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Tidal energy potential in coastal Vietnam

Huy Toan Do*, Thanh Binh Nguyen, Tuan Minh Ly

Center for Environmental Fluid Dynamics, University of Science, Vietnam National University, Hanoi

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Abstract:

Tidal energy is a renewable energy source produced by the rise and fall of ocean tides. Tidal energy can be exploited using a special type of generator that converts tidal energy into electricity. Tidal power generation has the potential to open up many prospects for energy field and minimize carbon dioxide emissions that cause the greenhouse effect. To evaluate the possibility of tidal power, it is necessary to have documents and data on average annual tidal amplitude, tidal regime, and main tidal waves in the study area. To calculate the tidal power potential for the east coast of Vietnam, this article applies the calculation formula of tidal power energy by Russian scientist L.B. Bernstein. The annual mean tidal amplitude and the K1, O1, and M2 wave amplitude data at nearly 2000 calculation points along the coast of Vietnam were extracted from the TPOX8-Atlas harmonic constant set. Research results showed that Vietnam has great potential for tidal energy along the Hai Phong - Quang Ninh coastal area and the southeast region with a prospective 41.6 GWh/km²/y.

Keywords: **tidal energy, tidal energy potential, TMD toolbox, TPOX8-Atlas.**

Classification number: **4.4**

Introduction

Energy is an important factor in the socio-economic development of a country. However, increasing energy demands have caused fossil energy reserves to quickly deplete. Environmental and politics issues have made energy security an urgent matter and a great concern for all nations. Nuclear power technology is unsafe and there is always a potential radiation hazard, such as Chernobyl (1986) and Fukushima (2011), leaving behind long-term damage to the global socio-economy and environment [1, 2]. Therefore, people are now looking for new sources of energy to replace fossil fuels and nuclear energy in effort to overcome their disadvantages.

With a global sustainable development strategy, especially during the period of "green economic development", the world is beginning to see new technologies for cleaner electricity generation. In the 21st century, humanity has witnessed the rapid development of new energy sources, especially from the ocean. Scientific and technological advances have allowed new resources to be exploited to produce electricity from marine renewable energy sources such as wind, ocean waves, tidal current, sea temperature gradient, and salt gradient, etc. Among these, some have already been commercialized on a large scale such as wind power stations (coastal and island), tidal energy stations, ocean wave power stations, and marine thermal gradient power stations [3].

Currently, research on tidal energy has particularly interested many countries with great potential for tidal energy such as the UK, France, Russia, India, China, Korea, and Canada. However, research on tidal energy in Vietnam is still limited. The few results have yielded mostly general assessments and sometimes used only tidal data from one location for simulations across a large region. This paper conducts research over a large area along the coast of Vietnam with the farthest data extraction point about 250 km from the coast (area 7). This is a new point compared to previous studies because research on tidal electric energy has been focused on coastal areas with a distance of 30-40 km [4].

This work evaluated the potential of tidal power for the coastal area of Vietnam by the Bernstein formula developed by the Russian scientist L.B. Bernstein

*Corresponding author: Email: dohuytoan@hus.edu.vn

[5]. Input data sources for the Bernstein formula were extracted using Tide model driver (TMD) tool with exploitation of the TPOX8-Atlas harmonic constant, which was researched and developed by Oregon State University, USA, with a resolution of 1/6°. The TMD TPOX8-Atlas tool uses new generation map data and satellite elevation data assimilation methods of Padman and Erofeeva (2005) [6] and Egbert, Bennett, and Foreman (1994) [7] into the global shallow water model. Research results are the basis for comparison with other evaluation methods and contribute to building a scientific basis for future related studies.

Materials and methods

Study area

The study area is the coastal area of Vietnam with a diverse and complex topography stretching from 7°N - 22°N, 103°E-111°E (Fig. 1). According to research by Nguyen Ngoc Thuy (1984) [8], Vietnamese tides are very diverse with all the tidal regimes of the world such as diurnal tide, mixed diurnal tide, semi-diurnal tide, and mixed semi-diurnal tidal all distributed alternately.

