Feasibility Analysis of Standalone PV/Wind/Battery Hybrid Energy System for Rural Bangladesh

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Abstract- Bangladesh is one of the largest populated countries of the world, where more than one third of the population is living without electricity. Being a developing country, the demand of electricity is increasing tremendously. Meanwhile, fossil fuel based electricity generation plants are lagging behind to supply the rising demand and the fossil fuel sources are very limited. As an alternative, renewable energy based systems are becoming popular in Bangladesh, particularly solar, wind and hydro based systems, which are being set up in different sizes and configurations. This paper presents feasibility analysis of renewable energy based hybrid system for the village of Kuakata, in the southern area of Bangladesh. The system is designed based on the resources available at the location. The sources considered in the analysis are solar PV, wind, diesel generator and battery backup system. HOMER simulation model has been developed for simulating the system with real weather data and nominal load profile. The cost of the system is determined based on the real market price of the components. Sensitivity analysis has also been carried out on the best suitable system to prove the system sustainability in the future. For sensitivity analysis, the change in load and change in rate of interest has been considered. Based on the factors such as initial cost, replacement cost, operating cost, total net present cost (TNPC), cost of energy (COE) and exhaust gas emission, the results show that PV-Wind-Battery based system is a feasible solution for the situation. The optimum system has the initial cost of 126,586 $, replacement cost of $ 125,280, operating cost of 5007 $/year, TNPC of 224,345 $ and COE of 0.161 $/kWh with no exhaust gas emission. Foremost, the emission is zero, which means it is green energy system.

Keywords Hybrid power system, renewable energy, photovoltaic, wind, HOMER, Optimization, sensitivity analysis.

1. Introduction

Availability of electricity is a key point of socio-economic development of a country. Being a developing country, the government of Bangladesh is focusing on improving the living standard of the people. Bangladesh has a vast population, and the booming industrial and commercial sectors require enormous amount of electricity supply. Thus, developing the electricity sector has been the main focus of Bangladesh in recent years. Until now, 68% of the total population has been allocated under electrification scheme [1]. However, these people face severe electricity interruptions, and majority is still out of electricity. The rural electrification sector has made a very little progress compared to urban areas. Among the total population having electricity, 80.4% are from urban areas and 18.7% are from rural areas [2]. To avail electricity in rural areas via electricity grid is a matter of huge investment, as well as infrastructure limitation. So far, the main source of electricity in Bangladesh is power plants based on crude oil, coal, natural gas and hydro-electricity. Except hydroelectricity, other sources depend on fossil fuel, which is limited in amount. Moreover, burning of fossil fuel produces greenhouse gases (GHGs) that are responsible for global warming. An easy solution is by introducing distributed generation schemes based on renewable energy resources such as photovoltaic, wind, biomass and hydro [3]. Due to the geographical position, Bangladesh possesses abundant solar energy as well as wind speed. The solar irradiation of the country is 4.67 kWh/m2 and the average wind speed at southern part is above 5 m/s [4, 5]. Thus, distributed generation systems are ideal for Bangladesh. System hybridization with multiple renewable energy sources is efficient and cost effective and can cover larger area. To maximize efficiency, renewable energy sources are combined with conventional diesel generators. Researchers have proposed various configuration of hybrid systems based on renewable energy resources of the concerned locations. The popular configurations are PV/Diesel/Battery [6-8], PV/Wind/Diesel/Battery [9-11], PV/Wind/Diesel [12], PV/Wind/Battery [2, 13] and so on. Different government and non-government organizations are working on renewable energy based systems to make them popular in Bangladesh [14, 15]. Among various configurations, PV/Wind/Diesel generator system is quite common to the researchers. Zuabir et al. proposed such system capable of producing 19.4MW for coastal areas of Bangladesh [16]. Similar configuration has been proposed by Islam et al. for Saint Martin Island [17]. A PV/Diesel/Battey system has been proposed by Salehin et al. for the norther part of Bangladesh in [18]. Grid connected PV system viability has been analyzed by Mondal and Islam in reference [19, 20]. Nandi et al. proposed a PV/Wind/Battery system for hilly area of Bangladesh [21].

Renewable energy based system viability is limited to the resources available at certain location such as solar irradiation, wind speed, diesel price etc. Besides, feasibility study performed on Bangladesh is limited. Although some locations of southern part of Bangladesh are covered in the previous studies, this cannot be generalized to the whole of Bangladesh as there are places with different situation. These locations may be potential to set up Renewable Energy based system, as they may have usable renewable energy resources. In this study, a rural location called Baultali Muslim Para in southern part of Bangladesh has been chosen, where sufficient renewable energy resources are available to set up a hybrid system. The solar data and wind speed data are taken from the NASA website and surveys done by other researchers [5, 22]. The optimum system configuration is defined by economic feasibility analysis done by using HOMER software, and finally the different aspect of the system is discussed. The main focus of this study is to come up with a feasible configuration based on renewable energy, which can serve the purpose for long time. For this purpose, sensitivity analyses of concerned factors have been done.

