Feasibility Assessment of Tidal Current Along the Bay of Bengal to Generate Electricity as a Renewable Energy

Myisha Ahmad and G. M. Jahid Hasan

Abstract Electricity is the pinnacle of human civilization. At present, the growing concerns over significant climate change have intensified the importance of use of renewable energy technologies for electricity generation. The interest is primarily due to better energy security, smaller environmental impact and providing a sustainable alternative compared to the conventional energy sources. Solar, wind, biomass, tidal, and wave power are some of the most reliable sources of renewable energy. Ocean approximately holds 2×10^3 tW of energy and has the largest renewable energy resource on the planet. Various forms constitute ocean energy namely, encompassing tides, ocean circulation, surface waves, salinity and thermal gradients. Ocean tide in particular, associates both potential and kinetic energy. The study is focused on the latter concept that deals with energy due to tidal current. Tidal currents generate kinetic energy that can be extracted by marine energy devices and converted into transmittable electricity form. The study analyzes the extracted tidal currents from numerical model works at several locations in the Bay of Bengal. Based on current magnitudes, directions and available technologies, the most fitted locations were adopted and possible annual generation capacity was estimated. The paper also examines the future prospects of tidal current energy along the Bay of Bengal (BoB) and establishes a constructive approach that could be adopted in future developments.

Keywords Tide · Tidal current · Tidal turbine · Renewable energy
Energy potential · Bay of Bengal

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1 Introduction

In today's world, adequate supply of energy is a focal obligation for comprehensive development and constructive advancement of human lifestyle in any country. However, effects of global climate change and depletion of traditional energy sources of fossil fuel due to excessive consumption seem to be influencing the development trend to a significant extent. Recent studies also suggest that by 2100, the global energy demand would escalate by five times the current demand. A constructive and sustainable solution of this acute problem can be incorporation and analysis of renewable energy sources, as an effective means of power generation. Renewable energy chiefly includes wind, biomass, solar, ocean, and geothermal energies. Covering around 71% of the earth surface, ocean embodies the largest unused renewable energy resource on the planet. Theoretically, ocean is capable of producing 20,000–92,000 tW h/year of electricity that can meet the current world consumption of 16,000 tW h/year [1]. Ocean energy is attainable in various forms including wave, thermal, salinity gradient, and tide. Tidal energy in particular scores highly compared to the other forms in terms of availability of resources, supply security, and most importantly, minimal environmental impact. The extraction of energy from ocean tides can be achieved by "tidal current" and "tidal barrage" technology. The former concept, which is the main focus of this study, involves deployment of tidal current devices to the seabed to extract energy from fast moving tidal current utilizing kinetic energy, i.e., current velocity. A tidal current energy converter extracts and then converts this mechanical form of energy into transmittable form. This study is concerned with the assessment of feasibility of tidal current energy potentials along the Bay of Bengal and possible power generation through analysis of available data.

Until 20 years ago, the only form of tide energy for electricity generation was a barrage which harnesses potential energy. But recently, interest has been shifted toward harnessing the kinetic energy of tidal flows by tidal current turbines, using the principles similar to wind energy. Conversion efficiency of tidal current technology is less but predictable power generation capacity and relatively lower environmental impact makes the tidal current turbine technology potentially more acceptable and preferable than tidal barrage concept.

A river current turbine project ran from 1976 to 84, marks the origin of the marine tidal current concept. Peter Fraenkel used a vertical axis Darrieus-type rotor for irrigation pumping, which was anchored to the bank of the river Nile in Juba, Sudan. The turbine operated well through a head of 5 m and a current of 1 m/s, pumping 2000 L/h. With further development, the design was then marketed with a horizontal axis rotor [2]. Since then, projects supportive of similar technology started to develop and active research has been ongoing in the United States, Canada, Europe and Japan. However, the technology has yet to be developed to a great extent and devices are at early stages compared to other renewable energy technologies. Most of the designs for this technology are still at an experimental stage. Their commercialization is still at its infancy and has not yet matured to the extent of massive power generation. Many of them have great potentials for being used in large scale projects. The existing small-scale prototype models and some recent achievements of industrialized and pre-commercial large tidal current turbine (over 500 kW) technologies include: Open-hydro turbine-A 250 kW prototype installed in Orkney islands, Scotland, E-Tide turbine project (300 kW) installed in Norway, SeaGen S turbine installed in Strangford Lough, Northern Ireland-world's first grid-connected megawatt-level Marine Current Turbine (MCT) system, a 110 kW Voith Hydro Turbine has been operating since 2011 near the South Korean island of Jindo, and Sabella D10 turbines with a power capacity of 0.5–1.1 mW for current velocities of 3.0–4.0 m/s [3]. Moreover, a recent approach is the Deep Green—a 12 m diameter turbine mounted on a submerged anchored structure that intensifies the experienced water speed by a factor of 10, generating 220–500 kW units [4]. Studies and researches indicate huge potential of commercialization of these projects that are at prototype and testing phases.

