Identification of M2 tidal velocity and energy in the eastern waters of Aceh based on numerical simulation

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Abstract. The influence of the M2 harmonic component in the waters of East Aceh is more significant than the other components. It is due to the fluctuation in M2 amplitude, which affects the tides. This study aims to compare the model currents velocity simulation results with data from the Geospatial Information Agency and TPXO7.2 and find the tidal energy extraction value of M2. The modeling method used is the non-hydrostatic method. The research location is in Aceh's eastern waters by taking two research stations, namely Lhokseumawe waters and Langsa waters. The resulting tidal flow velocity in Lhokseumawe waters is 0.8344 m/s, while in Langsa waters, it is 0.8485 m/s. The tidal current strength in Lhokseumawe Waters is 1.2223 x 104 kW and Langsa Waters 1.2854 x 104 kW. Based on these results, Langsa waters have a tidal current speed higher than Lhokseumawe waters, which is 0.0241 m/s, with a tidal current strength of 6.31 x 102 kW. Due to differences in the depth layer or friction movement of the bottom of the waters and the characteristics of Lhokseumawe waters, which are wider than Langsa waters.

1. Introduction

The waters of East Aceh are influenced by the Andaman Sea and the Strait of Malacca which have relatively deep and steep bathymetry [1-3]. The topographical structure in East Aceh waters is in the form of a basin with a depth of 400 m to 1700 m [4]. The direction of current in Aceh's East Waters tends to follow the coastline, and there is no significant deflection [5].

The main constituent components for tidal generation in waters are the harmonic components M2, S2, K1, and O1 [6]. Souchay et al. [7] stated that the tides in waters that are influenced by the moon's gravitational movement are known as the harmonic constituents M2, the distance of the moon's movement also determines the magnitude of the tidal amplitude.

The extraction of offshore and strait energy produces more energy than using turbines in estuaries. Extraction in the estuary was carried out in basins, which were only affected by tides [8]. An example of Rathlin Sound [9] generally produces tremendous energy extraction in the strait between the island and the mainland. The topography determines the magnitude and direction of the flow, so that elevation
changes are relatively high. Therefore, the turbine location study depends on the tidal energy potential to be achieved [10].

Tidal extraction can be utilized as hydrokinetic energy, which is environmentally friendly and renewable [11]. There are currently many uses of tidal energy, which are used as renewable energy [12]. The method used to obtain the tidal strength is by calculating tidal currents velocity [13]. The numerical hydrodynamic model can be used to calculate the tidal extraction potential [14].

2. Materials and Methods

2.1. Numerical model design

The research domain for the East Aceh Waters was obtained from the Shuttle Radar Topography Mission 30 seconds (SRTM30) with a resolution of $\Delta x = \Delta y = 2.5'$ and $\Delta t = 25''$ following the Courant-Freiderichs-Lewy (CFL) criteria from Kämpf [15].

$$\Delta t \leq \frac{\Delta x}{\sqrt{gh_{max}}}$$

where $h$ is the maximum depth, $g$ is the gravitational acceleration of the earth, $\Delta t$ is the time step, and $\Delta x$ is the minimum edge characteristic length scale.

2.2. Initial and open boundary data

The amplitude and phase data for the M2 tidal component are obtained from the Geospatial Information Agency (GIA) (http://tides.big.go.id/pasut/konstanta/) with a resolution of $\Delta x = \Delta y = 2.5'$. Open boundary data are as follows [16,17]:

$$\eta = A_{M2}\cos\left(\frac{2\pi}{T_{M2}} t - \phi_{M2}\right)$$

where $A_{M2}$ and $\phi_{M2}$ are amplitude and phase of M2 elevation, $T$ is M2 period (12.42 hours), and $t$ is time.

2.3. Analysis of the numerical model output

Numerical simulations were obtained for each quarter of the M2 period ($\eta_{T/4}$, $\eta_{T/2}$, $\eta_{3T/4}$, and $\eta_{T}$). It was analyzed with the equations Eq (2) and (3) and obtained the amplitude and phase values, with the following equation:

$$A = \sqrt{0.5 \left(\eta_{T/4} - \eta_{3T/4}\right)^2 + 0.5 \left(\eta_{T/2} - \eta_{T}\right)^2}$$

$$\phi = \tan^{-1}\left(\frac{\eta_{T/4} - \eta_{3T/4}}{\eta_{T/2} - \eta_{T}}\right)$$

where elevation $\eta$ is the level of the sea. $T$ is the last period data stored from each layer of M2 components ($T/4$, $T/2$, $3T/4$, and $T$ with a value of $T = 12.42$ hours), $A$ as M2 amplitude, and $\phi$ as M2 phase.

The model analysis results were then verified with amplitude and phase M2 data sampled from TPXO7.2 (https://www.tpxo.net/regional) with a spatial resolution of $\Delta x = \Delta y = 2'$ for the Aceh East Waters domain, in two research locations, namely in Lhokseumawe Waters and Langsa Waters.

| Table 1. Research domain |
|--------------------------|
| **Latitute (°N)** | **Longitude (°E)** | **Location**         | **Depth (m)** |
| 5.2333          | 97.1166           | Lhokseumawe             | 160.872      |
| 4.9501          | 97.9              | Langsa                   | 50.72        |
2.4. Power extraction based on turbine

Based on the shape of the turbine cross-section, the power or hydrodynamic energy of the tidal \[18\] can be written as follows:

\[ P = \frac{1}{2} \rho \pi R^2 V^3 C_p \]  

where \( \rho \) is the density of seawater (1024 kg/m\(^3\)), \( V^3 \) is the resultant of velocity \( u \) and \( v \) (m/s), \( R \) is cross-sectional radius (m), and \( C_p \) is the power coefficient of the kinetic energy.

