Applicability of Tide Height Difference-Based Metric for Rapid Tidal In-Stream Energy Resource Assessment in the Philippines

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Abstract
The Philippines is well-known for its relatively strong persistent currents in its straits and channels. Having a less complex methodology with acceptable accuracy for tidal in-stream resource assessment will enable geographic information system (GIS)-based data to increase turn-around time for site suitability, technology matching, and feasibility studies for ocean renewable energy installations. Tidal current flow simulations using DELFT3D are compared with in-situ data using a combination of acoustic doppler current profiler (ADCP) and drifter measurements. Hourly power generation estimates are calculated for some test sites and one month’s energy production is projected. A proposed energy potential (EP) metric is investigated and benchmarked in comparison with calibrated simulations and in-situ measurements for three test sites. Results show that a simple EP metric may be used for monthly energy projection with a certain level of confidence.

Keywords
tidal power, energy potential, resource assessment

1. INTRODUCTION
The global ocean energy resource available is in the same order of magnitude of the present worldwide electricity consumption. Five basic forms for ocean energy can be harnessed to generate electricity by various means [1], [2].

1.1 Tidal Power
A significant number of technologies for harvesting energy from tidal currents are being developed worldwide (see Fig. 1). Some of these technologies are at or near full-scale development and are undergoing sea trials [1], [2].

Tidal Power has been harnessed by a number of countries around the world since the 1970's. France has an existing 240 MW tidal power plant. UK has projected its tidal energy potential to be 50 TWh annually. A combination of barrage-type and hydrokinetic energy extractions have been used around the world [3,4].

Recently, a few countries leaned towards using Tidal In-Stream Energy Conversion (TISEC) devices which is a more environment-friendly, relatively cheaper option with the same predictability and reliability as that of existing barrage-type tidal power plants. Existing pilot sites in the U.K., Ireland, the Amazon, and Korea among others have installed TISEC devices. Resource assessment of potential tidal in-stream energy sites have been done by other countries as well such as Canada, U.S.A., Australia, and even Malaysia.

1.2 Resource Assessment for Tidal In-Stream Energy
Resource assessment for tidal energy covers both the tidal barrage potential and the tidal stream potential. Tidal barrage resource assessment is mainly dependent on the tidal range of the site to be assessed and the
volume of water that a reservoir can hold. Tidal stream power, on the other hand, is dependent on the average flow velocity of the site [3, 4]. The better the velocity of tidal currents is modeled, the more accurate the power estimation is of a site [3, 4]. The basic equations used for tidal stream power and energy density calculations are:

\[ p = \frac{1}{2} n \rho U^3, \quad \text{in W/m}^2 \]  \hspace{1cm} (1)

\[ E_d = pt, \quad \text{in W-h/m}^2 \]  \hspace{1cm} (2)

where:

- \( p \) is power density (i.e. available power per unit of cross-sectional capture area),
- \( n \) is the product of turbine and power equipment efficiencies as used by [8],
- \( \rho \) is sea water density (~ 1025 kg/m\(^3\)),
- \( U \) is the depth-averaged flow velocity (m/s)
- \( E_d \) is energy density, and
- \( t \) is time.

Fig. 2 show two energy density map examples for resource assessment of tidal power. The locations with strong tidal currents are primarily those in straits and channels where constricted passages act as links to two basins or larger bodies of water. Models have been formulated, investigated, and tuned to provide a good alternative resource assessment method to in-situ measurement of currents [5]. Simulations in 2D and 3D have been used in practice for tidal current prediction and depth-averaged velocities are used in conjunction with the power law for site assessment around the world [6, 7, 8].

A simplified methodology has been proposed in [9] making use of a calibrated energy potential (EP) metric that makes use of the tide height difference at the boundaries of a channel. Fig. 3 shows a crude map of the EP metric benchmarked with the energy density result from a DELFT3D-based hydrodynamic simulation output.

### 2. METHODOLOGY

In this work, a similar framework (see Fig. 4) is used as that in [9] with the addition of an in-situ validation component to calibrate the simulation output of Delft3D. The same EP metric is used for more sites in the Philippines (see Fig. 5) to validate the performance in terms of consistency and correlative accuracy when compared with the results of hydrodynamic simulations.

**In-situ** measurements to get depth-averaged velocities of underwater currents are done using the “gold standard” Acoustic Doppler Current Profiler (ADCP) together with a modified tri-depth drifter scheme used by [10] for assessment of tidal in-stream energy.
Fig. 4  Selected Study Sites in the Philippines

Fig. 5 shows a map of the Cebu site with tide-height nodes overlayed. The dataset from which the tidal components (i.e. M2, S2, K1, O1, N2, P1, K2, Q1) of each of these nodes are from the same source as that used in [9].

Fig. 5  Tide-height nodes for Santander, Cebu Site

Fig. 6 shows a snapshot of a series of quiver plots for the depth-averaged velocities of the Cebu study site. All four sites undergo hydrodynamic simulations using Delft3D using tidal forcing along from 8 tidal components at their respective pre-defined grid boundaries.

As in [9], the same method is used for choosing the relevant tide-height nodes for calculating the EP metric. In Fig. 5, the nodes labeled A, B, C, and D fall within the criteria set by [9] as boundary nodes for the channel. The EP metric is computed following the calculation flow in Fig. 7.

3. RESULTS & DISCUSSION

3.1 In-Situ Measurements

Shown in Fig. 8 is a comparison of the depth-averaged velocity data derived through ADCP and the drifters. Note that the drifter method gives the same trend as the ADCP but we see a mild scaling in the velocity values.

Fig. 8  ADCP versus Drifter Measurements of Depth-Averaged Velocities

Both the Cebu and Davao sites had in-situ measurements done with the use of ADCP and the drifters. The Matnog site, however, only used drifters to measure the velocities.

Comparing the in-situ depth-averaged velocity data to the output of the Delft3D simulation, a scaling effect is observed (see Fig. 9). The measured velocities are higher than those predicted via the simulation. Thus, a scale factor is used to serve as a correction multiplier to calibrate the simulation results with the field data.
3.2 Calibrated Velocity Histograms

Once the hourly current predictions are calibrated using the scale factor computed above, velocity histograms are generated for the locations within sites selected. Shown in Fig. 10 are two velocity histograms for two sites (i.e. Davao and Cebu) generated for one month.

3.3 Energy Density Maps

Fig. 11 shows a series of energy density maps that illustrates areas with high energy density for the simulated 1-month period.
3.4 Performance of the EP Metric

To validate the performance of the EP metric, the relationship between the 1-month energy density (derived from the calibrated current simulations) is investigated using a scatter plot (see Fig. 12) where a good correlation is observed.

![Energy Density vs EP Metric](image)

Fig. 12 Scatter Plot for Energy Density (max per bounded location) and the EP Metric

The EP metric seems to have certain operational ranges or sections where clustering of low, medium, and high energy densities are observed but this will have to be investigated further.

4. CONCLUSION

The tide-height difference metric was tested in a total of four sites. The relationship between this proposed energy potential metric and the calculated energy densities of selected sites was shown and a consistent correlation was observed.

Significant energy densities per month of the selected sites range from 3 to 5 MWh/sq. m in Verde, around 3.5 to 6 MWh/sq. m in the Matnog-Samar area, about 100 to 220 kWh/sq. m in Davao-Samal-Talicud, and just 10 to 25 kWh/sq. m in Santander, Cebu.

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