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Hydrokinetic Turbine Technology and Its Prospect in Bangladesh: A Review

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ABSTRACT

As a sustainable alternative to fossil fuel, hydropower is becoming increasingly popular since the concern over global warming is growing worldwide. Conventional hydropower technology involves the use of hydraulic turbines, which require a large static head of water created by constructing a dam across the river. This technology, though widely used, has a negative impact on river hydrology and aquatic lives. Hydrokinetic turbine, on the other hand, having a working principle similar to wind turbine doesn't require a dam or barrier and has negligible impact on the aquatic environment. Bangladesh being the land of rivers can effectively implement hydrokinetic turbine-based technology for supplying electricity in off-grid remote areas. In this article, a review of hydrokinetic turbine technology for extracting the kinetic energy of rivers and oceans has been conducted. The status, merits, and applications of this technology have been briefly discussed. Finally, the prospect of this technology in Bangladesh has been assessed.

Keywords: Bangladesh, Environment, Hydrokinetic, Turbine, Electricity, Technology, and Water.

INTRODUCTION:

The growing recognition of global warming owing to the use of fossil fuels raises the necessity of the advancement of renewable energy-based technologies. Moreover, the reserve of fossil fuel is depleting day by day making it vital to use other alternative energy sources. Hydropower, a sustainable energy source, is regarded as a promising alternative to fossil fuels as it doesn't cause the emission of CO_2 or other atmospheric pollutants. Most hydropower systems use a large static head of water to operate the turbine for generating electricity. The hydraulic head required in this type of system is attained from a natural source like a waterfall or created artificially by constructing a dam across a river, thereby creating a reservoir. However, this method, despite being suitable for large-scale power generation, is becoming unpopular in some countries because of the high cost and environmental impact associated with dam construction. Another hydropower technology that has attracted attraction recently is hydrokinetic turbine technology which offers methods to gain energy from flowing streams without constructing dams. Hydrokinetic turbine-based power conversion system uses water turbines working in a manner similar to that of a wind turbine to convert kinetic energy from the flowing water of rivers, oceans, canals, or man-made channels into electricity. Though this technology has been mostly explored in the marine domain, various technologies have lately emerged for river stream. In Bangladesh, a very small portion of the total generated power comes from the hydro source, entirely obtained from the country's only hydroelectric power plant located at Kaptai. The plethora of rivers in Bangladesh offers an opportunity to increase the share of hydropower in total energy generation.

Alongside conventional hydropower technology, hydrokinetic turbine-based technology can be beneficial for this purpose if implemented properly.

Working Principle and Power Output

Hydrokinetic turbine utilizes the kinetic energy of flowing water to rotate an electromagnetic energy converter which subsequently generates electricity. It extracts energy from stream by reducing flow velocity just like a wind turbine. Therefore, it has a relatively simple design without the necessity of a reservoir. A hydrokinetic turbine's governing equation is analogous to that of a wind turbine. The power converted from the water into rotational energy can be calculated using the following equation:

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

Here, P is power (W), ρ is the density of water (kg/m^3), A is the area of the rotor blades (m^2), V is the velocity of water flow (m/s), and Cp is power coefficient, a measure of the efficiency of the turbine. For axial flow turbines, area ***A*** is the swept area of the rotor –

$$A= \frac{1}{4}\pi D^2 \qquad (2)$$

For Darrieus turbine and others, the area is equal to diameter multiplied by the height

$$A= H \times D \qquad (3)$$

C_p is the function of Tip Speed Ratio (TSR) which is the ratio of the linear speed of the blade tip to the water speed.

$$TSR\ (\lambda) = \frac{\omega R}{V} \qquad (4)$$

Where, R is the turbine radius and *ω* is the rotational speed of the turbine. Theoretically, there is a limit to the quantity of energy that can be collected from the flowing water, independent of the design of a hydrokinetic turbine. This limit is called the Betz limit. The Betz limit has a value of 59.3 percent, meaning that a maximum of 59.3 percent of the kinetic energy from streams can be utilized to spin the turbine. It is notable that the Betz limit is valid only for open free flow. For a ducted hydrokinetic turbine, the efficiency can exceed the limit.

Comparison with conventional hydropower system

In most conventional hydroelectric systems large static head created artificially by a dam is used for electricity generation. The hydraulic turbine is driven by the regulated discharge of water from the reservoir created by a dam. In contrast, hydrokinetic turbines are designed to be placed in natural water streams and to be driven by the kinetic energy of water. A comparison between working conditions of a conventional hydropower system and a hydrokinetic turbine-based energy conversion system is shown in **Fig. 1**.