From north to south, the tidal regime changes its features, the study has divided the tidal regime into the following areas (Fig. 1):

- Area 1: North Sea to Thanh Hoa, diurnal tide.

- Area 2: Nghe An to Cua Gianh sea area, mixed diurnal tide, number of diurnal days accounts for more than half a month.

- Area 3: Southern sea area from Cua Gianh to Thuan An, mixed semi-diurnal tidal.

- Area 4: Thuan An and adjacent waters, semi-diurnal tidal.

- Area 5: Nam Thuan An to northern Quang Nam sea area, mixed semi-diurnal tide.

- Area 6: middle of Quang Nam to Binh Thuan sea area, mixed diurnal tide.

- Area 7: Ham Tan to Ca Mau cape sea area, mixed semi-diurnal tide.

- Area 8: Ca Mau cape to Ha Tien sea area, mixed diurnal tide.

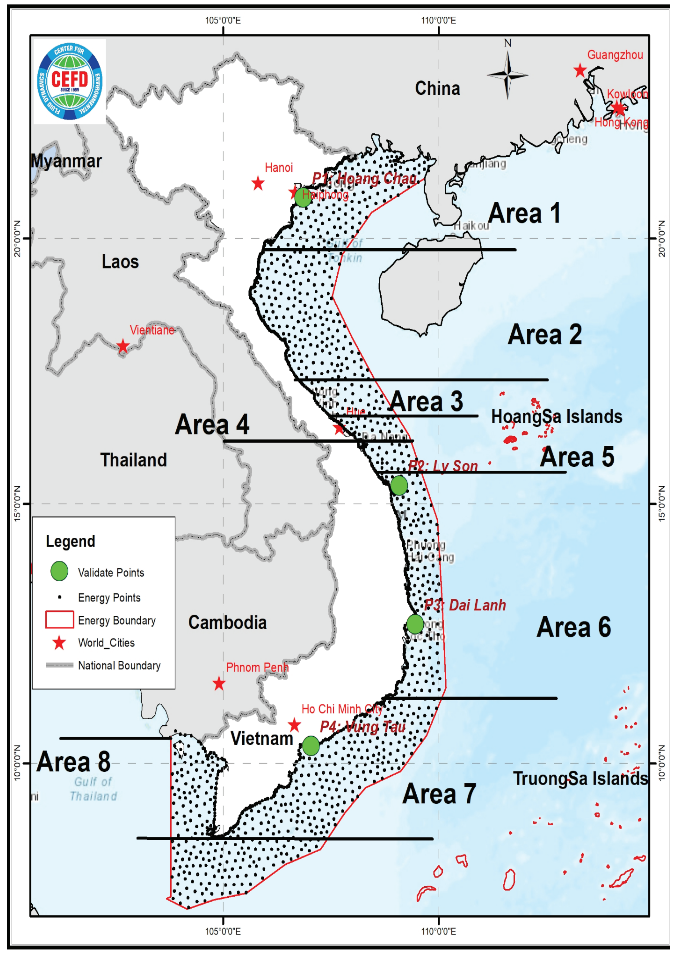

Fig. 1. Map of study area and calculation tool validation locations.

Data

The annual mean tidal amplitude and the K1, O1, and M2 wave amplitude data (calculated for year 2019) for nearly 2000 calculation points along the coast of Vietnam were extracted from the TPOX8-Atlas harmonic constant set.

Water level data used to validate the quality of TMD TPOX8-Atlas tool were observed water levels (10 min/obs) measured at Hoang Chau, Ly Son, Dai Lanh, and Vung Tau (Fig. 1).

Methods

The Bernstein formula has been widely applied when calculating coastal and estuary areas in the world.