Oceans are propitious resource, capable of providing clean energy on a grand scale. On the other hand, Bangladesh, with its 710 km long coast line, with suitable tidal range variations, and effective current speed, has promising renewable energy potential. Accelerated development of harnessing ocean energy along the Bay of Bengal can offer a wide sphere of long-term benefits including: identifying new prospects of de-carbonization of power supply, creating manifold energy generation portfolio, improved energy security in terms of production, distribution, and plausible economic development of the whole nation.

2 Tidal Current Technologies

2.1 Tidal Current

Tide is the result of mutual gravitational interaction among earth, moon and sun. Due to the floods and ebbs, the tides rises and falls generating horizontal movement of water called 'tidal current'. The current is not only influenced by tide but also by temperature, wind, salinity difference, relative positions of the sun and moon with respect to earth along with changing angles of declination. The extreme declination of the moon results largest currents, while lowest currents occur at zero declination. These astronomic characteristics results in periodic variation of tidal currents which can be predicted with high accuracy.

2.2 Harnessing Tidal Current Energy

The technique of harvesting current energy is to obstruct the free flowing water, trapping the kinetic energy and converting into transmittable electric energy.

The basic physical principle of extracting kinetic energy is virtually similar to that of wind. Tidal current devices are placed directly in stream to draw energy from tidal currents in a manner resembling wind turbine. In practice, tidal current devices are employed as fences or arrays of turbines in restricted channels and inlets, where the optimal tidal power is extractable with the option of few multiple rows. Tidal current power varies with density of the medium and cube of velocity. The density of water being 832 times of the density of air is capable of producing substantial power at lower tidal flow velocities, compared to wind speed. However, the tidal current technology is not yet adequately developed for large scale exploitation of energy resource. Some of the turbine designs have been developed to prototype stage for testing and some have been built to full scale for pre-commercial testing. The methods that have undergone prototype testing phases till date are highlighted as follows:

Vertical axis turbine technology. Vertical axis turbines typically consist of two or three blades attached to a vertical shaft forming a rotor. Incoming water flow hits the axis of rotation perpendicularly, as shown in Fig. 1a. The incoming flow generates a lift force to drive the rotor, which eventually rotates the generator and produce power.

Horizontal axis turbine technology. Horizontal axis turbines usually have two or three rotor blades which can generate lift and result axial rotation to drive a generator. These turbines ought to be aligned to the current either by rotating the device or by pitching the blades through an angle of 180° (Fig. 1b).

Oscillating hydrofoil turbine technology. This device consists of a hydrofoil connected to the end of a swing arm whose angle changes with the water stream as displayed in Fig. 1c. It rests on gravity-based foundation. The lift and drag force oscillates the arm, resulting in extension of the hydraulic cylinder. The cylinder is connected to the main arm and used to pump high pressure oil to a generator. Upon entering into the turbine of hydraulic design, the oil drives a generator and produce electricity.

Tidal kite. In this technology, the turbine is attached to a wing which moves forming loops in water. They are attached to the seabed with a moving wire, like a kite. The device moves through water at a speed higher than the water speed and are able to generate electricity from very low velocity currents (Fig. 1d).

Helical screws. Flumill's Helix screws' turbine is shaped like a screw. It has only one moving part and is slow-rotating. As water flows through the helix, the screws extract power from the tidal streams. The gearless turbine drives a permanent magnet synchronous generator and generates power (Fig. 1e).