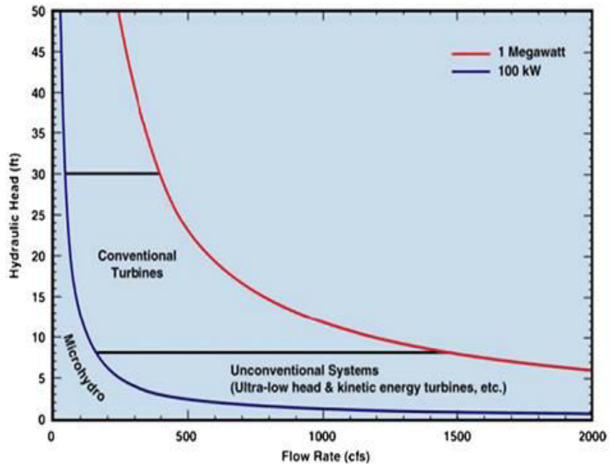

Fig. 1: Conventional hydro versus hydrokinetic turbine-based conversion schemes (Khan *et al.,* 2009).

Hydrokinetic turbines are highly regarded for their advantages in terms of cost-effectiveness and environment-friendliness. Construction of a hydrokinetic turbine-based energy conversion system doesn’t require many civil works; as a result, the erection cost is significantly reduced. Dams and reservoirs utilized in traditional systems can have serious consequences for river ecosystems, such as preventing aquatic creatures from migrating upstream, cooling and deoxygenating water released downstream, and nutrient loss owing to particulate settling (Wikipedia, 2021). However, there are a few disadvantages associated with hydrokinetic technology when compared to traditional hydro energy technology. Since these turbines are dependent on flow conditions and the volume of water available it may be impossible to operate at a certain time of the year. Due to the rotating structures being positioned on the normal course of aquatic migrations and the resulting noises, these turbines can be damaging to the lives of aquatic species (Hasan *et al*., 2020; Linquip, 2021).

Types of hydrokinetic turbine

Hydrokinetic turbines are classified primarily by the orientation of their rotational axis in relation to the direction of water flow. The horizontal axis hydrokinetic turbine and the vertical axis hydrokinetic turbine are the two most common types. The cross-flow hydrokinetic turbine is another form.

Horizontal Axis Hydrokinetic Turbine

This type of turbine is installed in such a manner that its rotational axis is parallel to the direction of water flow. The rotor plane is placed perpendicularly to the flow to ensure appropriate power conversion efficiency. Horizontal axis turbines are mostly used in tidal energy conversion and are analogous to modern wind turbines with regard to concept and design. This type of turbine can be two-bladed, three-bladed, or multiplied with open or ducted structures. Two-bladed type turbines were used in SeaGen, which was the world's first large-scale commercial tidal energy converter (Douglas *et al.,* 2008). The developer of SeaGen 'Marine Current Turbine Ltd' demonstrated their first prototype of a tidal energy converter in 1994 in Loch Linnhe, off the west coast of Scotland. The prototype of SeaGen, 'SeaFlow', was installed off the coast of Lynmouth, North Devon, England in May 2003 (Sauser, 2008). SeaFlow was a single rotor turbine with 300 kW capacity which became the world's first offshore tidal generator (Wikipedia, 2021). The first SeaGen generator was erected in April 2008 in Strangford Narrows, Northern Ireland, between Strangford and Portaferry, and was grid-connected in July 2008 (Wikipedia, 2021).

Fig. 2: SeaGen (HydroReview, 2013)

Fig. 3: Seaflow (Wikipedia, 2021)

Three bladed designs have been used in turbine manufactured by Verdant Power. The company installed several turbines in New York City's East River under their first project, the Roosevelt Island Tidal Energy Project. The turbines installed in Kvalsund, Finnmark County, Norway under the Hammerfest Storm tidal project in 2003 were also three-bladed horizontal axis type. The multiplied design has been used in turbines manufactured by Lunar energy Ltd, UEK corporation, Open Hydro Group Ltd, and a few other companies. Luner energy manufactured bidirectional axial turbine housed in a symmetrical venturi ductwhich is appropriate for usage in tidal currents.

Fig. 4: Verdant Turbine (Wikipedia, 2021)

Fig. 5: Hammerfest storm Turbine (Scottishpower, 2011)

UEK (Underwater Electric Kit) used dual hydro turbine system with a multiplied structure. The system is suitable for stream velocities between 2 and 4 m/s and can be installed in a free flow manner or at the river bed (Güney & Kaygusuz, 2010).

