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Optimal Planning of Standalone Solar-Wind-Diesel Hybrid Energy System for a Coastal Area of Bangladesh

Ahmed Zubair*, Aman Abdulla Tanvir**, Md. Mehedi Hasan**

* Departement of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology
**Department of Electrical and Electronic Engineering, International Islamic University Chittagong

Article Info	ABSTRACT
	For sustainable development of a country access to electricity in every moment is now the basic need for the current civilization. Power crisis is one of the major barriers for economic development of Bangladesh. Bangladesh lacks in fossil fuel reservation. Abundance of renewable energy sources in the form of solar energy, wind energy provides opportunities of renewable energy based hybrid energy system in the coastal areas of Bnagladesh. Energy generation by hybrid system reduces the generation cost and will help in balancing the cost of energy. Again a standalone renewable enegy incorporated hybrid energy system will reduce load demand from the grid and will be an eco-friendly energy system. This paper proposed a cost effective design of standalone solar-wind-diesel hybrid power system in a coastal area of Bangladesh. Considering different conditions for a coastal area design and simulation of the hybrid power system was performed. Detailed economic analysis and comparison with solar based and diesel based energy system clearly reveals that proposed hybrid power system was found a cost effective solution for coastal areas of bangladesh.

Corresponding Author:

Ahmed Zubair,
Departement of Electrical and Electronic Engineering,
Bangladesh University of Engineering and Technology,
Dhaka-1000, Bangladesh.
E-mail: ahmedzubair.003@gmail.com

1.   INTRODUCTION

Bangladesh is a developing nation with huge population of almost 160 million people with electricity access rate of about 50%. In the rapidly growing economies of the developing countries like Bangladesh the demand for electricity is considerably increasing. The present demand of energy is increasing day by day due to various reasons such as increasing population, the aspiration for improved living standards and general economic and industrial growth. At present electricity demand growth is about 10% which is expected to be more in coming years. The power demand in Bangladesh is about 7500MW at this moment, whereas the generation ranges only 5000- 6000MW. The installed generation capacity is 6693 MW and derated capacity is 6061 MW. Demand is estimated to exceed 10,000 MW by 2015. So Bangladesh is experiencing a significant amount of load shading. Again Bangladesh relies heavily on fossil fuels for its energy especially on gas resources. Natural gas is used as fuel for 76% of the energy generation. But the present proven reserve would be depleted by a decade. Around the world coal is still a main fuel for power generation. Bangladesh has sufficient high quality coal resources. But the coal mining is at its initial stage. The exploration of gas and coal continues to remain uncertain. Another important issue is that fossil fuel based power plant is not eco-friendly. Alternative way of energy generation in Bangladsh is the need of time. The lack of energy resources can be met by renewable energy which is abundant in nature. Renewable energy is also considered as green or clean energy, because it does not produce toxins or pollutants that are harmful

to the environment. Much of the world today is converting to renewable energy sources as a means of providing power to homes and businesses in order to function more environmentally friendly and to utilize the unlimited supply of renewable energy. Renewable energy resources like solar, wind, hydro and tidal could be utilized in some areas of Bangladesh to establish renewable enrgy based power generation stations.

Bangladesh is situated between 20°34' and 26°38' north latitudes and 88°01' and 92°41' east longitudes and the coastal area in the southern part of Bangladesh has a huge potential of establishing solar and wind power generation. Kuakata a scenic sea beach on the south of Bangladesh situated at 21°49' north latitudes and 90°7' east longitudes.The total population of Kuakata 174921. The most important attraction of the beach is that one can see both sunrise and sunset from some of its locations. This sandy beach slopes into the Bay of Bengal. Other attractions at Kuakata include blue sky, huge expanse of water, the evergreen forest in surrounding areas, rows of coconut trees, boats of many different kinds and their colourful sails, and surfing waves. Kuakata is also a sanctuary for migratory winter birds. And hence Kuakata has become a popular tourist spot due to its natural beauty.The annual average wind speed is 6.742 m/s at 50m height which is good enough to harness wind energy and the solar irradiation is 4.651 kWh/m^2/day which is suitable for setting up solar energy system. An off-grid hybrid energy system can be launched to meet energy demand of this coastal area.

