Tidal Power Plant Exploration: Low Head Water Turbine in Barrage System

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***Abstract*— Tidal energy is an environmentally benign, practical, and cost-effective renewable energy source. The hydropower potential appropriate site for electrical power production accessible in Bangladesh's coastline region is investigated in this article. We propose a model for determining the feasibility of power production via the tidal barrage system using a Compact Axial Kaplan (CAK) turbine in a low-head water turbine. Tidal power supplies enormous quantities of electrical energy in coastal locations across the globe without generating carbon or harming the environment. The world's wealthiest nations are increasingly resorting to tidal power generation. Where tidal power is available, we may be used tidal energy to alleviate the power shortage in coastal areas. A hydropower station may supply clean energy and fulfill a significant amount of the country's electrical demands. The notion of establishing a tidal power plant with a barrage model system would be a better long-term outlook for energy production and flourishing economic expansion. Dublar Char is an ideal location for tidal energy to be used to solve the electricity crisis in distant coastal regions. This article analyzes the electricity generating capability of Dublar Char, estimated at 120.17 megawatts (MW).**

Keywords - Tidal Power; Ocean Energy; Energy Production; Tidal wave; Renewable Energy Resource; Sustainable Development

I. Introduction

Due to the Earth's ultimate tides caused by gravitational interaction with the Moon and Sun as well as rotation, tidal power is endless and categorized as a renewable energy resource [1]. Tidal power is a type of hydropower that uses oceanic electricity generated by tidal surges to produce electricity. Tidal surge electricity is less expensive than electricity generated from coal, heavy fuel oil (HFO), high-speed diesel (HSD), gas, and LNG facilities and reduces the emission of greenhouse gas. Although most energy resources are confined to a few countries, renewable energy resources are found worldwide. Bangladesh is ideal for solar, wind, and tidal energy to address looming fossil fuel shortages and supply considerable energy needs. This study aims to look into the long-term effects of renewable energy sources. The 7th Sustainable Development Goal (SDG) tries to maximize the proportion of clean energy sources in the energy supply by 2030. These days, budgetary organizations, and financial sponsors support investment in these industries [2]. As the country aims to meet middle-income status by 2021 and high-income status by 2041, the government's biggest concern is supplying sufficient electricity to accommodate future demands. By 2021, the government plans to provide electricity to Bangladesh's entire population. The government has devised a comprehensive plan to increase power generation capacity to 40,000 megawatts (MW) by 2030 and 60,000 megawatts (MW) by 2041 [3]. Bangladesh has located between 20.30 and 26.38 degrees north and 88.04 and 92.44 degrees east. It is one of the largest and most influential countries, with a 32% coastal area [4]. Many people reside in coastal regions, still suffering from a power crisis. Some coastal areas that can meet the electricity demand, like Dublar Char, Hiron point, Teknaf, Sandip, and Kutubdia, have a potential tide range for constructing a tidal power station and fulfilling power crises in local areas. Bangladesh can easily overcome its power crisis by switching to tidal power generation. Its geographical location has a favorable and feasible impact on the bulk of tide motions across extended coastline areas [5]. The ocean is drained by low-head water turbines after the tidal barrage system forces it into a sizable basin. The Kaplan turbine is a sophisticated model with a highly efficient one that can easily extract the kinetic strength of tidal surge into current [6,7] by considering its efficiency, compassion for ocean life, economic preference, and capacity to absorb the power in two ways. This study is presented to exterminate power issues in Dublar Char's coastal areas:

- Evaluated the range of the tide heads.
- Modelling of tidal barrage system with CAK turbines.
- Estimated the potential for tidal power production using the Probability Density Function Model.

This research makes this model perfect for the implementation of these. It helps to analyze and determine the best turbine for the barrage system and research geological

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interpretation to predict the advantages and challenges for Dublar char. Exploring the fundamental part of a tidal turbine, such as the tubular bulb unit, rim generator unit and crossflow unit, can optimized in our design sketch. It will help our research to improve power efficiency research.