According to Bernstein [5], the formula for evaluating the annual tidal energy potential for an area with a semi-diurnal tidal regime is as follows:

$$E_{tn} = 1.97 * 10^6 A_{tb}^2 S \quad (1)$$

For the area with the annual tidal regimes other than semi-diurnal tide, Bernstein applies the following formula:

$$E_{tn} = 1.97 * 0.5 * 10^6 A_{tb}^2 S(1 + \frac{4-D}{D}) \quad (2)$$

with E_{tn}: tidal energy potential/year; A_{tb}: annual average tidal amplitude; S: sea surface area (km^2); D: tidal feature value.

$D = \frac{H_{K1} + H_{O1}}{H_{M2}}$; H_{K1} moon-sun tidal waves amplitude K_1; H_{O1} diurnal tide wave amplitude O_1; H_{M2} semi-diurnal tide wave amplitude M_2.

In this study, Bernstein's formula (1) was applied to area 4 and formula (2) was applied to the remaining study areas along the coast of Vietnam.

Results and discussion

Simulated water level extracted from TMD TPXO8-Atlas tool for 4 locations (Hoang Chau, Ly Son, Dai Lanh, and Vung Tau) was compared with observed water level. Fig. 2 shows the evolution of water level in Hoang Chau (from 22nd August 2012 to 30th August 2012), Ly Son (from 14th June 2013 to 30th June 2013), Dai Lanh (from 9th August 2014 to 16th August 2014), and Vung Tau (from 31st August 2020 to 7th September 2020) showed that the TMD TPXO8-Atlas tool has well simulated the phase and magnitude of tides. The simulation results (Table 1) have high reliability with the Nash-Sutcliffe efficiency correlation coefficient (NSE) greater than 0.88. Therefore, the data set of annual average tidal amplitude and tidal wave amplitude K1, O1, and M2 extracted from the TMD TPOX8-Atlas tool is reliable enough to be included in Bernstein's formulae.

