Design of an often cost affective wind power system for a remote Bangladesh locality

A thesis

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Declaration

I hereby declare that this thesis is based on the results found by myself. Materials of work found by other researcher are mentioned by reference. This thesis, neither in whole nor in part, has been previously submitted for any degree.

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Abstract

Demand for Energy is increasing day by day because of population increase and industrialization but we have very limited resources. In this critical stage of energy crisis, renewable energy is one of the most important alternative energy sources. Wind power is the cheapest energy source at this stage.

Since Wind energy is a non polluting cost-effective renewable energy source, Wind Power technology in Bangladesh has been growing significantly in the last decade. To reduce our annual cost on fuel and meet the demand, wind power can be a cost effective solution. On the other hand, we are facing huge effect of environmental pollution because of the emission of harmful gasses like Carbon dioxide and Surfer dioxide. But major portion of our Power generation system is depending on fuel like Diesel, Coal, and Gas. By using Wind power system, we can stop the pollution through reducing the emission of harmful gases.

In our thesis, we are going to design and simulate a cost effective wind power system for a remote Bangladesh localicty. Detailed cost analysis and comparison with other systems will be made.

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Chapter I

Introduction

1.1 An Overview

Bangladesh is situated between 20°34' and 26°38' n latitudes and 88°01' and 92°41' e longitudes with nearly 162 million people living on 144,000 sq. Km. The country has a 724 km long coastal line along the Bay of Bengal **[1]**. The average population is 2917.6/sq.mile **[2]**. The electrical load demand of Bangladesh is nearly 6,000 MW. To meet this demand coal, gas, Diesel etc are used as Energy resources. But still we are in shortage of energy production due to the leaking of reliable Energy resources. The coastal area in the southern part of our country has provided us a huge potential of wind power generation. On the other hand isolated Islands like Sandwip, Kutubdia, Maheshkhali, St. Martin etc are not suitable for grid-connected system. But the wind speed of the coastal areas and islands are very suitable for the electricity generation. Considering the variation of wind velocity and pattern **[1]** for certain area, existing Diesel generator can be partially or fully replaced by wind-energy conversion system. All the research results of Bangladesh power development board (BPDB) and Local Government Engineering Department (LGED) indicate that Bangladesh has huge potential of Wind-Diesel Hybrid system and in future, it could be a sustainable option for rural Electrification **[3]**.

Wind-Diesel Hybrid system can be very efficient for isolated island where establishing a grid-connection is quiet expensive. Our study reflects that Sandwip is one of the most promising sites for Wind-Diesel Hybrid system.

Sandwip is an Island along the south-eastern coast of Bangladesh. Nearly 400,000 people inhabit in the Island. Its approximate electric load demand is peak 24 MW. It has a sufficient wind velocity for electricity generation **(5)**.

In this paper we are going to design and simulate a cost-effective Wind-Diesel Hybrid system (stand-alone) by using a software HOMER (Hybrid optimization model for electric renewable) for a particular isolated island and compare that system with other traditionally used Electricity generation system.

1.2 History of wind power system

The first practical windmills were built in Sistan, a region between Iran and Afghanistan, since at least the 9th century, or possibly earlier in the 7th century. The first windmills in Europe appear in sources dating to the twelfth century. These early European windmills were horizontal-axle sunk post mills **[6].** In Denmark by 1900 there were about 2500 windmills for mechanical loads such as pumps and mills, producing an estimated combined peak power of about 30 MW. In 21^{st} century oil crisis make wind power system more essential for electric generation in the world.

Denmark is the pioneer of wind power system of 21^{st} century. They produce 19-20% of the total consumption of electricity of their country from the wind power system. They have the total capacity of 3,733 MW include both offshore and in-land grid connected system. **[7]**

Beside Denmark, USA, Germany, Sweden, Norway, Finland, India are the leading country of wind power technology. There are lots of companies like Vestas, Enercon, Nordtank; Enova etc are the leading wind power technology company.Enercon has a largest wind turbine capacity of 7 MW.

Table 1-Installed wind capacity, production, share in Denmark by year

Year	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**
Installed wind capacity(MW)								0.052	0.813	1.090
Electricity generated (GWh)									0.12	0.24
Year	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**
Installed wind capacity (MW)	2.7	6.3	10.6	14.3	19.8	47.0	72.0	111.9	190.3	246.7
Electricity generated (TWh)	0.002	0.005	0.012	0.019	0.026	0.044	0.104	0.154	0.266	0.396
Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Installed wind capacity (MW)	326	393	436	468	521	600	814	1123	1438	1753
Electricity generated (TWh)	0.57	0.68	0.83	0.92	1.06	1.09	1.119	1.89	2.76	3.00
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Installed wind capacity (MW)	2,390	2,497	2,890	3,116	3,123	3,127	3,135	3,124	3,163	3,482
Electricity generated (TWh)	4.22	4.31	4.86	5.56	6.58	6.61	6.11	7.14	6.98	6.72
Wind power share in the	14.1	14.2	13.9	15.8	18.5	18.5	16.5	19.7	19.1	19.3

Wind power system is getting more popular day by day for energy crisis and for its non- polluting characteristic. High emission of carbon dioxide and sulfur gasses can be totally avoided by wind power system.

1.3 Background of wind power system in Bangladesh

For geographical position of Bangladesh wind power system has a good potential. Bangladesh power development board (BPDB) and Local Government Engineering Department (LGED) have committed lots of research work on wind power system. There is a project in Muhuri which have a rated capacity of .99 MW . All the research works in Muhuri indicate that it has a potential of 100 MW wind power capacity. Kutubdia,Patenga,Barguna also have ongoing wind power project.

Electrification in the coastal area is not sufficient till now .but coastal areas have high Wind velocity to produce Electricity commercially. Grid power system cannot be introduced to the isolated Island because of the cost of transmission line .So this shortage of Electricity can be resolved by introducing wind power system in those areas.

