ASSESMENT OF EXTRACTABLE ENERGY USING OCEAN CURRENT AS RENEWABLE ENERGY SOURCE ALONG THE BAY OF BENGAL, BANGLADESH

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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, tide, and wave 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. Ocean energy has many forms namely, encompassing tides, ocean circulation, surface waves, salinity and thermal gradients etc. Ocean tide in particular, associates both potential and kinetic energy. The study is focused on the latter concept that deals with tidal current energy conversion technologies. Tidal streams or marine currents generate kinetic energy that can be extracted by marine current energy devices and converted into transmittable energy form. The principle of technology development is very comparable to that of wind turbines. Conversion of marine tidal resources into substantial electrical power offers immense opportunities to countries endowed with such resources and this work is aimed at addressing similar prospects of Bangladesh. The study analyses the extracted current velocities 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 and establishes a constructive approach that could be adopted in future project developments.

Key Words: Tide, Tidal current, Tidal Turbines, Renewable energy, Energy potential, Bay of Bengal.

1.0 INTRODUCTION

In today's world adequate energy supply is a focal obligation for overall development and constructive improvement 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 seems to be influencing the development trend to a significant extent. Recent studies also suggest that the global energy demand would increase by five times of the current demand by 2100. 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 broadly includes ocean, wind, solar, biomass and geothermal energies. Ocean covers around 71% of the earth surface and has the largest untapped renewable energy resource on the planet. Theoretically, ocean can produce 20,000 to 92,000 TW h/year of electricity, to match the current world consumption of 16,000 TW h/year (Esteban and Leary, 2010). Ocean energy is available in many forms including tide, wave, thermal, salinity gradient, and biomass. 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. A tidal curent 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 towards 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 to tidal barrage concept.

The origins of the marine tidal current concept can be traced back a long way, starting with a river current turbine project that ran from 1976-84. Peter Fraenkel, used a vertical-axis Darrieus-type rotor, which moored off the bank of the river Nile in Juba, Sudan where it was used for irrigation pumping. The turbine performed well, pumping 2000 liters/hour through a head of 5m from a current of 1m/s. The design was subsequently developed further, and has been marketed with a horizontal-axis rotor, both as a water pump and an electric generator (Thake, 2005). 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. A number of designs for this technology are still in an experimental stage. Their commercialization is still at its infancy and hasn't yet progressed to the point 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-world's first grid-connected megawatt-level marine current turbine (MCT) system installed in Strangford Lough in Northern Ireland, a 110 kW Voith Hydro Turbine has been in operation near the South Korean island of Jindo since 2011, and Sabella D10 turbines with a power capacity of 0.5~1.1 MW for 3.0~4.0 m/s current velocities (Zhou et al., 2015). Moreover, a recent approach is the Deep Green a 12m dia turbine mounted on a submerged anchored structure that amplifies the experienced water speed over the rotor by a factor of 10, generating 220-500 KW units (Hammer et al., 2012). Studies and researches indicate huge potential of commercialization of these projects that are at prototype and testing phases.

Oceans are virtually untapped resource which could provide 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 range of long-term benefits including: enabling new routes to de-carbonization of energy supply, creating a diverse generation portfolio, greater energy security in terms of supply, and potential economic development of the whole nation.

2.0 TIDAL CURRENT TECHNOLOGIES

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 wind, temperature, salinity difference, relative positions of the sun and moon with reference to earth and varying angles of declination. The largest currents occur at the extreme declination of the moon and lowest currents at zero declination. These astronomic characteristics results in periodic variation of tidal currents which can be predicted with high accuracy.

2.1 Harnessing Tidal Current Energy using Tidal Turbines

The technique of harvesting current energy is to intercept 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 similar to that of wind turbine. In practice tidal current devices are employed as fences or arrays of turbines in constrained channels and inlets, where the optimal tidal power can be extracted with very few 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, can produce significant power at low 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:

2.1.1 Vertical Axis Turbine Technology

Cross flow turbines typically have two or three blades riding on a vertical shaft which forms a rotor. The axis of rotation is perpendicular to incoming water stream as shown in Figure 1(a). The incoming flow creates lift force to drive rotor, rotor then rotates the generator for producing power.

