetic energy of ocean currents because the density of water is higher than the wind, the onshore turbine can produce more incredible power with the same size as the wind turbine where the tides can also be utilized so that they can drive turbines and generators. This explanation can be seen in figure 4

**Figure 4. Tidal Turbine in the Sea**
Where to calculate the amount of energy produced can be calculated using the following equation:

\[ E = \frac{1}{2} \times A \times \rho \times g \times H^2 \]  

(3.2)

Where:
- \( E \) = Energy (Joule)
- \( A \) = Sea area (m\(^2\))
- \( \rho \) = Sea water density (kg/m\(^3\))
- \( g \) = Gravity (m/s\(^2\))
- \( H \) = Head (m)

For the sea area (A) which is estimated to be able to push and produce energy movement in the sea area, it is assumed that the surface of the tidal energy generator is 9 km\(^2\) (Theocsbury, 2020).

### 3.7. Tidal Harmonic Components

The tides are periodic so they can be predicted. To predict tides, the amplitudes and faces of each component of the tidal generator are needed. The main features of waves consist of the daily central part, daily tides and long period tides. However, due to the interaction with the shape of the beach morphology and the superposition between the primary tidal waves, new tidal components are formed. These main components, also called astronomical frequencies, are used in the creation of interactive programming for the decomposition of tidal components. In the tidal analysis using the least-squares method, the amplitude and phase components of the tidal harmonic equation are calculated based on observational data on the position of the water level within a certain period, using ingredients with known frequencies. The number of tide components that can be decomposed depends on the length of the data, the longer the observation data, the more tidal details that can be produced. For example, the number and pairs of components resulting from observation with a length of 1 month will differ from an observation length of 1 year. The tidal parts can be seen in Table 3.2 as follows.

### 3.8. Least Square Method

The principle of tidal analysis with the least-squares method is to minimize the difference in the composite signal and the signal size. The equation for the least-squares process can be seen in the following equation:

\[ h(t) + v(t_n) = h_m + \sum_{i=1}^{k} A_i \cos(\omega_i t - g_i) \]  

(3.3)

Where:
- \( h(t) \) : water level a function of time
- \( A_i \) : the amplitude of the ith component
- \( \omega_i \) : the angular velocity of the ith component
- \( g_i \) : the ith component phase
- \( h_m \) : mean water level
- \( t \) : time / time interval
- \( k \) : the number of components
- \( v(t_n) \) : residue

### 3.9. Error Rate

Root Mean Square Error (RMSE) is the average value of the squares of the error; it can also express the size of the error generated by a forecast model. A low RMSE value indicates that the variation in the amount generated by a forecast model is close to the variation in its observation value, meaning that the closer to zero the RMSE cost, the more accurate the elevation prediction results are. RMSE is the simulation result error rate. The calculation of the error rate aims to determine how much difference the simulation results from data with the measurement data. The analysis of the RMSE value is calculated using the following equation:
\[ RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{n}} \]  

(3.4)

Information:
- \( Y_i \): initial data (observational data)
- \( \hat{Y}_i \): final data (predictive data)
- \( n \): the amount of data

3.10. Water Level Elevation

Given the sea level elevation is always changing every time, it is necessary to set a height based on tidal data, which can be used as a guide in planning a port. Some of these elevations are; High Water Level (HWL), Low Water Level (LWL), Mean High Water Level (MHWL), Mean Low Water Level (MLWL), Mean Sea Level (MSL), Highest High Water Level (HHWL), Lowest Low Water Level (LLWL), Higher High water level (HHWL), dan Lower Low Water Level (LLWL).

Sea level elevation can be calculated from the value of the tide components obtained from the calculation of the tide analysis. The following are some equations for determining the design water level (Dalpan et al., 2015).

3.11. Bathymetry

A bathymetric map is a map of the depth of the sea which is expressed in several depths or depth contours measured against a vertical datum. Bathymetry (from the Greek meaning "depth" and "measure") is the study of the centres underwater and the three-dimensional study of the floor of an ocean or lake. A bathymetric map generally displays base or direct relief with contour lines called depth contours (isobaths) and may have additional information in the form of surface navigation information.

In general, the seabed relief is not very varied compared to land relief. This is due to weak erosion and sedimentation.

4. Results And Discussion

4.1. Tidal Data Analysis

The data to be analyzed is tidal data from observations in the field which take place every hour for 15 days, from March 14, 2020, to March 28, 2020.

From the data observation process, table compilers can be made to facilitate tidal data analysis. Then from this table, we can obtain a graph of the tidal observations as follows in figure 5:

![Toaya Beach Tide Observation Chart](image)

Figure 5. Tide Observation Graph

4.2. Results of the Least Method of Tidal Data Analysis

Based on the results of tidal data analysis at Toaya Beach with the Least Square method, the tidal constituent value of 2 harmonic constants is obtained, namely, amplitude and phase difference. The following is the final result of harmonic constants between Amplitude (A) and Phase Difference (\( \varphi \)) using the Least Square method in Table 2.
Table 2. Final Result Harmonic Constants Least Square Method

| No. | Tidal constituents | Amplitude (A) (m) | Different Phase (g) |
|-----|--------------------|-------------------|---------------------|
| 1   | K1                 | 0.199             | 174.394             |
| 2   | O1                 | 0.127             | 189.575             |
| 3   | M2                 | 0.545             | 348.719             |
| 4   | S2                 | 0.369             | 126.771             |
| 5   | N2                 | 0.072             | 66.343              |
| 6   | M4                 | 0.003             | 222.122             |
| 7   | K2                 | 0.091             | 94.080              |
| 8   | P1                 | 0.076             | 15.351              |
| 9   | MS4                | 0.001             | 154.844             |