II. Related Work

To achieve the power demand, both developed and developing countries search for alternative power solutions to overcome their national power lack. For this reason, researchers introduced tidal energy over different renewable energy are discussed. Zaidi et al. concentrated on an overview of the possibilities for ocean energy while discussing the steam turbine technology currently employed to produce electricity from ocean current. As green, longevity and consistent, tidal energy is the better option over other different renewable energies [8]. According to Wang et al., tidal power plants throughout the globe have an effective mechanism for distributing electricity and using current [9]. They also discussed power utilization by comparing turbines and significant parts of a tidal power plant and introduced a proposed models and future work. In remote locations of Bangladesh like Sandip and Saint-Martin Island, where natural electricity distribution is more difficult, Hossain et al. addressed the potential for a tidal power plant. Their research proposed a model to generate an approximately 17MW tidal power plant, which implemented cost is near USD 17 million [10]. The three basic modes of a barrage type tidal power plant—ebb-generation, flood-generation, and double-effect operating modes— explored by Ghaedi et al. in relation to advanced level barrage type tidal power plants, the use of hydro-pump, and these topics [11]. Unexpected flood water is harmful to human life and can be water-borne diseases [12]. In their study, Qian Ma and colleagues suggested a seven-barrage model and assessed the prospects for clean energy. They examined that using barrage could significantly reduce flood effects in coastal areas. It would be a small effect but can act on a large scale for landless people [13]. Nowadays, people can easily farm in agriculture with the blessing of modern technology. A barrage system can mitigate irrigation problems in isolated areas and may diverge unexpected floods for smart farming [14]. In their study, Z. Ren et al. suggested a PPF approach based on Monte Carlo simulation for power systems involving tidal current production. In PPF analysis, both the periodicity and unpredictability of tidal power recorded and taken into consideration. The suggested method's accuracy and efficacy validates using measured data of tidal current speed retrieved from two locations in Florida and Alaska, USA, using the IEEE 57-bus standard test system. Information analyzed on the effects of TCGFs on PPF that have various tidal resource potency and power output properties [15]. To store fossil fuels for future generations and make the earth's environment neat and clean alternative sustainable, longevity another effective option needed, and the tidal energy much more efficient than any other renewable energy resource [16]. Alam et al. explored the tidal potential and their article on the economic and ecologic effects of a tidal barrage, an effective power generating model with accurate resource modelling [17]. Coal and gas-fired electricity in Bangladesh are one of the causes of CO_2 emissions and other unexpected environmental situations. It can reduce by using advanced fuel technology and management systems using green energy [18]. To create more precise tidal power plant parts, PBL Neto et al. optimized the operating problem. They suggested a more trustworthy way for making decisions and deploying turbines, as well as an ideal turbine dispatch [19]. The abundant energy of tides can include in Bangladesh energy regulatory commission (BERC). Due to a lack of environmental concern and interest in investing money in this modern technology, the authorities are not interested in the implementation. In contrast, the developed countries took these advantages and made them more robust in the green, sustainable, and renewable energy sectors [20].

III. Proposed Tidal Power Station

Compared to wind and solar farms, the lifetime of tidal power station infrastructure is four times longer. The term "tidal barrages" refers to long concrete structures that span river estuaries. The tunnel turbines spin as water comes from one side of the barrier. The lifetime of these dam-like structures is around 100 years. Tides have a far higher energy density than wind power and other energy sources, which implies that little power is lost when kinetic energy is converted to electricity. Although numerous large-scale projects are in distinct phases of development throughout the globe, tidal is still in its infancy compared to several other renewable energy sources. The constancy that tidal energy provides is undisputed. It potential is seen with considerable hope. In this regard, even tiny nations with a long enough stretch of coastline may use tidal power in ways that land-rich countries like the United States, China, and India could not otherwise compete on solar and wind.

A. Site Selection

Dublar Char is situated on the south side of the Sundarbans mangrove forest, southeast of Hiron Point and southwest Kotka. A site for a tidal power station has been chosen at Dublar Char, which covers an area of approximately 26.3 km^2.