2.1.2 Horizontal Axis Turbine Technology

Horizontal axis turbines usually have two or three rotor blades which generate lift. This results in axial rotation which drives a generator. They have to be aligned to the current by either rotating the device or pitching the blades through 180° (Figure 1b).

2.1.3 Oscillating Hydrofoil Turbine Technology

This device consists of a hydrofoil at the end of a swing arm whose angle changes with the water stream as displayed in Figure 1(c). It rests on gravity based foundation. The arm oscillates by the lift and drag force, resulting in the extension of the hydraulic cylinder. The cylinder is attached to the main arm and used to pump high pressure oil to a generator. Then, the oil goes into a turbine of hydraulic design which drives a generator and produce electricity.

2.1.4 Tidal Kite

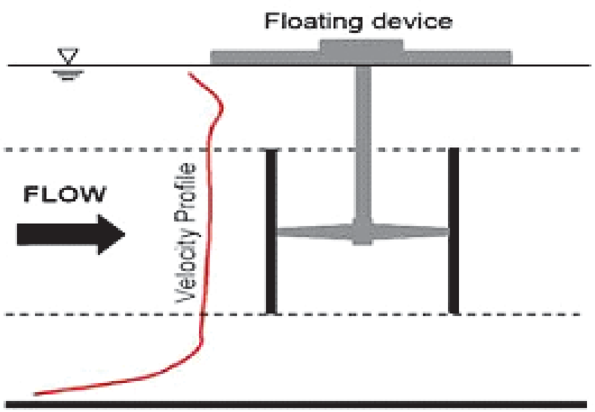
In this technology, the turbine is attached to a wing which move forming loops in water. They are attached to the seabed with a moving wire, like a kite. The device moves through water at a speed higher than the water speed and are able to generate electricity from very low velocity currents (Figure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

2.1.5 Helical Screws

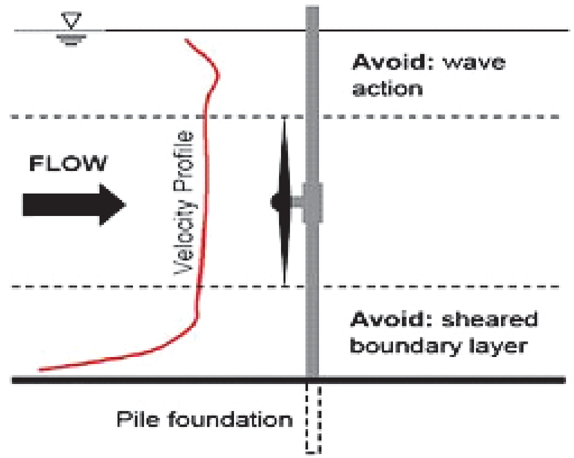
Flumill's Helix screws' turbine is shaped like a screw, has only one moving part, and is slow-rotating. The screws draw power from the tidal streams as water flows up through the helix. The turbine gearlessly drives a permanent magnet synchronous generator and generates power (Figure 1e).

2.1.6 Enclosed Tip - Venturi

Enclosed Tips (ducted) devices are essentially contained within a shrouded structure. The duct may be used to accelerate and concentrate the fluid flow, allowing the use of smaller rotor diameters. Other ducted structures could help to minimize turbulence and align the flow of water into the turbine (Figure 1f).



(a)



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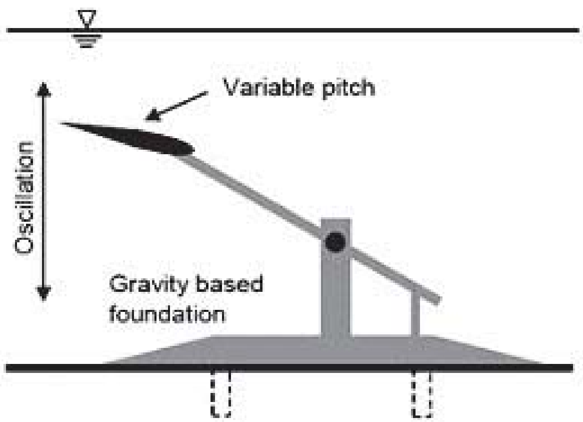