By experimenting with 9 constituents, the results are the Formzahl number, RMSE, water level elevation, as follows:
- Formzahl number \( F \) : 0.357
- RMSE : 0.028
- HHWL : 2.7 m
- MSL : 1.2 m
- LLWL : -0.3 m

The results of the calculation using the Least Square method, can be obtained the type or type of tides based on the Formzahl number with comparisons \[ F = \frac{(AK_1) + (AO_1)}{(AM_2) + (AS_2)} \]. Here’s how to calculate it with a comparison of the F value:

\[
F = \frac{(AK_1) + (AO_1)}{(AM_2) + (AS_2)} \\
= \frac{(0.199) + (0.217)}{(0.545) + (0.369)} \\
= 0.357
\]

Terms:
- \( F \leq 0.25 \) : Double daily pairs (semi diurnal)
- \( 0.25 < F < 1.50 \) : Mixed tide prevailing semi diurnal
- \( 1.50 < F < 3.00 \) : Mixed tide prevailing diurnal
- \( F \geq 3.00 \) : Single daily tide (diurnal tide)

Based on the requirements for the Formzahl number, the F value for the Least Square method is obtained, namely 0.357 (0.25 <F <1.50), so the type or type of tide for the Toaya Beach area, Donggala Regency, Central Sulawesi is mixed tide prevailing semi diurnal). This means that in one day there are two tides and two ebbs with different heights and intervals.

4.3. Calculating the Potential Electrical Energy Generated

To calculate the electric power that can be generated based on the tidal height of Toaya Beach, the description of the calculation of the power / energy that can be generated is as follows, by comparing the energy produced by forecasting sea water waves.

Known:
- \( \rho = 1025 \text{ kg/m}^3 \)
- \( g = 9.81 \text{ m/s}^2 \)
- \( h_{\text{tidal}} = \text{HHWL} - \text{LWLL} = 3.0 \text{ m} \)
- \( A = 9 \text{ km}^2 \) (assumed that the surface area utilizes tidal energy)

\[
E_{\text{tidal}} = \frac{1}{2} \times A \times \rho \times g \times h^2 = 39.8 \times 10^{10} \text{ J}
\]
From the results of the previous discussion that on Toaya Beach there were 2 tides and 2 receding times a day, then the potential energy produced when the sea water receded was zero (0). So that the total electrical energy that can be generated in one day can be: $79,6 \times 10^{10}$ J

From the values obtained in the above calculations, it can be calculated that the amount of electrical energy that can be produced per day in energy units is as follows:

$$E_{\text{day}} = \frac{79,6 \times 10^{10}}{24 \times 3600} = 9,22 \times 10^6 \text{ Watt}$$

It is assumed that the efficiency value of the generator is 60%., So the potential generated by the tidal effect of sea water on Toaya Beach with an estimated sea area can encourage and produce energy movement in the sea area covering an area of 3x3 km2 and a head as high as 3 meters which is roughly 5, 53 MW.

4.4. Determining the Position of TPP

Bathymetry maps can be interpreted as a measure of the depth of the sea, both regarding the size of the seafloor elevation which is a source of information and an overview of the seabed, and provides many clues about the structure of the sea (Nurjaya, 1991).

The following is a bathymetry map of Toaya beach which can be seen in Figure 6.

![Figure 6. Bathymetry Map of Toaya Beach](image)

The image above is the Toaya Beach Contour Map. The tool used when measuring is a depth meter; this is a tool to measure the depth of the sea, which is flashed from above the sea level to the bottom of the sea. The purpose of bathymetry measurement is to determine the condition of the seafloor depth which will then be used as the basis for determining the position of the power plant so that it can be known and also as a reference point for determining the height of MSL, HHWL and LLWL. In the data collection process, the depth of seawater is measured at an interval of 10 meters from the coast, and then the surfer software is used to make the results of the bathymetric map image.

5. Conclusion

Based on the tidal constituent harmonic constant value using the Least Square method, the type or type of tides at the research location at Toaya Beach with an observation time of 15 days, based on the calculation of Formzahl (F) numbers, the F value is 0.357 which indicates that the type The tides that occur are mixed wave prevailing semi-diurnal, where every day there are two tides and two ebbs a day but sometimes there are one tide and one ebb with different heights and times. With the error rate in this study calculated using RMSE, indicating that the RMSE value is 0.028, the difference between the predicted data and the observation data is accurate.

Based on the results of the planning water level elevation data, the MSL value = 1.2 m, HHWL = 2.7 m, LLWL = -0.3 m, so that the resulting head value reaches 3.0 m.
Toaya Beach is one of the beaches in Central Sulawesi which has the potential to be a place for a Tidal Power Plant, so based on the calculation of the potential energy generated by tides with a head value of 3 meters and a sea area which is thought to encourage and produces energy movement in the sea area covering an area of 9 km², namely the total energy potential of around 5.53 MW.

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