ZERO HEAD WATER TURBINE FOR SMALL SCALE ELECTRICITY GENERATION IN BANGLADESH

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Abstract A study on harnessing the kinetic energy from river current using a zero head water turbine similar to the horizontal axis wind turbine is presented in this paper. A rotor with three NACA 4415 blades having a radius of 934 mm can generate about 400 Watts at a river current of 0.9 m/s. To assess the potential of river current, three sites of two rivers have been considered as preliminary test cases. At these sites the river current has a seasonal variation from 0.37 m/s to 2.5 m/s with an average of 0.9 m/s to 1 m/s.

INTRODUCTION

Bangladesh is a sub-tropical country located between 20° 34’ and 26° 38’ N Latitude and 88° 01’ and 92° 41’ E longitude. It is surrounded by India to the east, west and north, by Myanmar to the south-east and by the Bay of Bengal to the south. It has an area of 148,393 Sq. km with a population of about 130 million. The per-capita GDP of the country is US$240 whereas the per-capital consumption of commercial energy is 67 KGOE (Kilogram of Oil Equivalent) and generation of electricity is 90 kWh, which is one of the lowest among the developing countries [World Bank, 1998/99]. In total only 10% of households have electricity connections [Unnayan Probah: 1991-95]; whereas the rest of the population depend on some sort of renewable sources of energy for cooking, lighting etc. During the last few years some government and non-government organisations have attempted to introduce renewable energy technologies such as Solar Home Systems, Biogas etc. to the rural areas [Khan, 1999]. Some studies have also been reported for mini-hydro potential in the country [Werszko, 1998 and Choudhury, 1998] which has not been implemented yet. Bangladesh is a riverine country. Energy extraction from river currents has not yet been studied extensively. A study has recently been undertaken to assess the potential of energy from river currents and this paper illustrates a preliminary survey and suggests a suitable water turbine for small scale electricity generation.

RIVER SYSTEM

Bangladesh is mainly a flat delta plain covered by the three major rivers viz. the Ganges, the Brahmaputra and the Meghna (Fig. 1). The elevation of most of the country is less than 33m above the mean sea level except the districts of Chittagong, Cox’s Bazar, Bandar Ban, Rangamati and Khagrachari, which are hilly. In addition, the neighboring areas of India near the northeast border of the country are also hilly. As many as 230 rivers flow over the country; out of which, 57 are transboundary coming from India and Myanmar. The combined length of the river courses is approximately 24,000 km and these cover 9,770 sq. km or 7% of the country area [Chowdhury *et al.*, 1997].

With these rivers, Bangladesh has a tremendous water resource. The average discharges of the three major rivers are 20,200m^3/s in the Brahmaputra, 11,300 m^3/s in the Ganges and 4,600 m^3/s in the Meghna [Chowdhury *et al.*, 1997]. The major rivers and their tributaries contribute about 90% of their annual flow originating outside the country and Bangladesh offers an outlet for the entire volume of flood flows. The water slopes of these rivers, except the ones in the hilly regions, are very low i.e. about 200 to 700 mm per km. However, the border rivers usually have their upper basin in India with a high channel slope, which flattens somewhat on the entry into Bangladesh.

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They pass through alluvial fans having relatively high slope and then enter the flood plain before discharging into larger rivers. In the region of high channel slope the rivers have a reasonable current flow rate which may be utilized for small-scale electricity generation.

This is a primary stage of the study and this paper has considered only 3 sites of the rivers where the mean river current data are analyzed. A turbine made of three NACA 4415 blades is considered for harnessing the kinetic energy of the river current.

RIVER CURRENT DATA

In this paper only three sites have been considered for the analysis of river current data. The sites are: (i) Jamuna river at Bahadurabad, (ii) Padma at Baruria (iii) Jamuna at Sirajgonj. The monthly mean velocities of these stations are shown in Figure 2. The velocity data are calculated from the volume flow rate data cited at reference [River Survey Project, 1996]. The annual average velocity of these sites and the maximum and minimum values is listed in Table 1.

Table 1 : River current at three stations.