In the rural area where gird connection is expensive, can have hybrid system if the Wind velocity is high enough to produce electricity .diesel-wind system or PV-wind power system is suitable for this kind of situation.

Chapter II

Wind data analysis

2.1 Perspectives of wind energy in Bangladesh

Bangladesh has a 724 km long coastal line along the Bay of Bengal. There are also many islands in the Bay where wind speed is high enough to produce Electricity commercially. The strong south/south-western monsoon wind come from the Indian Ocean traveling a long distance over the Bay of Bengal, through the coastal area of Bangladesh. This wind blows over Bangladesh from March to September with a monthly average speed 3 m/s to 9 m/s at different heights . According to studies of Meteorological Department, BCAS, LGED, and BUET winds are available in Bangladesh mainly during the Monsoon. (7 months, March to September). Rest of the months (October to February) wind speed remains either calm or too low. The peak wind speed occurs during the months of June and July **[8]**. Wind velocity at the coastal area and isolated island is quite higher than rest of the locations.

Table 2: average wind speed in coastal region of Bangladesh (2003)

Locations	Month						
	Mar	Apr	May	Jun	Jul	Aug	Sep
Teknaf	2.85	2.56	2.39	4.71	2.83	4.14	3.11
Kutubdia	3.78	12.02	2.37	4.71	5.73	4.78	2.92
Sandwip	6.23	8.34	2.28	3.93	5.44	4.44	5.18
Kuakata	3.07	5.26	3.10	3.69	4.28	3.37	2.03
Mongla	3.07	2.41	2.94	4.23	4.34	4.44	2.92

Table 3 – Wind Data at various locations at 20 m height

Locations	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
Barisal	2.90	2.57	2.57	3.56	3.23	2.90	2.71	2.64	2.57	2.11	2.07	2.05	2.66
Bogra	1.95	2.20	3.05	4.03	4.15	3.66	3.42	3.05	2.56	2.20	1.83	1.71	2.82
Chittagong	3.64	2.88	4.95	5.01	5.51	6.89	7.09	6.83	4.64	2.82	3.39	2.20	4.65
Comilla	2.26	2.70	2.57	5.45	3.83	3.20	2.88	2.95	1.82	2.38	1.63	1.70	2.78
Cox'sBazar	3.76	3.83	4.51	5.58	3.83	4.14	3.83	3.95	3.20	3.26	2.57	3.26	3.81
Dhaka	3.39	3.26	4.39	5.77	6.33	5.71	6.01	5.89	4.39	3.45	2.64	2.95	4.52
Dinajpur	2.68	2.44	4.88	2.44	2.93	2.68	2.56	2.44	2.44	3.54	2.44	2.44	2.83
Hatiya	3.04	2.64	4.16	3.97	4.82	6.47	5.75	2.64	2.96	2.77	3.06	2.57	3.74
Jessore	2.88	2.95	4.95	8.34	8.34	6.27	6.15	4.95	4.33	3.45	3.32	3.20	4.93
Khepupara	4.20	4.39	3.83	7.09	5.83	4.71	4.14	3.95	3.57	3.70	2.95	2.57	4.24
Khulna	2.96	1.65	3.04	3.05	4.16	3.89	3.31	2.44	2.51	1.98	3.31	2.38	2.89
Kutubdia	1.77	1.82	2.32	2.70	2.77	3.65	3.61	3.14	2.11	1.45	1.19	1.29	2.32
Mongla	1.07	1.25	1.72	2.51	2.92	2.63	2.48	2.35	1.83	1.27	1.02	1.01	2.20
Rangamati	1.45	1.65	4.42	3.10	2.11	3.23	1.72	2.24	1.45	1.45	1.39	1.59	2.15
Sandip	2.32	3.01	3.20	4.83	2.44	3.83	3.39	2.70	2.32	1.63	1.70	1.70	2.76
Sylhet	2.20	2.93	3.29	3.17	2.44	2.68	2.44	2.07	1.71	1.95	1.89	1.83	2.38
Teknaf	3.70	4.01	4.39	4.01	3.32	3.89	3.83	2.88	2.44	2.20	1.57	1.76	3.17
Patenga	6.22	6.34	7.37	7.92	8.47	8.69	9.20	8.54	7.48	6.93	6.71	5.91	7.48
Sathkhira	4.21	4.40	3.84	7.10	6.11	4.76	4.27	4.03	3.62	3.78	3.54	2.81	4.37
Thakurgaon	4.15	5.06	7.93	8.43	8.66	8.05	7.93	6.59	6.34	5.98	5.25	4.76	6.59

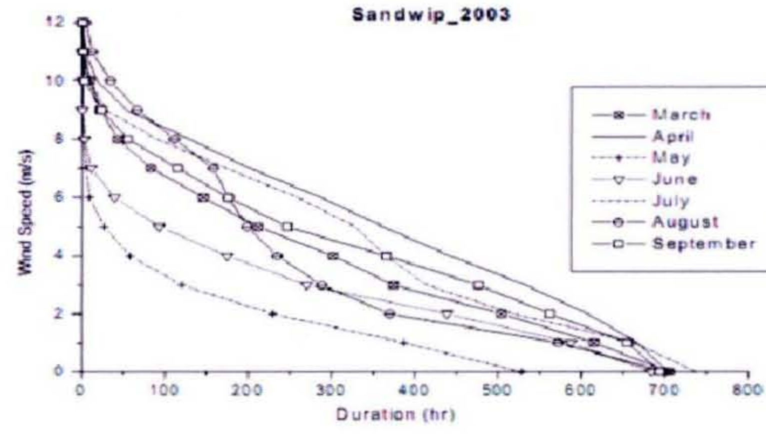

Fig 1-graph of wind speed of 7 months for Sandwip

2.2 Wind velocity calculation

Wind velocity changes with height. The rate of increase of velocity with height depends upon the roughness of the terrain. The variation of average wind speed can be determined from the following power law expression [8],

$$\frac{V_z}{V_{ref}} = \left(\frac{h}{h_{ref}}\right)^{\alpha}$$

Where,

V_z and V_{ref} are the average speeds at height of h in meter and at the reference height of h_{ref} =20 above the ground respectively and α varies from 0.1 to 0.4 depending on the nature of the terrain. [8]