Hybrid energy system with incorporation of renewable energy system helps improve load factors and assist on maintainence and replacement costs as the enrgy sources can harmonize each other [1], [2]. However to construct an optimized hybrid energy system, evaluation of the suitable type of and size of renewable energy system is essential. Effort is being made to study the viability of renewable energy incorporated hybrid system as alternative of diesel generator [1]-[4]. Wind-diesel hybrid power systems considerably reduce the need for storage of fuel, fuel consumption cost, and greenhouse gas emission [5]-[7]. Performance analysis of solar-wind-diesel hybrid system has been carried out by several researchers [8], [9]. Optimization of sizing of solar-wind hybrid sytem has been investigated [10], [11]. This paper discusses different system components of hybrid energy system and presents a design of off-grid solar-wind-diesel hybrid power system for Kuakata of Bangladesh. Detailed economic analysis of the proposed system is also carried out to validate the design.

2.   RESEARCH METHOD

In this work, an optimal design of a standalone hybrid system is proposed for a coastal area of Bangladesh. This system design can be applied to other coastal areas and also some remote areas of Bangladesh. At first, Energy resources are analized to find out the most suitable energy resources for planning a hybrid energy system. Then using the best suitable enrgy resources a hybrid energy system is designed. For the optimal planning of sizing of different components of the system the simulation software HOMER (Hybrid Optimization Model for Electric Renewables) is employed. HOMER performs the energy balance calculations for each system configuration that can be considered. The system cost calculations are done studied which account costs such as capital, replacement, operation and maintenance, fuel, and interest. This economic analysis is carried out to determine the feasibility of the proposed system. Comparison with solar photovoltaic (PV) based other energy systems and diesel based energy system is studied for confirming the practicability of the proposed system.

2.1   Energy Resources

For a suitability energy system design, energy resources selection is vital. Renewable energy can sometimes be called infinitive energy, because it relies on energy that is in infinite supply and there is no fuel cost for renewable energy system. Renewable energy is also considered as green or clean energy, because it does not produce toxins or pollutants that are harmful to the environment. In the location of our study, wind energy and solar energy is enough for harvesting these renewable energys for power egeneration. Natural Gas is major reserve fossil fuel of Bangladesh. But as gas transmission line is not extended to our study location, gas can be used as a fuel. Diesel is used as the fuel for power generation from fossil fuel.

2.1.1 Solar Energy Resources in Kuakata

Solar energy is the sun's rays that reach the earth being converted to energy through different processes. Solar can be converted to electricity. Photovoltaic systems use solar cells or panels to convert sunlight directly into electricity. Solar irradiance, measure of incoming solar radiation, of Bangladesh is very good for the purpose of electricity generation. The monthly averaged global radiation data has been taken from NASA (National Aeronautics and Space Administration) and clearness index is a measure of the cleaness of the atmosphere has an average value of 0.499 for Kuakata. Table 1 shows the clearness index and

daily radiation for Kuakata. Figure 1 shows the monthly averaged values of cleaness index and daily radiation.

Table 1. Solar irradiation in Kuakata

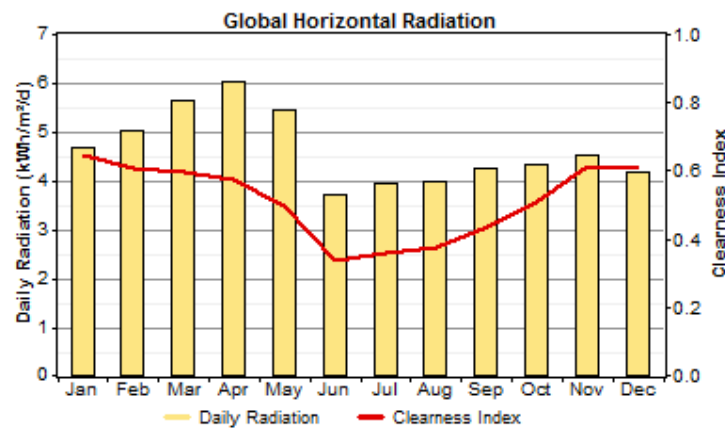| Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.647	4.67
February	0.607	5.010
March	0.595	5.650
April	0.575	6.030
May	0.499	5.470
June	0.336	3.720
July	0.359	3.940
August	0.377	4.000
September	0.436	4.270
October	0.506	4.350
November	0.611	4.540
December	0.610	4.190
Annual Average	0.499	4.651