River/Station	Annual Average Velocity (m/s)	Maximum Velocity (m/s)	Minimum Velocity (m/s)
Jamuna/ Bahadurabad	0.9	1.42	0.65
Padma/ Baruria	1.0	2.5	0.37
Jamuna/ Shirajganj	0.95	1.55	0.67

TURBINE DESIGN

To the authors' knowledge Marlec Engineering Co. Ltd of UK and Tyson Turbine of Australia are manufacturing zero head turbines for harnessing energy from river currents. Marlec Engineering uses a horizontal axis wind turbine with NACA blades whereas Tyson uses a propeller turbine. In this study we have considered Marlec's idea to design a turbine with NACA profile blades suitable for the conditions of Bangladesh.

Based on the annual average velocity of 0.9 m/s we have considered a turbine made of 3 blades similar to the Marlec wind turbine. A typical rotor radius of 934mm with a hub of 34 mm radius is considered in the present analysis. The blades have NACA4415 profile and are 900mm long with a 34mm hub radius. The schematic diagram of the zero head turbine system is shown in figure 3. The blade chord and twist angle are calculated according to [Jansen and Smulders, 1977]:

$$\text{Chord, } C = \frac{8\pi r(1-\cos\phi)}{B C_{ld}}$$

where B is the number of blades, C_{ld} is design lift coefficient and

$$\phi = \frac{2}{3}\tan^{-1}(1/\lambda_r)$$

$\lambda_r = \lambda_d$ (r/R) is the tip speed ratio at radius r and λ_d is the design tip speed ratio. We have chosen $\lambda_d = 4.89$ which corresponds to river current of 0.9 m/s at 45 rpm of the turbine. The twist angle is calculated as:

$$\beta_T = \phi - \alpha_d$$

where α_d is the design angle of attack. In the present study the values of C_{ld} and α_d are 1.07 and 7^o respectively [10,11]. The calculated chord and twist angle of the blade is shown in figures 4 and 5 both for the ideal case and a linearised case. The linearisation has been done by the following equation [Jansen and Smulders, 1977]:

$$\beta_T = 2.5\,(\beta_{90} - \beta_{50})\, r / R + 2.25\,\beta_{50} - 1.25\,\beta_{90}$$

$$C = 2.5\,(C_{90} - C_{50})\, r / R + 2.25\,C_{50} - 1.25\,C_{90}$$

where the subscripts 50 and 90 refer to the conditions at 50% and 90% radius respectively.

The characteristics of the blades are calculated using a conventional blade element code [12] and the results for power coefficient (Cp) vs. tip speed ratio (TSR) are shown in figures 6 and 7. The power extracted is also shown in the figures. The power is calculated based on a constant rotor rpm of 45. Assuming a system efficiency of 50%, the turbine can have an output of around 200 watts at the designed tip speed ratio.

CONCLUSION

The river current data of 3 different stations of Bangladesh have shown a potential of small-scale electrical energy generation. A turbine with three NACA 4415 blades of 934mm radius can generate up to 400 watts of electrical energy at a river current of 0.9 m/s.