Table 4- Wind velocities of Sandwip at the 60 m and 80 m height

	60 m height (assumed)			80 m height (assumed)		
Month	.2	.3	.4	.2	.3	.4
Jan	4.34	4.86	5.42	4.60	5.32	6.26
Feb	3.41	3.82	4.26	3.63	4.18	4.78
Mar	7.72	8.66	9.65	8.22	9.46	10.84
Apr	10.34	11.59	12.93	11.01	12.67	14.51
May	2.82	3.16	3.53	3.01	3.46	3.96
Jun	4.87	5.46	6.09	5.18	5.97	6.83
Jul	6.74	7.56	8.43	7.18	8.27	9.46
Aug	5.50	6.17	6.88	5.86	6.75	7.72
Sep	6.42	7.20	8.03	6.84	7.87	9.01
Oct	5.13	5.75	6.41	5.46	6.29	7.20
Nov	4.67	5.24	5.84	4.97	5.73	6.55
Dec	4.37	4.90	5.47	4.60	5.36	6.15
Avg	5.52	6.19	6.91	5.88	6.77	7.77

Table 5-wind velocities of Sandwip at the 45m and 50m height

	45 m height (assumed)			50 m height (assumed)		
Month	.2	.3	.4	.2	.3	.4
Jan	4.09	4.45	4.83	4.20	4.50	5.04
Feb	3.11	3.49	3.79	3.3	3.60	3.96
Mar	7.28	7.91	8.59	7.47	8.16	8.97
Apr	9.75	10.59	11.50	10.00	10.92	12.00
May	2.66	2.89	3.14	2.70	2.98	3.28
Jun	4.59	4.99	5.42	4.71	5.14	5.65
Jul	6.38	6.90	7.50	6.52	7.12	7.83
Aug	5.19	5.63	6.12	5.32	5.81	6.39
Sep	6.06	6.50	7.14	6.21	6.78	7.45
Oct	4.84	5.25	5.71	4.96	5.42	5.96
Nov	4.41	4.78	5.20	4.52	4.93	5.42
Dec	4.13	4.48	4.87	4.20	4.62	5.08
Avg	5.25	5.65	6.14	5.34	5.83	6.41

The wind velocity at the height of 20 m of Sandwip is not sufficient to generate electricity commercially. So far wind data which have been recorded for Sandwip was at 20 m height **[9,10]**. So we use power law equation **[8]** to determine the wind speed above 20 m height for Sandwip. From the table the wind velocity at 45 m and 60 m is sufficient to generate electricity commercially. For our analysis we consider 45 m height to avoid the extra cost of Tower construction.

2.3 SWERA Data

We can also use wind data from SWERA to find the available power in watt/m^2 in the air at 50 m above the ground .SWERA is operated jointly by NASA, UNEP, and NERL. Wind data provided in SWERA is annual average wind speed. The By that

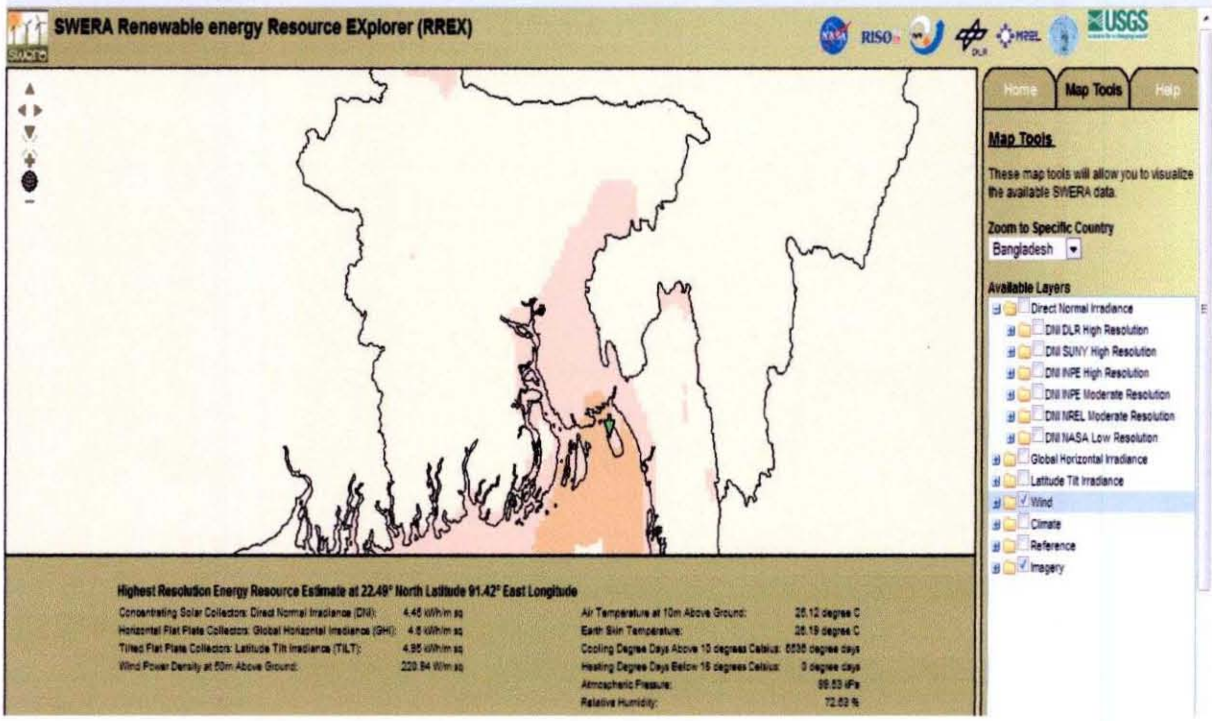

Fig 2- Renewable energy Resource explorer (RREX)

2.4 Power generation by turbine:

Power generated by a wind turbine at particular height, can be calculated by following equation

Power generated by the turbine:

$$P = 1/2.\, \rho.a.v^3.C_p$$

Where,

ρ = wind power density (w/m^2)

A = area swept by the rotor (m^2)

V = velocity of wind (m/sec^2)

C_p = rotor efficiency

C_p = rotor efficiency

From that equation we can find out the theoretical wind power density at a certain height. We can also find the range of velocity of wind if we are aware of Wind Power density of that particular area and vice-versa.