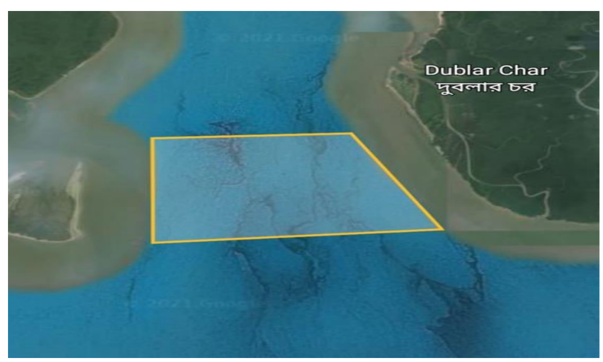

Fig. 1. Site location in Bangladesh for proposed tidal power plant.

The average high tide in this area is 3.08m, with a useable tidal head of 1.95m. A review of current trends and prospects of tidal energy study with an exemplary block diagram and modelling. A more integrated engineering design, integrated grid network from the offshore transmission and the construction cost can reduced [21].

B. Turbine Selection

Low head hydro plants have a capacity of 1 MW and intended for 20metres or below water levels. Here Compact axial Kaplan turbine (CAK) considered for its flow rate of 6-60m^3/s and head of 2-12m. The turbine used in power generation where water is available at low charge and high flow rates. That is also fulfilling our required head and flow rate. From this turbine, we can get power up to 6MW. One of the substantial advantages of using this tidal power station is that it can operate in parallel connection with diesel and wind units. Baykov et al. aggregated few research and proposed mathematical modelling of tidal power stations with diesel and wind units [22]. By discussing various parameters of the construction and sustainability of the turbine, The Kaplan turbine has the benefit of being more effective at low water heads and high flow rates [23, 24, 25]. The Kaplan turbines are more accessible to construct than other turbines. Compared to diverse types of hydraulic turbines, the Kaplan turbine is more efficient and has a smaller size [26, 27].

C. System Design and Modeling of Tidal Power Station

The tropical waters satisfy two criteria: large collecting regions and vast storage capacity. Oceans have taken up 71% of the world's land. Tidal barrages create the tides' potential energy. A tidal barrage is a dam built across a bay or estuary with more than 5metres of considerable wave heights. Tidal barrages produce energy in the same way that hydroelectric dams do, except those tidal currents flow in both directions [28]. Method of taking advantage of the kinetic energy of the ocean tide in the coastal area turbine technology is the best option. It is low cost and zero impact on the ecological environment. Turbine technology is a way better option for a vast energy source, especially in the coastal area where the water flow & tide is frequent and steady. Hydropower is a type of motion energy absorbed from the tidal current resulting from the gravitation of nature.

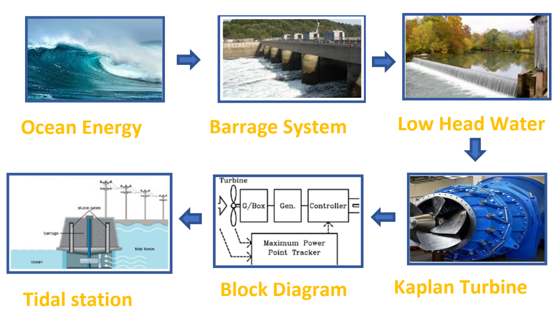

Fig. 2. Block diagram of tidal system.

