INSIGHTS INTO STABILITY ASPECTS OF HYBRID SYSTEM; AN ENABLING TECHNOLOGY FOR RURAL ELECTRIFICATION IN BANGLADESH

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ABSTRACT

The development of a country is dependent on the per person energy consumption rate, which is very low in Bangladesh. Bangladesh installed a capacity of 10416 MW electricity on June 2014 and three fourth of which is considered to be accessible. Near about 45% people has no access to electricity. Therefore, electricity shortage is an acute crisis in Bangladesh. As Saint Martin Island is far away from the main land, it is almost impossible and cost ineffective to supply electricity from the national grid. For connection of nearly 6000 peoples of Saint Martin to the main stream of development and to make this island more attractive to the tourists, it is very essential to provide electricity for them. Power generation by combining solar, wind and diesel, known as hybrid system can be the most efficient technique for the electrification of these types of Island. Based on this principle, in this paper a hybrid system is designed for electrification of Saint Martin's Island. In the analysis, realistic data is used for load calculation and optimization analysis for most effective solution. Hybrid Optimization Model for Electric Renewable (HOMER) software is used to find out the final optimization and sensitive analysis of hybrid system. This system satisfies the load demand and reduces carbon emission which will help to generate green energy.

KEYWORDS

Biomass, Solar PV, Hybrid System, Gasification, HOMER, Power Generation

1. INTRODUCTION

There are about 30 islands in Bangladesh. The Saint Martin's island (20°37′38.12″N 92°19′21.28″E) is a small island (area only 8 km2) in the north-eastern part of the Bay of Bengal, about 9 km south of the tip of the Cox's Bazar-Teknaf peninsula, and forming the southernmost part of Bangladesh. Nearly 6000 populace live there, primarily lived on fishing and on average 4000 tourists visit the island daily from November to March. To meet the increasing tourists demand construction development is booming.

With flourishing concrete structure power demand is also thriving. Now, private parties are operating diesel generators for generation of electricity to the shopping areas at the beachfront of the Uttar Para. The electricity is supplied from 5 PM to 10 PM on a daily rental basis. Some shops and the entire island folks use kerosene lanterns in their houses. Rest of the houses has their own generation of electricity either through solar power or diesel engines.

To connect these large amount of poor people to the main stream of development, education and other development facility should be provided, which is impossible without electricity. In addition, Saint Martin is one of the beautiful tourist spot in Bangladesh. Tourist based development can change the economic and social development of local residential. The island has a good potential of solar and wind resources. Therefore, for electrification of this Island, in this paper we tried to develop an optimal system from the practical view point. HOMER a simulation software has been used to find out an energy efficient system for this island combining conventional (diesel), renewable (Solar-Wind-Biomass) energy sources.

Input information to be endowed with HOMER comprises are: primary load, solar and wind resources, cost, constraints, controls etc. The software focused on an optimal configuration to meet the desired electric loads.

In journal article [1], data was considered for 100 households and 10 shops. That was the prototype. But, in this analysis, we have tried to design a real system on the basis of present inhabitant and visitors. We have also tried to find out the real outcomes.

2. HYBRID SYSTEM

Hybrid power system consists of two or more energy conversion devices. In Bangladesh, solar and wind resources are available and it's reliable also. In this analysis, conventional (diesel) source is combined with non conventional resources (solar, wind & biomass). We have designed the hybrid system to meet the base load with renewable generation and peak load with diesel and biogas generator. The hybrid system consist of an electric load, diesel generators, solar resources, wind resources and other system components such battery, converter [2]. A schematic diagram of standalone hybrid system is represented in Fig. 1.