2. Methodology

The objective of this study is to investigate the feasibility of renewable energy based system for rural area of southern Bangladesh. The distributed generation system is connected to the load in a micro grid structure and all loads are considered as AC load, thus, no high voltage conversion is required. To achieve the goal, the following procedures are required: choosing a suitable location, exploring the availability of resources at that location, modeling the hybrid system based on the resources and optimization.

2.1. Location and Background Information

The selected location for this study was Baultali Muslim Para under Kalapara sub-district of Pathuakhali district. The location was selected based on renewable energy availability and strategic importance of the location. The place is near the famous sea beach of Kuakata. The coordinates are 21˚58 north and 90˚14 east. The number of households in the village is 51, and the population is only 220, consisting of 97 males and 123 females. Majority of the tenants live on farming and fishing. Electricity supply is available in the main Kalapara sub-district, but yet to cover this selected area. Because of no electricity, the village people depend on kerosene and candles for lighting and there is no way to use fans, television or refrigerators. To facilitate electricity for these fifty households, a renewable energy based system is proposed.

2.2. Solar energy Potential of the Location

According to Bangladesh Metrological Department and NASA website, the solar radiation range is 4 kW/m2/d to 5.9 kW/m2/d at the selected place [5, 23]. From Figure 1, the maximum value of radiation is achieved in March, April and May and the minimum value is in July, August and September. The clearness index can be achieved from solar radiation data by considering it in HOMER software. According to the data, the clearness index is highest in winter season, and lowest during rainy season. The value ranges from 0.4 to 0.65.

2.3. Wind Energy Potential of the Location

As a coastal area, the location experiences high wind speed. The wind speed during the monsoon is highest and lowest in winter. According to the survey done by A.A. Bhuiyan et al., the wind speed varies from 2.8m/s to 5.9 m/s. The average wind speed is 4.18 m/s at the height of 30m. A 1kW wind turbine can produce 3170kWh energy every year from this wind potential [22]. Thus by deploying higher number of turbines or by selecting higher capacity of turbines more power can be produced. Figure 2 shows the variation of wind speed throughout whole year, where the tower height is considered as 30m. The wind speed is ideal for implementing wind turbine for power generation.

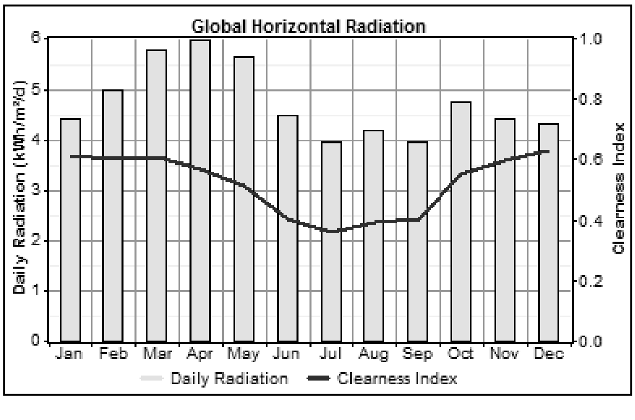


Fig 1. Solar radiation and clearness index data [4].

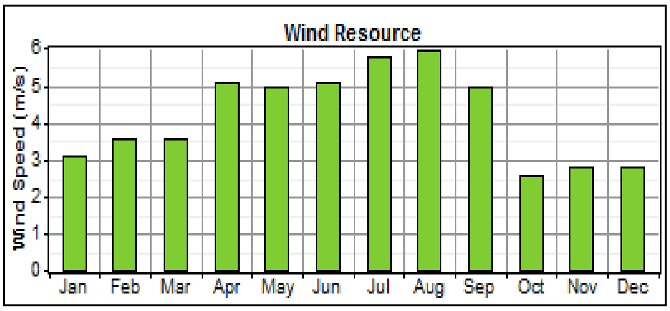


Fig 2. Wind speed variation throughout the year [21].

2.4. *Diesel Price in Bangladesh*

The average diesel price in Bangladesh is 68.00 BDT, equivalent to $ 0.88 (1 USD= 78 BDT). The price of diesel may increase if transportation cost is included. As the location is a rural area and the transportation facility is not sufficient, the price may rise up to $ 1.5 to $ 2.00. Government does not provide any subsidy on diesel price, thus the price increases throughout the country while it increases in the international market.

2.5. *Simulation Software*

There are several software available to analyze the feasibility of power generation systems, such as RETScreen, HOMER, iHOGA and Hybrid2 [24]. All of them have different features like application area, power range of application or analysis method. HOMER software has been selected for this analysis, because this tool is widely used, easy to model a microgrid and the legacy version is free. Moreover, it can estimate the size based on technical compatibility as well economic feasibility. The operating strategies can be defined as input, based on which the tool performs its analysis [11, 12, 25-28]. National Renewable Energy Research Laboratory (NERL), USA has developed HOMER tool for renewable system analysis. This software not only defines the components specifications, but also estimates different types of costs including the life cycle costs, operation and maintenance (O&M) cost, per year operating cost, total net present cost (TNPC), as well as cost of energy (COE). Besides, the models can be compared with other systems based on technical and economic aspects. In this study, where the system consists of PV, battery, wind turbine, diesel engine and converter of various sizes, HOMER has been used to determine the best feasible system which can meet the load in the most economical way. The main focus of this study is determining the initial cost, replacement cost, operating cost, TNPC, COE and the pollutant gas emission of the system.

