International Journal of Scientific Engineering and Technology (ISSN : 2277-1581
Volume No.2, Issue No.12, pp : 1211-1215 1 Dec. 2013

Optimal Planning of Hybrid Energy System in Remote Area of Bangladesh

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Abstract—This paper proposed an optimal design and planning of hybrid renewable energy system consisting of wind turbines, photovoltaic modules and diesel units. The purpose of a hybrid power system is to produce energy at all times requested by consumers and reduce per unit cost of electricity. The study was performed for a remote area near Barisal, a coastal area located in Kuakata, Bangladesh. The main scenario of this paper is to investigate the entry of renewable energy technologies into remote areas electricity markets, with particular focus on a new technology. Finally, HOMER software is used to analysis the simulation result and compares the generation cost of proposed hybrid energy system with utility system.

Keywords— Distributed Energy Resources (DERs); Renewable energy; HOMER software; Energy policy; Hybrid system design.

I. Introduction

Bangladesh is a developing country with large population and most of the people are deprived from the supply of electricity due to the difficulties of grid extension in remote areas which are separated from the mainland and from each other by wide rivers, creeks and hills. To provide electricity for these Island and remote area renewable energy source is consider as an alternative energy source. The advantages of using renewable energy sources for generating power in remote areas are obvious such as the cost of transported, fuel are often prohibitive fossil fuel and that there is increasing concern on the issues of climate change and global warming. At present 68% of the nation's total energy comes from traditional fuel wood, crop, natural gas and animal biomass, while 32% is supplied by commercial energy (including hydro power). Currently renewable energy is considered as the primary fuel for electricity generation in different countries due to having some advantages and recent ongoing research on renewable energy sources shown excellent potential as form of contribution to conventional generation system. Bangladesh is situated between 20.30^o- 26.38^o north latitude and 88.04^o-92.44^o east longitude, with average solar radiation between 4 and 5 kWh/m^2-day, is in a very favourable position in respect of the availability of solar energy. As distributed generations Photovoltaic cell, wind energy, biomass, diesel engine are used and most important growing part of the energy concept in remote areas. Due to the special features of Distributed Energy Resources (DERs) and their weather dependent behaviour, small generation and power market challenges this group of energy sources are often used integrally [2,3,4]. A hybrid electric energy system is a platform where two or more different sources of electricity are connected to a common grid and operate hand in hand to supply the desired load [2]. Due to promising benefit at remote area near Esfarjan, a village located in Shahreza, Iran[3], it has to evaluate the effect of possible energy policy changes on multi-objective optimal design and planning of a hybrid energy system and to analysis of power supply using Solar and Wind hybrid energy in south-west of Rajasthan [8]. It has been solved the energy and water shortage in remote areas with standalone renewable power system utilizes a main energy source photovoltaic (PV) panel controlled by maximum power point tracking (MPPT) technique and energy storage devices to smooth the fluctuation of solar power to mitigate load transient and variations [5]. In [6], this paper has to elaborates on the analysis of small capacity hybrid power system for supplying electricity and clean water demand in rural and remote areas by using mini-grid hybrid power system consisting of renewable energy (Solar Photovoltaic cells & Windmill) and battery with a load. Moreover, another paper to analyses the costs of the solar-wind-diesel hybrid systems and the cost of electricity generated by such a hybrid system in remote place [10].

Hybrid Optimization Model for Electric Renewable or briefly known as "HOMER" developed by National Renewable Energy Laboratory (NREL), United States [9], is a computer based software that is utilized by designers to simulate and optimize stand-alone and grid-connected electric power system operation. HOMER can model any combination of wind turbines, solar PV panels, hydro, conventional generators, and

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battery storages [8]. Several papers have investigated the use of HOMER for optimal design, planning and analyses the costs of a hybrid energy system [3, 7]. In this paper, we have proposed a hybrid energy system by investigating HOMER software, utilizes main energy sources PV panel, Wind energy and Diesel engine, storage devices to mitigate load at lower generation cost in remote coastal area Kuakata, Bangladesh.

