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Wind Energy Potential in Bangladesh

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ABSTRACT: *Bangladesh is encountering difficulties in supplying energy to maintain its economic growth. Government of Bangladesh is looking for renewable energy sources to meet up the total power demand in this country. The present study aims to assess wind energy potential in Bangladesh as a sustainable solution to overcome the energy crisis. Wind speed at six coastal zones Patenga, Cox's Bazar, Teknaf, Char Fassion, Kuakata and Kutubdia at Bay of Bengal of Bangladesh have been analyzed. A near shore wind farm has been considered at these locations having a coastal line of 574 km. The turbines are spaced 7D apart in the prevailing wind direction, and 3D apart in the perpendicular direction, where D is rotor diameter. This near shore wind farm with an array of 5104 horizontal axis wind turbines with hub height of 100 m and rotor diameter of 75 m with a wind speed of 7 m/sec is capable to generate 1855.25 MW of electrical power. This can mitigate 55.93 per cent of energy shortage in 2016. By developing renewable energy sources it is possible to compensate 11.25 per cent of total power demand by 2020.*

Keywords: *Coastal Zones of Bangladesh; Horizontal Axis Wind Turbines; Near Shore Wind Farm; Turbine Height, 100 m; Rotor Diameter, 75 m; Wind Speed, 7 m/s*

I. INTRODUCTION

Power is the backbone of development of a country. It is the most important factor for a developing country like Bangladesh. In Bangladesh, demand for power is increasing day by day, but the sources of energy are not increasing in satisfactory level. Fossil fuels are getting diminished day by day. The growth rate of industrialization in Bangladesh has slowed down due to shortage of energy supply. Wind can be a solution to this problem.Wind energy has the potential to provide mechanical energy or electricity without generating pollutants [6]. Bangladesh is situated between 20.30 - 26.38 degrees North latitude and 88.04 - 92.44 degrees East [9]. Bangladesh has a 574 km long coast line 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 [1]. The power sector of Bangladesh is mainly dependent on natural gas, accounting for around 72% of the total commercial energy consumption and 63.19% of the total electricity generated [2, 3, 10]. Total reserve of extractable gas (proven and probable) is 20.5 TCF (Trillion Cubic Feet). Total consumption of gas up to April 2010 is 8.5 TCF, total reserve remaining 12 TCF. The daily consumption is about 2000 MMCF (Million Cubic Feet) [4]. But the supplied amount of natural gas is not enough to support the present power demand. Moreover, it will be finished after a certain period. Several small deposits of coal exist on the north eastern region of the country, but these consist of peat, with low calorific value, and very deep bituminous coal [5]. The objective of this study is to focus on six coastal zones Patenga, Cox's Bazar, Teknaf, Char Fassion, Kuakata and Kutubdia at Bay of Bengal of Bangladesh, analyze the measured values of wind speed at these locations and estimate the possible power generation through installation of near shore wind farm to find wind energy as a sustainable solution to mitigate shortage of electric power generation in Bangladesh.The present study encompasses the future prospects and utilization of wind energy in Bangladesh.

II. METHODOLOGY AND ESTIMATION

2.1 Power Generation Scenario In Bangladesh

The Electric power consumption (KW-hr per capita) in Bangladesh is very insignificant [6]. Table 1 shows electric power consumption in different countries of the world during 2011 to 2015 [6]. Bahrain is the country which has topped the list in electric power consumption of 17,395 KW-hr per capita and Canada ranks second with a value of 15,615 KW-hr per capita. The lowest value is 119 KW-hr per capita found in Nepal.