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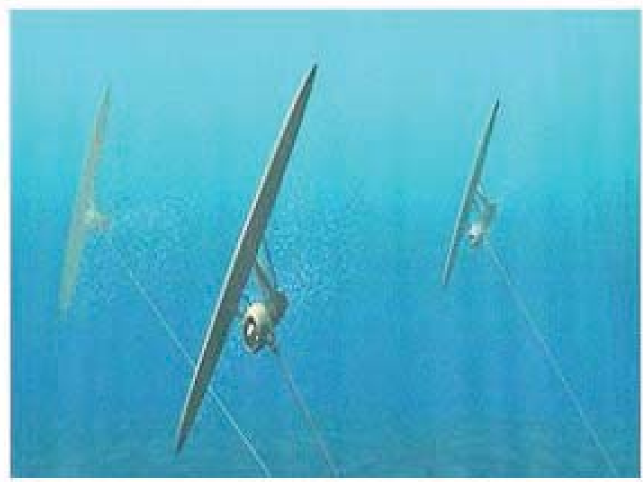

(d)

(e)

(f)

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.

2.2 Mooring of Tidal Turbine

There are typically four mooring options (Figure 2) that can be considered for fixing a tidal turbine to the sea floor. These are highlighted as follows:

2.2.1 Monopile

Monopile foundations could be used for fully submerged devices as an alternative to gravity or pinned foundations. Surface piercing foundation types of this design are generally limited to approximately 30m water depth. Single tubular steel tower can be drilled and grouted into a deep socket in the sea bed.

2.2.2 Pined

These foundations are suitable for turbines mounted close to the bottom of the water column. Foundation structures can be pinned by drilling and grouting small sockets in the sea bed. These anchor points may utilize pins of several meters in length, but will generally be shorter than the drill depth required for monopole foundations.

2.2.3 Gravity base

This foundation type will hold a tidal energy converter to the sea bed by means of a substantial mass, with the gravitational forces keeping the device fixed in place. These foundations are suitable for turbines that are mounted close to the bottom of the water column.

2.2.4 Floating

Designs of this type can access the faster flowing currents located higher within the water column. Buoyant turbine devices can be moored to the sea bed using either flexible or rigid moorings. There may also be an option of mounting multiple devices on one floating platform.

3.0 PROSPECTS OF TIDAL ENERGY IN BANGLADESH

3.1 Origin of Tides in the Bay of Bengal

Originating in the Indian Ocean, tides enter the Bay of Bengal through the 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 Hatiya River Entrance, and f) The Sandwip Channel Entrance (Mondal, 2001). The tides are predominantly semi-diurnal type 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, 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 (Ahmad, 2013).