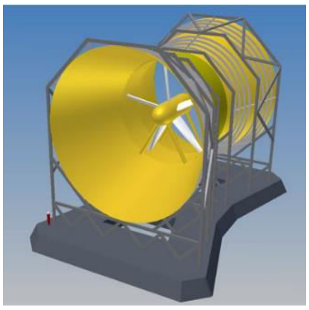

Fig. 6: Lunar Energy Tidal Turbine (REUK.co.uk)

Fig. 7: Open Hydro Turbine (The Irish Time, 2018)

Multibladed type turbine manufactured by Open-hydro is suitable for marine use and is designed to be installed on the sea-bed (Güney & Kaygusuz, 2010). The slow-moving rotor and lubricant-free operation of the system minimize the risk of marine life (Güney & Kaygusuz, 2010).

Vertical Axis Hydrokinetic Turbine

If the rotational axis of a turbine is perpendicular to the water flow direction, the turbine is called a vertical axis turbine. The most common types of vertical axis turbines are Darrieus, Gorlov, and Savonius turbines. Darrieus turbine is the most popular of these types. Straight bladed Darrieus Turbine also known as H-Darrieus turbine has been mostly used in hydro applications. This turbine is suitable for small and medium-sized rivers (AIHIT, 2021). However, there is no example of the curved bladed type used in the hydro domain (Linquip, 2021).

The Gorlov helical turbine has evolved from the Darrieus turbine design by altering it to have helical blades/foils (Wikipedia, 2019). It consists of two or three helical blades welded between two discs. This turbine can be installed in river, tidal current and any manmade canals (Lalander & Leijon, 2009)

Fig. 8: Darrieus Turbine (Behrouzi *et al.,* 2014).

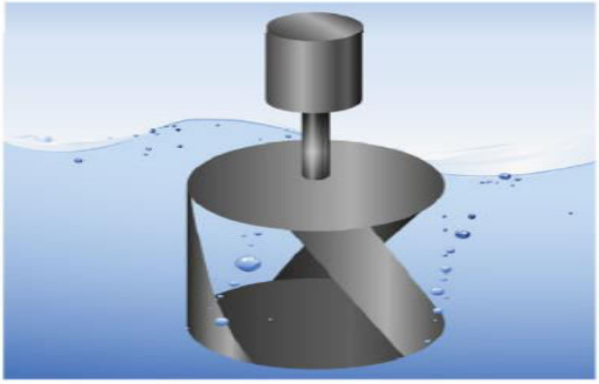

Fig. 9: Gorlov Turbine (Behrouzi *et al.,* 2014).

Savonius hydrokinetic turbine is a drag-type turbine that consists of straight or skewed blades. The construction is simple and associated with low cost. It is capable of accepting fluid from any direction and shows good starting characteristics.

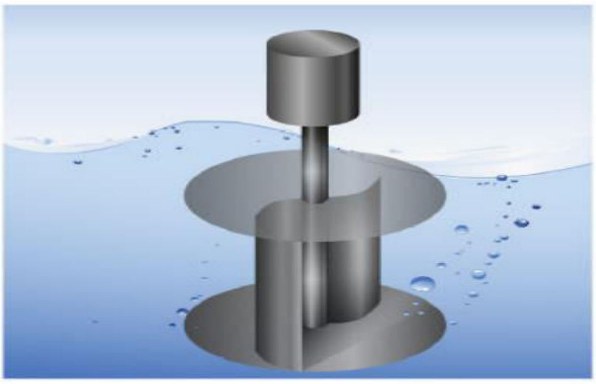

Fig. 10: Savonius Turbine (Behrouzi *et al.,* 2014).

Cross Flow Hydrokinetic Turbine

The rotational axis of a cross-flow turbine is orthogonal to the water flow direction and parallel to the surface of the water. Cross-flow turbines are preferred for usage in hydrokinetic farms or arrays because they take up less space and have a larger swept area, which increases output power (Cavagnaro, 2016). This turbine runs at a low speed, which reduces cavitations' and noise, and makes it safer for marine creatures (Forbush *et al.,* 2017). Cross flow turbine has been used in RivGen Power System built by Ocean Renewable Power Company. In 2014, the system was installed for the first time in the isolated Alaskan region of Igiugig (Wikipedia, 2021).

Fig. 11: Rivgen Power System (OPRC).