Table 1: Electric power consumption (KW-hr per capita)

Country	Electric Power Consumption (KW-hr per capita) (2011-2015)
Australia	10,398
Bahrain	17,395
Bangladesh	279
Canada	15,615
China	3,475
France	7,344
Germany	7,270
India	744
Japan	7,752
Malaysia	4,345
Myanmar	153
Nepal	119
Pakistan	452
Singapore	8,690
Sri Lanka	527
Sweden	14,290
Switzerland	7,886
United Arab Emirates	10,463
United Kingdom	5,452
United States	12,954

In Bangladesh, only 59.60% of the population has access to electricity with a per capita availability of 279 KW-hr per annum [7, 8]. There are more than 87,319 villages in Bangladesh, and most of them are not connected to the national grid [9]. Power generation in Bangladesh faces some problems, such as shortage of natural gas, unreliable old power plants, increasing number of population, etc. It largely depends on natural gas, almost 63% [10]. This excessive dependence causes several problems. Due to fall of natural gas generation or shortage of natural gas supply, electricity production will be hampered. 23% of power is produced from more than 20 years old power plants [11]. Figure 1 shows the Installed Capacity of BPDB Power Plants as on February 2016. Total Installed Capacity of BPDB Power Plants as on April 2016 is 12229 MW.

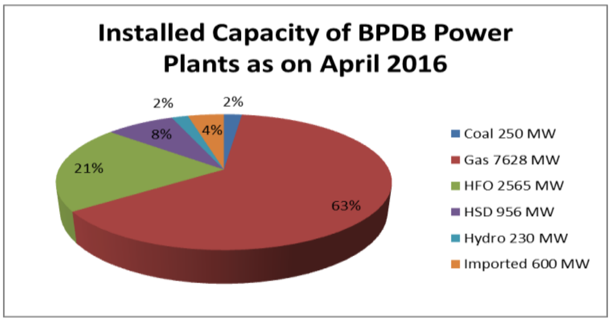

Figure 1: Installed Capacity of BPDB Power Plants as on April 2016

There is a small capacity of hydro-electric power source in Kaptai, Chittagong. Bangladesh is going to set up 2400 MW nuclear power plant at Ruppur with two reactors, each of which will generate 1,200 MW of power [12]. Bangladesh is encountering difficulties in supplying energy to maintain its economic growth. The electrical load peak demand of Bangladesh in 2016 is nearly 11,405 MW. Maximum generation in 2016 is 8088 MW leaving a shortage of 3317 MW [41]. Government has planned to produce 19000 MW within 2021 [13]. To meet up the target, Bangladesh should focus on the substantial amount of renewable energy resources. Bangladesh has 15 MW solar energy capacities through rural households and 1.9 MW wind power in Kutubdia and Feni**.** Bangladesh has planned to produce 5% of total power generation by 2015 & 10% by 2020 from renewable energy sources like air, waste & solar energy [4].

2.2 Wind Energy Scenario

Scientists and engineers are working a lot doing research extensively for pollution free renewable energy sources. As a result of technological advancement, the wind energy generation cost has come down from 25 cents (19.5 BDT) to 5 cents (3.9 BDT) per KW-hr during the last 20 years in the USA [14]. Wind Energy Conversion Systems (WECS) are now extensively used in Germany, Denmark, UK, Netherlands, Russia and Australia. Asian countries like China, India, Indonesia, Japan, etc. are also using these technologies [15].
Figure 2 shows the top ten countries with the most wind power capacity in 2014. According to the Global Wind Energy Council China, United States, Germany, Spain, India, UK, Canada, France, Italy, Brazil are producing 311,124MW, accounting for 84.2 per cent of the global total [16].

