Research Journal of Applied Sciences, Engineering and Technology 10(8): 895-902, 2015
DOI:10.19026/rjaset.10.2445
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 19, 2015 Accepted: February 27, 2015 Published: July 20, 2015

Research Article

Optimization and Generation of Electrical Energy using Wind Flow in Rural Area of Bangladesh

[1]Md. Sanwar Hossain, [2]Bipul Kumar Raha, [3]Dipankar Paul and [4]Md. Ershadul Haque
[1]Department of EEE, Bangladesh University of Business and Technology, Dhaka, Bangladesh
[2]Operation and Maintenance, WÄRTSILÄ Bangladesh Limited, Bangladesh
[3]Operation and Maintenance, Huawei Technology Ltd., Bangladesh
[4]Department of Electrical, Electronics and System Engineering, Universiti Kebangsaan Malaysia (UKM), Selangor, 43600, Malaysia

Abstract: In this study, wind data of different location of Bangladesh has been analyzed collected from Local Government Engineering Department (LGED). From some analyses, Kuakata sea region has been selected as proper location for establishing wind power system. Through proper investigation it has been tried to find out the way for developing sustainable wind energy system which is to be developed in the coastal area of Bangladesh. Besides it has been analyzed different turbines and found which is better for a particular location. It has been observed that to provide a sustainable wind energy system, a minimum wind velocity of 4 m/sec is needed for specific turbine. Diesel generator has been used to supply deficiency of wind system during lower wind flow. Besides, converter and battery have been set up to store excess power. All of the theoretical endeavours have been observed through simulation. World renowned software named 'Homer' has been used for simulation. Using this software sensitivity analysis and optimization have been accomplished. Through all these efforts it has been tried to propose how to set up optimum wind power system.

Keywords: Diesel generator, hybrid system design, sensitivity analysis, wind data, wind turbine

INTRODUCTION

Airflows can be used to run wind turbines. Modern wind turbines range is from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5-3 MW have become the most common for commercial use; the power output of a turbine is a function of the cube of the wind speed, so as wind speed increases, power output increases dramatically (Muller *et al*., 2000). Areas where winds are stronger and more constant, such as offshore and high altitude sites are preferred locations for wind farms. Since wind speed is not constant, a wind farm's annual energy production is never as much as the sum of the generator nameplate ratings multiplied by the total hours in a year. The ratio of actual productivity in a year to this theoretical maximum is called the capacity factor. Typical capacity factors are 20-40%, with values at the upper end of the range in particularly favorable sites (Boccard, 2009). For example, a 1 megawatt turbine with a capacity factor of 35% not produce 8,760 MW-h in a year, but produce only 0.35×24×365 = 3,066 MWh, averaging to 0.35 MW. In the case of wind power intermittency is one of the frequently cited disadvantages, because the wind doesn't blow all the time. Wind projects can't produce a steady stream of energy for 24 h; hence they are regarded as "intermittent" power sources. Here the solution is the hybrid project. Hybrid power systems are combinations of two or more energy conversion devices (e.g., electricity generators or storage devices), or two or more fuels for the same device (Canales and Beluco, 2014). This integrated power systems overcome the limitations that may be inherent in either.
Examples of hybrid power systems include:

- Wind generation combined with diesel generation
- Photovoltaic generation combined with battery storage or diesel generation
- Fuel cell generation combined with micro-turbine generation

The objective of these hybrid power systems is to generate and optimize electrical energy using wind flow in rural area of Bangladesh.

METHODOLOGY

The wind turbine shown in Fig. 1 captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical

Corresponding Author: Md. Sanwar Hossain, Department of EEE, Bangladesh University of Business and Technology, Dhaka, Bangladesh

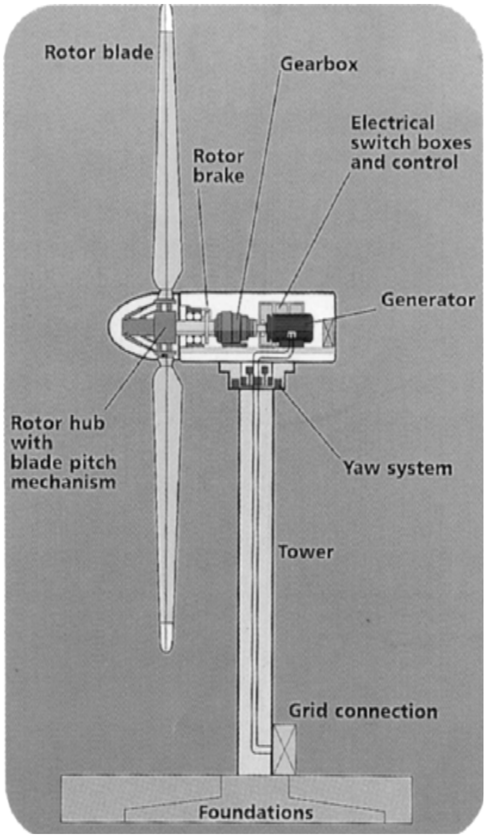


Fig. 1: Wind turbine

generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power production capacity. Obviously, sites with steady high wind produce more energy over the year. Two distinctly different configurations are available for the turbine design, the horizontal axis configuration and the vertical axis configuration (Tong, 2010). However, most modern wind turbines use horizontal-axis design (Okeniyi *et al*., 2014). The power extracted by the blades is customarily expressed as a fraction of the upstream wind power as follows (Burton *et al*., 2011):

