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Feasibility study of a community based micro- hydro system in Chittagong, Bangladesh

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ABSTRACT

Mini and micro hydro are environmental friendly power generation technology for remote micro grid system. Not much work on real feasibility of these types on remote micro grid has yet been reported in Bangladesh. This paper discusses the technical issues on conducting the feasibility study to determine the mini and micro hydro potential in Bangladesh, especially in Chittagong region. This paper also presents the data obtained through field study to give concrete proposal for installing such power plants, which can form a stand-alone micro-grid to ease the electricity crisis in the country.

KEYWORDS

Hydro-electric power plant;
Renewable energy;
Micro grid;
Global temperature rise;
Climate change.

INTRODUCTION

Today, like whole world, Bangladesh is also concerned about climate change and energy security. The government of Bangladesh is placing considerable importance on renewable energy technology for reducing energy related environmental problem as well as enhance the energy security of the country. In Bangladesh, there is a significant potential of renewable energy like solar, biomass, wind all over the country. But, due to country's topography, there are enormous potential of mini and micro hydro power potential at Chittagong region. At present, utilization rate of hydro power potential is very small in Bangladesh. The general definitions of various hydro power plants are given in TABLE 1[1].

TABLE 1 : Types of hydro power plants

Pico-Hydro	100W-1kW
Micro-Hydro	1kW-10kW
Mini-Hydro	10kW-100kW
Small-Hydro	1000kW-10MW
Medium-Hydro	10MW-100MW
Large-Hydro	Above 100MW

Although the scope of hydropower generation is very limited in plain lands of Bangladesh, but hilly region in the northeast and southeast parts of the country seem to be promising. There are many canals, tributaries of main river Karnafuli, Shangu, Matamuhuri as well as tiny waterfalls having potentials for setting up mini/ micro hydropower unit in Chittagong Hill Tracts region.

Harnessing micro-hydro and mini-hydro resources and setting up decentralized small-scale water power or micro-hydro schemes are particularly attractive option in terrain areas without hampering ecosystem. Although several scattered studies were carried out on the potential sites in Chittagong region by different people, concrete works to explore site-wise potential on installation of mini/micro hydro power plant based micro grid is needed. Potential of pumped hydro scheme for Kapti hydro-electric power plant can also be explored. One of such works conducted by the researchers of Chittagong University of Engineering & Technology (CUET) is presented in the paper as a case study.

STRATEGIC IMPORTANCE OF HYDRO POWER PLANTS

Hydropower accounts for about 20% of the total power generation in the world. Only 34% of potential capacity has been developed[2]. The continent wise breakdown of hydropower is given in Figure 1.

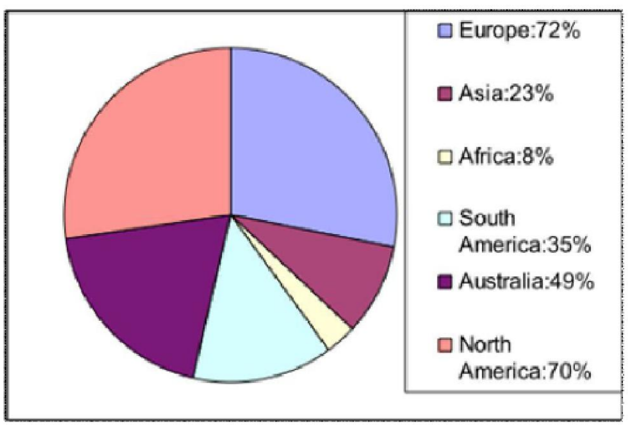

Figure 1 : Hydropower share in different continent

More than 60% of hydropower of the world has been developed in developed countries. Country wise developed hydropower share is given below.

USA: 82%

Japan: 84%

Canada: 65%

Germany: 73%

France, Norway, Switzerland >80%

Bangladesh: 2.5%

Bangladesh is one of the poorest and most densely populated countries in the world. Although electricity is a key ingredient for the socio-economic development of the country, only around 40% of the population (30% in urban areas and 10% in rural areas) has access to electricity, and per capita commercial energy consumption is among the lowest in the world[3].