Table 6- wind speed vs. Available power [11]

Wind power Classes	10 M		50 M	
	Wind Power Density (W/m sq.)	Average Wind Speed m/s (m.p.h)	Wind Power Density (W/m sq.)	Average Wind Speed m/s (m.p.h)
1	0-100	0-4.4 (0-9.8)	0-200	0-5.6 (0-12.5)
2	100-150	4.4-5.1 (9.8-11.5)	200-300	5.6 - 6.4 (12.5-14.3)
3	150-200	5.1-5.6 (11.5-12.5)	300-400	6.4-7.0 (14.3-15.7)
4	200-250	5.6-6.0 (12.5-13.4)	400-500	7.0-7.5 (15.7-16.8)
5	250-300	6.0-6.4 (13.4-14.3)	500-600	7.5-8.0 (6.8-17.9)
6	300-400	6.4-7.0 (14.3-15.7)	600-700	8.0-8.8 (17.9-19.7)
7	400-1000	7.0-9.4 (15.7-21.1)	700-800	8.8-11.9 (19.7-6.6)

Chapter III

Design of a Hybrid system

3.1 Basic Data

For Sandwip only Diesel generator is not cost-efficient to meet the current Electric load demand. Hybrid system is a system which consists of a primary source parallel with one or two types of secondary sources. There can be a power storage unit for the stand-alone system or the Hybrid system can be connected directly to the grid without consisting of a storage unit. By using HOMER we can find the best cost efficient Hybrid System (stand-alone) for Sandwip. We can also compare with the cost of power production from Diesel generator to a wind-Diesel Hybrid system or pv system.

Considering the data of Sandwip (45 m height), we would be using Enercon E33 turbine which has a minimum cut-in speed 2.5 m/s.

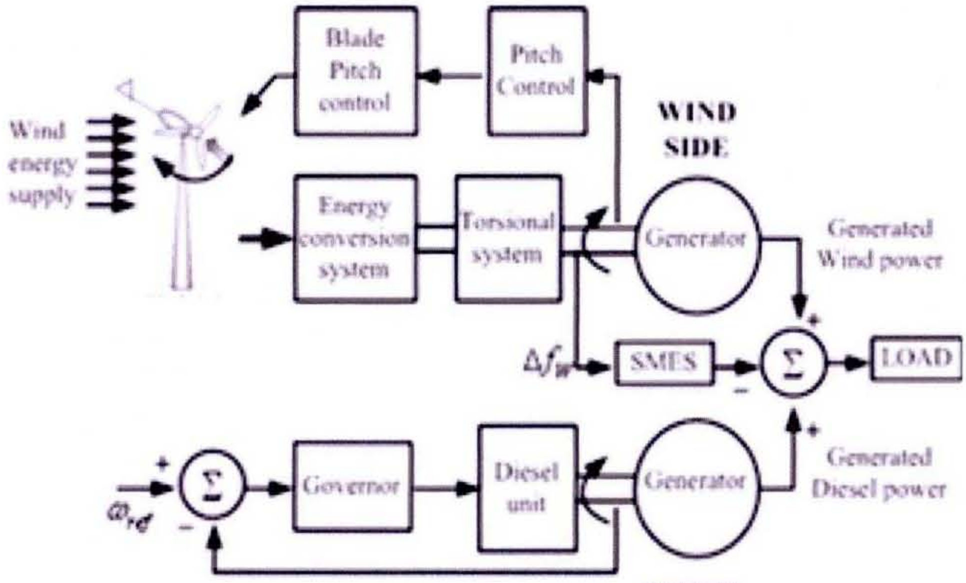

Fig 3 (a) – Block diagram of a Wind-Diesel Hybrid system

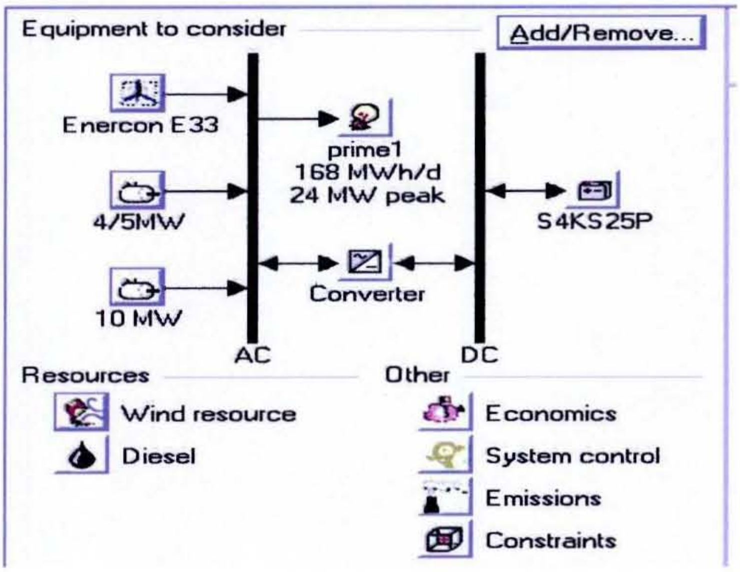

Fig 3 (b) – Proposed Hybrid diagram by HOMER

3.2 Electrical load demand

A typical electrical load system (Table-7) for a single home in a remote island has been considered for load analysis for Sandwip. For a particular house we consider a light, fan, TV as load. In HOMER we made a 24 hours load profile for a single house. There are 45389 units of households in the entire Island **[5]**. If we consider an average load demand of all the houses is same then we can find the total electrical load demand for the Island. For random variability factor of the load profile we consider Day-to-day factor at 17% and Time-step-to-time-step 19%. From the calculation of HOMER we can find the energy demand per day is 168 MWh and the peak demand is 24 MW [Fig. 4]. The Sandwip power network ltd (10mw) is mainly produced electricity from Diesel generator and the cost lies between 15-32 BDT per KW. [6]