$$P_0 = \frac{1}{2}\rho A V^3 C_p \tag{1}$$

where, ρ is air density (kg/m), A is area swept by the rotor blades (m^2), V is velocity of the air, m/sec^2 and C_p is the fraction of the upstream wind power, which is captured by the rotor blades. The theoretical maximum value of C_p is 0.59 (Kumar *et al*., 2013). In practical designs, the maximum achievable C_p is below 0.5 for high-speed, two-blade turbines and between 0.2 and 0.4 for slow speed turbines with more blades (Table 1).

The LGED (Local Government Engineering Department) provided us the data for 6 regions named Kuaktata, Kutubdia, Sitakunda, Khagrachori, Nawga and Pakshi. We have analyzed the three regions Kuaktata, Kutubdia and Sitakunda data with the help of the software named WINDOGRAPHER (Windographer, 2014).

RESULTS AND DISCUSSION

At first, we have found out the Weibull probability distribution function ‘h’ with two parameters, the shape parameter ‘k’ and the scale parameter ‘c’ (Odo *et al*., 2012). At most sites the wind speed has the Weibull distribution with k = 2, which is specifically known as the Rayleigh distribution. Here, at Kuakata at 30 m height, the value of the shape parameter ‘k’ is 2.003 and the scale parameter ‘c’ is 4.68 m/sec and the mean wind speed at Kuakata at 30 m height is 4.14 m/sec i.e., most of the time the wind speed is 4.14 m/sec. The mean wind power density found at the Kuakata at 30 m height is 85 W/m^2 and the mean energy content is 745 kW/m^2/year and the energy pattern factor is 1.958. On the other hand the mean wind speed, wind power density and mean energy content at the Kutubdia are,

Table 1: Wind speed sensor summary of different locations

	Kuaktata		Kutubdia		Sitakunda	
Variables	At 30 m height	At 20 m height	At 20 m height	At 10 m height	At 30 m height	At 20 m height
Mean wind speed (m/sec)	4.140	3.130	3.620	2.580	3.680	2.960
Median wind speed (m/sec)	3.700	2.720	3.170	2.120	3.360	2.550
Min wind speed (m/sec)	0.000	0.000	0.000	0.000	0.000	0.000
Max wind speed (m/sec)	22.630	38.120	15.340	13.860	29.710	25.790
Mean power density (W/m²)	85.000	47.000	59.000	32.000	73.000	48.000
Mean energy content (kWh/m²/year)	745.000	409.000	516.000	282.000	636.000	424.000
Energy pattern factor	1.958	2.475	2.020	3.048	2.386	3.042
Weibull k	2.003	1.742	1.937	1.351	1.752	1.405
Weibull c (m/sec)	4.680	3.530	4.090	2.830	4.130	3.260
1-h autocorrelation coefficient	0.868	0.183	0.855	0.887	0.761	0.830
Diurnal pattern strength	0.022	0.084	0.151	0.202	0.151	0.231
Hour of peak wind speed	16.000	14.000	15.000	14.000	16.000	15.000
Mean turbulence intensity	0.178	0.271	0.208	0.359	0.182	0.252
Standard deviation (m/sec)	2.170	1.900	1.960	1.930	2.170	2.130
Coefficient of variation (%)	52.400	60.500	54.200	74.700	59.100	71.800

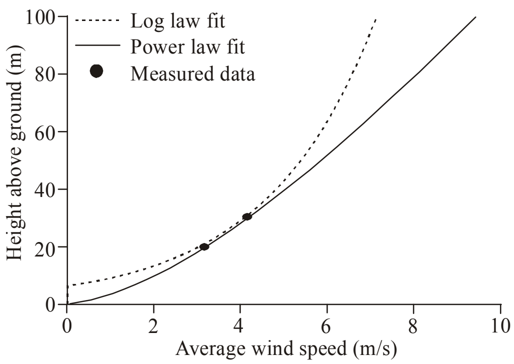


Fig. 2: Wind shear profile for kuakata

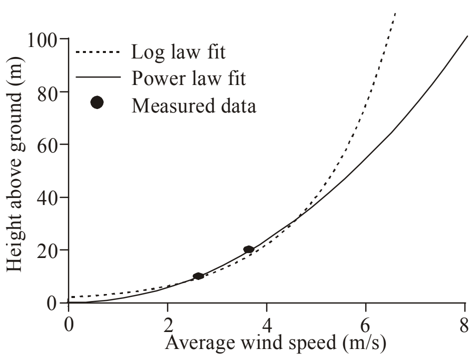


Fig. 3: Wind shear profile for kutubdia

respectively 3.62 m/sec, 59 W/m^2 and 516 kW/m^2/year. The mean wind speed, wind power density and mean energy content at the Sitakunda are, respectively 3.68