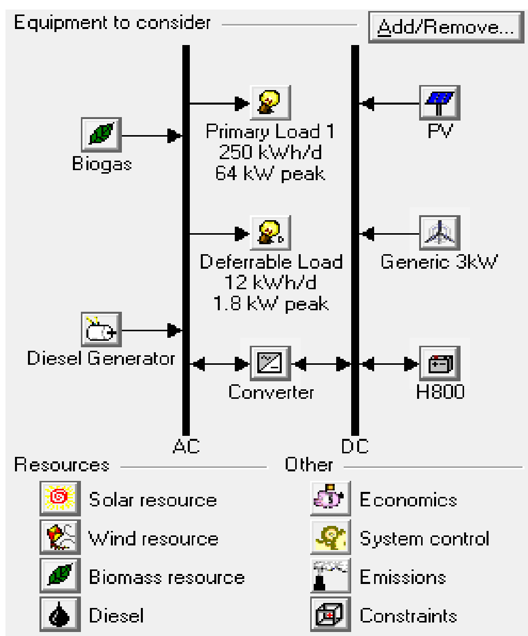

Figure 1. Hybrid energy renewable system

2.1. Electric Load

A community of 6000 people, 750 households, 30 shops, 50 tourists based cottage (each has 20 rooms which can accommodate 4 personnel in each room), a school and one health-post has been considered for estimation of electric load. Two energy efficient lamps (CFL, 12W each) for each family are considered. One fan (ceiling fan, 100W) for 300 households each, one television (70W) is considered for 50 households all. Two lights (12W each) and two fans (100W each) are considered for health post and fourteen lights (12W each) and seven fans (100W each) are considered for school. For street lightning, 50 street lights (12W each) are considered. For each shops, two energy saving lamp and a fan is considered. In tourists based cottage, an energy saving lamp (12W) in each room, wash room lamp (5W each) and one TV for each cottage is considered.

Fan load is considered for summer except winter season from evening to next morning for household consumers.

For deferrable load, seven water pumps, one for school and health-post and the remainder for household use are assumed. Each water pump has a 150 W power rating with a pumping capacity of 10 liter/min. The pumps supply 20,000 liter per day for 200 families (primarily considered for 200 households instead of 750 households) as 100 litter per family, and 2000 liter per day for school and clinic. The average deferrable load form April to October is calculated to be 6kWh/day. In winter (November to March) deferrable load is calculated 21kWh/day as one water pump (150 W each) is considered for each cottage assuming 1,000 litter water demand in each cottage. And overall 5 refrigerators (1.2kWh/day each) are considered in load calculations. Load data are synthesized by specifying typical daily load profiles and adding some randomness of 10 % daily. These scaled up the primary load 250kWh/day with 64 kW peak and average deferrable load is 12kWh/day with 1.8 kW peak annually. Daily load profile is represented for winter in fig. 2 and summer in fig. 3.

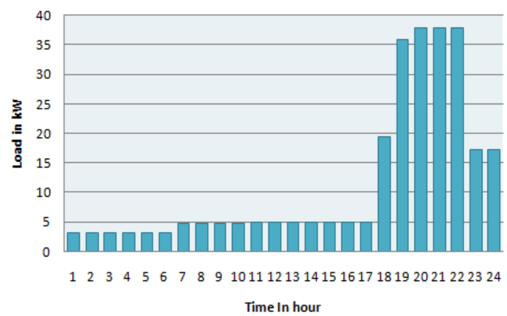

Figure 2. Load profile of a day (November-February)

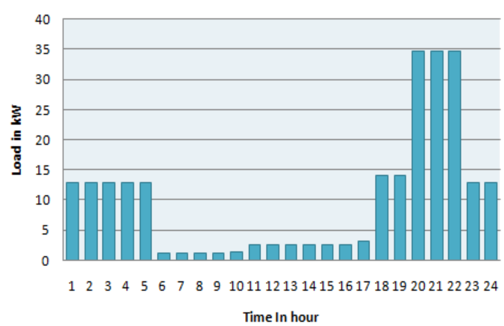

Figure 3. Load profile of a day (March-October)

3. RENEWABLE ENERGY RESOURCES

3.1. Solar Resource

Bangladesh has good prospects of solar photovoltaic generation. The average insolation in Bangladesh is 5kWh/m^2/day. In this analysis, monthly average global radiation data has been taken from NASA (National Aeronautics and Space Administration) to estimate the generation of solar system. Solar data at Barisal (Latitude: 22.75, Longitude: 90.36) in Bangladesh is presented graphically by using HOMER software in Figure 4. Homer use the solar resources input to calculate the PV array power. And, the synthesized data is obtained by putting the longitudinal and latitudinal value in HOMER software.