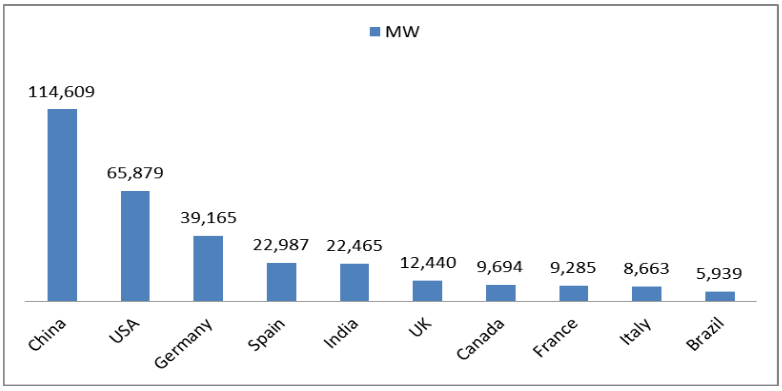

Figure 2: Top ten cumulative capacity of Wind Energy, December 2014

2.2.1 Wind Energy Scenario In Bangladesh

At a glance, references show that with a population of 146.2 million electrification rate is 59.60%. Total electrical energy installed capacity is 12229 MW (2016) [10] and total installed wind energy is 1.9 MW. Wind energy potential in Bangladesh is over 20,000 MW [39], the wind speed being < 7 m/sec.
In Bangladesh, research in the field of wind energy began only a few years ago, which had shown that some southern districts of Bangladesh have a very good potential of wind energy [18, 19]. Bangladesh Centre for Advanced Studies (BCAS) in collaboration with Local Government and Engineering Department (LGED) and an international organization namely Energy Technology and Services Unit (ETSU) from UK with the funding from Department of Foreign and International Development (DFID) has attempted to monitor wind conditions at seven coastal sites for a period of one year in 1996-97. They measured wind parameters at a height of 25 m [33]. At present, several wind resource work is ongoing in the country by Bangladesh Power Development Board (BPDB), Bangladesh Council of Scientific and Industrial Research (BCSIR), Local Government Engineering Department (LGED) and Bangladesh University of Engineering and Technology (BUET). They have already started measuring wind speeds at some typical locations of Bangladesh [20]. In Bangladesh first-ever generation of electricity from wind is at Muhuri Dam, Feni having a capacity of 0.9 MW (225 KW, 4 Turbines) and another one at Kutubia Island (20 KW, 50 turbines) with a capacity of 1 MW [21]. Vesta Company of Denmark will invest 100 MW wind power plant which will be made in Patuakhali. This will be the largest wind power plant of Bangladesh [6].

Bangladesh is situated between 20.30 - 26.38 degrees North latitude and 88.04 - 92.44 degrees East [17]. Analysis of upper air data by Center for Wind Energy Technology (CWET) India shows that wind energy resource of Bangladesh for electricity production is not good enough (< 7m/s) in most of the region of the country for grid connected wind parks. This sector is under research mainly at coastal zone [28, 21]. Bangladesh has a total of 574 km long coast line in the Bay of Bengal. The strong south/south-westerly monsoon wind coming from the Indian Ocean, after travelling a long distance over the water surface, enters into the coastal areas of Bangladesh. This trade wind blows over the country from March to October. This wind speed is enhanced when it enters the V-shaped coastal regions of the country [29]. This wind blows over the surface of Bangladesh, having an average speed of 3 m/s to 6 m/s. During October to February, wind speed remains relatively lower. The maximum wind speed is gained during June-July [30]. Along the coastal area of Bangladesh, the annual average wind speed at 30 m height is more than 5 m/s [17]. Wind speed in northeastern parts in Bangladesh is above 4.5 m/s while for the other parts of the country wind speed is around 3.5 m/s [17, 31]. To have excellent power extraction, the site should have at least 7 m/s wind velocity [35]. For proper operation of the wind turbine, hub-height generally ranges from 20 to 40 m [32]. After height correction, it has been observed that at 30 m there is a great potential for harnessing wind power for electricity generation in some regions like Patenga, Cox’s Bazar, Teknaf, Char Fassion, Kuakata, Kutubdia, etc.

2.2.1.1 Wind Energy Study Project (West)

Bangladesh government had a project named as Wind Energy Study Project (WEST). A year-long systematic wind speed study at seven coastal sites in 1996-97 at a height of 25 m was done [22]. Figures 3(a) – 3(f) show monthly average wind speed from six WEST stations Patenga, Cox's Bazar, Teknaf, Char Fassion, Kuakata and Kutubdia at 25 m height.