Table 7 – a single home avg. load demand [8]

Appliance	Number	Capacity (W)
Florescence Light	2	20
Fan	1	80
TV (colored)	1	100
Total		220

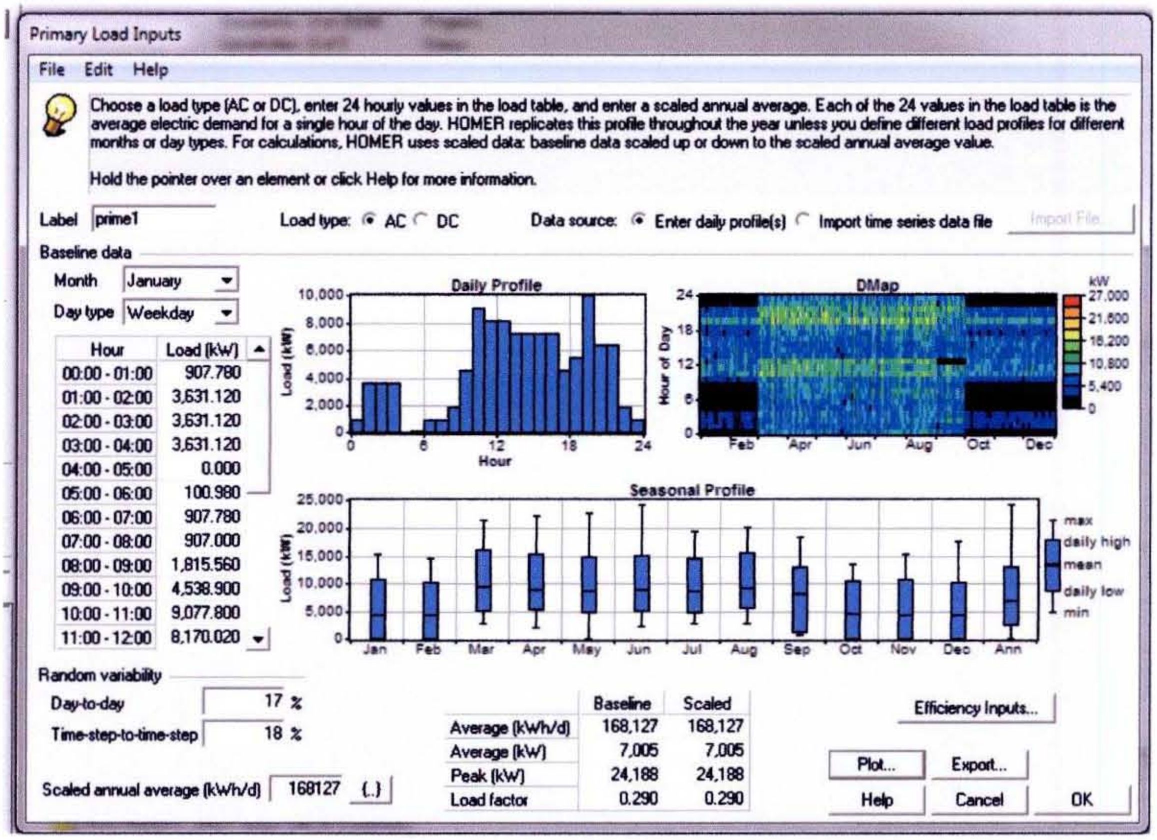

Fig 4- Total load for 45,389 units of households

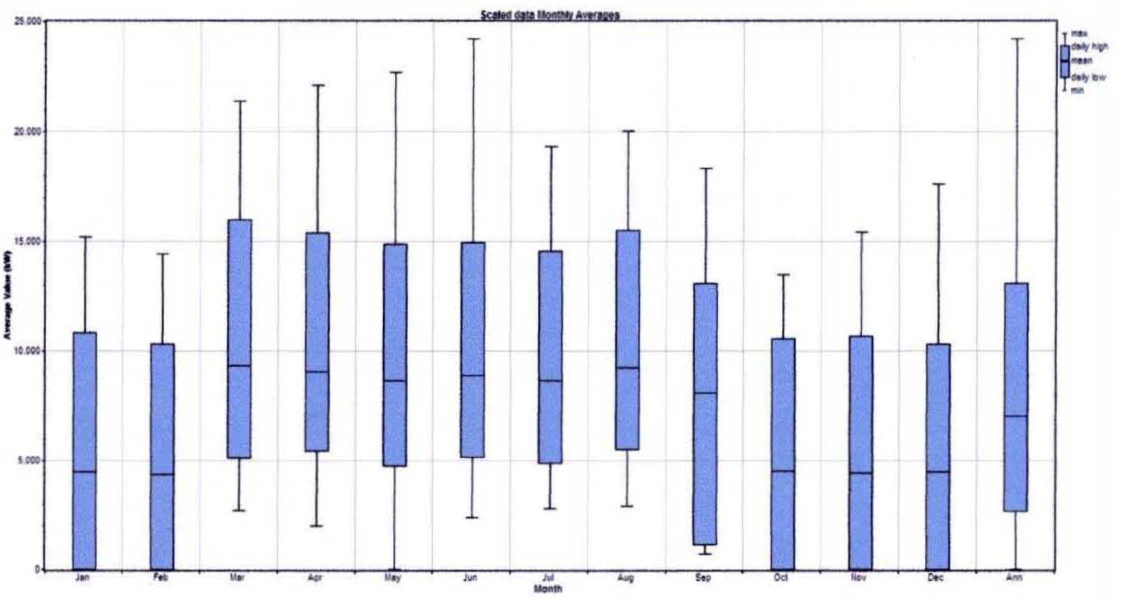

Fig-5 **(a)** Avg. load for 45,389 units of household given as HOMER input

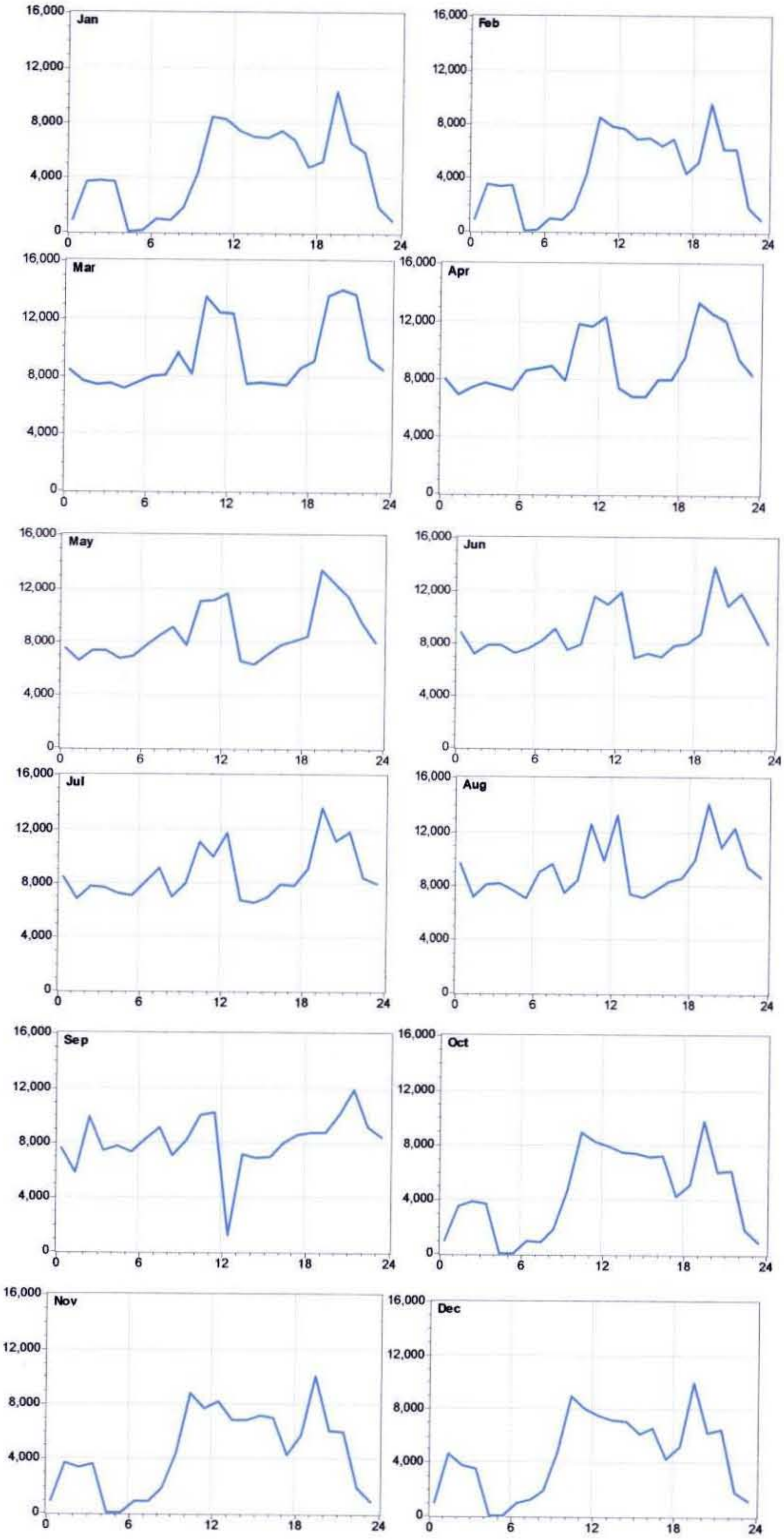

Fig 5(b) – Monthwise hourly load profile for the system

3.3 Wind data

We consider the calculated data for 45 m above the ground (table-5) as wind data input for the Hybrid wind-Diesel system .HOMER synthesized these monthly average data based on the other parameters such as-

Weibull factor "k" = 1.8,

Autocorrelation factor (randomness in wind speed) = 0.90,

Diurnal pattern strength (wind speed variation over a day) = 0.25,

Surface roughness length of .3.

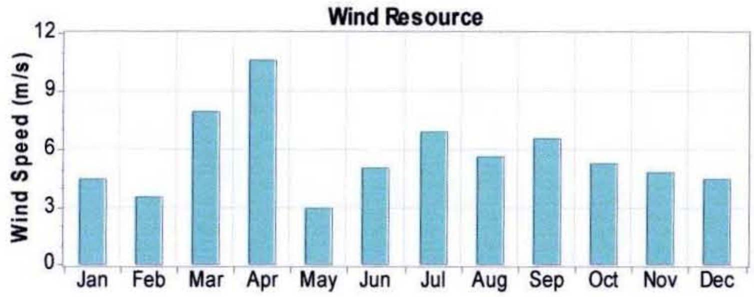

Figure 6 – monthly wind speed data profile curves

3.4 Wind turbine

Wind turbine and generator: average wind velocity at 60m and 45m height are accordingly 6.19m/s and 5.65 m/s (calculated). But at winter, wind velocity goes below the avg. Wind velocity. To fulfill Electrical load demand of Sandwip we should use high capacity wind turbine. But those turbines are having cut-in velocity more than 4 m/s .On the other hand small turbine cannot generate sufficient electricity to support the whole system. Now a day, research and development are going on to improve the technology and design medium or high capacity turbine with low cut-in speed at 2.5 to 3.5 m/s for feasibility. We compare two wind turbines .one is Vestas V82 which is very suitable for high velocity .Its rated capacity is 1.65 MW and cut-in velocity is 3.5 m/s .Another is Enercon E33 which is more suitable for low velocity. The irregularity of wind speed can be fixed by gear system. It has a rated capacity of