Bangladesh has small reserves of natural gas, oil and coal. Natural gas and coal are used for mainly in power generation. Since this reserves are evacuate after next few years, power generation will then be in most critical position. The need for electrification of entire Bangladesh is extremely vital since all industrial and other economic activities rely heavily on electricity or other means of power. Bangladesh has a large unsatisfied demand for energy, which is growing by 10% annually. The country has an installed capacity of 5,275 megawatts; however, only maximum 4,500 megawatts are considered "available" at any given time. To respond to the growing demand for energy, the government of Bangladesh has, since 1996, permitted the entry of private-sector and independent power producers into the Bangladeshi market. However, both supply and demand sided management is required to bring about renewable energy solutions and achieve the sustainable development that is sought for in Bangladesh.

The rural areas of Bangladesh, where 76% of the population live, are seriously deprive of electricity[4]. A major portion of the un-electrified population will not be able to get electricity in the foreseeable future due to several contents constraints, including low consumer density and inaccessibility. Bangladesh has lack of power as well as system efficiency, though demand increase but power generation would not be able to run with demand linearly. There are many areas in the country where electricity will not reach in the next 30 years[5]. Experts is worrying that the rate of current electrification will take decades to provide access to electricity to all people in the country, although Government has the vision to electrify the whole country within the year 2020. Installation of any large hydropower plants may lead to bitter political conflict again in the Hill Tracts region. One of the possible solutions of electricity crisis at remote hilly region in Chittagong is the installation of micro and mini hydro power plants based micro grid.

A recent USAID study's findings and assessments about impact of the rural electrification program in Bangladesh are the following[6].

- 93.7% of the electrified households reported decrease in fuel cost.
- 78.2% reported an increase on working hours.
- 62.0 % reported an increase in household income
- 81% reported an increase in reading habits
- 93.7% reported an increase in children's study time.
- 92.0% reported an increase in amusement as well as standard of living.
- 94.7% reported an improvement in security.

Greenhouse Gas Emission is seriously affection sea-level rise in Bangladesh. Even a very cautious projection of 10 cm sea level rise, which would most likely happen well before 2030, would inundate 2500 sq. km, about 2% of the total land area. Patuakhali, Khulna and Barisal regions are most at risk from sea level rise. On average, the sea would move in about 10 km, but in the Khulna region, the sea will likely move in further[7]. With the high end estimates, sea level rise in Bangladesh would inundate 18% of the country by 2100[8]. So, Bangladesh should encourage clean RETs to combat greenhouse gas emissions to avert the potential threats.

Clean energy services is essential for sustainable development and poverty eradication, provides major benefits in the areas of health, literacy and equity. The various prospects of micro and mini hydro power generation are:

- Power would supply into the remote areas.
- Low generating cost and better plant efficiency.
- Reduce the maintenance cost.
- Power for a family or a group of family.
- Provides option for decentralization of rural electrification.
- Make efficient use of local energy resource.
- Reduce the dependence on natural gas, coal, oil.
- Provide much cleaner and sustainable energy that they would not pollute environment.
- Relatively small investments are needed that are within the reach of low-income communities.

MICRO AND MINI HYDRO POTENTIALS IN CHITTAGONG

Several attempts have been made in the past to find out the potential of micro and mini hydro power generation in Greater Chittagong Region. To explore the possibility of hydropower from small hilly rivers/ streams in the country, a working committee was constituted on February 1981 with officers from Bangladesh Water Development Board (BWDB) and Bangladesh Power Development Board (BPDB). A study was also conducted by a group of Chinese experts and by LGED in 2002-2003[5]. Some of the previous studies are complied and shown in Figure 2 on the potential of mini and micro hydro power. First five locations are in Chittagong and others are in Chittagong Hill Tracts regions. The average potential is around 30 kW which encourages exploring more potential sites in Chittagong.

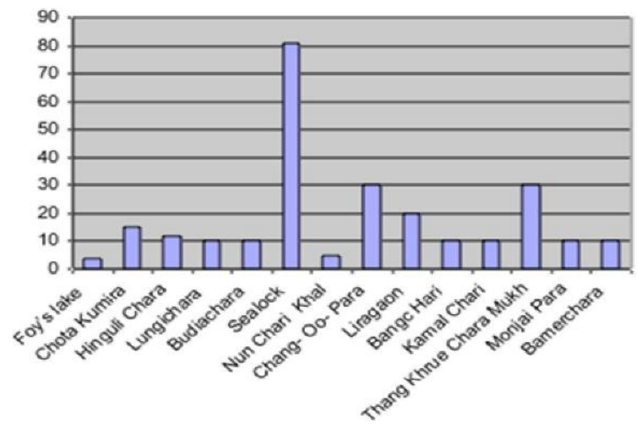

Figure 2 : Mini and micro hydropower potential (kW) in greater Chittagong

A CASE STUDY

To find out the hydro power potential, as a case study in a new area name Godown area is chosen. Godown area is about 6 km from CUET, and 22 km from Chittagong city. The latitude of this place is 22°27' N and the longitude is 92°02' E. The data were taken under the Godown Bridge of the river. It's a branch of river Karnafully, which is called ISAMATI by the local people.

