Kinetic energy of M2 tide in the Makassar Strait

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Abstract. The Makassar Strait (MS) is the main passage through the Pacific to Indonesian waters, which divides the islands of Kalimantan and Sulawesi. These waters are rich with natural resources. The research objective was to determine the energy produced by the M2 tides in the Makassar Strait. Ocean currents and energy are analyzed from the output of a two-dimensional numerical model. The results showed that the tidal flow velocity in the Makassar Strait was above 1 m/s, especially in Balikpapan (1.1975 m/s), Mamuju (1.3379 m/s), and Pantoloan/Palu (1.2728 m/s). While the power or tidal current energy in Balikpapan is 3,6238 x 10^4 Watt, Mamuju is 2,0215 x 10^5 Watt, and Pantoloan/Palu is 7,4006 x 10^5 Watt. The tidal energy is intense in Pantoloan/Palu compared to other stations.

1. Introduction
Rapid development in population, infrastructures, and technology globally drives 9% of energy demand per year [1]. Therefore, as the maritime region, Indonesia should pursue renewable energy from the ocean [2-3]. Makassar Strait (MS), connects the islands of Kalimantan and Sulawesi, is the main route for Indonesian throughflow from or to the Pacific Ocean [4-7] (Fig. 1). MS currents are complex, influenced by the fluxes of the Pacific Ocean as well as the tides [8-9]. Most ocean dominated by M2 tide, it can interact with itself or with other tidal components such as N2 and S2 or the diurnal tidal component [10]. In shallow waters, bottom topography can modify the M2 tide by nonlinear interactions [11]. As a result, the phase and currents of M2 tide vary in spatial [12]. This study examines current velocity and tidal energy at the Makassar Strait stations. The tidal flow was obtained from a simulation of a two-dimensional numerical model. Furthermore, the tidal energy of MS was analyzed from the current velocity.

2. Material and Methods

2.1 Numerical model design
Topographical of MS were obtained from the Shuttle Radar Topography Mission (SRTM30). The model is discretized with a resolution of Δx = Δy = 3' and Δt = 25' following the CFL (Courant-Freiderichs-Lewy) criteria [13].
where \( h \) is the maximum depth, \( g \) is the Earth's gravitational acceleration, \( \Delta t \) is the time step, and \( \Delta x \) and \( \Delta y \) is the spatial resolution of numerical model as in (1).

2.2 Initial and open boundary data

The amplitude and phase for the M2 tide were obtained from the Geospatial Information Agency (BIG or GIA) (http://tides.big.go.id/pasut/konstanta/) with \( \Delta x = \Delta y = 3' \) resolution. The open boundary values of sea level (\( \eta \)) are as follow (2):

\[
\eta = A_{M2} \cos \left( \frac{2\pi}{T_{M2}} t - \varphi_{M2} \right) \tag{2}
\]

where \( A_{M2} \) and \( \varphi_{M2} \) are the amplitude and phase of M2 tide, \( T \) is the period of M2 (12.42 hours), and \( t \) is the time (in second).

2.3. Model analysis

Sea level elevation is obtained quarterly from simulated M2 tides (\( \eta^{T/4}, \eta^{T/2}, \eta^{3T/4}, \) and \( \eta^T \), where \( T = 12.42 \) h). Then, to get the amplitude (\( A \)) and phase (\( \varphi \)) values, it was analyzed by equations (3) and (4).

\[
A = \sqrt{\left( \frac{\eta^{T/4} - \eta^{3T/4}}{2} \right)^2 + \left( \frac{\eta^T - \eta^{T/2}}{2} \right)^2} \tag{3}
\]

\[
\varphi = \tan^{-1} \left( \frac{\eta^{T/4} - \eta^{3T/4}}{\eta^T - \eta^{T/2}} \right) \tag{4}
\]
Amplitude and phase of M2 tide in three locations of MS, namely Balikpapan waters, Mamuju waters and Pantoloan/Palu waters, are then validated and analyzed. Table 1 is a research domain of the present study.

| Latitude (°N) | Longitude (°E) | Location    | Depth (m) |
|--------------|----------------|-------------|-----------|
| 2.355294     | 117.2567       | Balikpapan  | 59.203    |
| 2.355294     | 118.8356       | Mamuju     | 442       |
| 0.680919     | 119.385        | Pantoloan/Palu | 818    |

2.4. Power extraction based on turbine

Based on the shape of the turbine cross-section, the power or energy of the tidal can be found as follows [14]:

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

(5)

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

3. Results and Discussions

3.1 Model verification

Table 2 indicates the data collection in the waters of Balikpapan, Mamuju, and Pantoloan/Palu. The amplitude of M2 tide in Balikpapan station is 0.5041 m (model output) and 0.5087 m (BIG). The phase of M2 tide from model output is 278.9152°, and BIG is 278.9482°. BIG amplitude is higher than the model output. The difference in amplitude is 0.0046 m, and the phase difference is 0.33°. The amplitude of M2 tide in Mamuju is relatively the same with Balikpapan. Amplitude from model output is 0.5554 m and BIG data is 0.5687 m. The phases of M2 tide are 280.7765° (model output) and 280.8351° (BIG). It is shown that the BIG amplitude is higher compared to the model output. The difference in amplitude is 0.0133 m, while the phase difference is 0.0586°. In Pantoloan/ Palu waters, the model shows an amplitude of 0.5693 m, while BIG is 0.5809 m. The M2 phase of the model is 280.9507°, while BIG is 281.1942°. BIG amplitude is also higher than that of model simulation. The difference in amplitude data is 0.0116 m, while the phase difference is 0. Figures 2 show the sea level elevation of M2 tide at three station points based on BIG data and model simulations. In general, in three locations, namely: Balikpapan, Mamuju, Pantoloan/Palu, the sea level model results are the same as BIG data (verification).