Enclosed tip—venture. Enclosed tips (ducted) devices are enclosed within a shrouded structure. The funnel effect accelerates and concentrates on the fluid flow, allowing applicability of smaller rotor diameters. Moreover, ducted structures assist minimization of turbulence and alignment of the water flow into the turbine (Fig. 1f).

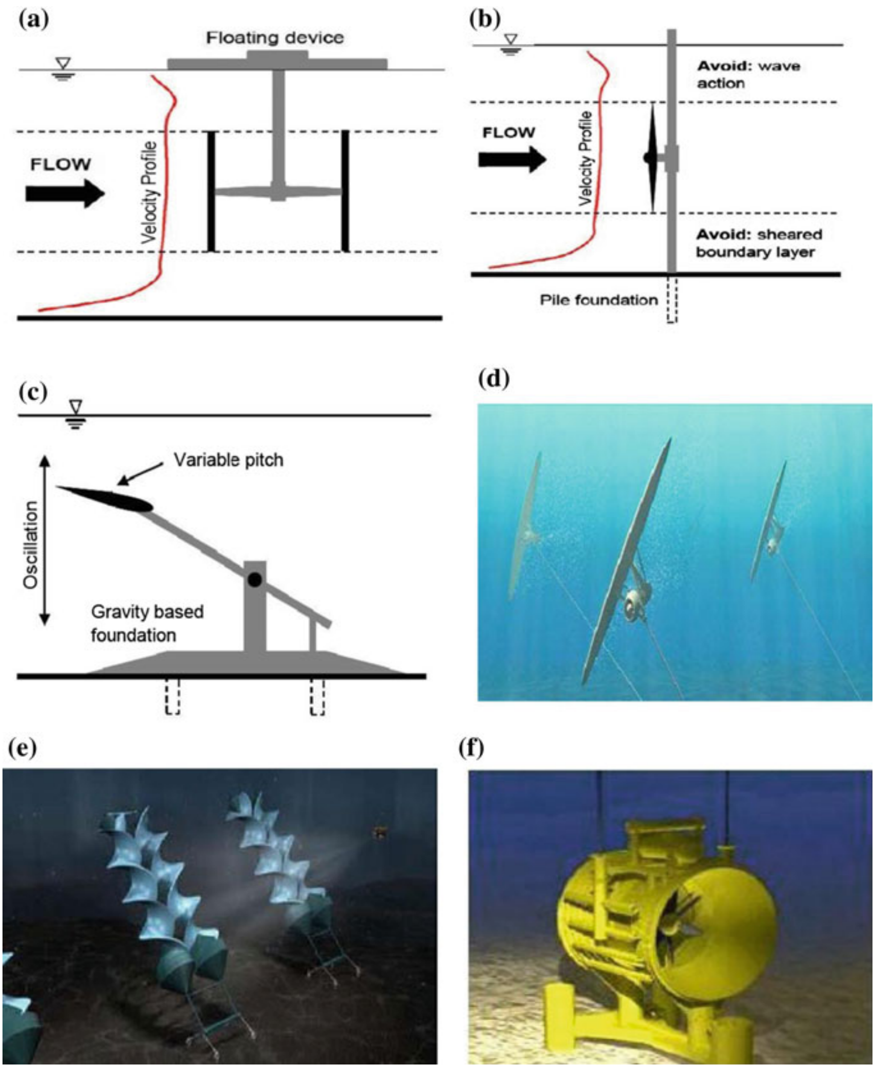

Fig. 1 Different types of available turbine technologies **a** vertical axis turbine, **b** horizontal axis turbine, **c** oscillating hydrofoil turbine, **d** tidal kite, **e** helical screws and **f** enclosed tip venture

3 Prospects of Tidal Energy in Bangladesh

3.1 Origin of Tides in the Bay of Bengal

The tides entering the Bay of Bengal originates in the Indian Ocean and gains access through two submarine canyons: the "Swatch of no ground" and the "Burma trench". There are six major entrances through which fresh water penetrate into the waterway system in Bangladesh and these are: (a) The Pussur Entrance, (b) The Haringhata Entrance, (c) The Tentulia Entrance, (d) The Shahbazpur Entrance, (e) The Hatia River Entrance, and (f) The Sandwip Channel Entrance [5]. The tides are predominantly semidiurnal with large variation in range corresponding to seasons, particularly during the monsoon. They are affected by the local conditions like geomorphology, configuration and orientation of the coast, upstream flow of rivers, number of openings in the coast. In some places, the tidal stream can reach up to 5.5 knots (2.8 m/s) which is suitable for establishment of tidal current turbine deployment [6].

