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Techno-economical analysis of off-grid hybrid systems at Kutubdia Island, Bangladesh

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ABSTRACT

Kutubdia is an island in the southern coast of Bangladesh where mainland grid electricity is not present or would not feasible in near future. Presently, electricity is generated using a diesel generator by Bangladesh Power Development Board (BPDB) for a limited time and location. Due to its remote location, the fuel cost in Kutubdia is very expensive. In the present study one-year recorded wind by Bangladesh Centre of Advanced Studies (BCAS) location and other three potential locations for hybrid system analysis is discussed. The system configuration of the hybrid is achieved based on a theoretical domestic load at the island. The sizing of the hybrid power systems is discussed with 0% and 5% annual capacity of shortage. This feasibility study indicates that wind–PV–diesel system is feasible with 0% capacity of shortage and wind–diesel system is feasible with 5% annual capacity of shortage at all locations. As 5% annual capacity of shortage can be considered, the wind–diesel hybrid system will reduce net present cost as well as cost of energy to about 20% and the diesel consumption on the island can be reduced to about 50% of its present annual consumption. Such a hybrid system will reduce about 44% green house gases (GHG) from the local atmosphere.

1. Introduction

Bangladesh suffers from acute energy shortage. The gap between demand and supply is gradually increasing. About 80% of the people in Bangladesh live in villages where the main source of income is agriculture. Most of these people are deprived of electricity, which is a necessity in today's life. Although there are some reserves of natural gas and coal, the country's economic and technical inability makes it hard to provide an energy supply network to the rural poor population (Ali, 2004). The dependence on importing fuel is increasing where the rural population is largely deprived due to their low purchasing power. Rural people have to depend on biomass, wind and sun, which leads to damage in the overall environmental quality. The country has a 724 km long coastline and many small islands in the Bay of Bengal, where strong south-westerly trade wind and sea-breeze blow in the summer months and there is gentle north-easterly trade wind and land breeze in winter months (Bangladesh Renewable Energy Newsletter, 2000) In Bangladesh, little systematic wind speed study has been carried out. Data collected by the meteorology department are usually meant for weather forecasting and are insufficient for determining wind energy potential. In an early study report in 1982, a 30-year meteorological data record from a number of stations throughout the country was considered and it was found that wind speeds in the districts of Chittagong and Cox's Bazar and the bay islands were the only ones that showed promise for possible electricity generation from wind (Bangladesh Renewable Energy Newsletter, 2000). The long-term wind flow of Islands and the southern coastal belt of the country indicate that the average wind speed remains between 3 and 4.5 m/s for the months of March–September and 1.7–2.3 m/s for the remaining period of the year (Government of the People's Republic of Bangladesh Ministry of Power, 2004). This indicates there is a good potential in islands and coastal areas for the application electricity generation from wind. But during the summer and monsoon seasons (March to October), there can be very low-pressure areas, and storm wind speeds of 200–300 km/h can be expected. Wind turbines should be strong enough to withstand these high wind speeds (Government of the People's Republic of Bangladesh Ministry of Power, 2004). The long-term average sunshine data indicate that the period of bright (i.e. more than 200 W/m^2 intensity) sunshine hours in the coastal region of Bangladesh vary from 3 to 11 h daily and the global radiation varies from 3.8 to 6.4 kW h/m^2/day (Ali, 2004). These data indicate that there are good prospects for solar, thermal and photovoltaic application in Bangladesh. Thus hybrid energy system can be an efficient alternative for the coastal locations of Bangladesh.

Kutubdia is the most promising island in Bangladesh that has excellent wind resource. Kutubdia has an area of 212 km^2, with a population about 1 million. Kutubdia is rich in producing salt and

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dried fish. The people of Kutubdia depend on the expensive and often erratic supply of kerosene for their lightning needs. Some people use solar panel to meet their demand. Due to increasing costs of fossil fuels, uncertainty of availability, increasing environmental pollution and general awareness amongst the common people, green energy sources are being encouraged. Bangladesh Power Development Board (BPDB) is trying to replace their existing diesel-based generator with a Wind–Battery system. The aim of this work is to find out the best energy option for the island to replace the existing diesel generator. The work was carried out with the help of simulation software HOMER (Hybrid Optimization Model for Electric Renewables) developed by National Renewable Energy Laboratory (NREL), USA (http://www.nrel.gov/homer).

2. Solar energy resource over Kutubdia

Measured solar radiation data for Kutubdia are not available. To predict solar radiation from other meteorological parameters, cloud cover and sunshine duration data were collected from Bangladesh Meteorological Department (BMD) for 1981–2003. The BMD changed card types for sunshine duration measurement in 1990. Hence data from 1992 to 2003 were used to avoid erroneous prediction of solar radiation. Cloud cover is a direct indicator of sunshine duration and they are correlated. An increase in cloud cover in the sky shows a decrease in sunshine duration. The variation of the yearly averaged daily sunshine duration and cloud cover data is shown in Fig. 1.