Proper design & modelling of a hydropower plant is an integral part of its efficiency considering all co-efficient related to natural phenomena like gravity, biological impact etc. Its output & efficiency depends on the sincerity of the solar system. The proposed design undergoes step-1 and step-2, including the barrage design, turbine position, the number of sluices and generating units based on hydropower capacity, provided by optimization analysis and the basic diagram of the total power plant mechanism. The entire energy output equation for the barrage type of tidal power plant is like that used for a regular hydropower plant, but the tidal range used instead of the hydraulic head. The design characteristics are shown below accordingly tidal barrage system:

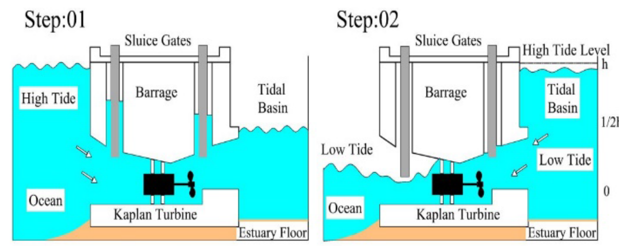

Fig. 3. Modeling of tidal barrage system.

Due to the relative position of the sun, moon and ocean water, the gravitation forces on the moon and sun on ocean water occur a periodic rise and fall of water twice each lunar day. The result of low and high tides and their differences make the ocean tidal energy as the higher wave has much potential power than the lower one. Equational, these differences are the actual tidal energy. In the above figures, Step:01 and Step:02, a dam constructed so that it can divide the seawater in a tidal basin in such a way that one side would be low tide, and another would be high tide. The constructed basin will be filled up with high tide discussed in figure Step:02 and emptied when it is low tide concerned in figure step:01, by passing through a turbine. The potential energy of water will be stored as electrical energy used to drive by the Kaplan Turbine.

D. Present Scenario in global

Sustainable energy sources have grown in popularity in several developing nations, particularly in Asia, such as India, central-southern China, and Bangladesh. The vast potential of hydropower in Bangladesh can be the country's most economical power upon maximum utilization [29, 30]. The hydroelectric power plant's low breakeven point results from low running and maintenance costs, as well as a good annual rainfall average, which offset its expensive building costs. As hydropower is more cost-effective than other green power sources, The money made by selling electricity overseas may be used to build up the economy and pay for infrastructure projects, healthcare, housing, and agriculture [31]. The following is a summary of the global hydropower project scenario:

TABLE 1: UPCOMING PROPOSED TIDAL POWER STATION

Station Name	Country	Capacity (MW)	Commission	Mean Tide(m)	Basin Area(km^2)
Incheon	South Korea	1320	On hold	5.3	110
Swansea	U.K.	320	2019	/	11.5
Seven Barrage	U.K.	8640	Proposed	7.8	450
Mezen	Russia	19200	Proposed	9.1	2300
Penzhin	Russia	87000	Proposed	9	20530

Due to a renewable and reliable energy resource, environmentally friendly maintenance, efficiency and predictable energy source, developed countries are focused on a tidal power plant. In Table 1, analytical data shows that the developed countries are moving towards tidal energy [32]. These data represent those countries like South Korea, the U.K., and Russia are planning to construct tidal power plants and, based on the basin area, how much energy could be stored from that specific power plant.

TABLE 2: EXISTING POWER STATION IN GLOBAL

Station Name	Country	Capacity (MW)	Year
Sihwa Lake Tidal Power Station	South Korea	254	2011
Rance Tidal Power Station	France	240	1966
Meygen	U.K.	6	2017
Jiangxia Tidal Power Station	China	3.2	1980
Uldolmok Tidal Power Station	South Korea	1.5	2009
Annapolis Royal	Canada	20	1984
Kislaya Guba Tidal Power Station	Russia	1.7	1968

In Table 2 shows each extant tidal power station name, geographical location, capacity, and year. South Korea generated 254 MW of electricity from the Sihwa Lake Tidal Power Station in 2011 [33, 34]. South Korea will generate roughly 1320MW of electricity from the tidal power plant when it is finished in Incheon. Indeed, it's a golden opportunity for South Korea. On the other hand, Russia is planning to construct two vast tidal power those capacities will be 19200 MW and 87000 MW in Mezen and Penzhin Respectively. Our research also calculated how much energy could be generated by constructing a tidal power plant in Dublar Char in Sections 4 and 5.