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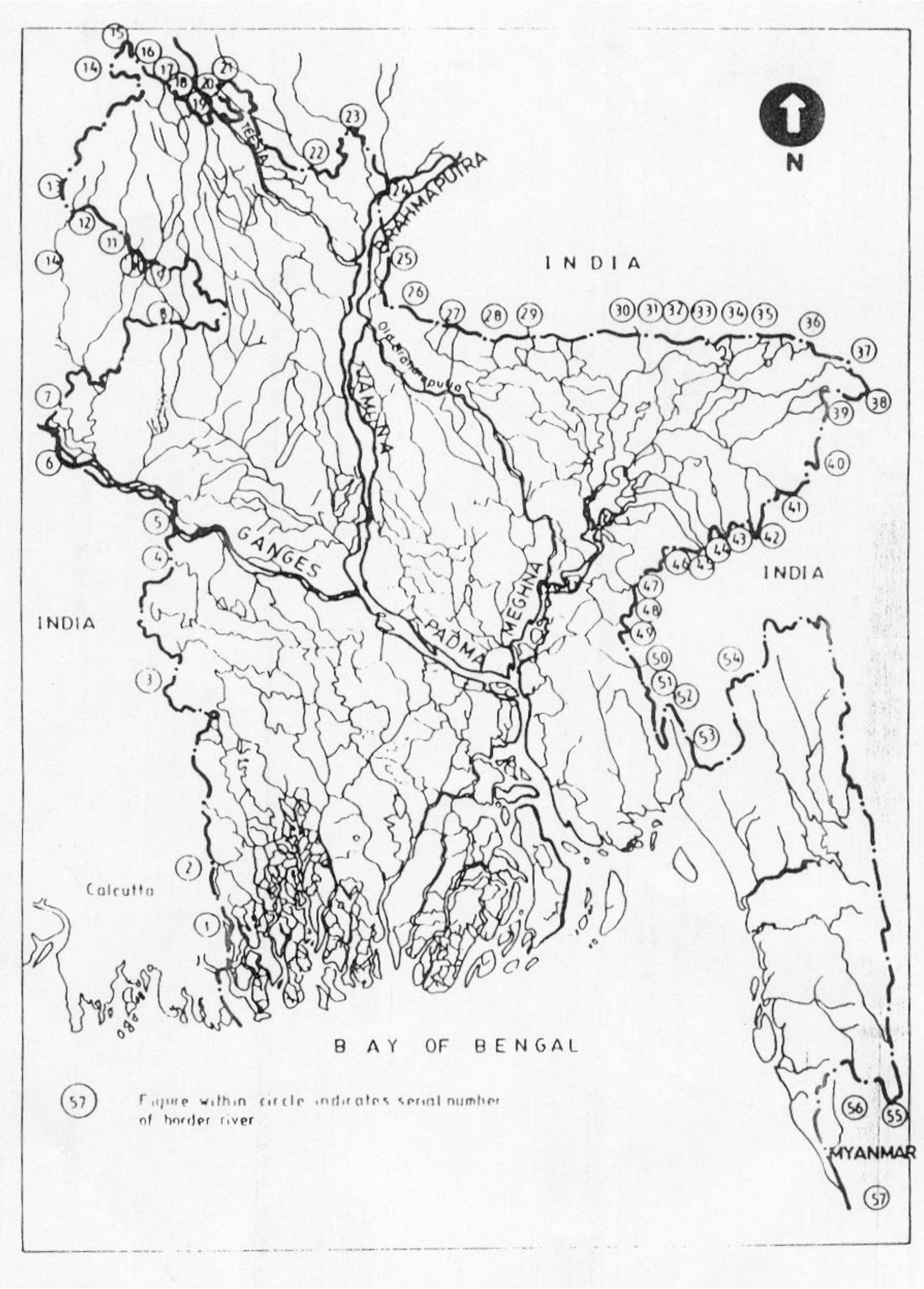