3. System Description

3.1. *Electrical Load Profile*

The load profile is based on a rural area with 50 families. The description of the village in the previous section clarifies that the place is a tourist attraction and quite busy area; however, there is no electricity there. To create the load profile, the loads considered for each family are 5 fluorescent bulbs, 2 fans, 1 refrigerator, 1 television and one CD/DVD set. The load calculation is shown in Table 1, where the maximum power consumption as well as the average power consumption throughout the year is shown. To generate realistic load profile probabilistic method is used [29]. Moreover, seasonal impact on the load profile is also considered. Figure 3 shows the different load conditions in six different seasons. Figure 4 shows the complete load profile generated by HOMER. The load characteristics show that, there is a base load throughout the day, and the peak load is at noon and mainly in the evening. The peak load is 30kW, recorded during summer season. The scaled annual average load is 213 kWh/day.

3.2. *PV generator Data*

The PV panels considered in this study is Astronergy 255 Silver Poly CHSM 6610P [30]. The technical parameters are shown in the Table 2. The cost parameters from the manufacturer is shown in Table 4.The lifetime of the PV panels are defined as 15 years and the de-rating factor is 90% of the electricity produced from each panel. Horizontal axis tracking system has been considered for the MPPT system.

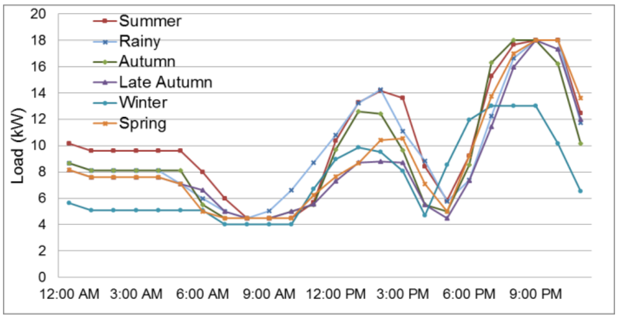


Fig 3. Hourly average load variation in different seasons.

Table 1. Considered load calculation to prepare the load profile

Appliance	no of units	power consumption of each unit (W)	power (Wh)	Maximum Power consumption (kWh/day)	Average power consumption (kWh/day)
Refrigerator	50	80	4000	96	96
TV	50	70	3500	84	18.55
Fluorescent light bulb	250	22	5500	132	40.7
Fan	100	50	5000	120	54.166
CD/DVD player	50	50	2500	60	4.34

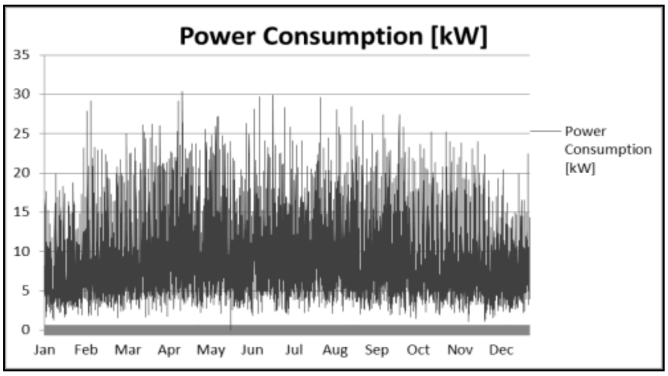


Fig 4. Daily average load for a complete year.

Table 2: Technical Specification of single PV panel

Specification	Value
Model	Astronergy 255 Silver Poly CHSM 6610P
Material	60 cell Polycrystalline
Maximum Power	255W
Voltage at maximum power point	30.68V
Open Circuit Voltage	38.40V
Short Circuit Curremt	8.69A
Current at maximum power point	8.33A

Ground reflectance is considered at 20%, and the temperature effect is also considered, where, the nominal operating temperature is 35°C and temperature coefficient is -0.5%/°C. The sizes considered for the optimization is from 0kW to 200 kW.

3.3. Battery

Surrette 6CS25P batteries have been used for making the battery bank. The capacity of this battery is 6V and 1156Ah. 8 batteries per string have been considered to develop a 48V bus. The lifetime is considered as 5 years for each battery, but may vary based on the number of charging cycles. The lifetime throughput of every battery is taken as 9645KWh. Initial cost and replacement cost are similar for a single battery, which is assumed as $1170 and no O&M cost is considered [31]. The roundtrip efficiency is 80% and the state of charge (SOC) is defined as 40% to 100% in the simulation [11]. The number of batteries is considered from 0 to 160.

3.4. Diesel Generator Data

Diesel generator is used in the study as base load server. In this work, diesel generator HDPK-10-1ph is considered [32]. The initial capital, replacement cost and O&M cost is given in the Table 4. The generator operating lifetime is defined around 15000 hours and the minimum load ratio is 10%. To consider the fuel efficiency, HOMER fuel curve parameters are used. The data is extracted from the manufacturer datasheets. The fuel efficiency Diesel generator is used in the study as base load server. In this work, diesel generator HDPK-10-1ph is considered curve is shown in Figure 5. The diesel generator size is considered from 0 kW to 50 kW on 10 kW intervals.