3.2 Potential Locations in the Bay of Bengal for Tidal Current Energy Extraction

High tidal flows commonly occur in areas with narrow straits, around headlands, and between islands, enhanced due to funneling effect. Some of the fundamentals and key criteria of site selection for tidal current turbine deployment can be given as considerable spring peak current, uniform and strong currents, close to coast, constricted channels [7]. Coastal areas in Hiron Points, Mongla, Char Changa, Cox's Bazar, Golachipa, Patuakhali, Sandwip, Barisal, etc., are some of the important and suitable locations along the Bengal coast. But assessing the coast line along the Bay of Bengal, the Sandwip channel tends to fulfill most of these criteria and possess huge potential of tidal current energy. Situated at the estuary of the Meghan River on the Bay of Bengal the non-navigable channel is surrounded by Sandwip Island on one side and Chittagong on the other. This geological criterion enhances the current speed of the location varying from approximately 0.1–2.5 m/s in the tidal channels [8].

3.3 Present Scenario and Future Goal of Renewable Energy Development in Bangladesh

Renewable energy shares only 1% of the total available energy in Bangladesh, while in the world it accounts for almost 19% of total energy consumption. It is high time to shift the dependency trend from conventional fossil fuel sources to alternative means. However, the country intends to rise electricity generation up to 10% through utilizing renewable energy, by the year 2020 (http://www.powerdivision.gov.bd). With that aim, the government is already working to reduce the dependency on natural gas in commercial energy consumption, declining to 42% in 2012 compared to 50% in 2009 [9].

With the recent ocean victory, Bangladesh has been assured rights over 118,813 km^2 of territorial sea. Now she has access to the open sea and sovereign rights over 200 nautical miles exclusive economic zone that can be used and explored of marine resources including oil and gas [10]. So, huge potential energy is available in this large sea zone which can be utilized for generating electricity. Moreover, in order to promote the importance of replacing indigenous nonrenewable energy sources as well as to encourage different public and private investments in this sector, renewable energy is included in the national energy policy in year 2008. Although different forms of renewable sources are already being explored and utilized to extract energy, the vast potentials of the ocean renewable source of the Bay of Bengal is yet to be analyzed and studied.

4 Generation of Energy

4.1 Tidal Energy Estimation

The instantaneous power density P produced by a tidal current turbine can be calculated by Eq. (1) [11]

$$P = \frac{1}{2}\rho A V^3 C_{\mathrm{P}} \tag{1}$$

where

- ρ the water density (in kilogram per cubic meter),
- A the cross-sectional area of the flow intercepted by the device, i.e., area swept by turbine rotor (in square meters),
- V the flow velocity (in m/s),
- C_{P} the turbine efficiency.

For each cycle of tidal current, V varies with time in a predictable manner and is characterized by the depth of water level as well as channel position and seasonal changes.

4.2 Methodology

A stepwise methodology has been adopted in this study that leads to an estimation of effective stream power potential of the site under investigation, presented by a flowchart as depicted in Fig. 2.

Initially, bathymetry data and satellite images of all suitable locations along the Bay of Bengal were analyzed and finally Sandwip Channel with an approximate width of 13 m and 12–16 m water depth variation was selected as stable and feasible location. Figure 3 displays Sandwip Channel which is located in between Chittagong district and Sandwip Island. Reason for selection of this location is due to its relatively