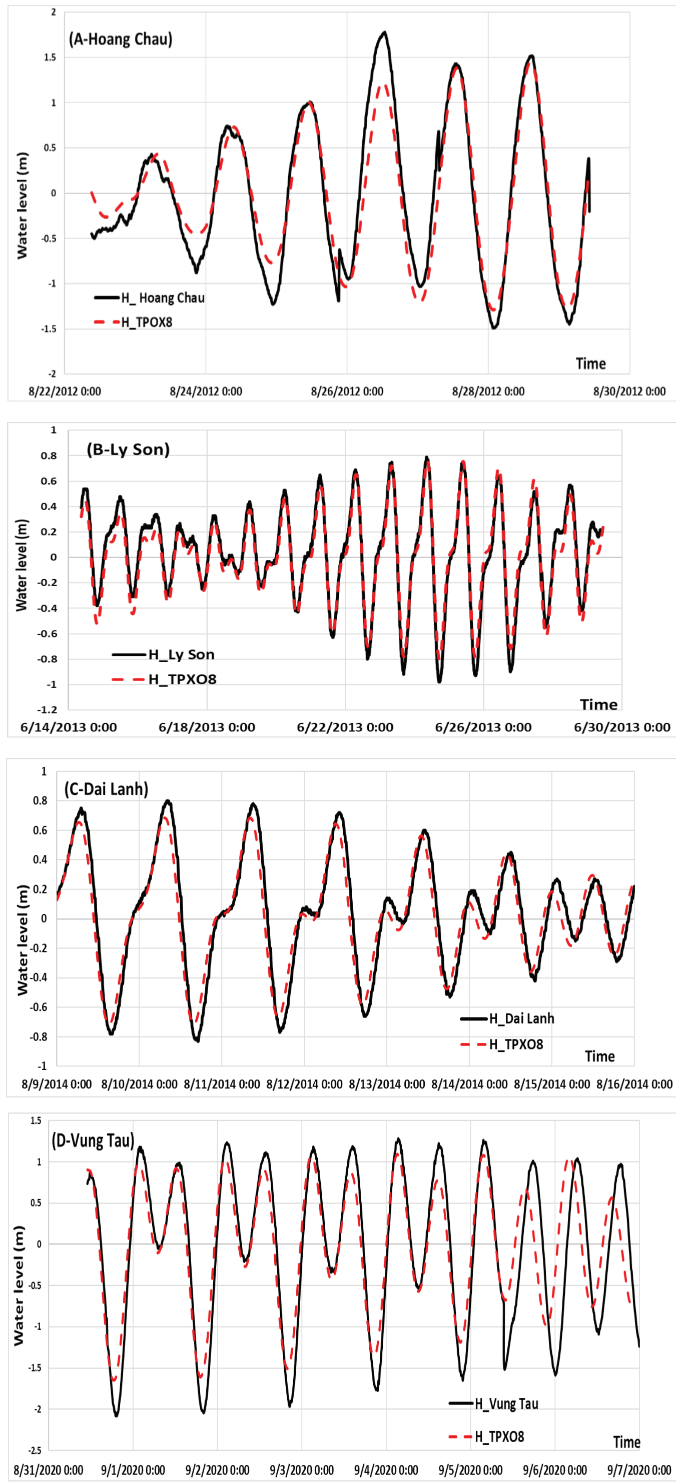

Fig. 2. Observed and simulated water level, TMD TPXO8-Atlas.

Table 1. Nash-Sutcliffe efficiency correlation coefficient (NSE).

Location	Hoang Chau	Ly Son	Dai Lanh	Vung Tau
NSE	0.91	0.94	0.97	0.88

The TMD TPOX8-Atlas tool was calculated for the simulation time of 2019. The obtained results were 1-year water level series and the amplitude of the tidal waves K1, O1, and M2 at nearly 2000 locations along the coast of Vietnam. From these series of water levels, the annual mean tidal amplitude for each location has been calculated.

Table 2 shows the annual mean tidal amplitude and tidal wave amplitude K1, O1, and M2 at some typical locations. Tidal amplitude decreases gradually from Quang Ninh to Thuan An and then gradually increases at the Ca Mau cape and decreases from Ca Mau cape to Ha Tien. Mong Cai, Ha Long, Vung Tau, and Dinh An has the largest tidal amplitude in Vietnam with results of 3.38, 2.95, 2.52, and 2.69 m, respectively. Thuan An and Ha Tien had the smallest tidal amplitude with results of 0.45 and 0.68 m, respectively. The study results have shown the correct distribution of the tidal range in the East Sea.

Table 2. Annual mean tidal amplitude and tidal wave amplitude K1, O1, M2 at some typical locations.

No	Location	A_{tb} (m)	H_{K1} (m)	H_{O1} (m)	H_{M2} (m)
1	Mong Cai	3.38	0.735	0.9439	0.2122
2	Ha Long	2.95	0.674	0.752	0.074
3	Hoang Chau	2.52	0.6797	0.7611	0.058
4	Sam Son	2.48	0.5985	0.6567	0.2584
5	Cua Gianh	1.48	0.2344	0.3181	0.2
6	Thuan An*	0.45	0.0383	0.048	0.1794
7	Ly Son	1.38	0.28	0.2242	0.1862
8	Dai Lanh	1.47	0.3331	0.2822	0.1724
9	Vung Tau	2.52	0.5819	0.3127	0.7408
10	Dinh An	2.69	0.5468	0.4189	0.7422
11	Ca Mau	1.66	0.4239	0.2354	0.2
12	Ha Tien	0.68	0.1935	0.1655	0.06

Note: formula (2) was not applied for Thuan An so K1, O1, M2 are not used.

The calculation results after applying Bernstein's formula are shown in Table 3 and Figs. 3 and 4. It can be concluded that area 7 has the greatest tidal power potential in the country, followed by areas 1 and 2. The largest, average, and smallest capacity in area 7 are 41.66, 10.39, and 0.91 GWh/km^2/y. The largest, average, and smallest capacity in area 1 are 17.33, 6.42, and 1.25 GWh/km^2/y, respectively. The largest, average, and smallest capacity in area 2 are 6.1, 3.02, and 0.27 GWh/km^2/y, respectively.