Basics of hydro power

Hydropower is energy from water sources such as the ocean, rivers and waterfalls. "Mini-hydro" means which can apply to sites ranging from a tiny scheme to electrify a single home, to a few hundred kilowatts for selling into the National Grid.

(A) Head and flow

Hydraulic power can be captured wherever a flow of water falls from a higher level to a lower level. The vertical fall of the water, known as the "head", is essential for hydropower generation; fast-flowing water on its own does not contain sufficient energy for useful power production except on a very large scale, such as offshore marine currents. Hence two quantities are required: a Flow Rate of water Q, and a Head H, those are shown in Figure 3. It is generally better to have more head than more flow, since this keeps the equipment smaller.

The Gross Head (H) is the maximum available vertical fall in the water, from the upstream level to the downstream level. The actual head seen by a turbine will be slightly less than the gross head due to losses incurred when transferring the water into and away from the machine. This reduced head is known as the Net Head.

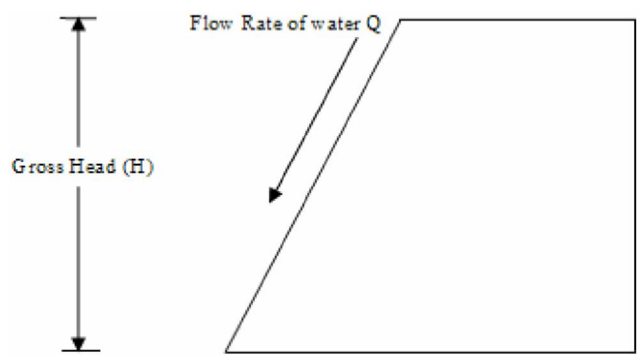

Figure 3 : Hydro power generation quantities

Flow Rate (Q) in the river, is the volume of water passing per second, measured in m^3/sec. For small schemes, the flow rate may also be expressed in liters/second or 1 m^3/sec.

(B) Power and energy

Power is the energy converted per second, i.e. the rate of work being done, measured in watts (where 1watt = 1 Joule/sec. and 1 kilowatt = 1000 watts).

In a hydro power plant, potential energy of the water is first converted to equivalent amount of kinetic energy. Thus, the height of the water is utilized to calculate its potential energy and this energy is converted to speed up the water at the intake of the turbine and is calculated by balancing these potential and kinetic energy of water.

Potential energy of water,

$$E_p = mgH \quad (1)$$

Kinetic energy of water,

$$E_k = \frac{1}{2}mc^2 \quad (2)$$

Where, m is mass of water (kg); g is the acceleration due to gravity (9.81 m/s^2); H is the effective pressure head of water across the turbine (m); c is the jet velocity of water at the intake of the turbine blade (m/s)

Thus, jet velocity

$$C = \sqrt{2gH} \quad (3)$$

If a hydro turbine is considered as a system which is shown in Figure 4, force equation and Bernoulli's energy equation are applicable for the surface area of the turbine.

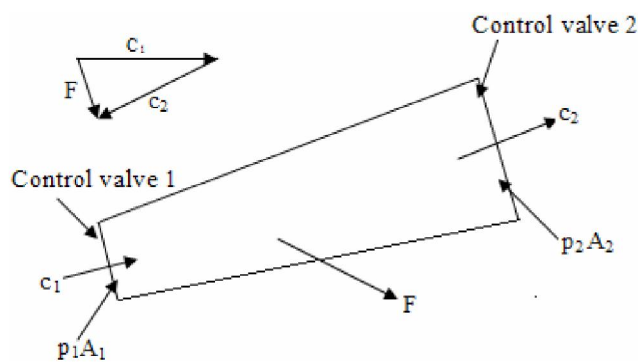

Figure 4 : Various force components of a hydro turbine

Force on control surface = Summation of Impulse and Pressure forces

$$m\frac{d\vec{v}}{dt} = \phi_m(\vec{c}_1 - \vec{c}_2) + (p_1A_1 - p_2A_2) \quad (4)$$