II. Research Methodology and Energy Sources

In this research work, an optimal design of a standalone hybrid power generation system is proposed for continuous power supply in coastal area Kuakata, Bangladesh. This hybrid system also can be applied to other coastal areas and remote areas of Bangladesh, where wind and solar power are available for electricity generation. At first, Energy resources are analyzed to find out the most suitable energy resources for planning a hybrid generation system to meet the daily demand of electricity consume in this remote place. Then check the per unit generation cost of electricity by HOMER(Hybrid Optimization Model for Electric Renewable) software providing sufficient information in different combination of energy sources such as Wind power-PV source, Wind power-Diesel engine , Diesel engine-PV source and combined all energy sources. For the optimal planning of sizing of different components of the hybrid system and cost analysis the simulation software is employed. The HOMER software performs the energy balance calculations for each combination and the system cost calculations are done studied on capital, replacement, operation and maintenance, fuel cost and interest. The economic analysis is carried for feasibility and practicability of the proposed hybrid power generation system.

Table-1 Monthly Average wind power and solar radiation

Month	Wind Energy		Solar Energy	
	Wind speed (m/s)	Average net power output	Barisal KWh/m^2-day	Kuakata KWh/m^2-day
January	5.08	45.7	4.12	4.17
February	5.29	46.2	4.75	4.81
March	5.12	41.2	5.20	5.30
April	7.19	106	5.82	5.94
May	6.98	102	5.65	5.85
June	7.24	109	4.33	4.39
July	7.79	125	4.15	4.20
August	7.55	121	4.35	4.42
September	6.08	73.8	4.41	4.48
October	4.22	29.6	4.61	4.71
November	4.28	26.2	4.29	4.35
December	4.96	40.2	3.90	3.95
Average	5.94	71.4	4.61	4.71

A. Wind Energy and Solar Energy

Kuakata is situated at coastal area along the Bay of Bengal and the wind speed in this area high enough to produce electricity in commercially. Data of wind speed (m/s), Average wind power output and solar radiation is given bellow for Kuakata.

According to the report of Bangladesh Centre for Advanced Studies (BCAS) wind speed [14] is high in Bangladesh during April to September (6 months). In the rest of the months wind speed remains calm or too low. The wind speed data and corresponding average net output power at Kuakata, Bangladesh is recorded at 50 m height. Solar energy can be converted to electric power through different process. Photovoltaic systems use solar cells or solar panels to convert solar energy directly to electricity. The monthly average incoming solar radiation from sun in Bangladesh is reasonable for generation of electricity (Shown in above Table-1), the average value of solar radiation at Kuakata is 4.71Kwh/m^2 per day.

B. Wind Power Equation

Wind energy is the kinetic energy of the moving air mass. The power, P in watts possessed by wind blowing with speed of V in m/s is directly proportional to the area swept by rotor and to the cube of wind speed-$P=½*\rho*A*V^3$ (1)

Where, swept Area: $A = \pi R^2$ and R is the radius of rotor, ρ is the density of air kg/m^3.

Total power in watts extracted from wind mill is-

$P=½*\rho*A*V^3*C_p$ (2)