335 KW and cut-in velocity is 2.5m/s .The installation cost of an unit of Vestas V82 turbine with 75 to 80 m Tower is 1.6 million USD. (1 USD = 70 taka). But installation cost for Enercon E33 (50 m height Tower) is only 500000 USD. For Economical analysis, we consider Enercon E33 turbine.

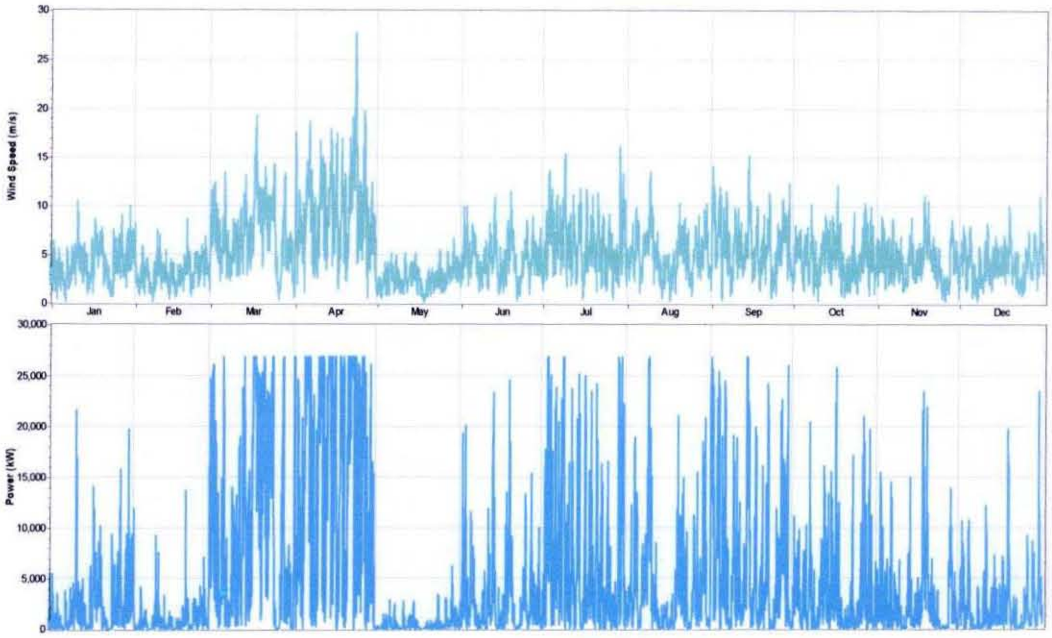

Figure 7- wind velocity vs Enercon E33 turbine efficiency

3.5 Diesel generator

Two Diesel generators are used to support the Hybrid system. Diesel generators are operating in parallel with the wind turbine to increase the flexibility, efficiency and distribute the electric load more optimally. Cost of per MW of Diesel generator is considered to be 15,000,000 BDT. The price of the Diesel generator is not linear with the capacity. We consider installation cost of 5 MW generator price is 70,000,000 BDT and 10 MW generator price is 125,000,000 BDT.

We have considered the fuel cost 45.50 BDT. It can vary with the market price.

3.6 Battery

To store the excess electricity we use battery bank. For this analysis we use Surrette (model -4ks25p). Nominal voltage and capacity is 4v and 1900 ah (7.6 kWh).The total life time is 15 years. The number of batteries per string is 60 and bus voltage is 240v.The cost of a battery is considered to be 900 USD. (1 USD = 70 BDT)

3.7 Converter

Converter is used to store ac current to battery bank and supply the power back to system when it is needed. It converts AC current into DC and DC current into AC. We assumed, inverter has 92% efficiency and rectifier has 94 % efficiency. The converter has the life time of 20 years .we consider the converter price 100000 USD per MW.

Chapter IV

Result and analysis

4.1 System Analysis

HOMER analyses the system according to the COE of the system. Other factors which are influencing the analysis are capital cost, operating cost, renewable energy factor, total NPC and Diesel consumption rate etc also to be considered. There are some sensitive operative factors like Diesel price factor, surface roughness length, minimum load ratio etc.