Fig. 1 River system of Bangladesh

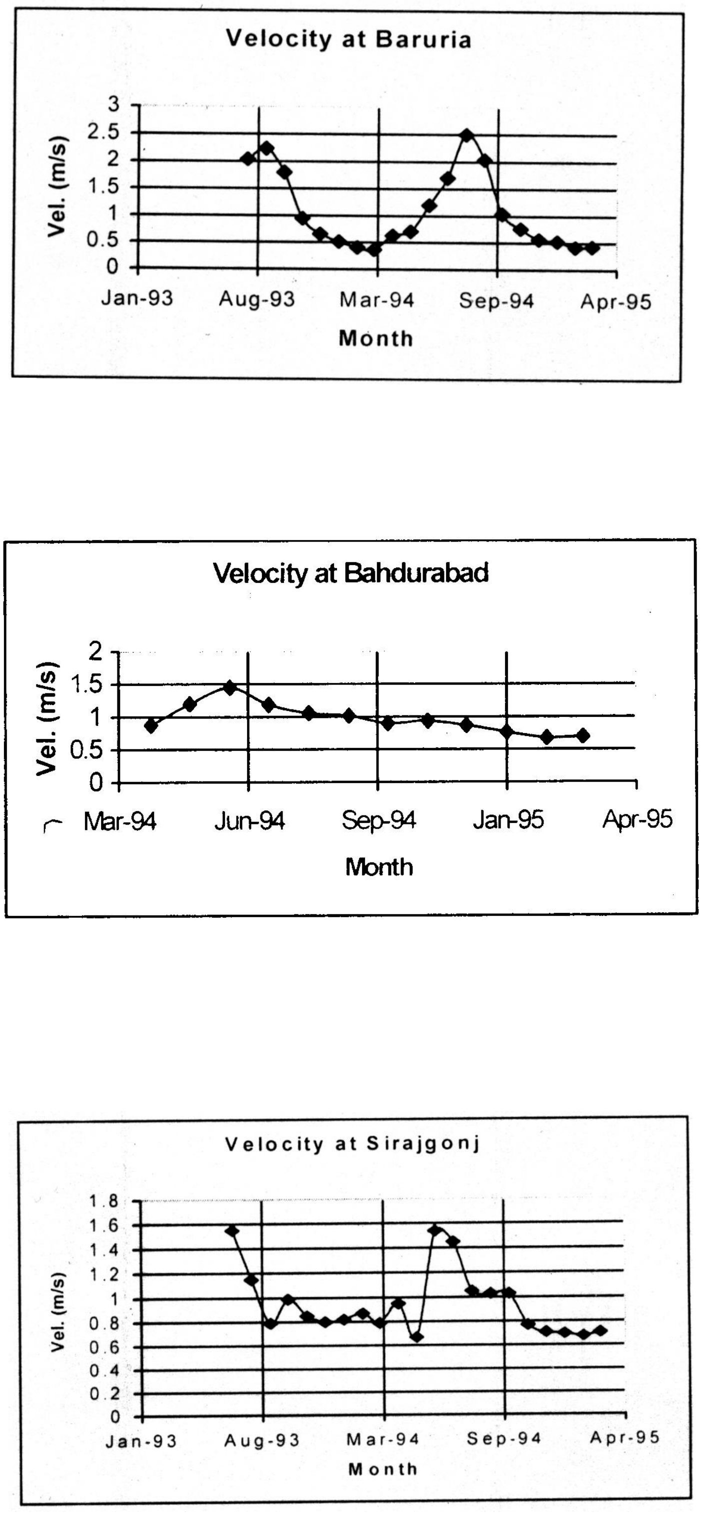

Fig. 2 Velocity at Bahadurabad, Baruria and Sirajgonj station

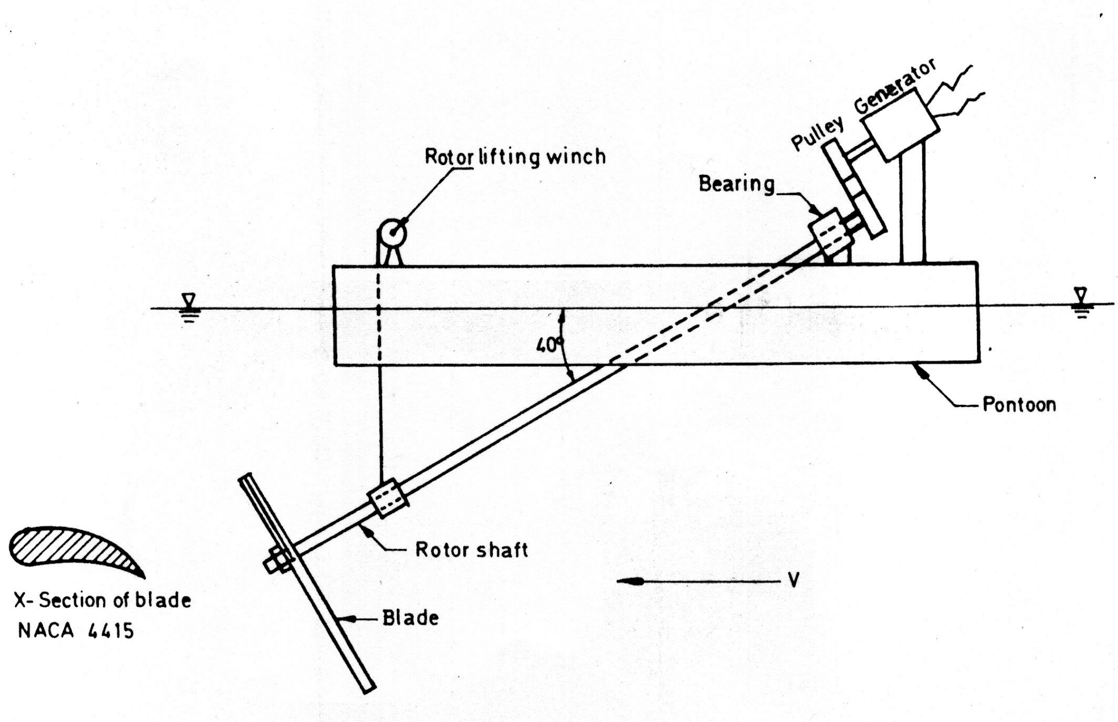

Fig. 3 Schematic of the zero head water current turbine