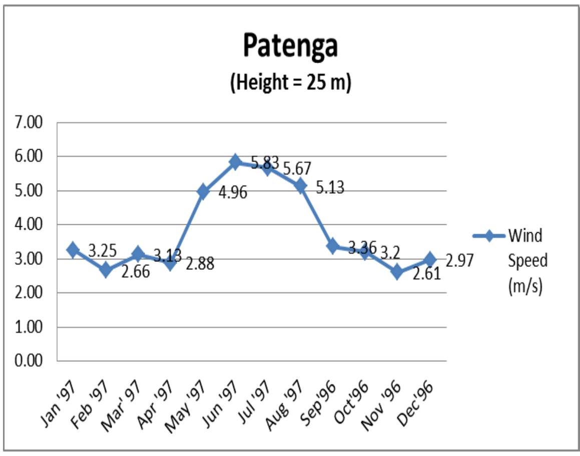

Figure 3(a): Monthly average wind speed at Patenga

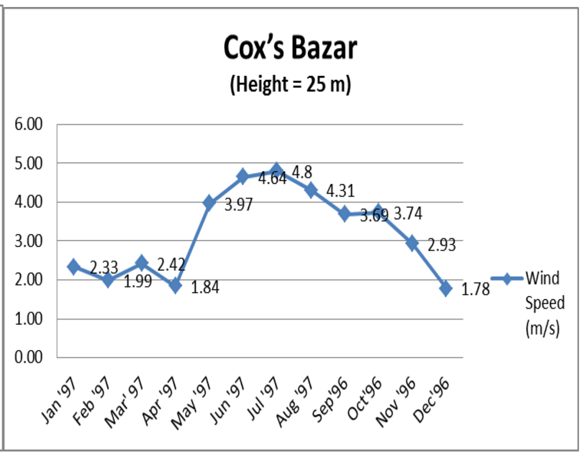

Figure 3(b): Monthly average wind speed a Cox's Bazar

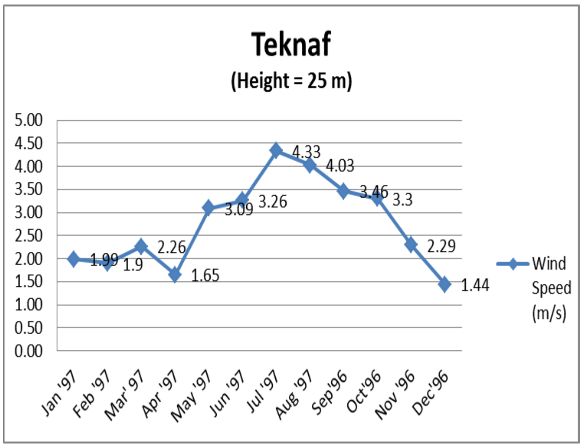

Figure 3(c): Monthly average wind speed at Teknaf

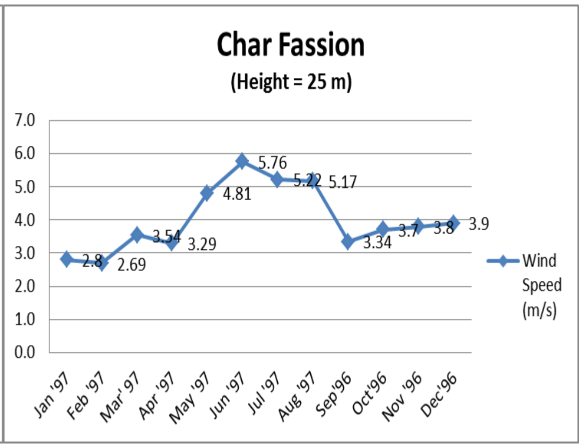

Figure 3(d): Monthly average wind speed at Char Fassion

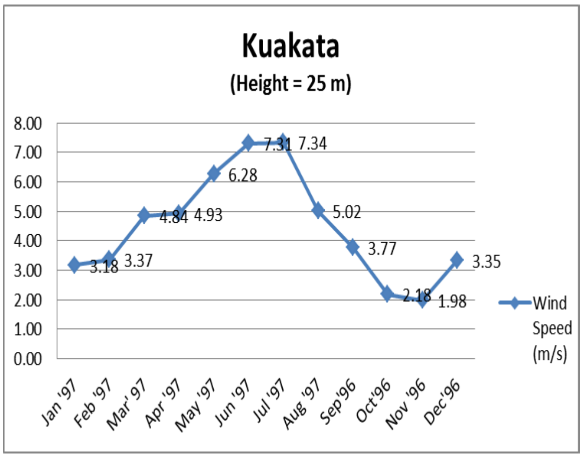

Figure 3(e): Monthly average wind speed at Kuakata

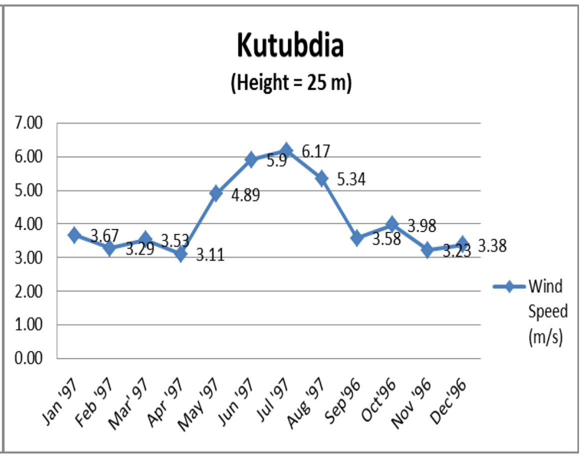

Figure 3(f): Monthly average wind speed at Kutubdia

Figure 4 shows yearly average wind speed at six WEST stations at 25 m height.These six places are the coastal areas of Bay of Bengal. According to this survey, the average monthly wind speed varies from 3 m/s to 5 m/s. Kuakata has the best wind speed and Teknaf has the lowest wind speed. But, wind energy is extractable from all the places from the six spots around the year.

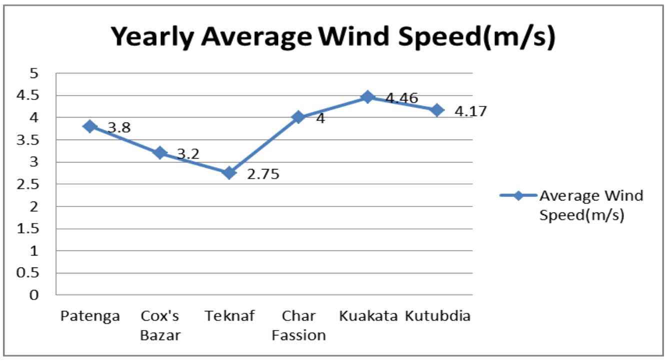

Figure 4: Yearly Average Wind Speed at six WEST stations at 25 m height

2. 3. Working Principle Of A Wind Turbine