IV. METHODOLOGY

Two dams are required to capture the tidal potential of all 26.3 km^2 of the Dublar char. At different periods of the day, the tide has varying magnitudes. As a result, a precise high and low tide model is critical for effective water management. High tide refers to the highest point on the water. The high tide occurs when the moon and sun are directly aligned to the earth. High tides are less severe when the moon and sun are at night angles. In Astronomical records, a 3.2 TW loss in the earth-moon cyclic system and around 0.5 TW loss in the sun creates tidal energy. In order to prevent power from being transmitted to vertically uniform and inconsistent tidal flow, the majority of the tidal power, or around 1TW, is wasted by bottom friction kinetically [35]. Table 3 shows the average high and low tides for other months of the year. They are two high tide data in a day derived from data of average high tides for a daily average high tide of a month is calculated from total days data.

A. Average Tide Range

The maximum quantity of high tide is observed in August, while the lowest amount is marked in January. The useable head listed in the fourth column of Table 3. This data collected from the website in the year 2018.

TABLE 3: AVERAGE HEADS OF HIGH AND LOW TIDE

Month	High tide(m)	Low tide (m)	Usable head(m)
January	2.77	0.68	2.09
February	2.59	0.78	1.81
March	2.75	0.78	2.04
April	2.8	0.8	2
May	2.87	0.91	1.96
June	2.92	1.05	1.87
July	3	1.11	1.89
August	3.03	1.11	1.92
September	2.9	1.06	1.84
October	2.97	1.02	1.95
November	2.89	0.92	1.97
December	2.8	0.82	1.98

First, a set of heads has chosen, and then the probability of the action calculated. After the set of heads has chosen, the total days for each range of heads has calculated

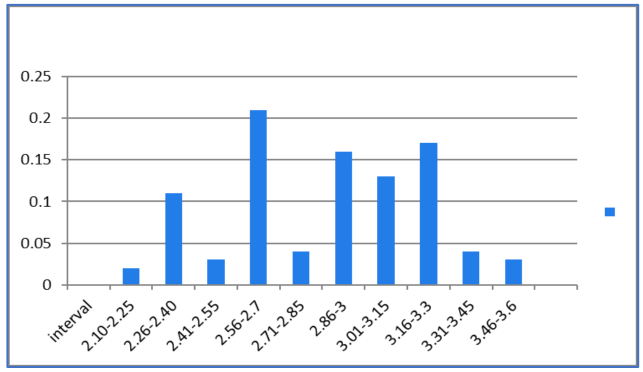

Fig. 4. PDF Model of high tide

Figure 4 presents a high tide probability density function (PDF) model. A continuous random variable is used to create a PDF. Whose value at a particular set-in simple space can be regarded as supplying a relative, like the low head, whose value at the random variable equals the sample. Chance ranges from 0.02 to 0.2, with the highest probability occurring within the tidal range of 2.56m to 2.7m, as seen in the graph.

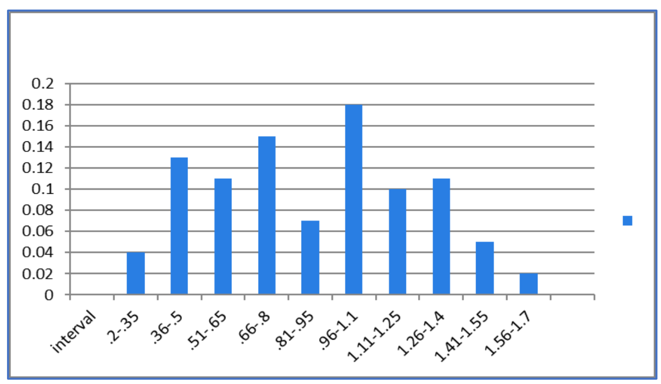

Fig. 5. PDF Model of low tide

Figure 5 also displays a PDF that has been created during low tide. Low tide probability ranged from 0.02 to 0.18, with the lowest probability occurring within the tidal range of 0.96m to 1.1m.