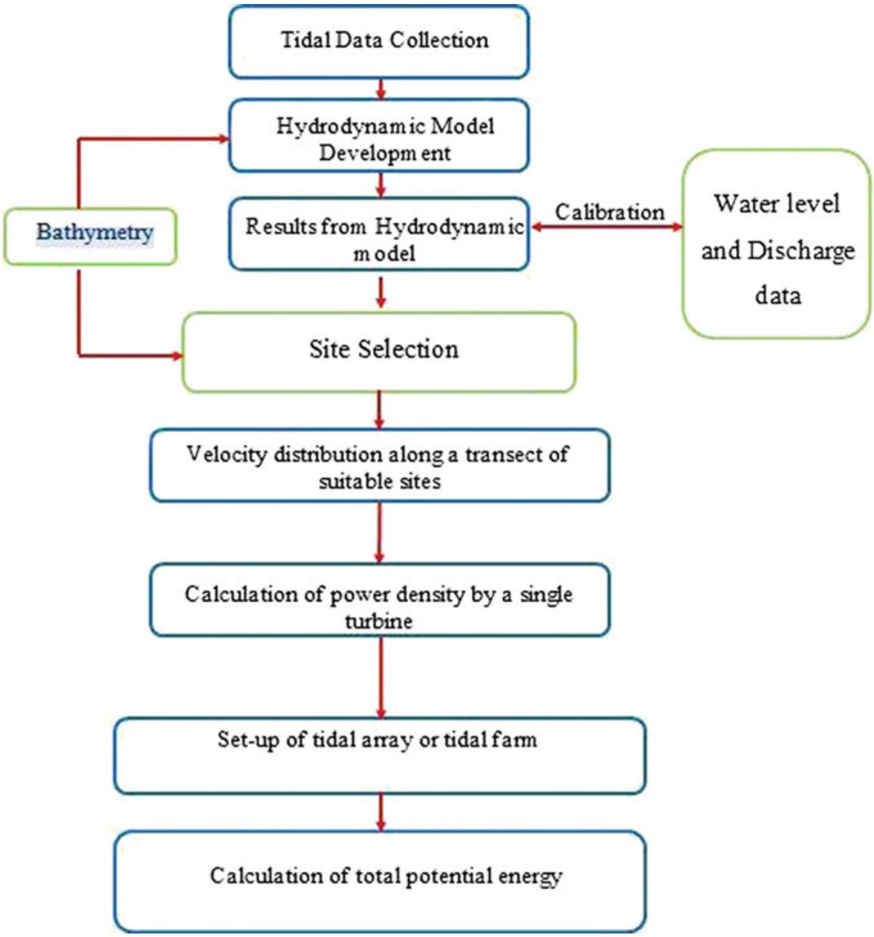

Fig. 2 Flowchart presenting stepwise methods followed for tidal current power potential calculation

stable channel, clean water, higher velocity, and it is nearer to the main land for connectivity. Then result from a hydrodynamic model obtained from a secondary source (developed by the Institute of Water Modelling) has been assisted in the analysis. The developed hydrodynamic model has been calibrated against measured water levels and discharges at different locations. Depth-average velocity and direction along a transect of Sandwip channel for a period of 14 days (covering spring-neap) during both monsoon (August) and dry period (March) for the year 2014 were extracted from the model results which were incorporated in the energy calculation procedure. During monsoon period, a maximum velocity of 2.41 m/s and minimum velocity of 0.19 m/s was observed. On the other hand, during dry period maximum and minimum velocity reached to 2.01 and 0.12 m/s, respectively.