Wind is actually another form of solar energy. The uneven heating of the atmosphere causes temperature gradient at the surface of the earth, which results in the wind flow. The rotation of earth and irregularities of earth has vital impacts on wind velocity. Wind turbine converts the kinetic energy of wind to generate electric or mechanical energy. Wind passes over the blades exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotation speed for the generator, which uses magnetic field to convert the rotational energy into electrical energy. The power output goes to a transformer, which converts the electricity from the generator to the right voltage for the distribution system [37]. In simplistic view, working principle of wind turbine is just opposite to that of a fan. Figure 5 shows the flow diagram of a wind turbine system.

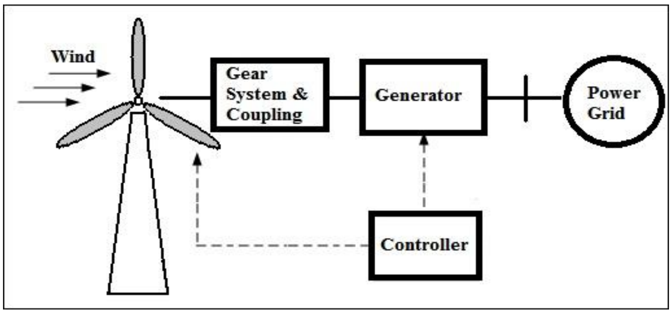

Figure 5: Flow Diagram of a Wind Turbine System

Here,

1) Wind Turbine: Converts wind energy into rotational (mechanical) energy
2) Gear system and coupling: It steps up the speed and transmits it to the generator rotor
3) Generator: Converts rotational energy into electrical energy.
4) Controller: Senses wind direction, wind speed, generator output and temperature and initiates appropriate control signals to take control action.