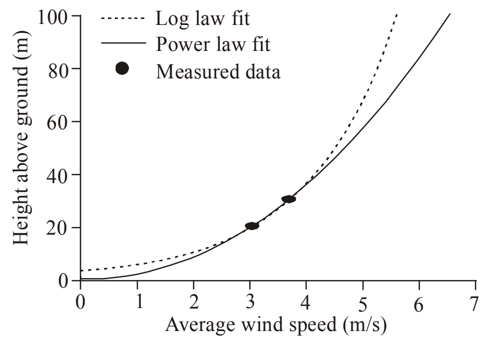
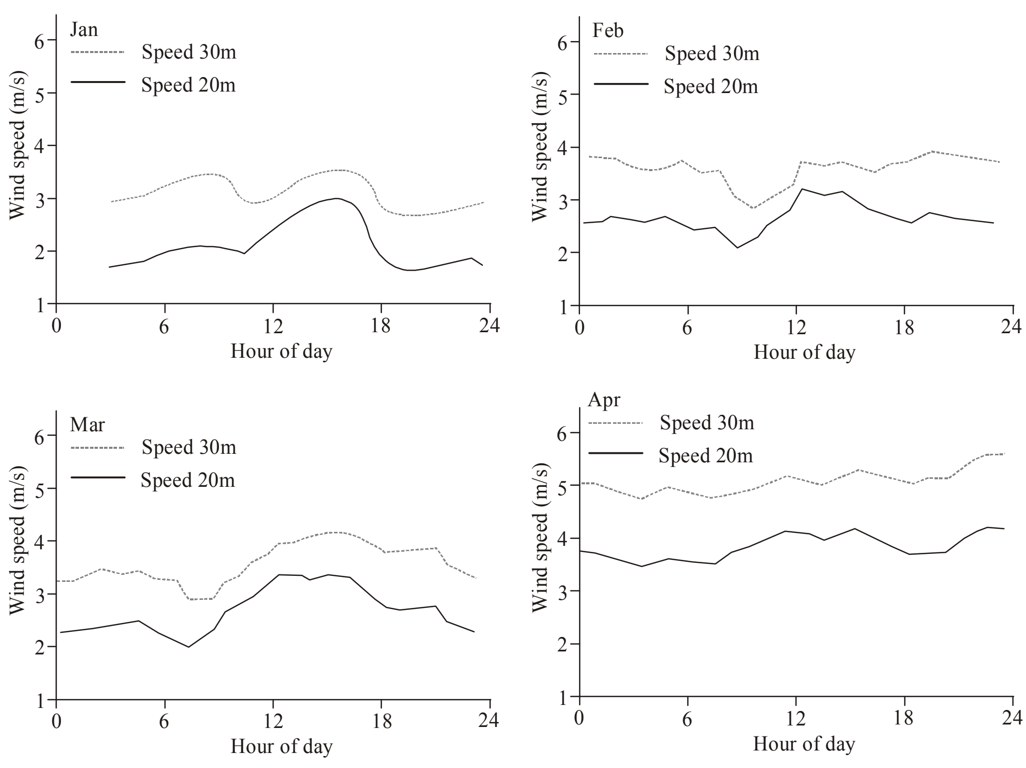


Fig. 4: Wind shear profile for Sitakunda

m/sec, 73 W/m^2 and 636 kW/m^2/year. From the above data it is seen that Kuakata is most suitable location for placing wind turbine.

Wind shear analysis provides the wind speed at any height (Pope *et al*., 2010). The wind shear profiles of Kuakata, Kutubdia and Sitakunda are shown in Fig. 2 to 4, respectively. From the figures it is seen at 50 m height the wind speed of Kuakata is 5.41 m/sec, the wind speed of Kutubdia is 5.41 m/sec and the wind speed of Sitakunda is 4.48 m/sec. The value of power law exponent at 50 m height at Kuakata is 0.687, at Kutubdia is 0.488 and at Sitakunda is 0.478.

Wind profile of selected location: The wind profile of any location represents all the necessary graph of a wind regime. The wind profile of selected location Kuakata are:



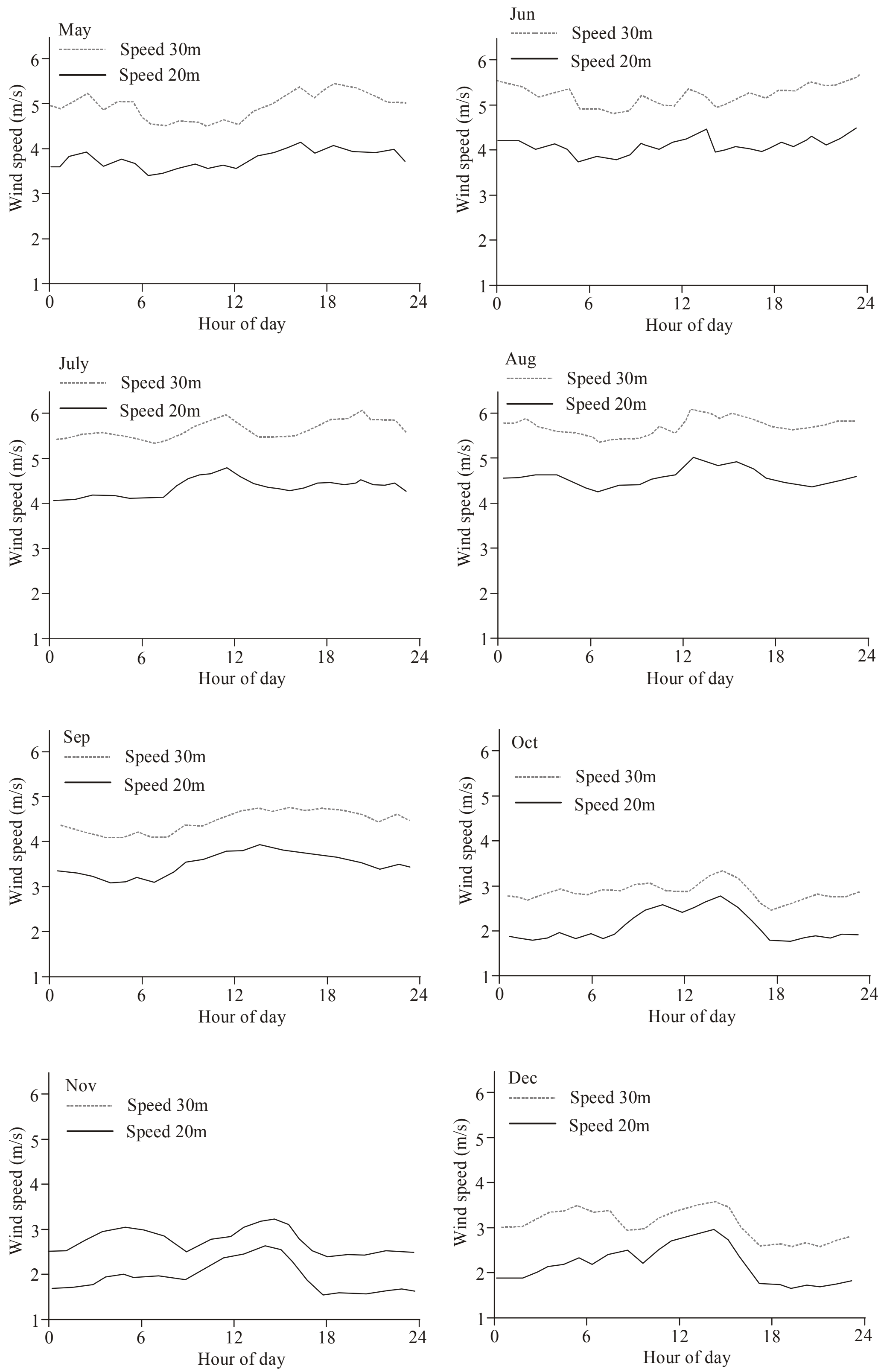


Fig. 5: Monthly wind speed profile

- Monthly wind speed profile
- Daily wind speed profile
- Seasonal wind speed profile
- Probability distribution function

- Power density

Monthly wind speed profile of Fig. 5 mainly shows the wind speed at a certain location for 12 months i.e., whole year and the wind speed are shown according to day time of 24 h. There are 12 graphs for 12 months. From this profile, we can easily understand how wind speed varied with different months.

Daily wind speed profile mainly shows the wind speed variation of a certain location with the single day (Fig. 6).

Seasonal wind speed profile includes the wind speed variation of a region during a season i.e., from January to December (Fig. 7).

The probability distribution function of Fig. 8 gives the probability that the wind speed will take a value. Here, it is expressed using a frequency histogram, which gives the frequency with which the wind speed falls within certain ranges (Alam and Azad, 2014).

Figure 9 monthly average power density shows that at the starting of the year i.e., in January the wind power density is low and it continues to march. From April, the speed starts to increase and at June, July and August, there is so much density. After that, it continues to decline and the rest of the year, there is no significant density.