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

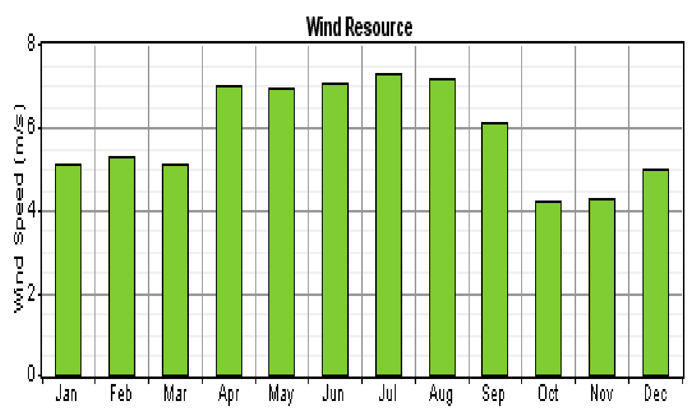

Fig.1 Monthly Average Wind Speed

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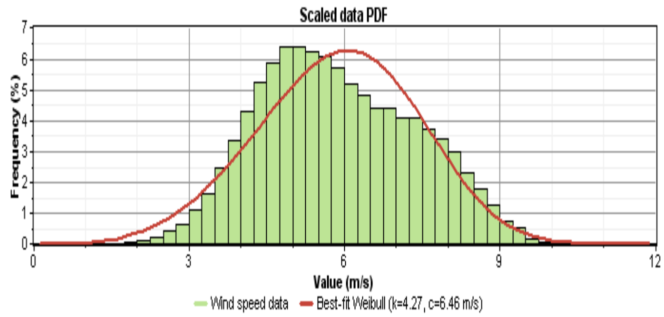

Fig.2 Probability Density Functions of Wind Power

Fig.1& and Fig.2 shows the monthly averaged values of wind speed and probability density function of wind.

C. Solar Power

Generally Photovoltaic (PV) and solar thermal plant technologies are use in solar power, is the conversation of sunlight into electricity. Solar energy is available only for a part of day, and cloudy and hazy atmospheric conditions cut the energy yield sharply. The upper atmospheric of the earth receives solar energy at a rate of 442.4 Btu per sq ft-hr ± 2%. The energy at the earth's surface is- $Q_a = S\eta_a$ where, Q_a= energy received at earth's surface, Btu per sq ft-hr, S = solar constant, 442.4 Btu per sq ft-hr, η_a= efficiency of transmission through atmospheric, fraction. Hourly solar radiation data for the year was collected from environment of Kuakata sea beach (Barisal). Scaling was done on these data to consider the long-term average annual resource. The average wind speed and solar radiation data for the latitude is shown in table [1]. According to solar radiation, Average daily radiation and clearness is available throughout the year is shown in fig.3 and in fig.4 represent the probability density function. In summer solar power is higher than winter season and in rainy season clearness index and solar power availability is lower than summer and winter season.