There are two basic types of wind turbines (WT): horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). Figures 6(a) and 6(b) show HAWT and VAWT respectively.

Figure 6(a): HAWT

Figure 6(b): VAWT

HAWT (more common) need to be aimed directly at the wind. Because of this, they come with a tail vane that will continuously point them in the direction of the wind. VAWT work whatever direction the wind is blowing, but require a lot more ground space to support their guy wires than HAWT [5, 34]. Figure 7 is the details of a WT with its components.

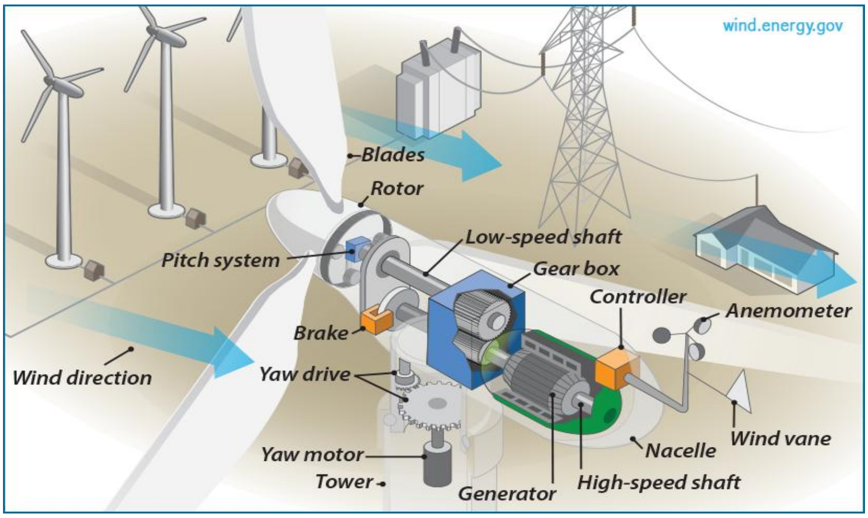

Figure 7: Components of a WT

2.4 Estimation Of Monthly Extractable Energy

Monthly extractable energy at the six target locations was estimated in the following way [23]:
Wind energy (ideal) = $1/2 \times \rho \times V^3$ Watt-hr/m^2
where,
Wind velocity = V m/s and Air density = ρ = 1.20 kg/m^3
Total loss = Co-efficient of performance of WT X Generator loss X Transmission loss
Usually, Co-efficient of performance of WT = 0.40
Generator loss = 0.85
Transmission loss = = 0.90
So, total loss = $0.40 \times 0.85 \times 0.90$
= 0.306
Actual available amount = $0.306 \times 1/2 \times \rho \times V^3$ Watt-hr/m^2
Figure 8 shows average extractable wind energy in Watt-hr/m^2 at six WEST stations. The average extractable wind energy in Watt-hr/m^2 at Patenga, Cox's Bazar, Teknaf, Char Fassion, Kuakata and Kutubdia are 13.235, 8.122, 5.138, 13.268, 24.124 and 16.115 respectively.

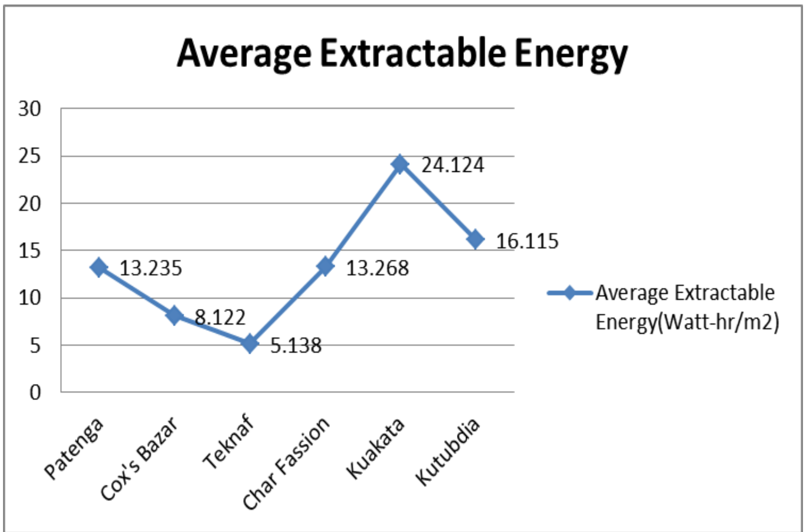

Figure 8: Average Extractable Wind Energy in Watt-hr/m^2 at six WEST stations.