Also, Bernoulli's energy equation -

$$p + \frac{1}{2}\rho c^2 + \rho gZ = \text{Constant} \quad (5)$$

In the above equations, speed remains constant at inlet and outlet of turbine and so also pressure. Thus, mechanical energy delivered by the turbine is mainly due to the height difference of the hydro system. Hydroturbines convert water force into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of head and flow rate. The general formula for any hydro system's power output is:

$$P = \eta\rho gQH \quad (6)$$

Where, P is the mechanical power produced at the turbine shaft (Watts); η is the hydraulic efficiency of the turbine; ρ is the density of water (1000 kg/m^3); g is the acceleration due to gravity (9.81 m/s^2); Q is the volume flow rate passing through the turbine (m^3/s); H is the effective pressure head of water across the turbine (m)

The best turbines can have hydraulic efficiencies in the range 80 to over 90%, although this will reduce with size. Micro-hydro systems (<100kW) tend to be 60 to 80% efficient.

(C) Capacity factor

'Capacity factor' is a ratio summarizing how hard a turbine is working, expressed as follows:

Capacity factor (%) = Energy generated per year (kWh/year) / {Installed capacity (kW) x 8760 hours/year}

(D) Energy output

Energy is the work done in a given time, measured in Joules. Electricity is a form of energy, but is generally expressed in its own units of kilowatt-hours (kWh) where 1 kWh = 3600 Joules and is the electricity supplied by 1 kW working for 1 hour. The annual energy output is then estimated using the Capacity Factor (CF) as follows:

Energy (kWh/year) = P (kW) × CF × 8760

Flow measurement

Two methods are commonly suggested for measuring the flow in small or medium sized streams. Large discharges are best determined by a hydraulic engineer. The float method of testing stream flow is the easiest test to conduct and will yield satisfactory data, except in cases where a stream is shallow or rocky and thus impedes the movements of a weighted float. Basically the cross section of an unobstructed area of the stream is measured and a weighted float such as a bottle weighted with pebbles is timed as it floats down a 100 foot course.

To measure the velocity of water current in different time we used the floating system, because it is simple and easier way of measuring the velocity of flow by means of floats. The surface velocity at any section may be easily obtained with the help of single float. Observing the time taken by the float to travel a known distance, we can calculate the current velocity, by dividing the distance traveled by the float by the time taken to travel that distance.

Head measurement

After the height of the water behind the proposed dam or diversion has been decided, it is necessary to measure the head of water that will result. To determine the difference in level between two points, we set a surveyor's level about midway between the points. Then we have an assistant hold of a surveyor's rod at one point, sight through the level and recorded the height reading on the rod. Moving the rod to the second point and read. The difference of the readings is the difference in elevation of the two points. Often it is impossible to see the two points from a single setting of the level so rods must be read at intermediate or turning points. The differences in readings between each pair of points can be added together to calculate the total elevation drop from the dam or diversion.

Measured data and calculation of power

The measured data in different times are given in TABLE 2 below.

TABLE 2 : Ranges of tidal current velocity in different dates and times

Date	Day time (24hr)	Velocity (m/s)	Day time (24hr)	Velocity (m/s)	Total (24hr)	Velocity range. (m/s)
21.09.07	11.00-13.00	0.64-0.748	13.30-14.30	0.88-0.96	03	0.64-0.96
22.09.07	9.00-13.00	0.55-0.78	14.00-16.00	0.92-1.00	06	0.55-1.00
05.10.07	11.00-12.30	0.44-0.80	13.30-17.00	0.90-0.94	05	0.44-0.94
27.10.07	10.00-13.00	0.563-0.75	13.30-18.00	0.55-0.78	7.5	0.563-0.78
02.11.07	9.30-13.30	0.66-0.889	14.00-17.30	0.80-0.90	7.5	0.66-0.90

Other hydrological data and calculations are given below.

Depth (measured at different locations):

D1=0.45 m, D2=0.50 m, D3=0.6 m, D4=0.7 m, D5=0.6m, D6=0.55m, D7=0.65m

Average Depth:

(D1+D2+D3+D4+D5+D6+D7) ÷ 7

= 0.578 m

Average Cross-sectional width of the river:

W=30 m

Lowest flow throughout the year = 12.9 m^3/sec.