3.5. Wind Turbine Data

The wind turbine used in this analysis is the H8.0-10KW AC wind turbine by Anhui Hummer Dynamo Co. Ltd. [33]. Table 4 shows the cost data and Table 3 shows the technical specification of the selected wind turbine. The wind speed versus power characteristics curve taken from the datasheet is incorporated in the HOMER simulator. The turbine hub height is considered as 30m. For simulation, 12 wind turbines are considered for each of 10 kW maximum capacities. The speed vs power curve for the selected turbine is given in Figure 6.The lifetime of each turbine is considered 15 years.

Table 3. Technical Specification of single Wind Turbine

Specification	Value
Model	H8.0-10KW
Rotor blade diameter	8.0m
Number of blades	3blades/ horizontal axis
Cut in/ cut off wind speed	3/25 m/s
Rated power	10kW
Rated Voltage	220V AC

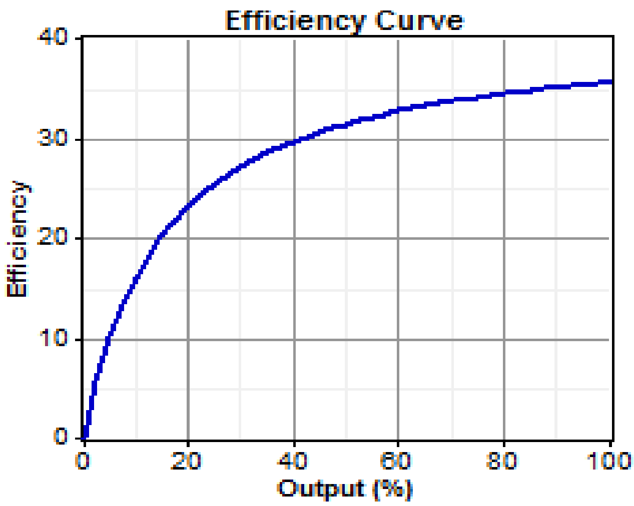


Fig 5. Fuel efficiency curve of diesel generator.

Table 4. Input Data on Component Cost

Components	Capital Cost	Replacement Cost	O&M Cost
PV [29]	890 $/1kW	890 $/1kW	10 $/yr
Battery [30]	1170 $/pc	1170 $/pc	0
Diesel Generator [31]	6782 $/10kW	6782 $/10kW	0.05 $/hr
Wind Turbine [32]	9050 $/10kW	9050 $/10kW	100 $/yr
Converter [33]	518 $/kW	518 $/kW	0

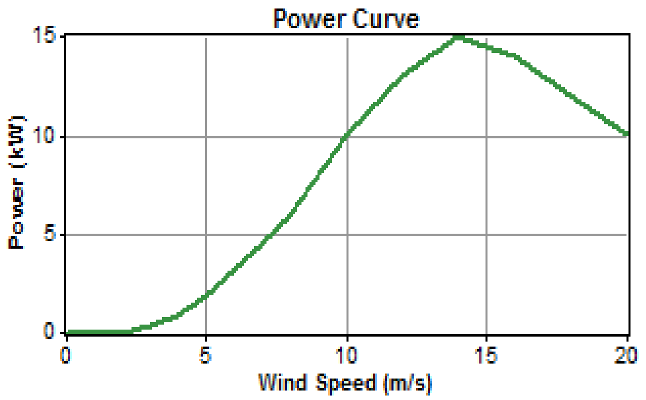


Fig 6. Wind speed vs power curve of wind turbine.

3.6. Converter

For generating sufficient power, conversion converters are necessary. Solectria PVI-10kW converter is used for pricing in the HOMER software [34]. The conversion efficiency of both inverter and rectifier are considered as 90% and the lifetime of converter is 15 years. The sizing of converter is considered from 0 kW to 30 kW at 4kW interval, while the relative conversion ratio of AC and DC is considered 100%. The HOMER input data for the system component is given by Table 4.

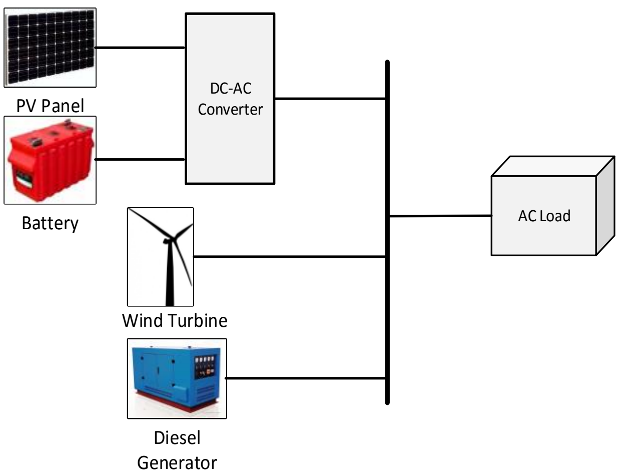


Fig 7. Hybrid system model based on input sources.

4. Hybrid System Modelling and Strategy of Operation

Based on the input data, HOMER provides the hybrid system, as shown in Figure 7. To get the optimum system the economic inputs, constraints and the control strategy need to be defined [35]. These are necessary to get realistic results which will be helpful for practical implementation.