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2.5 The Theory Of WT

WT works by converting the kinetic energy of wind to electrical energy. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine.

The power can be defined as

$$P=\frac{1}{2}\rho AV^3 C_p$$

According to Betz Limit or Betz' Law the theoretical maximum power efficiency of any design of WT is 16/27 or 0.59. That is, not more than 59 per cent of the energy carried by the wind can be extracted by a WT [23]. In real world, Betz Limit with values of 0.35-0.45 is common even in the best designed WT. It varies with wind speed, turbulence and operating characteristic [24].

For our purpose, a HAWT has been considered. Figure 9 shows dimensions of the body of a HAWT.

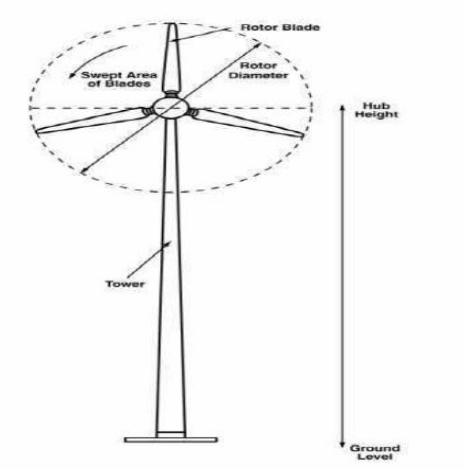

Figure 9: Dimensions of the Body of a HAWT

Here,
P= Power generation (W)
ρ = Density of wind (kg/m^3)
A= Swept area (m^2)
r = Radius (m)
V= Velocity of wind (m/s)
C_p = Power coefficient

Near Shore is that type of wind farm in which the wind turbines are arranged on that location which is almost in the radius of 3 km. Those locations are beneficial for creating a wind farm, because the pressure of the wind in those areas is comparatively high from other locations. So, they are able to generate more power. Figure 10 shows a near shore wind farm.

Figure 10: Near Shore Wind Farm

For our purpose of power generation, a near shore wind farm like this has been considered along the coastal zones of Bangladesh with 4 rows of HAWT with two rows of turbines in water and two rows of HAWT on land. The turbines are spaced 7D apart in the prevailing wind direction, and 3D apart in the perpendicular direction, where D is rotor diameter. Figure 11 shows placement of WT in the near shore wind farm considered.

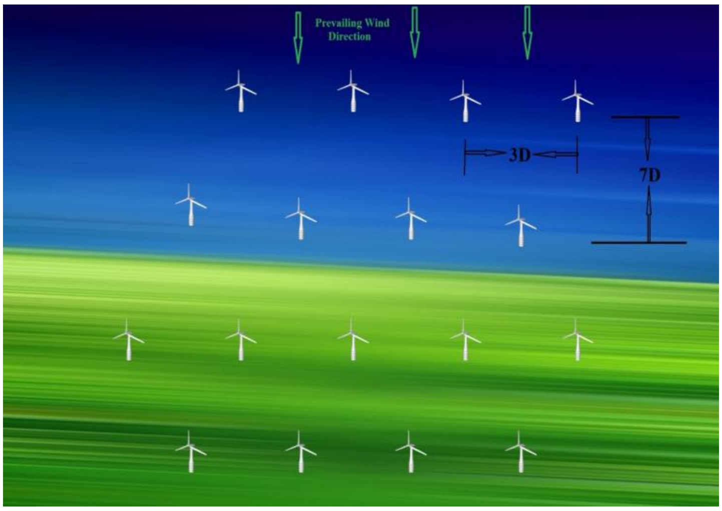

Figure 11: Placement of WT in the Near Shore Wind Farm considered.