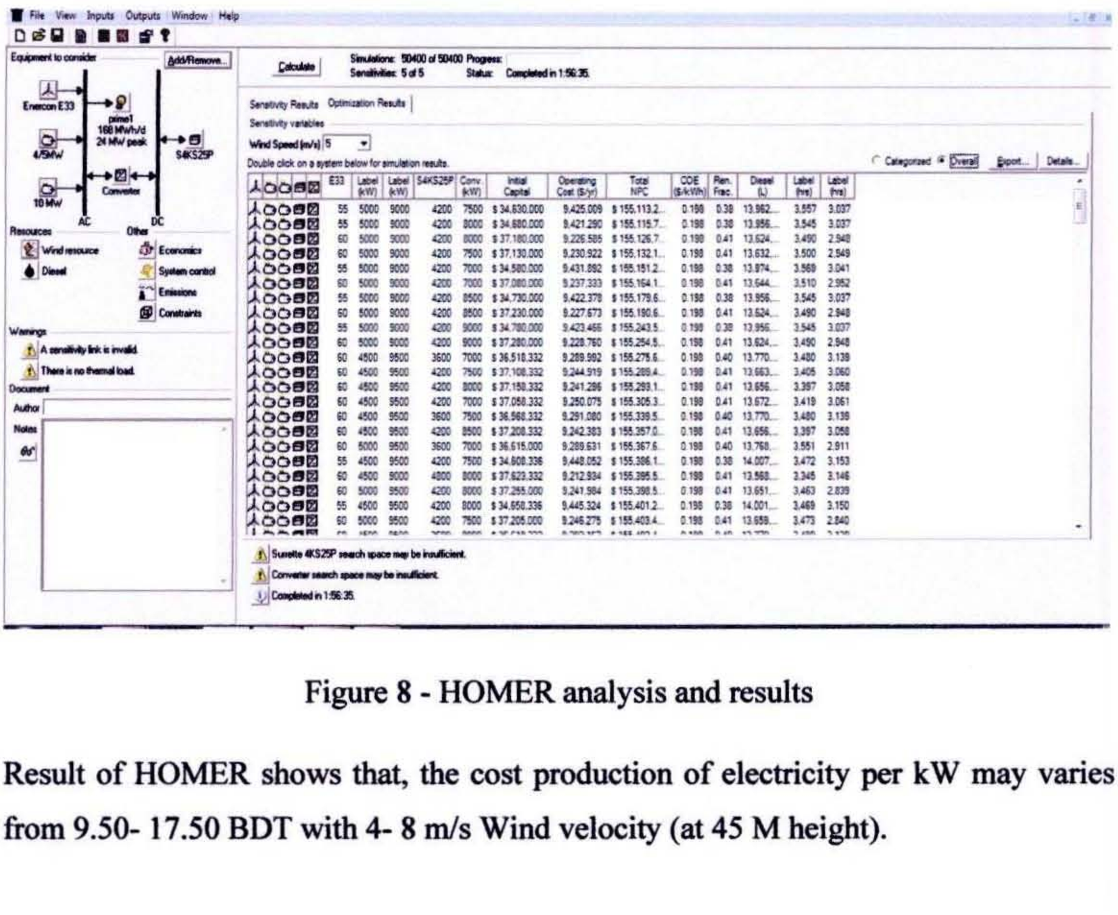

Figure 8 - HOMER analysis and results

Result of HOMER shows that, the cost production of electricity per kW may varies from 9.50- 17.50 BDT with 4- 8 m/s Wind velocity (at 45 M height).

Table 8 – Cost comparison between wind power system and other traditional power generation system [12]

Energy Technology	Fuel cost per kWh, (Tk)	Initial investment per kWh, (Tk)	Trans. and distribution cost per kWh, (Tk)	Total cost per kWh, (Tk)
Coal (mine)	0.75	1.25	1.25	3.25
Coal (imported)	7.00	1.25	1.25	8.50
Oil	17.89	1.50	1.25	20.64
Gas	1.11	1.10	0.85	3.06
Wind (11KV, AC)	0.00	5.91	1.75	7.66
Solar PV (11 kV, AC)	0.00	79.18	1.50	80.68

Table 9 – Wind velocity Vs. per kW cost

Wind velocity (m/s)	Operating cost ($/year)	Initial capital($)	Cost of electricity ($/kWh)	Renewable faction
5	8,737,127	33,150,000	0.195	45
6	7,978,978	29,754,668	0.182	57
7	7,163,876	21,894,683	0.171	71
8	6,219,836	18,878,639	0.159	78

After analyzing the proposed results of HOMER we come to the conclusion that wind –Diesel Hybrid system is most cost effective system for Sandwip. Our analysis shows that, Wind-Diesel Hybrid system will cost 9.75-18.50 BDT according to the Wind variation. Total cost would be low if the turbine cost can be reduced.

Wind speed is much higher at the height above the 50 m. But we have to consider the installation cost of Tower. After comparing large Tower cost and the production cost of electricity at that level, we have came to the conclusion that most economical height for the wind turbine in our analysis is 45 m.

4.2 Environmental affect:

By using hybrid system like wind diesel hybrid system we can control the emission of gasses like carbon dioxide and carbon monoxide. By HOMER we can find the annual data of reduced emission of gasses.

Table 10-Reduction of emission of gasses

Pollutant	Emissions (kg/yr)
Carbon dioxide	33,053,228
Carbon monoxide	81,587
Unburned hydrocarbons	9,037
Particulate matter	6,150
Sulfur dioxide	66,377
Nitrogen oxides	728,009

4.3 Limitations

From the beginning of our work, we found that there are several fault that we have to overcome and in most cases, the work around needs to be followed. The limitations that we indentified are-

- The Data we have collected from various sources is not 100% accurate.

- We have calculated wind velocity for certain height by power law equation. There is a chance of occurring error of ±5 %.
- Wind data of some years are not available so we cannot predict wind pattern.
- Wind velocity measure above 50 meter height has not been done by any organization which is very important.
- Data of Electric load demand is not available for Sandwip and other isolated Island.
- Huge range of Wind variation is observed which is not suitable for wind power system.

Chapter V

Conclusion

5.1 Conclusion

As we standing in the 21st century, our life is directly depending on Electricity. But the energy crisis is becoming a huge threat for Economical development of our country. Still only 39% of the populations have access to electricity. In the coastal area and the isolated Island where grid connection is not feasible, alternate electric source like wind power system can be very cost effective. On the other hand other renewable energy system like PV system is at least 4 to 5 times more expensive than wind power system. As we know wind velocity is not constant, only wind power system cannot fulfill the whole demand of electricity. So hybrid system like wind diesel system is more appropriate for this kind of situation.

Bangladesh is suffering from environmental pollution. The presence of carbon dioxide and sulfur dioxide is above the limit. To control the pollution consumption of fuel must be controlled. To reduced pollution wind power system is very effective.

The cost of per kW of wind power system is less than diesel generated system. So government and the private sectors should emphasis on wind power system as a solution to our power crisis.

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