Figure 1. Monthly averaged daily radiation and cleaness index

2.1.2 Analysis of Wind Data in Kuakata

Kuakata is situated at coastal line along the Bay of Bengal. The areas near the Bay have wind speed high enough to produce electricity commercially. Through the coastal area of Bangladesh the strong south/south-western monsoon wind come from the Indian Ocean traveling a long distance over the Bay of Bengal, This wind blows over Bangladesh from March to September with a monthly average speed of 3 m/s to 9 m/s at different heights. According to the studies of Bangladesh Meteorological Department (BMD), wind speed is high in Bangladesh during the Monsoon (7 months, March–September). In rest of the months (October –February) wind speed remains either calm or too low. The peak wind speed occurs during the month of April and May. The wind speed data at Kuakata is recorded at 50 m height. Table.1 shows the monthly average wind speed around the year at Kuakata.

Wind energy is the kinetic energy of the moving air mass. The power, P, in watts, possessed by wind blowing with a speed of V, in meter per second (m/s), is directly proportional to the area swept by rotor and to the cube of the wind speed, and is given by,

$$P = \tfrac{1}{2}.\rho.A.V^3 \tag{1}$$

where, A is the area perpendicular to the direction of flow (m²), ρ is density of air, kg/m³, is approximately 1.2 kg/m³. Only a part of the total available power calculated by equation (1) can be extracted and is given by,

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

C_p is the power coefficient [12] is the ratio of power extracted by a wind turbine to power available in wind at that location. A theoretical maximum of 59.3% of available power can be extracted; i.e. C_p is 0.593. Practically a typical maximum of 40% is achievable.

The Weibull value, k which is a measure of distribution of wind speed over the year is taken as 1.87 [13]. The autocorrelation factor measures the randomness of the wind. Higher values indicate that the wind speed in 1 h tends to depend strongly on the wind speed in the previous hour. Lower values mean that the wind speed tends to fluctuate in a more random fashion from hour to hour. The autocorrelation factor value is taken as 0.85. The diurnal pattern strength is the measure of how strongly the wind speed depends on the time of the day. In this study, 0.25 is used. The hour of peak wind speed is simply the time of day tends to be windiest on an average throughout the year. In this study, 15 hours are used as the hour of peak wind speed.

Table 2. Wind speed at 50 m height in Kuakata

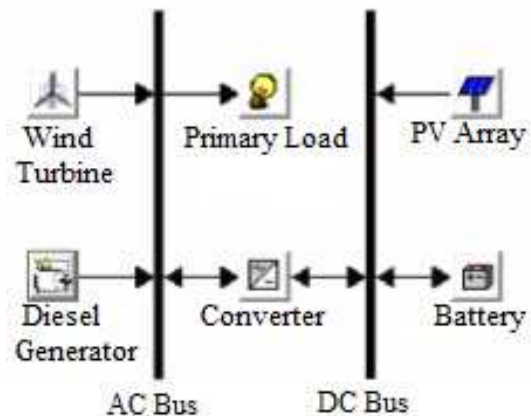| Month	Wind Speed (m/s)
January	5.80
February	5.50
March	7.70
April	8.30
May	7.90
June	6.90
July	7.70
August	7.50
September	6.90
October	6.30
November	5.50
December	4.80
Annual Average	6.742

Figure 2. Single line Diagram of hybrid enegy system

2.2 Design of Hybrid Energy System

A hybrid power system for Kuakata is desgined where diesel generator has been combined with wind and solar power generation. Diesel generator has been chosen for its operating feasibility, low cost, quick start and small size. It has good thermal and electrical efficiency. Moreover it has low fuel consumption and good load support. But only diesel generator is not cost effective to meet the current electrical demand. A solar-wind-diesel hybrid system can be a cost effective solution. Figure 2 shows the diagram of the hybrid system.