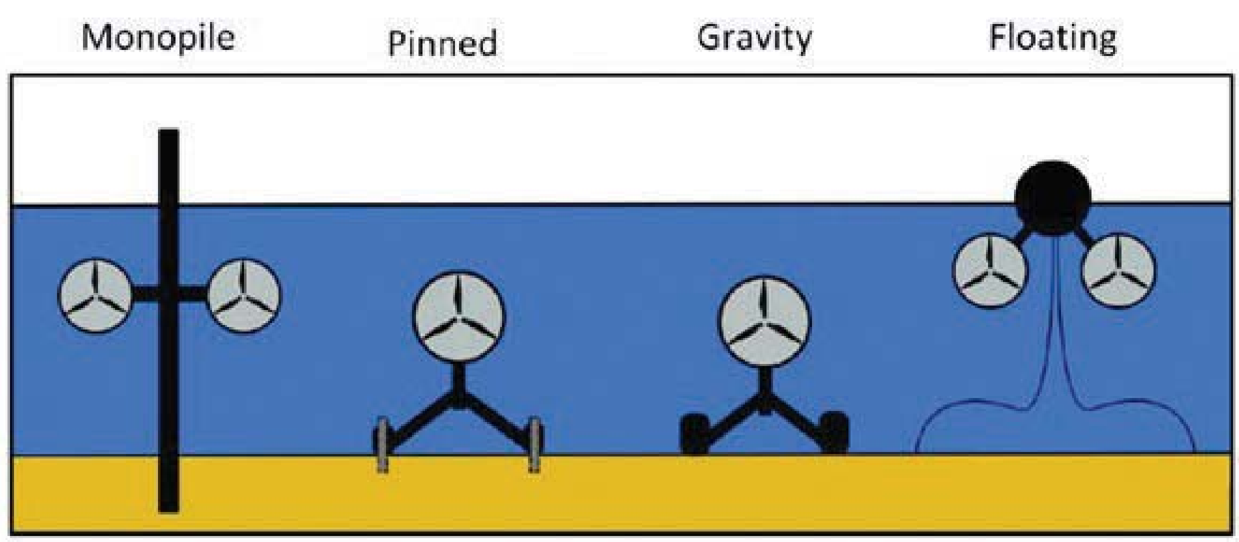

Fig 2. Types of foundation generally used for tidal energy converter.

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

Areas with high tidal flows commonly occur in narrow straits, between islands, and around headlands, enhanced due to funneling effect. Some of the key criteria and general principles for tidal current turbine site selection can be given as, considerable spring peak current, uniform flow with strong currents, close to coast and constricted channels (Li et al., 2010). Coastal areas in Hiron Points, Mongla, Char Changa, Cox's Bazar, Golachipa, Patuakhali, Sandwip, Barishal 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 surroundedby 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- 4 m/s in the tidal channels (Hasan, 2011).

3.3 Present Scenario and Future Target in Renewable Energy Development in Bangladesh

In Bangladesh, renewable energy shares only 1% of country's total energy mix whereas in the world it accounts 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 has a plan to increase the renewable energy utilization for electricity generation up to 10% by the year 2020 (http://www.powerdivision.gov.bd). With that aim, the government is already working to reduce the share of natural gas in commercial energy consumption, declining to 42% in 2012 compared to 50% in 2009 (Halder et al., 2015).

With the recent ocean victory Bangladesh has been assured rights over 118,813 square kilometers 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 (Islam, 2014). So, huge potential energy is available in this large sea-zone which can be utilized for generating electricity. Moreover, renewable energy is included in the national energy policy in year 2008 to encourage different public and private organizations for investment in replacement of indigenous non-renewable energy sources. 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.

4.0 GENERATION OF ENERGY

4.1 Tidal Energy Estimation

The instantaneous power density P produced by a tidal current turbine can be calculated by the following equation (Lim et al., 2009)

$$P=\frac{1}{2}\rho A V^3 C_P \quad (1)$$

where, A = the cross-sectional area of the flow intercepted by the device i.e area swept by turbine rotor (in square meters), ρ = the water density (in kilogram per cubic meter), 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 sites under investigation, presented by a flowchart depicted in Figure 3.

Initially, bathemetry data and satellite images of the all suitable locations along the Bay of Bengal were analysed and finally Sandwip Channel with an approximate width of 13063 m and 12m - 16m water depth variation was selected as the stable and feasible location. Figure 4 displays Sandwip Channel which is located in between Chittagong district and Sandwip Island. Reason for selection of these location is due to its relatively stable channel, clean water, high velocity and nearer to the main land for connectivity. Then results from a hydrodynamic model obtained from a secondary source (developed by the Institute of Water Modelling (IWM)) has been assisted in the analysis. The developed hydrodynamic model has been calibrated against measured water level and discharge at different locations. Depth-average