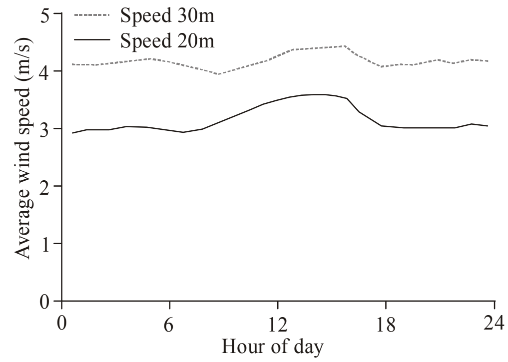


Fig. 6: Daily wind speed profile

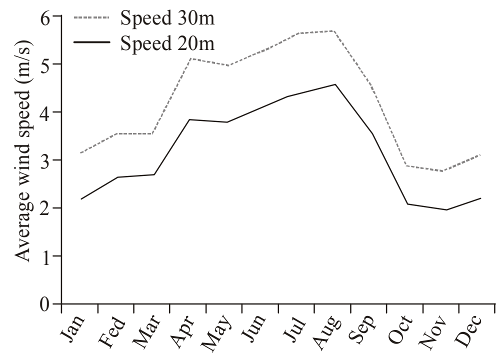


Fig. 7: Seasonal wind speed profile

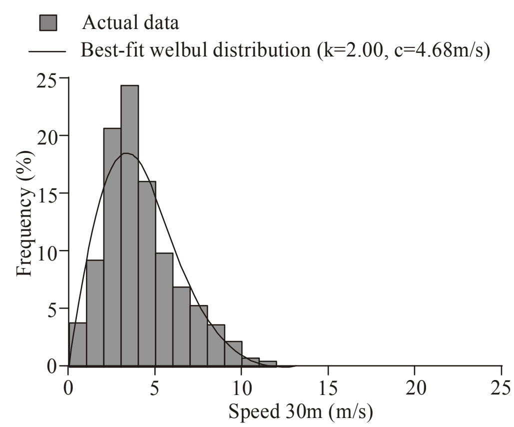


Fig. 8: Probability distribution function of kuakata at 30 m height

Wind turbine analysis: A wind turbine needs five types of data for calculating its output power, these are:

- Annemeter height where the mean speed is found
- Power law Exponent
- Mean wind speed
- Weibull K
- Air Density

Here we have analyzed different ratings turbine from MW range to few kW. Here, we use five different ratings turbine these are:

- Suzlon S.62/1000
- Enercon E33
- Entegrity eW-15 50 Hz
- Fuhrländer FL 30
- Southwest skystream 3.7 kW

Figure 10 compares the output power of different turbine according to percentage of rated power. From the figure it is seen that for a particular wind speed we will get a higher output for the turbine Entegrity eW-50 Hz and Fuhrländer FL 30.

The output of Fuhrländer FL30 and Southwest Skystream 3.7 are decreases with high wind speed but no change in the output of Enercon E33 and Suzlon S.62/1000 (Windpower, 2014).

Hybrid power system: Figure 11 is a hybrid power system which is considered for simulation. Simulation results are essential to find the optimum system and sensitivity analysis through which we can choose our expected system (Bataineh *et al*., 2014).

Cash flow summary: HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 h in a year. This section describes how to enter cost data for diesel generators, wind turbines and batteries. For example cash flow summary tells that installing a spatial type of wind turbine in the system initial capital is costs \$30000, replacing the wind turbine cost is \$10422 and operation and

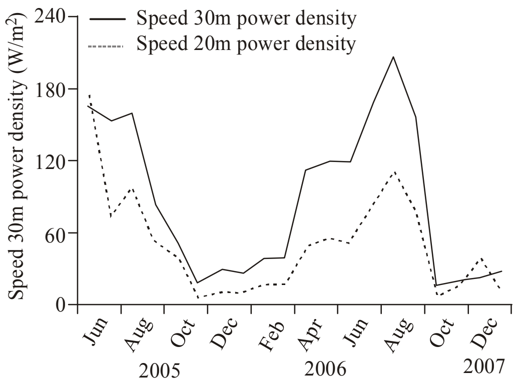


Fig. 9: Monthly average power density

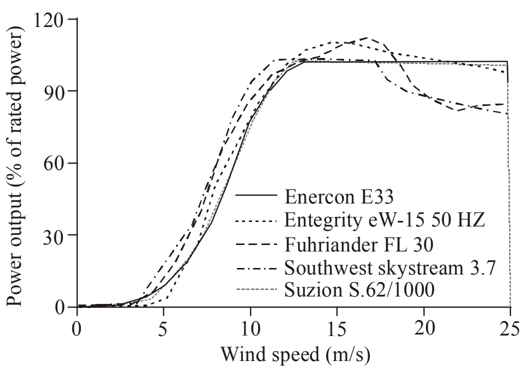


Fig. 10: Comparison of output power (% of rated output) of different type of turbines