3. Results and Discussions

3.1. Model verification

Table 2 shows the amplitude and phase values in Lhokseumawe waters from the simulation results, GIA, and TPXO7.2. The amplitude value of the simulation results obtained is 0.5674 m, GIA is 0.5652 m, and TPXO7.2 is 0.5670 m. As for the simulation results phase, it was found that it was 92.012°, GIA is 91.8711°, and TPXO7.2 is 90.82°. There is a difference in the phase value between simulation and GIA of 0.1409° and between simulation and TPXO7.2 of 1.192°.

Table 3 shows the amplitude and phase values in Langsa waters from the simulation results, GIA, and TPXO7.2. The amplitude value of the simulation results obtained is 0.5979 m. There is a difference between the simulation and TPXO7.2 of 0.014 m. The phase value in Langsa waters from the simulation results is 135.3°. The difference in the phase value between simulation and TPXO7.2 is 16.54°, and the difference between simulation and GIA is 5.141°.
Table 3. Amplitude and phase elevation data in The Waters of Langsa from model simulation, TPXO7.2 and GIA data

|                        | Amplitude in the Langsa waters (m) | Phase in the Langsa waters (°) |
|------------------------|------------------------------------|---------------------------------|
| Model Simulation       | 0.5979                             | 135.3                           |
| BIG                    | 0.5931                             | 130.159                         |
| TPXO7.2                | 0.6119                             | 118.76                          |

Figure 2. Elevation the Lhokseumawe waters taken from GIA, TPXO7.2, and model simulation results. Figure 3. Elevation the Langsa waters taken from GIA, TPXO7.2, and model simulation results.

Figure 2 and Figure 3 shows the similarity in elevation between the simulation results with TPXO7.2 and BIG in Lhokseumawe and Langsa Waters. Lhokseumawe waters and Langsa waters formed elevations starting from -0.4 m / s and forming two waves within 24 hours.

3.2. M2-tide power extraction

Figure 4. Current velocity u (a), current velocity v (b), and elevation (c) in Lhokseumawe waters

Figure 5. Current velocity u (a), current velocity v (b), and elevation (c) in the Langsa waters
Elevation and velocity \( u \) and \( v \) in Lhokseumawe waters can be seen in Figure. 4. The highest position at 2.80 x 10^4 seconds at a speed of 0.59 m/s. Whereas in Langsa Waters (Figure. 5), elevation, \( u \), and \( v \) are 0.6 m/s with a period of 2.45 x 10^4 seconds for the peak. The tidal flow velocity in Lhokseumawe waters is 0.8344 m/s (Table 5), and Langsa waters is 0.8485 m/s (Table 5). The speed of tidal currents depends on the wind, elevation, amplitude, and phase in the waters. These results indicate that the tidal flow velocity in Langsa waters is more significant than Lhokseumawe waters with a difference of 0.0241 m/s. The parameters used for the simulation of the \( M_2 \) component tidal extraction are shown in Table 4.

| Turbine parameter | Specifications |
|-------------------|----------------|
| Generator rate power | 600 kW |
| Power coefficient \( C_p \) | 0.39 |
| Number of blade | 2 |

Table 4. Turbine 600 kW parameters

The tidal current strength in Lhokseumawe Waters is 1.2223 x 10^4 kW, and Langsa Waters is 1.2854 x 10^5 kW. Based on these results, the difference in tidal current strength is 6.31 x 10^2 kW. It is due to differences in the depth layer or friction movement at the bottom of the waters and the characteristics of Lhokseumawe waters, which are wider than Langsa waters.

The ebb and flow of the \( M_2 \) component were extracted using a 600 kW turbine. An example taken for design is a two-blade turbine. It is due to the reference guidelines available. Based on Li et al. [13], the maximum rotor \( C_p \) value obtained was 0.39. The number of \( C_p \) obtained affects the length of the blade used. The results obtained in Table 5 show that the 600 kW turbine is not efficient because the value of the current strength obtained is minimal and unable to turn the turbine. So that a smaller turbine is needed, the 60 kW turbine [19] can be used as a guide to provide useful simulation data for the development of tidal flow turbines in East Aceh’s waters.

| Location          | \( U_\infty \) (m/s) | \( P \) (kW) |
|-------------------|---------------------|--------------|
| Lhokseumawe waters | 0.8344              | 1.2223 x 10^4 |
| Langsa waters     | 0.8485              | 1.2854 x 10^4 |

The tidal current strength in Lhokseumawe Waters is 1.2223 x 10^4 kW, and Langsa Waters is 1.2854 x 10^5 kW. Based on these results, the difference in tidal current strength is 6.31 x 10^2 kW. It is due to differences in the depth layer or friction movement at the bottom of the waters and the characteristics of Lhokseumawe waters, which are wider than Langsa waters.

4. Conclusion
The extraction results obtained were the \( U_\infty \) value for Lhokseumawe waters of 0.8344 m/s and Langsa waters of 0.8485 m/s. Meanwhile, the power value for \( M_2 \) in Lhokseumawe waters is 1.2223 x 10^4 kW and in Langsa waters is 1.2854 x 10^5 kW. The condition that causes the speed and strength of the tidal currents is small for \( M_2 \) constituents in the waters of East Aceh is because these waters are too deep and wide. The influence of the size and size of the current is seen in the amount of energy captured by the swept area of the turbine. This area has enormous energy potential. It is proven that using one harmonic component can reach the minimum speed of small scale turbines.

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