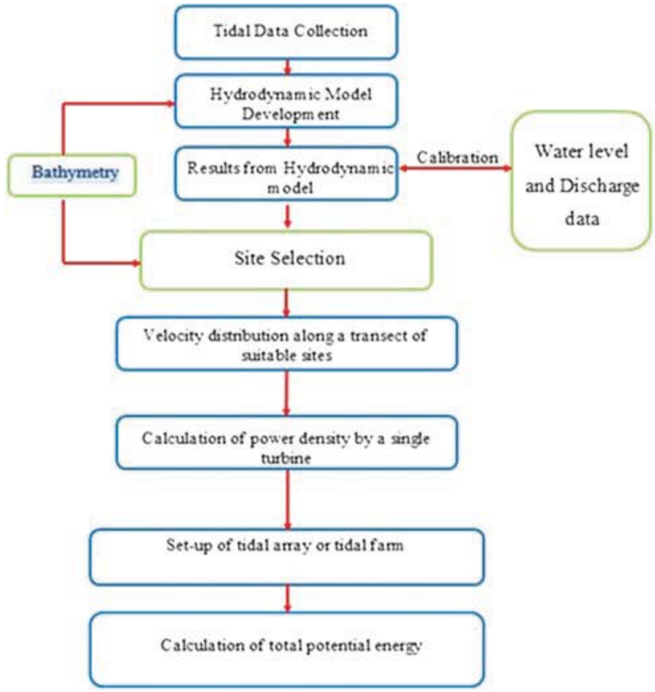

Fig 3. Flowchart presenting step-wise methods followed for tidal current power potential calculation.

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 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 m/s and 0.12 m/s, respectively.

The 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 Equation (1). Figure 5 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 (Figure 6).

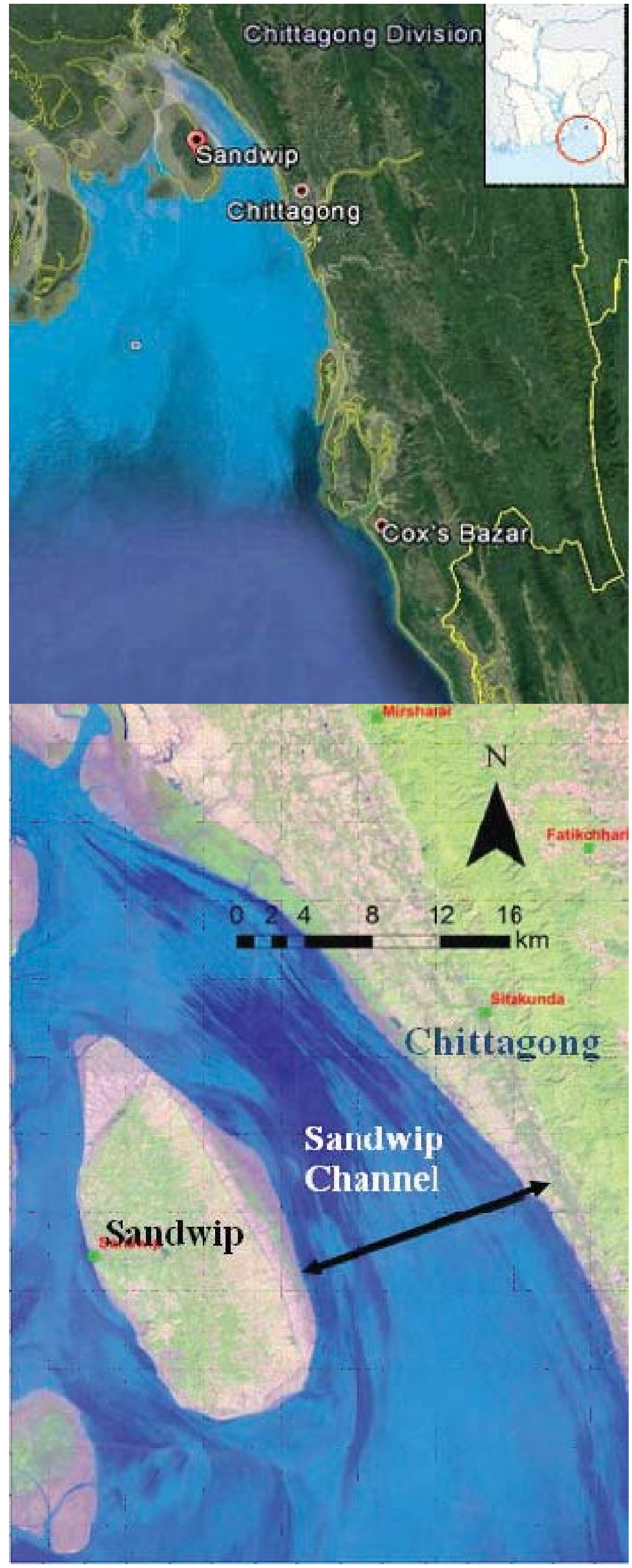

Fig 4. Suitable study location along the Bay of Bengal; Main study location (Sanwip channel) is highlighted by a zoomed box.