The sunshine duration and cloud cover are not correlated for most of the years and there are similar rising patterns for both sunshine duration and cloud cover. A study done by Ghosh et al. (2006a) showed that the cloud cover measurements are satisfactory in all the BMD stations. Hence sunshine duration values were estimated using the state of the sky method based on the work of Barbaro et al. (1981).

According to Barbaro et al. (1981) the relation between the relative sunshine duration and the state of the sky is

$$\frac{n}{N'} = \frac{an_1 + bn2_+ cn_3}{n_{123}} \tag{1}$$

where n is the number of bright sunshine hours. $N'$is the period when the Campbell–Stokes sunshine recorder remains sensitive over the representative day for the month and

$$N' = \frac{\text{arc}\cos\left((\cos 85 - \sin\varphi \sin\delta)/(\cos\varphi\cos\delta)\right)}{7.5} \tag{2}$$

φ is the latitude of the station and δ is the declination (Rangaranjan et al., 1984). n_1 is the number of clear days, n_2 is the number of mixed days, n_3 is the number of overcast days in a month, $n_{123}=n_1+n_2+n_3$ is the total number of days in the month under consideration and a, b, c are meteorological parameters.

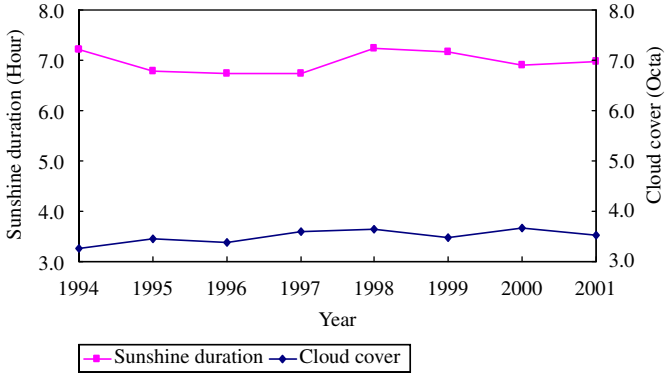

Fig. 1. Variation of sunshine duration and cloud cover over Kutubdia.

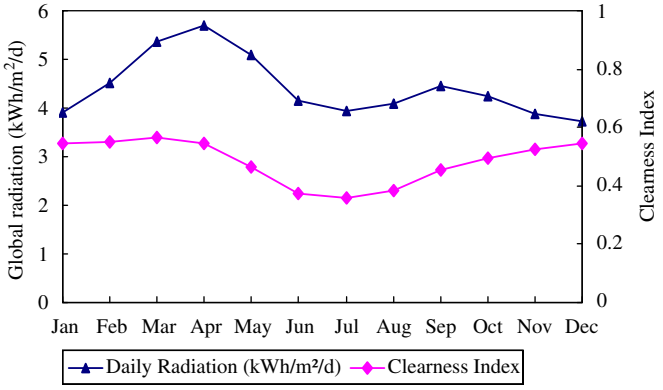

Fig. 2. Solar resource over Kutubdia Island.

To predict global solar radiation from sunshine duration the Angstrom equation (Angstrom, 1924) has been used. The equation is

$$\frac{H}{H_o} = a + b\frac{n}{N} \tag{3}$$

where H/H_0 is known as clearness index K_T. H represents the daily global radiation and H_0 the daily extraterrestrial radiation on a horizontal surface, N the maximum sunshine duration or day-length, a and b are correlation coefficients. H_0 and N were evaluated according to equations reported in Iqbal (1979) for sunshine duration and global radiation relation. The parameters of Eq. (3) have been chosen from a recent work of Ghosh et al. (2006b). which gives global radiation prediction with 3% error. For each day there exists an ordered set $\{k_T\}$ of hourly values of the clearness index values k_T. Estimation of hourly k_T values from daily K_T was carried out using and empirical model developed by Graham and Hollands (1990). The global horizontal radiation over Kutubdia is shown in Fig. 2.

3. Wind resources assessment

Wind energy varies with year, season, and time of day, elevation above ground, and form of terrain. Proper position of turbine, in windy sites, away from large obstructions, improves wind turbine's performance. The power in the wind is a cubic function of wind speed; changes in speed produce a profound effect on power. Doubling the wind speed does not double the power available, which increases a whopping eight times (Patel, 2006). It is important for the wind industry to be able to describe the variation of wind speed sand turbine designers need the information to optimize the design of their turbines, so as to minimize the generation cost. It has been found that BMD data give low values due to the obstacle effect by trees and buildings close to the met station (91.851E, 21.821N) (Final report of Solar and Wind Energy Resource Assessment-Bangladesh, 2007). Bangladesh Centre for advanced studies measured wind speed at a different site (91.84°E, 21.68°N) at a height of 25 m. Raw data at 10 min intervals at Kutubdia have been collected from BCAS for the period for September 1996–February 1998. The data in its original format were checked and unrealistic data were removed. The monthly variation in wind speed is high for Kutubdia and it has been found that during May–September the wind speed is high but for rest of the months it is low and annual wind speed is 3 m/sec. Diurnal cycles of the wind speed reaches the maximum during afternoon and minimum during the early morning. The