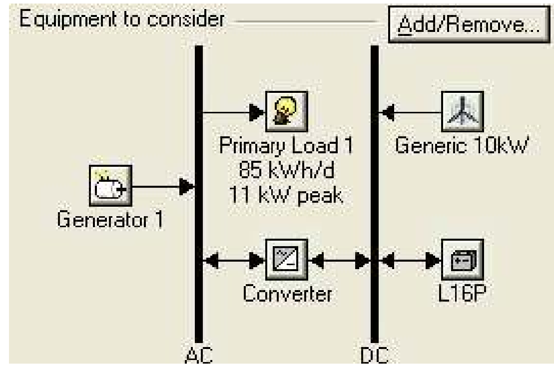
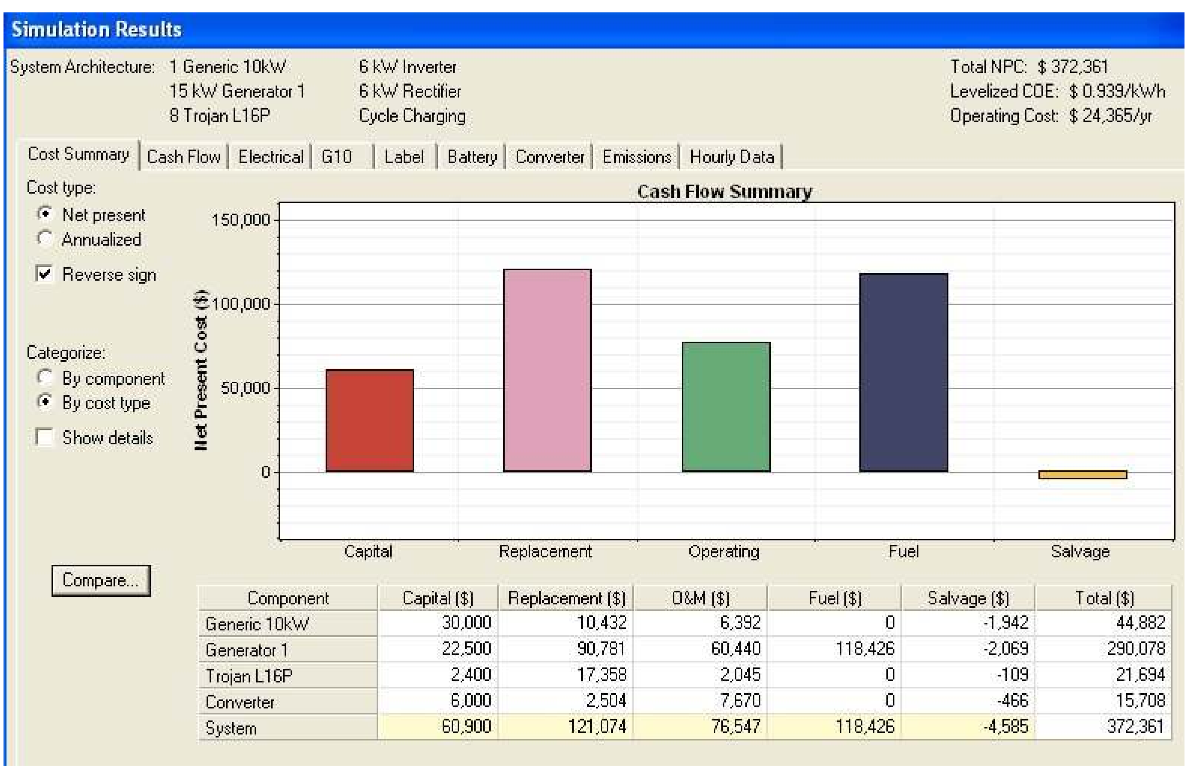


Fig. 11: Hybrid power system

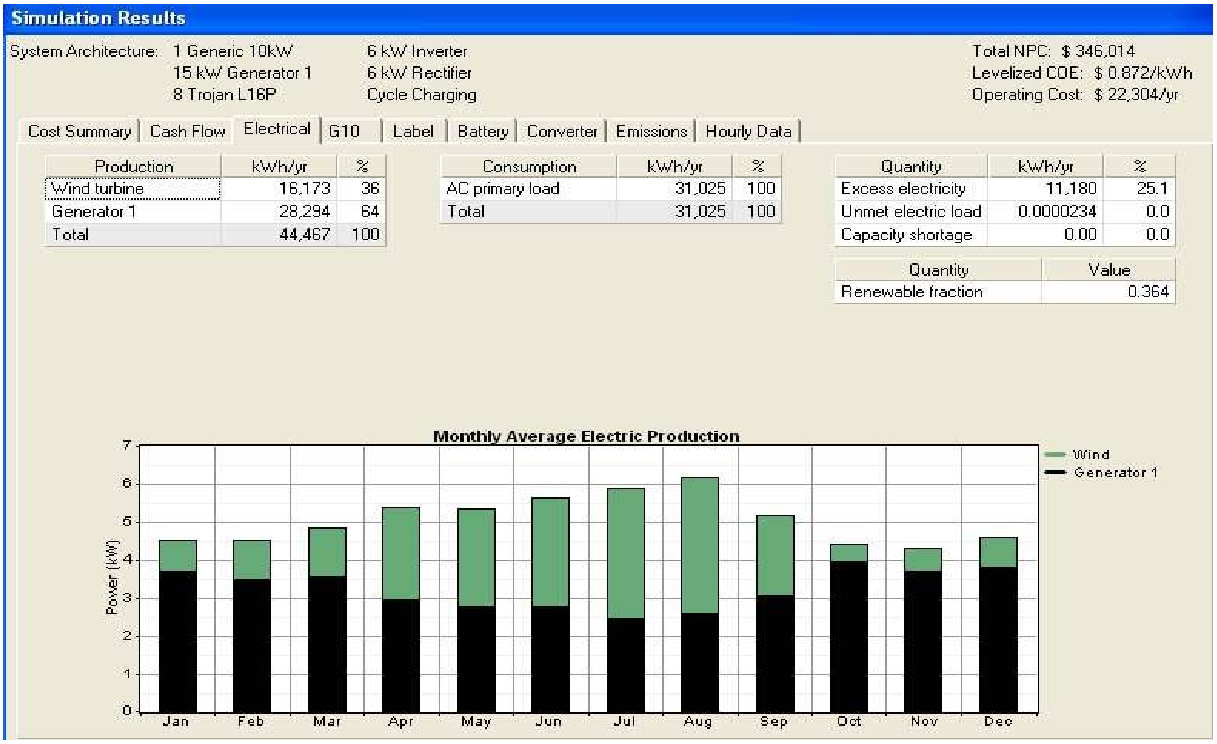
maintenance cost $6392. The costs in this exercise may not reflect real market conditions (HOMER Legacy, 2008). Figure 12 shows the lifecycle cost of the system, accounting for the capital, replacement, operation and maintenance, fuel and interest costs. Here we can view hourly energy flows for each component as well as annual cost and performance summaries.