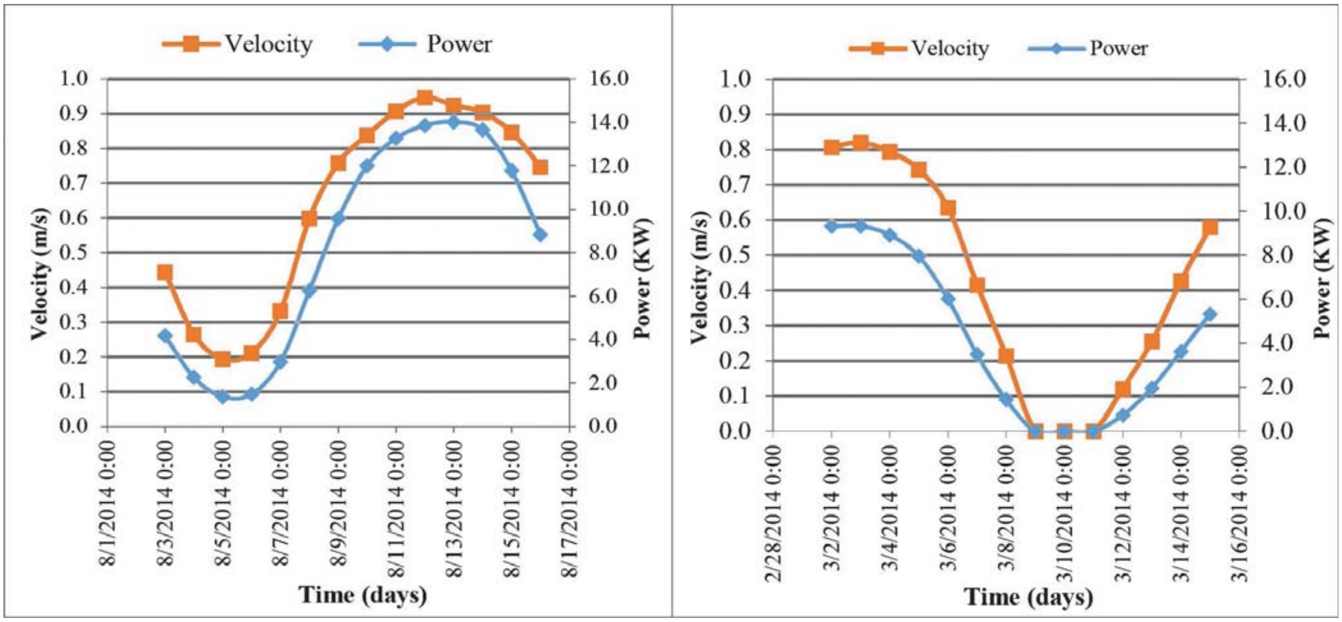

Fig 5. Variation of daily average velocity and estimated power covering a Spring-Neap tidal cycle during (a) monsoon period and (b) dry period, for the year 2014.

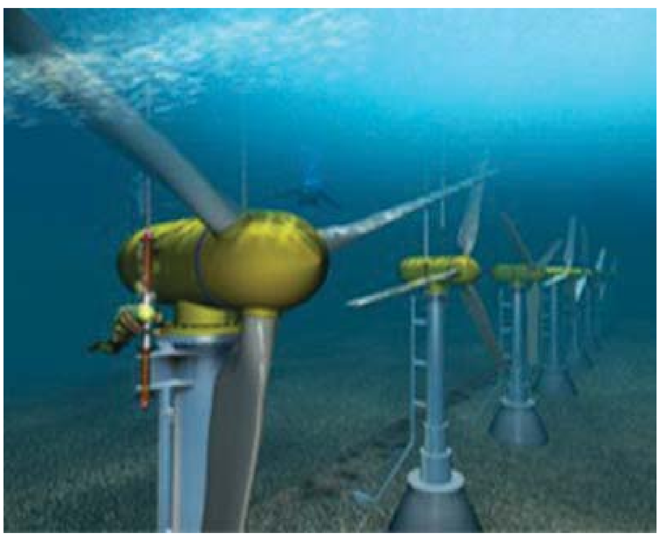

Fig 6. Proposed arrangement of tidal current turbine array in the selected location.

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.