Our Total coastal zone is 574 km (574000 m). We have taken 50% of the coastal zone (287000 m) for wind turbine and considering 30% more area for operation flexibility, office building and responsible personnel's residence & other facilities.

It has been observed that, average wind speed is higher as the height is increased. As a result, extractable power is increased [5]. Average wind speed at 25 m height at Kuakata is approximately 4.463 m/s. Increasing the height to 50 m the average wind speed becomes 6.734 m/s [5]. Obviously, the wind power generation at higher altitude will be more. It supports the relation between tower height and wind power. The maximum height of the turbines known is 140 m and the rotor diameter is 107 m [36].

Estimation of power generation using WT in our near shore wind farm has been done first with Hub height, H = 35 m and Blade diameter, D = 25 m for an average wind speed of 5 m/sec.Then estimation have been done also for H = 60 m, D = 50 m; H = 80 m, D = 60 m and H = 100 m and D = 75 m. Wind speed at these three heights have been taken as 7 m/sec.

III. RESULTS AND DISCUSSION

The electrical load Peak demand of Bangladesh in 2016 is nearly 11,405 MW. Maximum generation in 2016 is 8088 MW leaving a shortage of 3317 MW.The policy has set up targets for developing renewable energy resources to meet 5% of the total power demand by 2015 and 10% by 2020.

With H = 35 m, D= 25 m and V= 5 m/sec in 4 rows of the near shore wind farm considered a total of 15308 turbines will be required which will generate total power of 225.33 MW from wind energy. This is 6.79 per cent of the shortage of 3317 MW in 2016. Government's plan is to produce 19000 MW within 2021. This 225.33 MW is only 1.19% of 19000 MW.

With H = 60 m, D= 50 m and V= 7 m/sec in 4 rows of the near shore wind farm considered a total of 7656 turbines will be required which will generate total power of 1236.83 MW from wind energy. This is 37.29 per cent of the shortage of 3317 MW in 2016. This is 6.5 per cent of the total power to be produced within 2021.

With H = 80 m, D= 60 m and V= 7 m/sec in 4 rows of the near shore wind farm considered a total of 6380 turbines will be required which will generate total power of 1484.24 MW from wind energy. This is 44.75 per cent of the shortage of 3317 MW in 2016. This is 7.81 per cent of the total power to be produced within 2021.

With H = 100 m, D = 75 m and V= 7 m/sec in 4 rows of the near shore wind farm considered a total of 5104 turbines will be required which will generate total power of 1855.25 MW from wind energy. This is 55.93 per cent of the shortage of 3317 MW in 2016. This is 11.19 per cent of the total power to be produced within 2021.

We know, Bangladesh has 15MW solar energy capacities through rural households. Besides, energy production in Bangladesh from solid biomass and hydropower are 37 MW and 230 MW respectively [40].

Using 5104 WT with H = 100 m, D = 75 m and V= 7 m/sec power generation of 1855.25 MW is possible. So, from renewable energy sources of wind energy, solid biomass and hydropower a total of (1855.25

MW + 15 MW + 37 MW + 230 MW) = 2137.25MW power generation can be achieved. This is 2137.25 MW / 19000 MW = 11.25 per cent by 2020.

A wind speed of 7 m/sec has been considered at H = 60 m and also at higher altitudes. There is possibility that we may expect much for higher wind speed with the increase of height, which would result more power generation. In addition to that increasing rotor diameter more power production is possible.

To meet the present energy crisis, it is very needed to go for renewable energy. With the use of wind power we can minimize the problem to great extent.Wind energy is more reliable because it is totally free and pollution free. Now the most frequent current use of wind energy is electricity production. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation. As a result, interest upon wind as a source of energy is increasing day by day.

IV. CONCLUSION

Using an array of 5104 wind turbines in a near shore wind farm at coastal zones of Bangladesh 1855.25 MW of power generation is possible. It can compensate 56 percent of power shortage of 2016. By 2020, it is possible to produce power more than 10 per cent of the total power demand from renewable energy sources. Wind energy is a green energy. Generation of power from wind energy is a sustainable solution to mitigate energy crisis in Bangladesh. It is necessary to have accurate data for wind speed at higher altitudes.

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