4.1. Hybrid System Modelling

The system modelling includes defining the decision variables and size range of the components. The pricing and manufacturer of each component is described earlier. Now, to obtain optimum system, the following parameters need to be defined:

- Size range of PV, battery, converter and diesel generator
- Number of wind turbine
- Electricity shortage is considered 10% maximum. And operating reserve is 10% of hourly load.
- Annual real interest rate is considered 2%. It is calculated from nominal interest rate and inflation rate.
- Project lifetime is 25 years due to maximum component expires within that time.

4.2. Strategy of Operation

The strategy of operation can be summarized by following steps:

- At normal operation the renewable energy sources like PV, wind and battery will serve the load. When the generation by PV and wind exceeds the load demand, the battery gets charged. If the battery is fully charged, the excess power will be diverted to dump load.
- At the peak load duration, if the renewable subsystem cannot meet the load demand, the generator starts and supplies the necessary power. During the generator operation the battery is not charged by the power of generator. The generator power is solely for load supply. This strategy is called load following.

- In case of no solar radiation or no wind speed the generator supplies the full load.

5. Optimization Results

The input data of each component and variables defined for controlling and optimizing the system enable HOMER to come up with the most economical and efficient system. The optimization is performed considering flexibility in source selection. The optimal configurations are found after performing several simulations considering 4.7293 kWh/m2/day of solar radiation with 0.508 of clearness index, 4.18 m/s of annual scaled average wind speed and 0.88 $/L of diesel price. HOMER suggested four systems with different configuration, from which PV/Wind/Battery system is the most efficient system considering initial capital, operating cost, TNPC and COE. The next economic system is the PV/Wind/Diesel/Battery system which has the lowest capacity shortage, although the costs are higher than the previous system. The other two suggested system (wind/diesel and wind/battery/diesel) avoid PV system and the cost parameters are higher, thus they are omitted from discussion. The two most feasible configurations are shown in Table 5.

5.1. PV/Wind/Battery System

The configuration is shown in Figure 8, where the sources are PV, wind and battery system. This system does not have any diesel generator, thus there is no fuel cost, fuel transportation problem and exhaust gas emission. The optimization result as shown in Table 5, shows that the component sizing of the system is larger than the PV/Wind/Diesel/Battery system, thus the initial capital is higher than the diesel based hybrid system. The initial capital, operating cost and TNPC of the system are $ 126,586, 5007 $/year and $ 224,344 respectively.

Table 5. Optimization Results of the Hybrid Model

Component	PV/Wind/Battery System	PV/Wind/Diesel/ Battery System
PV (kW)	26	18
Battery (pc)	40	24
Converter (kW)	22	14
Wind Turbine (kW)	50	40
Diesel Generator (kW)	-	10
Initial Capital ($)	126,586	94,334
Operating Cost ($/yr)	5007	8,417
Fuel Cost ($/yr)	-	3,894
TNPC ($)	224,344	258,670
COE ($/kWh)	0.161	0.174
Capacity Shortage	10%	3%

As the PV/Wind/Battery system does not require any fuel, the COE is lower than the diesel based hybrid system, which is 0.161 $/kWh. The capacity shortage of the system is 7,846 kWh/year, which is around 10% of the total production. Table 6 summarizes the different costs of the proposed power system. It can be seen that the battery bank has the highest initial capital cost and replacement cost, followed by wind turbine and PV generator system. The battery bank does not have any O&M cost, compared to PV and wind systems, requiring costs of 260 $/yr and 500 $/yr, respectively. The lifetime of the system is estimated 25 years.

The electricity production and consumption information are given in Table 7. It shows that, the production capacity of Wind turbine is around 72% of the total generation. This power is used to satisfy the load, and excess energy is used to charge the battery. The location of the system is costal area and has enough wind speed, thus larger wind turbine size is selected, resulting in higher power generation.

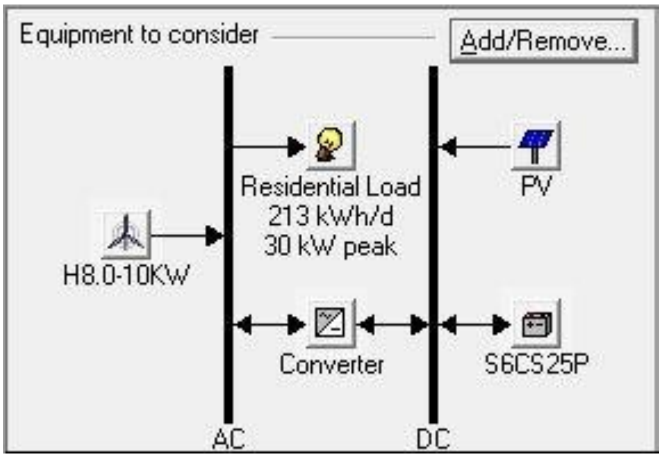


Fig 8. Schematic diagram of PV/Wind/Battery system.