Energy sharing: Figure 13 represents the monthly average energy production by wind turbine and diesel generator. Such as, from April to September when wind blows at a high speed then the wind turbine produces more energy. Average annually electricity production from the hybrid system is 44,467 kWh/year in which 36% electricity comes from a wind source and 64%



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 10kW	30,000	10,432	6,392	0	-1,942	44,882
Generator 1	22,500	90,781	60,440	118,426	-2,069	290,078
Trojan L16P	2,400	17,358	2,045	0	-109	21,694
Converter	6,000	2,504	7,670	0	-466	15,708
System	60,900	121,074	76,547	118,426	-4,585	372,361

Fig. 12: Cost at different sector



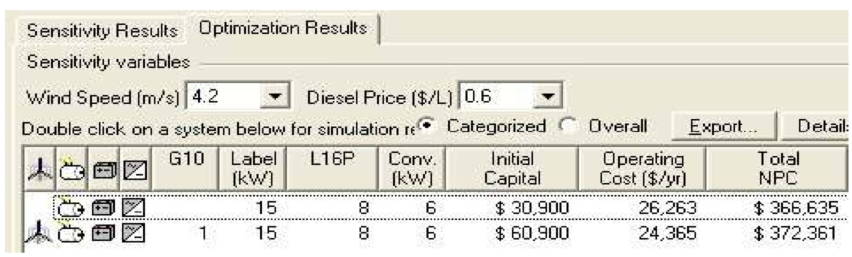
Production	kWh/yr	%
Wind turbine	16,173	36
Generator 1	28,294	64
Total	44,467	100

Consumption	kWh/yr	%
AC primary load	31,025	100
Total	31,025	100

Quantity	kWh/yr	%
Excess electricity	11,180	25.1
Unmet electric load	0.0000234	0.0
Capacity shortage	0.00	0.0

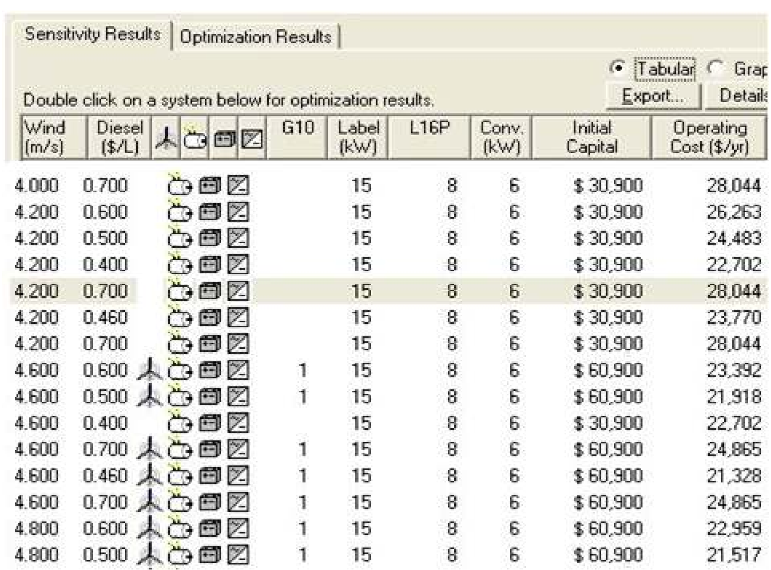
Quantity	Value
Renewable fraction	0.364

Fig. 13: Energy sharing between wind turbine and diesel generator



G10	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC
	15	8	6	$ 30,900	26,263	$ 366,635
1	15	8	6	$ 60,900	24,365	$ 372,361