2.2.1 Electricity Demand Profile

In this study, after doing necessary survey per capita power consumption is assumed about 300 kWhr per annum for analyzing the electrical demand for Kuakata. According to annual report of Bangladesh Power Development Board (BPDB), per capiata power generation is 212 kWhr. The daily load profile for summer season is as shown in the Figure 3. Figure 4 shows the daily load profile on a day of winter season. Randomness of the daily consumption is kept as 15%. And variability of hour to hour is considered as 20%. Taking all factors in consideration, energy demand per day is 119.4 MWhr and annual Peak load is taken 19.391 MW.

2.2.2 Wind Turbine

Average wind velocity at 50m height is 6.742 m/s in Kuakata. But at winter, wind velocity goes below the average wind velocity. High capacity wind turbines has cut-in speed of more than 4 m/s. Enercon E33 wind turbine is a suitable choice for low wind speed as its cut-in speed is 3 m/s. The irregularity of wind speed does not affect its function as its rotational speed can vary between 18 to 45 rpm. It has a rated capacity of 330 kW. The installation cost for Enercon E33 (50 m height tower) is $ 500000. It operates at 3 phase 415 Volt AC 50 Hz that is suitable for Bangladesh. It is a direct drive machine with no gear-box means reduced

maintenance, reduced noise and increased reliability. Considering the above factors, Enercon E33 turbine has been chosen for the hybrid system. Figure 5 shows an Enercon E33 wind turbine.
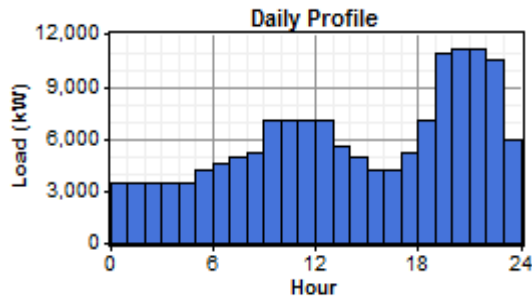

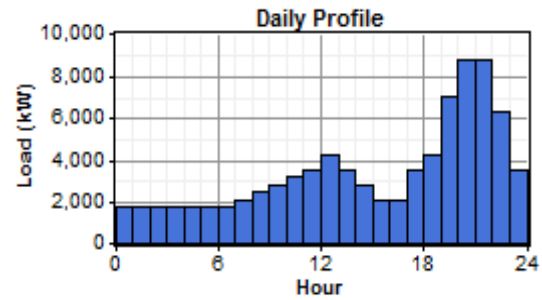Figure 3. Load Profile of a day in Summer Season

Figure 4. Load Profile of a day in Winter Season

Figure 5. Enercon E33 Wind turbine

Table 3. Optimum system architecture of Solar-Wind-Diesel Hybrid system

System Component	Size
PV	5000 kW
Wind Turbine	9900 kW
Diesel Generetor	10000 kW
Battery	7500 unit
Converter	5000 kW

2.2.3 Solar Photovoltaic Panel

The cost of PV module including installation has been considered as $ 7278. Life time of the modules has been taken as 25 years. 6.9 kW PV modules, Sunmodule SW 230 POLY V2.0 PALLET, are considered.PV modules output is DC and is connected to DC bus. The derating factor of the PV modules is 80% and no tracking system is kept with the PV modules.

2.2.4 Diesel Generator

Diesel generators operate in parallel with the wind turbine and solar enrgy system to increase the maintenance flexibility, efficiency and distribute the electric load more optimally. Capital cost for per MW of diesel generator is considered $ 180000. Minimum 10% of the load will be supplied by this generator.

2.2.5 Battery

Surrette 6CS25P battery is used for design of the hybrid system. This battery has energy storage capacity of 6.94 kWhr. The cost of a battery is considered to be $ 1000.

2.2.6 Converter

A converter can convert from AC to DC and DC to AC. Converter capital cost is considered $ 95 per kW. Inverter efficiency is taken 90% and rectifier efficiency is considered 85%.