The PV generator produces only 28% of the total electricity generation. The amount is comparatively low, because PV operates during day time only. The cost of PV panels is high, thus to optimize the system, a smaller size of PV panel is chosen. Thus, the generation capacity of PV is low. The battery system is kept as backup source which supports the load, while PV and wind system prove inadequate to meet the load demand. To provide an idea of production and consumption a scenario is shown in Figure 9. The figure shows the primary load graph, PV power supply, Wind turbine supply, battery state of charge (SOC) and the primary load served graph of 14th April, one of the highest load consumption day of a year. The monthly average electricity production by each energy source is shown in Figure 10. It is clear that throughout the year, wind turbine generates a major portion of electricity.

5.2. PV/Wind/Diesel/Battery System

The configuration is shown in the Figure 11, where the system contains PV, wind, battery and a diesel generator.

Table 6. Net Present Costs of the Hybrid System for its lifetime.

Component	Capital ($)	Replace - ment ($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	23,140	17,193	5,076	0	-4,702	40,708
Wind	45,250	33,621	9,762	0	-9,194	79,439
Battery	46,800	65,998	0	0	-26,149	86,649
Converter	11,396	8,467	0	0	-2,315	17,548
System	126,586	125,280	14,838	0	-42,360	224,345

Table 7. Annual Electric Energy Production and Consumption of the Hybrid System

Production (kWh/yr)			Consumption (kWh/yr)		
PV array	42,309	28%	AC primary load	71,260	100%
Wind turbines	109,726	72%			
Total	152,035	100%			

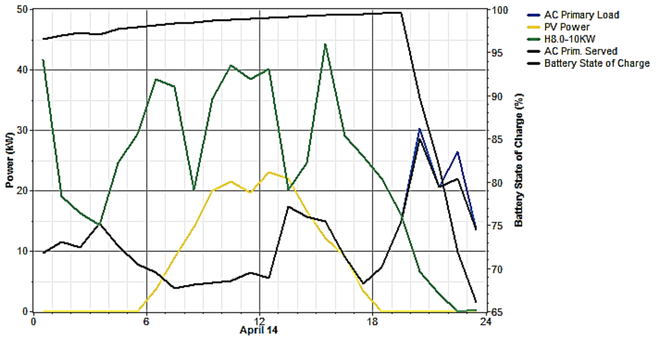


Fig 9. Daily load characteristics curve with sources

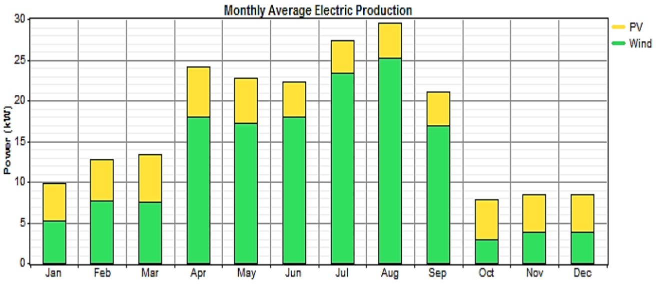


Fig 10. Monthly average electricity production.

The optimization results shown in Table 5 depict that, the diesel based hybrid system has an initial capital of $ 94,334, operating cost of 8417 $/year, TNPC of $ 258,670 and per year fuel cost $ 3,894. The operating cost of the system is high because of the high maintenance cost of diesel generator. This fact also increases the net present cost of the system.

The COE of this hybrid system is 0.174 $/kWh, which is high due to the fuel cost of the diesel generator. The O&M cost of PV, Wind and diesel generator are 180 $/yr, 400 $/yr and 133 $/yr respectively. The shortage of electricity is as low as 2,542 kWh/year (3%) of the total electricity generation. The reason is, the diesel generator meets the extra load while other sources cannot satisfy it. The major requirement of the system is continuous fuel supply to ensure maximum uptime. As the location is a rural area, fuel transportation can be a constraint. Moreover, the exhaust gas emission of system is a big threat to environment. Table 8 shows component wise net present cost distribution of the diesel based hybrid system. The diesel generator has the highest total net present cost which is $ 103,779, followed by Wind ($ 63,552) and battery system ($ 51,990). The major cost of this system is the fuel cost of diesel generator. It occupies almost 30% of the total cost of the system.

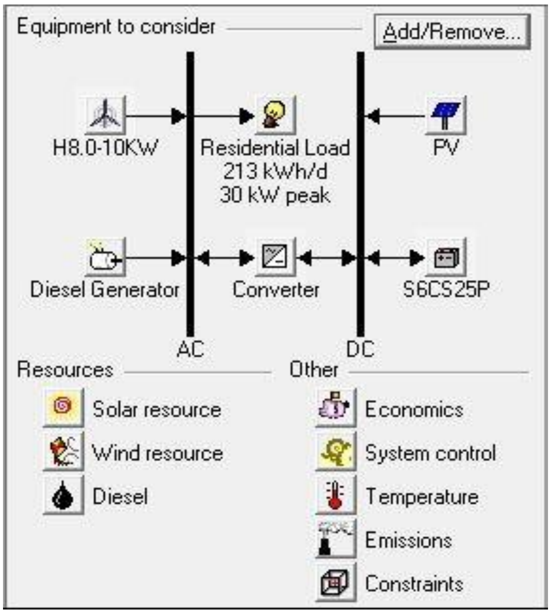


Fig 11. Schematic diagram of PV/Wind/Diesel/Battery system.