Av. Flood level (September-November) = 0.78 m

Av. Flood level (June-August) = 7m
Highest flood level = 10.00m (Occasionally)
Measured head, H = 0.786m.
Average velocity, V = 0.7433m/s.
Area, A = 17.36 m^2
Flow, Q = AV
= 17.36*0.7433 m^3/s
= 12.90 m^3/s.
Gravitational acceleration, G = 9.81m/s^2
Density of water, ρ = 1000kg/m^3
Efficiency = 50%, (as a rule of thumb)
Turbine output power (kW):
P= Efficiency (%) x Flow (m^3/s) x Head (m) x Gravity (9.81m/s^2) x Density of water (ρ)
=0.5*12.9*0.786*9.81*1000 = 49.73 kW

To obtain the amount of energy (kWh) produced, we have to, multiply the practical power capacity by the time (hours). The plant will be operating at the particular output. Seasonal flow variations will have to be considered for more applications, as the maximum flow may only be available for short periods each year.

Turbine and generator

The potential for development of small-scale hydro generation is frequently greatest in countries which have limited indigenous power plant industries[9]. This is true for Bangladesh also. Although lack of fund limits the purchase of plant by direct import, the local people may be trained to manufacture all the machines and components of a mini or micro hydro power plant and according a suitable design should be chosen.

The cross flow, Mitchell, or Barid turbine operates with the runner around atmospheric pressure, providing good efficiency down to low heads. The flow of water through the unit is controlled by a two piece guide vane. Selecting 1/3, 2/3 or full guide vane opening does not greatly alter the hydraulic characteristics of the unit, providing a particularly flat efficiency curve down to part load. Mitchell turbine offers good selection criteria for the site of the study.

A synchronous generator is proposed for the selected site with the following design parameters.
KVA=50
Voltage=440
Phase=3φ
Frequency= 50 Hz
RPM=150
Connection = Star
Pole = 40
Power factor = 0.8

A computer program using MATLAB has been developed to find out the performance of such a generation if it is constructed using cost-effective materials. The performance is given below. It seems that the performance is at acceptable level.
Total loss = 10.5262 kW
Rated output = 40 kW
Input = 50.5262 kW
Efficiency = 79.1669%
Temperature Rise of the Armature = 30.3113 ^{o}C
Temperature Rise of the Field coils = 70.9465^{o}C
Regulation = 7.58%
Short Circuit Ratio = 24.62

Formation of micro-grid

Electricity in remote off-grid areas may be used for a range of applications such as crop drying, milk chilling, poultry rearing, weaving as well as power supply to TV and agricultural pumps. To ensure reliable operation of loads, automatic control is required as loads are not always constant[10]. In such off-grid parts in greater Chittagong, the possibility of installing stand alone micro and mini hydro power plant based micro-grid may be explored. Micro grid needs enabling technologies for seamless interconnection of low environmental impact new generation technologies[11]. A suitable scheme is proposed and shown in Figure 5.

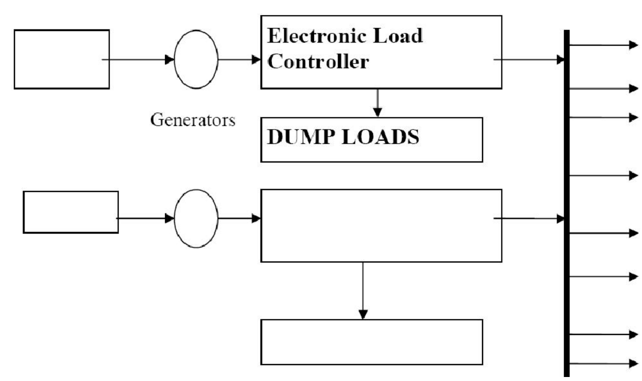

Figure 5 : A proposed micro grid based on mini and micro hydro plants in off grid areas

CONCLUSIONS

To limit green house gas emission and meet the increasing demand of electricity, one of the promising solutions is to install more hydro power plants. In Bangladesh large hydro plants may not be feasible due to political regions in hilly Chittagong regions, but there is good potential for mini and micro hydro plants. This paper discusses the strategic importance and potential of such plants. A detailed field survey has been presented to support this claim. Technical issues on installation of a micro-hydro plant have also been discussed. It is hoped that this study will also encourage exploring more potential sites and constructing micro grid based on micro and mini hydro plants in greater Chittagong regions.

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