The above results show that tidal power energy in coastal Vietnam has a huge potential for exploitation.

Table 3. Tidal energy for each study area.

Area	E_{tn} medium (GWh/km^2/year)	E_{tn} max (GWh/km^2/year)	E_{tn} min (GWh/km^2/year)
Area 1	6.42	17.33	1.25
Area 2	3.02	6.1	0.27
Area 3	1.18	3.85	0.16
Area 4	0.8	2.75	0.16
Area 5	1.11	2.7	0.33
Area 6	1.74	4.29	0.62
Area 7	10.39	41.66	0.91
Area 8	0.74	4.01	0.05

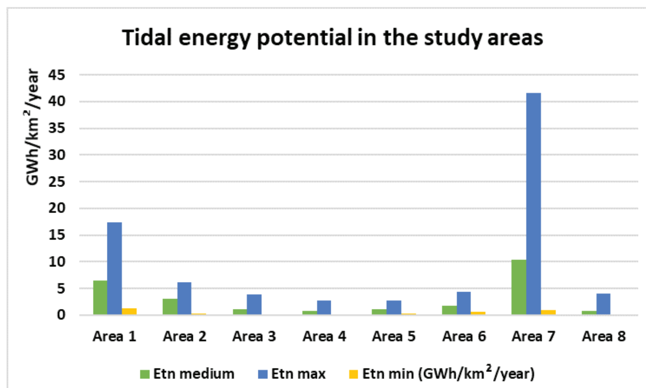

Fig. 3. Tidal energy potential in the study areas.

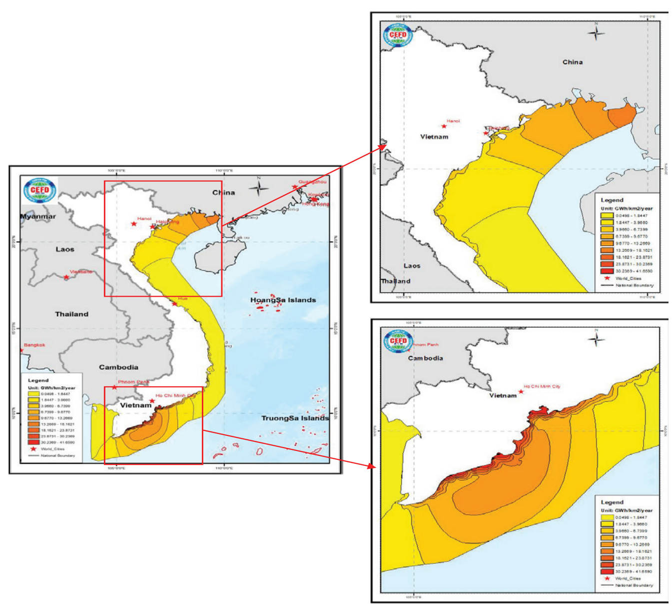

Fig. 4. Tidal energy potential in coastal Vietnam.

Conclusions

This article assessed the potential of tidal energy in coastal Vietnam using Bernstein formulae and the TMD TPOX8-Atlas tool. The annual mean tidal amplitude and the K1, O1, and M2 wave amplitude data at nearly 2000 calculation points along the coast of Vietnam were extracted from the TMD TPOX8-Atlas tool. The results showed that the three areas with the largest potential for coastal tidal energy in Vietnam, in descending order, are area 7, area 1, and area 2 with average potentials of 10.39, 6.42, and 3.02 GWh/km^2/y, respectively. The remaining potentials from the other areas ranged from 0.74 to 1.18 GWh/km^2/y. It can be concluded that tidal energy in areas 1, 2, and 7 have a high potential for tidal wave energy production.

Further studies need to have more complete and detailed input data on the annual average water level amplitude calculated from a tidal cycle of 18.6 years and detailed seabed topography for the coastal area and specific areas of the water bodies.

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COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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