Table 8. Net Present Costs of PV/Wind/Diesel/Battery Hybrid System

Component	Capital ($)	Replace -ment ($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	16,020	11,903	3,514	0	-3,255	28,182
Wind	36,200	26,897	7,809	0	-7,355	63,552
Diesel Generator	6,782	20,688	2,601	76,023	-2,315	103,779
Battery	28,080	39,599	0	0	-15,689	51,990
Converter	7,252	5,388	0	0	-1,473	11,167
System	94,334	104,476	13,924	76,023	-30,088	258,670

Table 9. Annual Electric Energy Production and Consumption of the Hybrid System

Production (kWh/yr)			Consumption (kWh/yr)		
PV array	29,291	22%	AC primary load	76,069	100%
Wind turbines	87,781	67%			
Diesel Generator	13,798	11%			
Total	152,035	100%			

The yearly electricity production and consumption information can be observed in Table 9. It shows that Wind turbine generates the major portion of the total electricity, followed by PV system and diesel generator. The purpose of diesel generator and battery system is to support the excess load. Thus the production of diesel generator is low. From the table, it is clear that there is excess electricity production of 48,639 kWh/year. Most of this amount is generated by PV or Wind due to their environment dependence, which can be reduced by load shifting. As this hybrid system has diesel generator, it will certainly emit exhaust gas. HOMER estimated the possible emission amount at the provided operation strategy. The pollutant gas emission information is shown in Table 10, where the total emission is 11,967 kg/year.

6. Sensitivity Analysis

The sensitivity analysis is mainly performed to view the effect of certain factors on the system such as change of solar radiation, wind speed, fuel price, load demand, and annual rate of interest. In this study, the average global solar radiation and wind speed for the location have been considered. Thus there is no need to perform this analysis for solar radiation and wind speed. The optimization results show that the PV/Wind/Battery system is the optimum one, so fuel price sensitivity is also not performed. Only the effect of load change and change of annual interest rate on the hybrid system is observed in this study.

6.1. Effect of Load Increase on PV/Wind/Battery System

Sensitivity analysis has been performed to demonstrate the effect of load change on the system [4]. The annual average load has been increased by 30% and with the two annual average load values, simulation has been carried out. With the increase of load, the TNPC has been increased by 29.57% and COE has been decreased by only 0.62%. The TNPC increased proportionately due to the size increase of sources. The COE is not reduced much because the excess electricity quantity is as high as the previous load. Moreover, the price versus component size relationship is linear. Figure 12 shows the relation of TNPC and COE with load.

6.2. Effect of Change in Annual Real Interest Rate

The annual real interest rate may vary based on the economy of a country. Since the lifetime of the hybrid system is estimated to be 25 years, and the annual interest rate can vary time to time within that range, it would be sensible to observe the effect of change in real interest rate. HOMER calculates the annual real interest rate from the equation [25]:

$$Annual\ real\ interest\ rate, i = \frac{i'-f}{1+f}$$

Here, i' is the nominal interest rate and f is the annual inflation rate.

The effect of change in real interest rate is observed under the load condition of 213 kWh/day. The annual real interest rate was set at 2%, 4% and 6%. The result shows that, for the all interest rates PV/Wind/Battery system is the optimum one.

Table 10. Pollutant Gas Emission of PV/Wind/ Diesel/ Battery System

Pollutant	Emission (kg/yr)
Carbon dioxide	11,652
Carbon monoxide	28.8
Unburned hydrocarbons	3.19
Particulate matter	2.17
Sulfur dioxide	23.4
Nitrogen oxides	257
Total	11,967

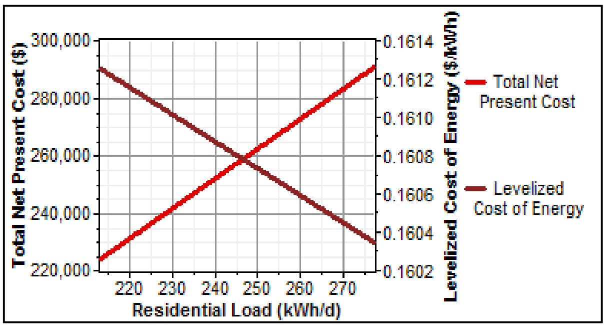


Fig 12. Sensitivity analysis for increase in load demand.

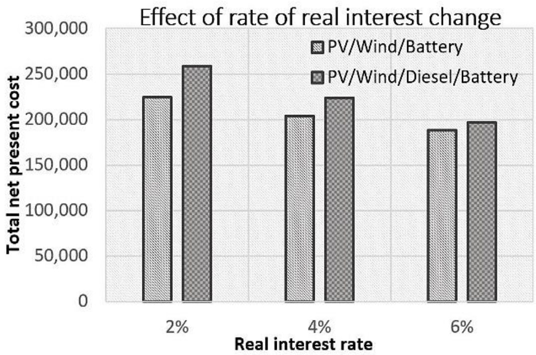
The effect of annual real interest rate on the total net present cost for the optimum system and its closest competitor is shown in Figure 13(a-b). It shows that with the increase of interest rate, the total net present cost gradually decreases. The cost of energy shows opposite result. For the optimum system, it increases from 0.161$/kWh to 0.207 $/kWh with the increase interest rate from 2% to 6%. For the same interest rate change, the COE of PV/Wind/Diesel/Battery system increases from 0.174 $/kWh to 0.204 $/kWh. It can be observed that, at 6% interest rate, the COE of the optimum system is higher than the nearest competitor. Although other costs are lower, it is determined as the optimum one.