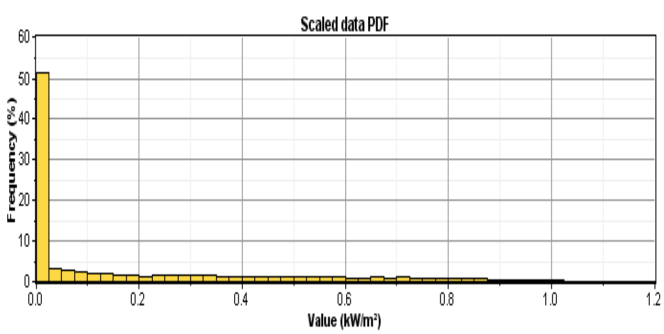

Fig.3 HOMER clearness index from the latitude information

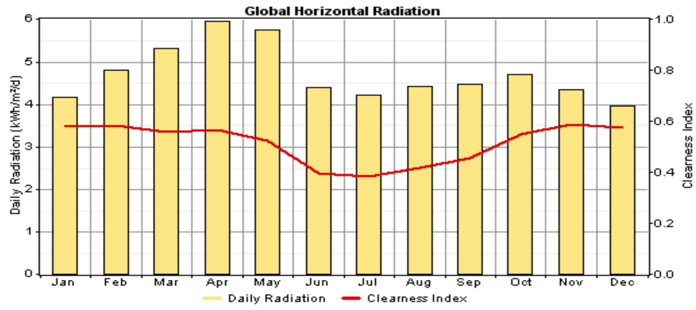

Fig.4 Probability density functions for solar radiation

III. Hybrid Energy System

In Bangladesh power crisis become a national problem, renewable energy source are consider and plays an important role to solve power crisis problem. Although the net present cost is high but the running and maintenance cost are low as compared to the grid power solution in remote costal area, Island and hilly place. Kuakata is a sea-beach and tourist sport in Bangladesh, but in this place grid supply is very limited comparatively the available of renewable resources. So, renewable power might be consider mitigating the demand and supplying electricity continuously in this place. The solar cell (PV) and wind power are not available at all time and have some limitation, it is not possible to supply electricity continuously, and at peak hour to mitigate consumer demand diesel generators are used for generation electricity. So, a hybrid power generation system might be considered mitigating the demand and continuously supplying electric power in remote costal area like Kuakata, Bangladesh. In this paper considering a hybrid system with PV, wind turbine, diesel generator, battery, converter and electrical load and simulate this system by HOMER software and investigate the generation cost of electricity. HOMER software can perform the energy balance calculation, determine whether a configuration is feasible to meet the electric demand and estimate the cost of generation.

A typical load system, (Table-2) for a single home in the remote areas has been considered for the analysis. Monthly average hourly load demand (Bangladesh perspective) has been given as an input of HOMER and then it generates daily and monthly load profile for a year. It has been found that for the system each home user consumes energy around 0.875KWh/day with a peak demand of nearly 63W and the peak demand of this proposed small hybrid energy system is 180 Kwh/day.

International Journal of Scientific Engineering and Technology (ISSN : 2277-1581
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Table-2 A typical load system

Appliance	Qua-ntity	Capa-city (W)	Maxi-mum use Hour/ day	Total capacity (Wh/day)	Capacity for a single home (KWh/day) Unit
Energy saving light	4	25	6	25*4*6 = 600	0.875
B/W TV	1	25	10	1*25*10= 250	
DVD player/ Radio	1	5	5	1*5*5 = 25	

To design a Wind-PV-Diesel hybrid energy system considering this typical load system (each home) to mitigate around 200 home consumer daily demands. The single line or simulation diagram of such a hybrid energy system is shown in fig.5.

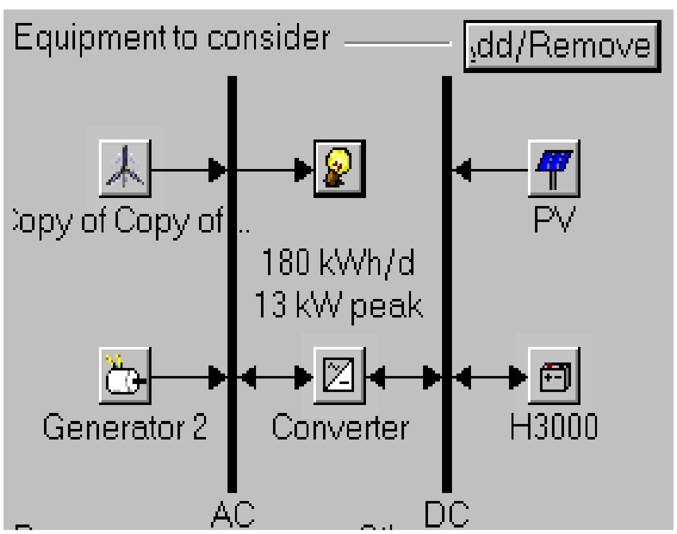

Fig. 5 Single line diagram of hybrid energy system

IV. Simulation Result and Discussion

The proposed wind solar hybrid system simulated by HOMER software and analyses the system according to the COE (cost of electricity) of the system. Other factors which influence the analysis are capital cost, renewable energy factor, total NPC (net present cost), replacement cost, Operation and maintenance cost and diesel consumption rate. Solar and wind system are most suitable for electrification of isolated remote areas in developing countries like Bangladesh. For this area we have designed separately solar, wind & diesel, combined system and hybrid system. It could be summarized from the cost analysis (shown in Table-3) we can see that, the generation cost of electricity from renewable energy source is comparatively lowest than diesel generator. The cost analysis of electricity generation represent that, the hybrid (Wind, PV and Diesel) combined system is more economical than other system.