Fig. 14: Optimization result



Wind (m/s)	Diesel ($/L)	G10	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)
4.000	0.700		15	8	6	$ 30,900	28,044
4.200	0.600		15	8	6	$ 30,900	26,263
4.200	0.500		15	8	6	$ 30,900	24,483
4.200	0.400		15	8	6	$ 30,900	22,702
4.200	0.700		15	8	6	$ 30,900	28,044
4.200	0.460		15	8	6	$ 30,900	23,770
4.200	0.700		15	8	6	$ 30,900	28,044
4.600	0.600	1	15	8	6	$ 60,900	23,392
4.600	0.500	1	15	8	6	$ 60,900	21,918
4.600	0.400		15	8	6	$ 30,900	22,702
4.600	0.700	1	15	8	6	$ 60,900	24,865
4.600	0.460	1	15	8	6	$ 60,900	21,328
4.600	0.700	1	15	8	6	$ 60,900	24,865
4.800	0.600	1	15	8	6	$ 60,900	22,959
4.800	0.500	1	15	8	6	$ 60,900	21,517

Fig. 15: Sensitivity result

electricity comes from a diesel generator with an annual capacity of shortage 0%.

Optimization and sensitivity analysis: Sensitivity results of hybrid power system display the operating cost variation with the variation of wind speed and diesel price. From the result shown in Fig. 14 and 15 it is seen that when the wind speed increases operating cost decreases. It is also seen that the wind and diesel system is more cost effective than the system with no wind turbine. For example, when the wind speed is 4.2 m/sec and the price of diesel price is \$ 0.70/L, then the operating cost of the only diesel system is \$ 28,044. At the same time when the wind speed is 4.6 m/sec and the price of diesel price is \$ 0.70/L, then the operating cost of the wind and diesel system is \$ 24,865.

CONCLUSION

Whole world is suffering from power crisis. This crisis is likely to be more severe if we mere depend on available mineral power resources. It is the high time we sought for alternative means. Renewable energy can be converted to electrical energy through proper means which is gainful. All of the analyses have presented here is helpful to obtain an optimum wind power system. Substantial amount of electrical energy can be produced from available wind power of coastal area. Basically this analysis provides a simulation based technical process and financial comparison of using wind energy to meet our present and future electrical energy demand. The system proposed here can be further optimized through the use of solar energy along with wind turbine. Such hybrid power system is suitable for low cost high profit production.

REFERENCES

Alam, M.M. and A.K. Azad, 2014. Wind energy analysis for 3 prospective costal sites of Bangladesh. Proceeding of the 2014 International Conference on Industrial Engineering and Operations Management. Bali, Indonesia, pp: 1770-1779.

Bataineh, A., A. Alqudah and A. Athamneh, 2014. Optimal design of hybrid power generation system to ensure reliable power supply to the health center at Umm Jamal, Mafraq, Jordan. Energ. Environ. Res., 4(3): 9-10.

Boccard, N., 2009. Capacity factor of wind power realized values vs. estimates. Energ. Policy, 37(7): 2679-2688.

Burton, T., N. Jenkins, D. Sharpe and E. Bossanyi, 2011. Wind Energy Handbook. John Wiley and Sons, Ltd., Chichester, UK.

Canales, F.A. and A. Beluco, 2014. Modeling pumped hydro storage with the micropower optimization model (HOMER). J. Renew. Sust. Energ., 6(4): 043131.

HOMER Legacy, 2008. National renewable energy laboratory. Operated for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2(68): 8-9.

Kumar, T.K., A. Tulasi and S. Swain, 2013. Hybrid wind diesel energy system using matlab simulation. Int. J. Eng. Sci. Innov. Technol., 2(5): 1-9.

Muller, S., M. Deicke and R.W. De Doncker, 2000. Doubly fed induction generator systems for wind turbines. IEEE Ind. Appl. Mag., 8(3): 26-33.

Odo, F.C., S.U. Offiah and P.E. Ugwuoke, 2012. Weibull distribution-based model for prediction of wind potential in Enugu, Nigeria. Adv. Appl. Sci. Res., 3(2): 1202-1208.

Okeniyi, J.O., A.L. Cleophas and A.P.I. Popoola, 2014. *Rhizophora Mangle* L. Effects on steel-reinforced concrete in 0.5 M H2SO4: Implications for corrosion-degradation of wind-energy structures in industrial environments. Energ. Proc., 50: 429-436.

Pope, K., I. Dincer and G.F. Naterer, 2010. Energy and exergy efficiency comparison of horizontal and vertical axis wind turbines. Renew. Energ., 35(9): 2102-2113.

Tong, W., 2010. Wind Power Generation and Wind Turbine Design. WIT Press, Billerica, MA, pp: 187-256.

Windographer, 2014. Retrieved form: www. windographer.com (Accessed on: October 12, 2014).

Windpower, 2014. Program. Retrieved form: http://www.wind- powerprogram.com/ turbine_ characteristics.htm.