The same variation of annual real interest is applied on the system with load condition of 277 kWh/day. The results show that, for 2% and 4% interest rate, the optimum system is the PV/Wind/Battery system. However, at 6% interest rate, the optimum system changes to PV/Wind/Diesel/Battery system. As seen in Figure 13(b), the total net present cost of PV/Wind/Diesel system decreases from $ 290,702 to $ 243,934, and the cost of energy increases from 0.160 $/kWh to 0.205 $/kWh.

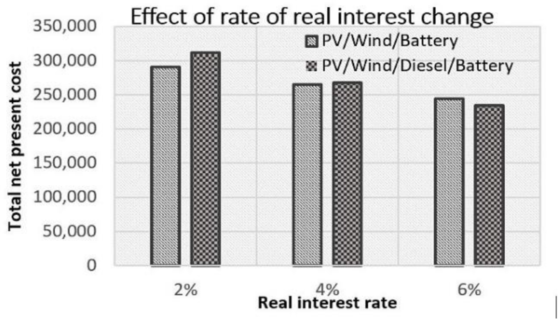
For PV/Wind/Diesel/Battery system, the total net present cost decreases from $ 311,490 to $ 234,311, and the cost of energy increases from 0.168 $/kWh to 0.194 $/kWh. It can be noticed that, at 6% interest rate, both the TNPC and COE for PV/Wind/Diesel/Battery system are lower than the PV/Wind/Battery system.

7. Discussion

The feasibility study of power generation system for the rural area of Bangladesh results in two most economic systems. The first one is a PV/Wind/Battery system and the other one is PV/Wind/Diesel system. Figure 14 shows the comparison of different types of cost of the two systems during 25 years of project lifetime. It is clear that, the initial capital and replacement cost of the PV/wind/Battery system are higher than the PV/Wind/Diesel/Battery system by 25% and 16%, respectively. The O&M cost is also slightly higher for the PV/Wind/Battery based system by 0.72%. However, this system does not have any fuel cost, whereas the PV/Wind/Diesel/Battery system has a fuel cost of $76,023, which also increases the TNPC by 13%. Moreover, the PV/Wind/Battery does not have any emission, whereas the diesel based system has significant emission which makes the system unsuitable from environmental perspective. As the system is considered for a rural area, where the environmental factor and fuel transportation constraint should be considered, a green energy system with no emission is preferred. Moreover, keeping in mind the TNPC and COE, the green energy based system is the best; however initially the investment is higher.



(a)



(b)

Fig 13. Effect of real rate of interest change for (a) load 213 kWh/day, (b) load 277 kWh/day

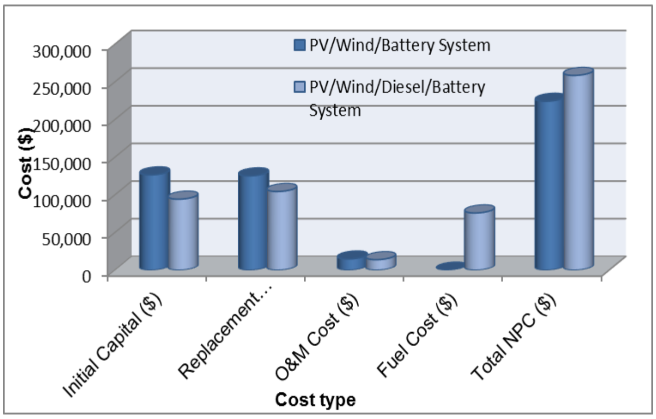


Fig 14. Cost comparison of the two hybrid systems.

8. Conclusion

This paper has presented the feasibility of a hybrid renewable energy based system in rural area of southern Bangladesh, where grid electricity is not present. The optimum design for the Kuakata, Pathuakhali consists of PV, Wind turbine and Battery system. The load is assumed based on regular rural lifestyle. The main parameters of analysis are per unit energy cost, initial cost, per year operating cost, and total net present cost of the system. The HOMER optimization is capable to clarify the viability of the system since the system has competitive energy costs with other possible configurations. The system is a non-polluting, reliable energy source with total net present cost $ 224,345, which cover the capital cost of $ 126,586, replacement cost of $ 125,280, and operation and maintenance cost of $ 14,838. Per year operating cost is $ 5007. The cost of energy is $ 0.161 /kWh, which is the lowest of all the possible configurations. Also, this system does not have any exhaust gas emission, whereas the nearest competitor hybrid system has 11,967 kg/yr of pollutant gas emission. The sensitivity analysis has proved that the system can also handle the increase in load in the near future. The sensitivity analysis also shows the effect of change in interest rate on the system, which is, in most cases the optimum system is sustainable. Therefore, this green system can be a replacement of conventional diesel based system, and can realize the government vision, which is to contribute 10% of the total electricity by renewable energies by the year 2020.

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