2.2.7 Ecomomics and Constraints

The energy system that is desgined in this work has assumed to have 25 years. Annal interest rate is considered 10%. The constraint that is applied is 50% of the load should be from the renewable enrgy.

3. RESULTS AND ANALYSIS

Simulation software HOMER is used for optimal planning and simulation of the hybrid system. After optimal planning the design components size is measured. The system components and their size for optimal design are shown in table 3. Figure 6 shows contribution from different source in the power supply. Solar PV energy supplies 14% of load demand, wind energy contribute 55% of demand and rest demand is fulfilled from diesel generator.
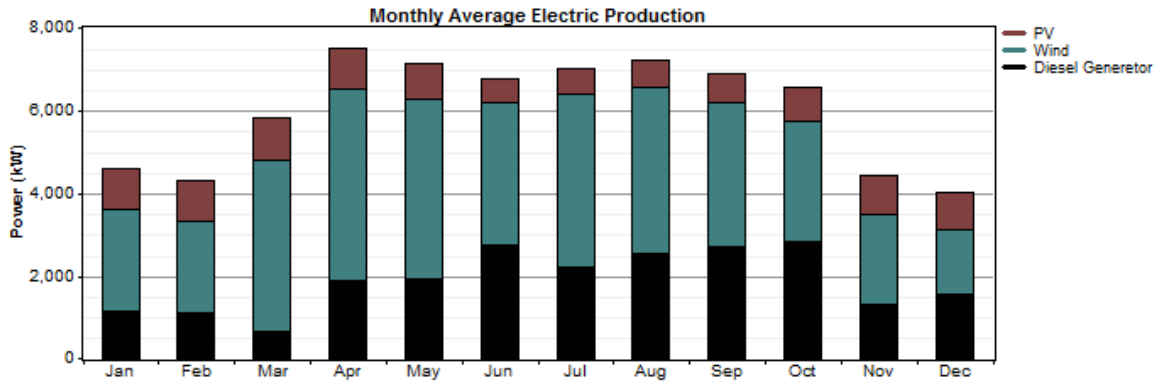

Figure 6. Monthly average electricity production

3.1 Economic Analysis

HOMER analyses the system according to the CoE (cost of electricity) of the system. Other factors which influence the analysis are capital cost, operating cost, renewable energy factor, total NPC (Net present cost) and diesel consumption rate. Table 4 shows the capital cost, replacement cost, operation amd maintanace cost and Fuel cost of different system components of the system. Figure 7 shows the cash flow summary of the optimized system.

Table 4. Net annualized cost of the Optimum Solar-Wind-Diesel Hybrid system

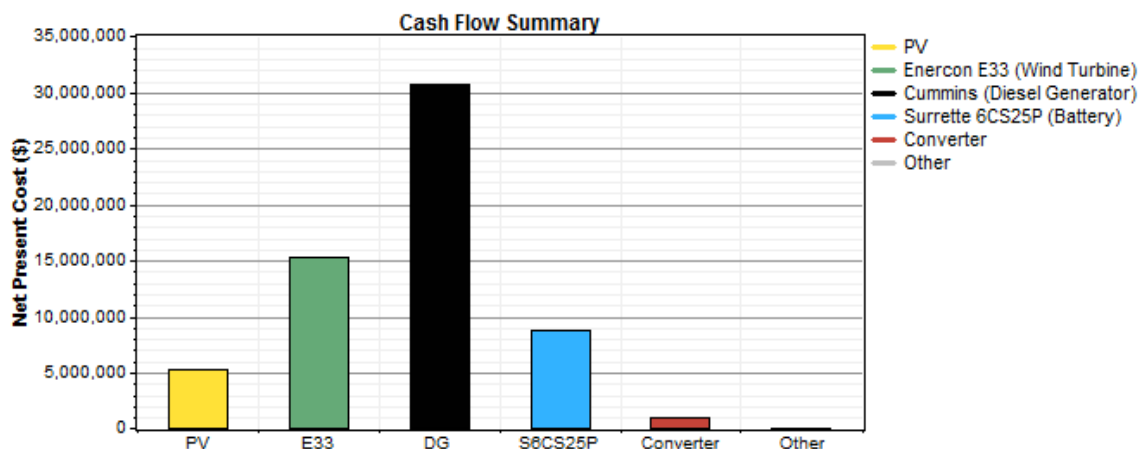| System Component	Capital cost ($)	Replacement Cost ($)	Operation & Maintanance Cost ($)	Fuel Cost ($)	Total Cost ($)
PV	5,273,913	0	6,578	0	5,280,492
Wind Turbine	15,000,000	0	272,311	0	15,272,310
Diesel Generetor	1,800,000	0	235,413	28,722,770	30,720,286
Battery	7,500,000	1,575,586	68,078	0	8,826,395
Converter	475,000	0	453,852	0	928,852
Others	8,000	0	4,539	0	12,539