V. POWER AND ENERGY ANALYSIS

- **Number of Turbines:**

The number of turbines is calculated by the equation (1)

$$N= (A\times h)/ (Q\times t) \quad (1)$$

The area of the confined reservoir location is 26.3 km^2, considering the water head is 0.91, the flow rate of the turbine is 53028 m^3/h, and the running time is 0.92 hours at a time. Using equation (1) evaluated turbine number is as follows:

N= (26300000× 0.91)/ (53028× 0.92) = 490

So, 490 turbines are needed to the value the dischargeable water of the proposed reservoir.

- **Power Calculation:**

The total output power calculation is given by the equation (2)

$$P= \eta\rho g Q * N \quad (2)$$

In this work, the selected Compact Axial Kaplan turbine has an efficiency of 85%, taking the practical value and calculation mentioned above. The total number of the turbine is 490 saline water density of 1025 kg/m^3; the constant for gravity is 9.8 m/s^2; the head of water is 1.95m, and the water flow rate is 14.73 m^3/s. Hence the output power is evaluated using equation (2):

P= 0.85 ×9.8× 1.95× 14.73× 1025× 490 =120.17 MW

So, the install capacity of electricity is 120.17 MW and can be obtained twice a day as per tidal wave.

- **Energy Calculation:**

Table 4 displays the resource and generation model together with the estimated monthly average energy production. A maximum of 128.79 MW of power can be accepted during January and a minimum of 111.54 MW during February. It is also seen that the total energy production in a year is 104.93× 10^4 MWh.

TABLE 4: MONTHLY POSSIBLE GENERATION CAPACITY

Month	Power (MW)	Energy (MWh)
January	128.79	$9.58*10^4$
February	111.54	$7.49*10^4$
March	125.71	$9.35*10^4$
April	123.25	$8.87*10^4$
May	120.78	$8.98*10^4$
June	115.24	$8.29*10^4$
July	116.47	$8.66*10^4$
August	118.32	$8.8*10^4$
September	113.39	$8.16*10^4$
October	120.17	$8.94*10^4$
November	121.4	$8.74*10^4$
December	122.02	$9.07*10^4$
Total	**1437.08**	**$104.93*10^4$**

VI. RESULT AND DISCUSSION

It's challenging to forecast how much electricity photovoltaic and wind power facilities will create depending on what nature provides. Nevertheless, tidal power is a dependable energy source that enables us to predict energy production daily, monthly, or year and accordingly plan. This tidal power is getting more attention than other renewable energy sources. Because tides are predictable, Tidal plants may be regulated and built to work at total capacity on alternate days. As a result of new technologies, many tidal energy sources have arisen, poised to revolutionize how we generate energy for our everyday requirements. In Bangladesh, the Karnafuli Hydro Power Plant, which has had a capacity of 230 MW since 1962, is the only hydropower plant. Even though Bangladesh's government has encouraged the use of renewable energy, the country currently lacks tidal power generation [17]. As per calculation, The Tidal power station at Dublar Char's annual generation will be approximately 1437.08 MW. Table 4 shows the estimated monthly generation.

VII. CONCLUSION

The global energy dilemma has been increasingly visible in recent years. At this pivotal point, renewable energy is the most valuable alternative energy source for encouraging the improvement of the world's future, which is essential. This research explored generating electricity from tidal potential in coastal areas, as specified by Dublar char. For actual power generation, resource modelling and generation modelling are utilized. This analysis shows that Dublar char can be generated 120.17 MW of electrical power along Bangladesh's coastline to alleviate the country's power issue. Tidal power can significantly influence renewable energy production due to its enormous potential, absence of pollution, and more predictability than wind and solar power. The construction of a barrage at the suggested location will spur growth in electricity demand and economic development. The structure of the barrage system at Dublar char point will have no negative consequences. It will function as a bridge of transportation for locals and potential to transform the island into the nation's most popular tourist destination. The diesel generator used by the Dublar char to supply electricity is expensive. Hence, tidal energy will be cheaper rather than diesel.

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