Prospect of Hydrokinetic Turbine Technology in Bangladesh

Bangladesh is a riverine country with lots of rivers flowing through in its territory. Moreover, it has a coastline of 710 kilometers and huge ocean area in the Bay of Bengal. If hydrokinetic turbine-based power stations can be set up in rivers and sea bed, the share of renewable energy In the country's total energy generation can be increased significantly, which is highly desired currently. Bangladesh has about 24000 km of rivers, streams and canals which cover about seven percent of the country's surface (BIWTA, 2014). The traditional hydroelectric power station is not viable in many river sites due to the negative impact of damson river hydrology and the subsequent effect on the environment. In those cases, hydrokinetic turbine-based technologies can be applied if it's efficient and cost-effective in those locations. There are many off-grid rural areas close to rivers where electricity is required for irrigation or domestic use. Small scale power plant using hydrokinetic turbine can be installed in those locations. However, it's not viable to implement this technology where the water velocity is significantly low. For a given amount of power output, the system becomes larger as the water speed decreases. A system if installed in a river current of 0.5 m/s has to be eight times the size of the system which is installed in a water current of 1m/s to produce the same amount of shaft power (Mamun, 2001). At a water velocity, less than 0.4 energy flux is so low that there would have to be very special economic conditions to justify the construction of a machine large enough to extract a useful amount of power (Mamun, 2001). At a speed, this low, construction of a power conversion system with a useful amount of power output won't be economically viable (Mamun, 2001). According to the Bangladesh Water Development Board water speed of most of the large rivers of Bangladesh remains above 0.4 m/s from July to December. Water speed of various rivers indicates that some of the rivers in the northwest part of Bangladesh are moderately potential for hydrokinetic energy conversion technology whereas rivers in the southeast and northeast region are highly potential (Mamun, 2001).

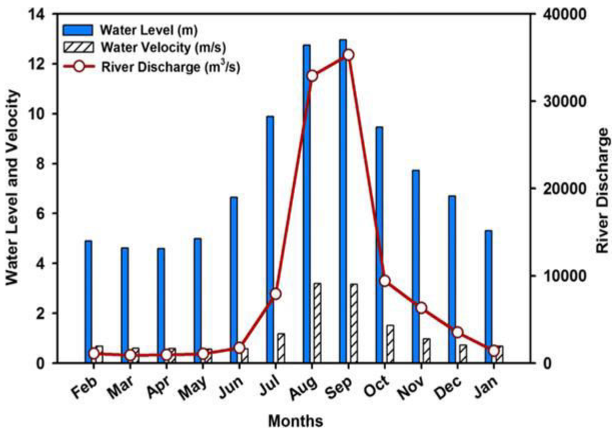

Fig. 12: Annual water level, velocity, and discharge of River Padma (Haque *et al.,* 2020).

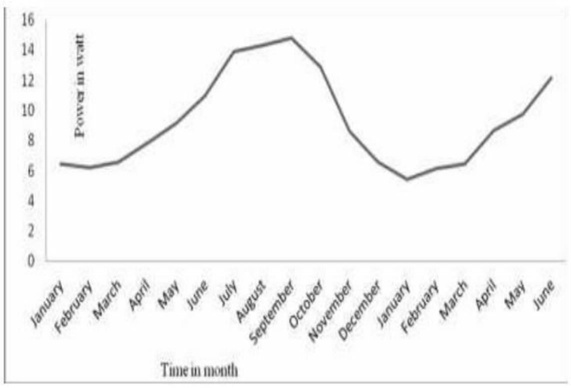

Fig. 13: Possible Power Production per hour per square meter at the Bay of Bengal (Estimated between January-2015, and June -2016) (Haque & Khatun, 2017).

Tidal power plants based on Hydrokinetic turbine technology can be built in coastal regions. The potential for power generation per square meter area shows that tidal power in Bangladesh has bright prospects (Haque & Khatun, 2017).

Bangladesh has numerous suitable spots for the construction of large-scale tidal power stationsin coastal places such as Hiron Point, Mongla, Sundorikota, Char-Changa, Cox's Bazar, Golachiipa, Patuakhali, Sandwip, etc. (Roy *et al.,* 2015). Moreover, Bangladesh has a 200 nautical miles wide exclusive economic zone and 354 nautical miles continental shelf in the Bay of Bengal. In the exclusive economic zone, Bangladesh is allowed to exercise sovereign rights over the exploitation of the hydro resource. Since space is not a factor for Bangladesh in the Bay of Bengal it could set up hydrokinetic turbines on the sea bed in series connection, the produced power would be considerable (Haque & Khatun, 2017).

CONCLUSION:

Hydrokinetic turbine technology offers an environment-friendly means of energy extraction from a natural stream. The technology is simple, cost-effective, and has a few advantages over conventional hydro technology. Different types of vertical and horizontal type turbine shave been successfully designed and installed in rivers and oceans around the world. Vertical axis turbines have been discovered to be suited for river use. However, the effectiveness of the technology largely depends on the speed of the water. The water speed of many rivers in Bangladesh seems to be promising for the application of this technology. There are few spots in the coastal region that are preferable for the establishment of the hydrokinetic turbine-based tidal power station. The sea current of the Bay of Bengal can be utilized for electricity generation by installing hydrokinetic turbines in series on the sea bed.

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CONFLICTS OF INTEREST:

With regard to the authorship and publishing of this paper, the authors declare that they have no possible conflicts of interest.

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