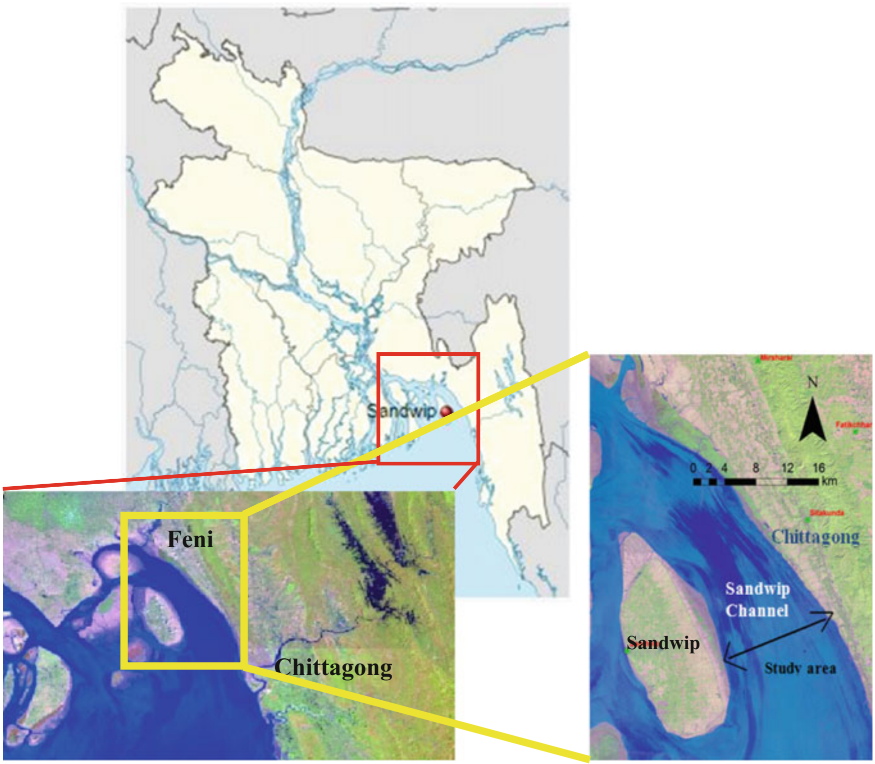

Fig. 3 Suitable study location along the Bay of Bengal. Main study location (Sandwip channel) is highlighted by a zoomed box

The developed hydrodynamic model divides the Sandwip channel into several grids. The depth-average velocities for each of the grids were taken from the 14 days modeled data of hourly variation. These data were averaged and the maximum value was taken into consideration for power calculation using Eq. (1). Figure 4 projects a graphical representation of change of generated power with the variation of velocity for both monsoon and dry period. An estimation of annual power generation has finally been made considering an array of turbines accommodated in a single row along the selected transects (Fig. 5).

For the purpose of this study, single-bed mounted horizontal axis turbine technology has been taken into consideration, given the fact that, it is the most efficient and practical concept and is most experimented among the existing technologies. Being similar to wind mill concept, it won't require exclusive technical expertise. Moreover, the bathymetry characteristics and sea bed nature of Sandwip channel prefers the deployment of the horizontal axis turbine.

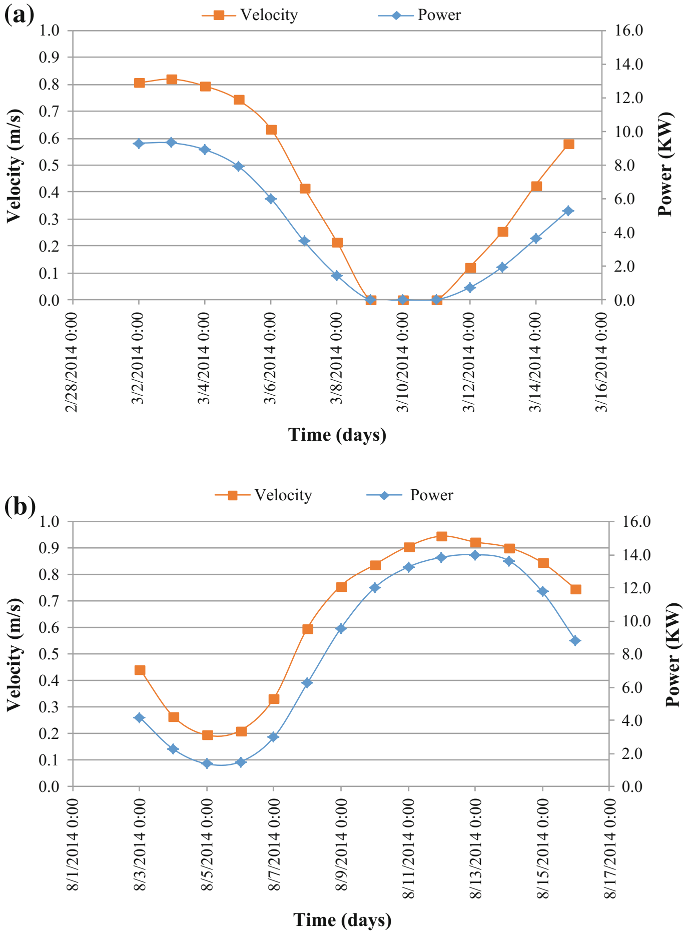

Fig. 4 Variation of daily average velocity and estimated power covering a spring-neap tidal cycle during **a** monsoon period and **b** dry period, for the year 2014