Figure 7. Cash flow summary of the Hybrid system

The hybrid energy system has a net present cost of $ 61,040,872. The operating cost per year is $ 3,413,444. Cost of energy is found $ 0.156/kWhr. Total load that is supplied by the system is 43,087,888 kWhr per year.

3.2 Comparative Study

Table 5 shows a comparative study of proposed energy sytem with other energy system for Kuakata. The simulation results clearly reveal that solar-wind-diesel hybrid system is the most cost effective offgrid power system.

Table 5. Cost Comparision with other energy system

Energy System	Net Present Cost ($)	Fuel Cost ($)	Cost of Enrgy ($/kWhr)
Solar-Wind-Diesel	61,040,872	28,722,770	0.156
Solar-Diesel	79,820,360	56,301,400	0.202
Solar	107,487,700	0	1.07
Diesel	99,138,145	92,654,097	0.252

3.3 Environmental Effects

The proposed Solar-wind-diesel hybrid system reduces gas emission by a significant amount due to reduced fuel consumption. This reduction in gas emission is determined using HOMER software. In this system carbon dioxide emission rate is 12,254,013 kg/yr, carbon monoxide emission rate is 30,247 kg/yr and sulfer dioxide emission rate is 24,608 kg/yr. The emission for this system has been decresed by 69 percent from the diesel based energy sytem.

4. CONCLUSION

In the modern civilization electricity has become one of a basic need. Severe scarcity of power in Bangladesh has become a threat to the economical development. In the coastal areas where grid connection is not feasible or grid extension is not available, alternate electric sources like wind and solar PV can be the potential solutions. Though renewable energy system technologies already exist but only one renewable enegy based system can not supply entire load and also financially less viable. Stanaolne solar-wind-diesel hybrid energy system can be cost effective solution for the coastal regions of Bangladesh where renewable energy is abundant. It also will reduce pressure on grid. Moreover this hybrid system reduces the emission of gases and help to trim down the environmental pollution.

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BIOGRAPHIES OF AUTHORS

Ahmed Zubair was born in Dhaka, Bangladesh. He received the B.Sc. in Electrical and Electronic Engineering and M. Sc. in Electrical and Electronic Engineering degrees from Bangladesh University of Engineering and Technology (BUET) in 2009 and 2011, respectively. His research work is in the field of solid state devices, solar cells, organic solar cell and nanoparticle (such as fullerne (C_{60}), nanotube) based electronic devices. He is also involved in research of Renewable Energy System and Hybrid Energy System. He has three years of academic experience. He is currently working as a Lecturer in the department of Electrical and Electronic Engineering of Bangladesh University of Engineering and Technology.

Aman Abdulla Tanvir was born in Dhaka, Bangladesh on October 18, 1990. He received his B.Sc. in Electrical and Electronic Engineering Degree from International Islamic University Chittagong, Bangladesh on July 01, 2012. His research work in the field of Renewable Energy System. His area of interest is in field of solar thermal power system, wind energy and nuclear energy system.

Md. Mehedi Hasan was born in Jordia, Satkhira, Bangladesh on October 02, 1989. He received his B.Sc. in Electrical and Electronic Engineering Degree from International Islamic University Chittagong, Bangladesh on July 01, 2012. His research work in the field of Renewable Energy System. His area of interest is in field of hybrid renewable energy system, hydro energy system and power system protection.