Table-3 Cost comparison with other energy system

System Design	Cost of electricity ($/KWh)	Cost of electricity (BDT/KWh) [1$= 70 Taka (BDT)]
PV system	0.037	2.59
Wind system	0.035	2.45
Diesel generator	0.556	38.92
PV & wind system	0.030	2.1
Diesel generator & PV	0.053	3.71
Wind & diesel generator	0.037	2.59
Hybrid system	0.022	1.54

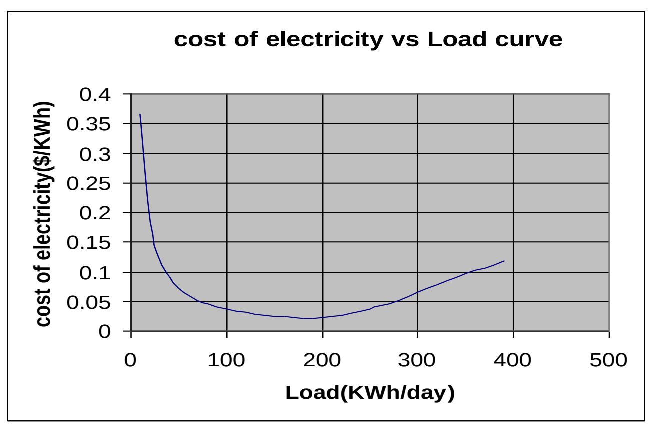

Fig. 6 Generation Cost of electricity Vs load curve

Table-4 Relation between generation cost with load

Load KWh/day	Cost of Electricity $/KWh	Load KWh/day	Cost of Electricity $/KWh
10	0.367	210	0.024
20	0.184	220	0.027
30	0.122	230	0.030
40	0.092	240	0.033
50	0.073	250	0.038
60	0.061	260	0.042
70	0.052	270	0.046
80	0.046	280	0.052
90	0.041	290	0.059
100	0.037	300	0.065
110	0.033	310	0.072
120	0.031	320	0.078
130	0.028	330	0.085
140	0.027	340	0.091
150	0.025	350	0.097
160	0.024	360	0.102
170	0.023	370	0.107
180	0.022	380	0.112
190	0.022	390	0.118
200	0.023		

In the proposed combined hybrid system also investigate that with increasing load the generation cost of electricity gradually decreased up to a certain load and above it start to increase (shown in Table-4). The simulation results (Fig. 6) clearly reveal that this combined hybrid energy generation system is the most cost effective off-grid power system and at the peak demand the electricity generation cost is lowest. This type of hybrid energy system is suitable for a small remote place like Kuakata and others coastal area where conventional power grid extension is difficult to continuous power supply at lowest generation cost.

V. Conclusion

Energy is the backbone and key instrument for development but, severe scarcity of power in Bangladesh has become a threat to the economical development. In this paper we have analyzed the off grid electrification through a hybrid power, because in this remote or isolated areas the national grid extension is not feasible and available. Alternative electric source like solar PV and wind system are most suitable and potential solution for electrification of isolated remote areas, Island and hilly place. These solutions of power supply to the households are cost effective and available throughout the year. The circumstance of each sites are studied in order to decide the feasible combination of alternative energy resources. In this paper studied the generation cost and feasibility analysis of different combinations like PV-wind power, Wind power-diesel generator, PV- diesel generator and combination of PV-Wind power and diesel generator system. With the help of above pre-feasibility study the solar (PV) –wind power and diesel generator based hybrid energy system are most viable power solution for coastal area (Kuakata) in Bangladesh sites over conventional grid supply system. Moreover this hybrid system also reduces the pressure on grid, the emission of gases and help to trim down the environmental pollution.

Acknowledgement

The authors would like to express special thanks to BCAS (Bangladesh Center for Advanced Studies) for the documentary support in part to accomplish this paper.

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