5 Result and Discussion

Total width of the Sandwip Channel is approximately 13 km. As the channel is bounded on both sides by stable landmass, naturally seabed is shallow at the corners and deeper at the center. Considering the fact, the effective width for tidal turbine deployment is selected to be 12 km. Spacing between subsequent turbine is considered as 10 times the diameter of a rotor. This spacing is required to reduce the wake effects of nearby turbines. Diameter of turbine rotor is considered as 6 m that yields a swept area of 28.274 m^2. Approximately 200 turbines can be deployed in a single row along a tidal stretch of 12 km and with a 35% turbine efficiency (i.e., C_p = 0.35), the total power output by all the turbines would sum up to 470 mW per

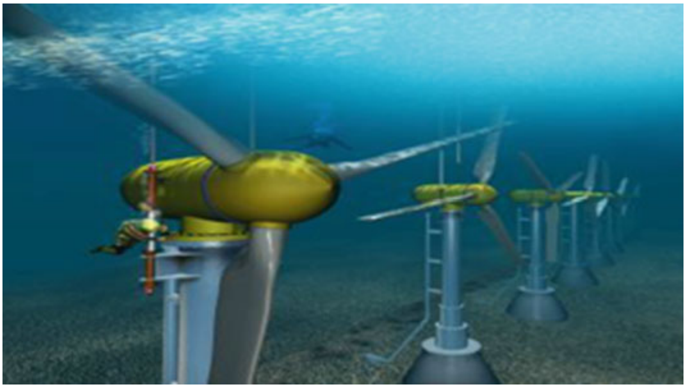

Fig. 5 Proposed arrangement of tidal current turbine array in the selected location (extracted from [12])

Table 1 Summary of annual generated power at the study location

Parameter	Dimension
Width of study location (Sandwip channel)	12 km
Turbine type	Submerged horizontal axis turbine
Turbine diameter and number of blades	6 and 3 m
Average daily power generation during monsoon period (per turbine)	8.25 kW
Average daily power generation during dry period (per turbine)	4.15 kW
Number of turbines	200 nos
Annual generated power (per turbine)	2.355 mW
Total annual generated power	470 mW

year. Each turbine is yielding an annual energy output of 2.355 mW. Table 1 summarizes the total annual power yield using tidal current turbine concept.

6 Concluding Remarks

Power demand is increasing rapidly in Bangladesh and there is no constructive plan yet, to meet the forthcoming power deficit by renewable energy. The traditional energy sources being limited and unsustainable, the country has to face a great challenge in upcoming days. In this respect, tidal power, as a renewable energy source with multifarious benefits, can be a fundamental provision for our future energy necessities. Fundamental of this paper is to highlight the prospects and potentials of the Bay of Bengal for developing research focusing on tidal current technologies, in conjunction with assessment of the feasibility of the concept.

In order to quantify the tidal power potential of the Bay of Bengal, an extensive and elaborate investigate has been carried out in this study. Sandwip channel with its desirable geological location, a considerable channel width of 12–16 m, and a variable current speed of 0.12–2.4 m/s (approx) was found to be one of the most preferable locations for energy extraction. A set of depth-averaged velocity data for the study area was obtained through a hydrodynamic model study. The velocity varies higher during flood than ebb and the maximum value reached 2.41 and 2.01 m/s during monsoon and dry period, respectively. The magnitude of generated electricity being directly proportional to the cube of velocity and the area of water surface swept by the turbine suggests that power generation is more effective and maximum during monsoon than dry period, as available kinetic energy is more. The power density reached its maximum with a value of 8.25 kW daily, at mid-flood of a mean spring tide of monsoon period, whereas it accounted to 4.15 kW daily power during dry period for a single-bed mounted horizontal axis turbine. Due to ease of installment, and simpler technical features, horizontal axis turbine technology has been preferred over the other existing technologies to be used applied in the study area. Finally, theoretical design of deploying 200 tidal turbines in a single row sums up to 470 mW annual power generation.

The potential for progression of the techno economic ability of ocean power conversion technologies is enormous and propitious. Ocean energy conversion technologies are speculated to make appreciable contributions in achieving miscellaneous objectives of environmental, social, and economic policies in many countries around the world, after their integration into the world electricity market. Bangladesh too needs to keep pace with this advancing trend by exploring the renewable energy possibilities in the country. A comprehensive, holistic energy strategy should be developed to address the shortcomings related to research and studies acquainted with the suggested technology.

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