| Location         | Model Simulation | BIG       |
|------------------|------------------|-----------|
|                  | Amplitude (m)    | Phase (°) | Amplitude (m) | Phase (°) |
| Balikpapan        | 0.5041           | 278.9152  | 0.5087        | 278.9482  |
| Mamuju           | 0.5554           | 280.7765  | 0.5687        | 280.8351  |
| Pantoloan/Palu    | 0.5693           | 280.9507  | 0.5809        | 281.1942  |
Figure 2. Sea-level elevation in Balikpapan, Mamuju, and Pantoloan/Palu based on BIG and model simulation.

3.2 M2-tide Power Extraction

The eta, $u$, and $v$ velocity are visualized in Figure 3 for Balikpapan waters at a speed of 0.79 m/s so that the highest peak occurs at 1.75 s with an altitude of 0.5 m. Figure 4 visualize the velocity eta, $u$ and $v$ in Mamuju waters at a speed of 0.9 m/s so that the highest peak occurs at 3.1 s with an altitude of 0.59 m. Figure 5 visualize the velocity of eta, $u$ and $v$ of the Pantoloan/Palu waters at a speed of 0.9 m/s so that the highest peak occurs at 3.25 s with an altitude of 0.59 m.

Table 3. Turbine 600 kW parameter.

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

Table 3 indicates the indicators used in the tidal energy extraction simulation for M2 components. After getting the values of eta, $u$ and $v$, calculating the value of power will be carried out [14]. Table 4 indicates $U_{in}$ obtained from the velocity values $u$ and $v$. The difference in wind concentration, wave elevation, amplitude, and phase will affect the value of the water's current velocity [16]. Tidal flow velocity in Balikpapan waters (1.1975 m/s), Mamuju waters (1.3379 m/s) and Pantoloan/Palu (1.2728 m/s).
Figure 3. Current velocity of u, v, and resultant of current velocity in The Waters of Balikpapan.

Figure 4. Current velocity of u, v, and resultant of current velocity in The Waters of Mamuju.
Figure 5. Current velocity of u, v, and resultant of current velocity in The Waters of Pantoloan/Palu.

Table 4. The results of the M2 currents and power in the Makassar Strait.

| Location       | U_m (m/s) | P (kW)          |
|----------------|-----------|-----------------|
| Balikpapan     | 1.1975    | 3.6238 x 10^4   |
| Mamuju        | 1.3379    | 2.0215 x 10^5   |
| Pantoloan/Palu| 1.2728    | 7.4006 x 10^5   |

The power of the M2 tidal (P) is given as follows [17], namely:

\[ Cp = \frac{P}{\frac{1}{2} \rho AV^3} \]  \tag{6}

Table 4 indicates the current strength in Balikpapan (3.6238 x 10^4 kWatt), Mamuju (2.0215 x 10^5 kWatt), Pantoloan/Palu (7.4006 x 10^5 kWatt). The current strength in Balikpapan waters is small, while in Pantoloan/Palu waters, it is high. This difference is due to the influence of Arlindo and the influence of long waves from the Indian Ocean, causing propagation. Winds contribute to MS in April, August, and October. During these periods, the circulation increases with an average speed of 2 m/s due to southeast winds. However, August and October are dominated by water masses of the Java Sea due to the south wind [18]. The extraction of M2 components uses a horizontal tidal current turbine (HATCT) of 600 kW because it can absorb greater energy [19]. The current strength of Mamuju and Pantoloan/Palu waters is so great that it can use a 600 kW turbine and a maximum Cp of 0.396. In comparison, Balikpapan can only use a 70 kW turbine with the consideration that the Cp value is minimized. The Cp number will affect the length of the blade in obtaining the amount of current extracted. Using two blades with a high rotor diameter is an
economical option. It makes the friction force higher so that it is minimized by the pitch control technique [20]. The tidal currents' strength must exceed 2 m/s to produce electric power [21]. The turbine is located at a depth of 1.5 m.

Conclusion
The conclusion is that the current strength at the three MS station points is relatively high. In Balikpapan it is 3.6238 \times 10^4, Mamuju is 2.0215 \times 10^5, and Pantoloan/Palu is 7.4006 \times 10^5 (m/s). Balikpapan station has a little energy among other station points. Meanwhile, the energy recovery in the Pantoloan/Palu area is very high. It is because the waters of Mamuju and Pantoloan/Palu have a steeper topographic slope than the waters of Balikpapan. Then, the depth of the waters also affects the quantity of tides in producing energy. Balikpapan waters have a very small depth compared to the waters of Mamuju and Pantoloan/Palu.

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