5.0 RESULT AND DISCUSSION

Total width of the Sandwip Channel is approximately 13 km. As the channel is bounded on both sides by landmass, naturally seabed is shallow at the corners and deeper at the centre. Considering the fact, the effective width for tidal turbine deployment is selected to be 12km. Spacing between subsequent turbine is considered 10 times the dia of a rotor. This spacing is required to reduce the wake effects of the 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. Cp = 0.35), the total power output by all the turbines would sum up to 470 MW per 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.

6.0 CONCLUDING REMARKS

With the increasing power demand in Bangladesh, there is no substantial plan to meet the upcoming power crisis by renewable energy.The country has a great challenge in the upcoming days due to unsustainable and limited energy sources. In this respect tidal power, as a renewable source of energy with numerous profits, can be a the prime supplier for our future energy necessities.

Table 1: *S*ummary of annual generated power at study location.

PARAMETER	DIMENSION
Width of study location (Swandip channel)	12 km
Turbine Type	Submerged Horizontal-Axis turbine
Turbine Dia and no of blades	6m and 3
Average Daily Power Generation during monsoon period (per turbine)	8.25 KW
Average Daily Power Generation during dry period (per turbine)	4.15 KW
No of Turbines	200 nos
Annual Generated power (per turbine)	2.355 MW
Total annual generated power	470 MW

Fundamentals 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 study has been carried out in this report. Sandwip channel with its desirable geological location, a considerable tidal range of 12m to 16m, and a variable current speed of 0.12-2.4 m/s (approx) was found to be one of the most preferable location 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 m/s 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 improvement of the techno-economic performance of ocean power conversion technologies is large. After their integration into the world electricity market, ocean energy conversion technologies are expected to make substantial contributions to the achievement of a wide range of objectives of environmental, social, and economic policies in many countries around the world. 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.

References

[1] Ahmed, C.S.F., [2013], "Bathymetric Survey in the Coastal Area of Bangladesh - A Challenging Experience for the Surveyors", Report, North Indian Ocean Hydrographic Commission (NIOHC 16-14), 12P.

[2] Esteban, M. and Leary, D., [2010], "Current developments and future prospects of offshore wind and ocean energy", *Journal of Applied Energy,* 90, Pp. 128-136.

[3] Hammar, L., Ehnberg, J., Mavume, A., Cuamba, B.C. and Molander, S. [2012], "Renewable Ocean Energy in the Western Indian Ocean." *Journal on Renewable and Sustainable Energy Reviews,* 16(7), Pp 4938–4950.

[4] Halder, P.K., Paul, N., Joardder, M.U.H. and Sarker, M., [2015] "Energy scarcity and potential of renewable energy in Bangladesh", *Journal on Renewable and Sustainable Energy Reviews,* 51, Pp. 1636-1649.

[5] Hasan, M.S., [2011], "A study on morphological change from Chadpur to Sandwip Channel in the Meghna Estuary", Masters Thesis, Department of Water Resource Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, 103P.

[6] Islam, M.A., [2014], "Second victory at sea", The Prothom Alo, 10 July, 2014.

[7] Li, D., Wang, S. and Yuan, P., [2010], "An overview of development of tidal current in China: Energy resource, conversion technology and opportunities", *Journal of Renewable and Sustainable Energy Reviews,* 14, Pp. 2896–2905.

[8] Lim, Y.S. and Koh, S.L., [2009], "Marine Tidal Current Electric Power Generation: State of Art and Current Status, Renewable Energy", T J Hammons (Ed.), ISBN:978-953-7619-52-7, InTech, 211P.

[9] Mondal, M.A.M., [2001], "Sea Level Rise along the Coast of Bangladesh", Report Ministry of Shipping, Dhaka, Bangladesh.

[10] Thake, J., [2005], "Development, installation and testing of large-scale tidal current turbine", Report IT Power, Marine Current Turbines, Seacore, Bendalls Engineering, Corus, 74P.

[11] Zhou Z., F. Scuiller, J. F. Charpentier, M. Benbouzid and T. Tang, [2014], "An up-to-date review of large marine tidal current turbine technologies," *2014 International Power Electronics and ApplicationConference and Exposition,* Shanghai, China, Pp. 480-484.