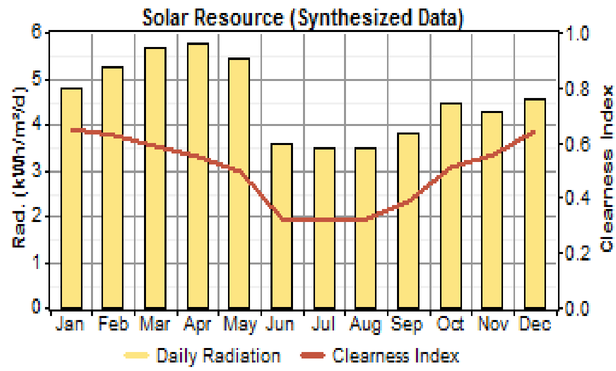

Figure 4. Solar Radiation data throughout the year

3.2. Biomass Resources

Biomass is the oldest source of energy known to humans. The term biomass encompasses a large variety of materials, including wood from various resources, agricultural residues, and animal and human waste. Bangladesh is an agree-based country and main sources of biomass are agricultural residues. And in villages, mainly in Barisal, cow is still utilized for plowing land and farming. So, animal dung is available in resourceful amount.

Biomass contains stored energy. That's because plants absorb energy from the sun through the process of photosynthesis. When biomass is burned, this stored energy is released as heat.
Many different kinds of biomass, such as wood chips, corn, and some types of garbage, are used to produce electricity. Some types of biomass can be converted into liquid fuels called biofuels that can power cars, trucks, and tractors. Leftover food products like vegetable oils and animal fats can create biodiesel, while corn, sugarcane, and other plants can be fermented to produce ethanol.

More than 25000 bio gas plants are already set up in Bangladesh and they are mainly family sized and used only for cooking purposes. But, we need to focus to use this biomass energy for rural electrification. And that will be helpful for our economic advancement.

3.2.1. Gasification

Gasification of biomass has been known as one of the effective technology options for the utilization of this renewable energy resource. Gasification is the process of converting solid fuels into a combustible gas mixture with a controlled amount of oxygen and/or steam; this is accomplished by reaction of the material at high temperature (more than 700^0c). The resulting gas mixture is called syngas or producer gas. The power delivered from gasification of biomass and combustion of the resultant gas is considered to be a source of renewable energy. The calorific value of this gas varies between 4.0 and 6.0 MJ/Nm^3 or about 10 to 15 percent of the heating value of natural gas [3][4]. The process of generation of electricity from biomass is illustrates in Figure 5.

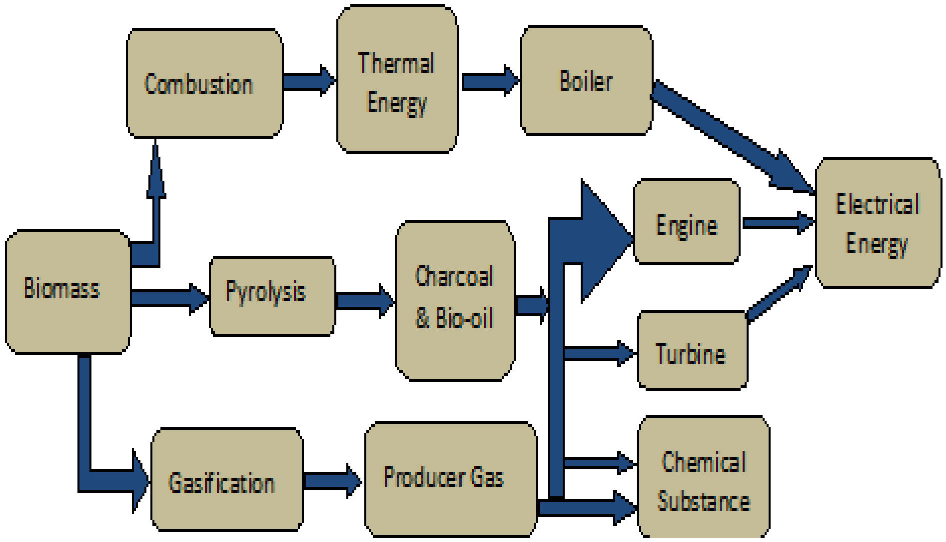

Figure 5. Biomass Conversion into Energy

The three different stages of total gasification produces are:

1) Gasification process starts as auto thermal heating of the reaction mixture.
2) In the second stage, combustion gases are pyrolysis by being passed through a bed of fuel at high temperature.
3) Initial products of combustion, carbon dioxide (CO_2) and (H_2O) are reconverted by reduction reaction to carbon monoxide (CO), hydrogen (H_2) and methane (CH_4).

Biomass gasification is an alternative option of thermal biomass utilization for the production of heat and power based on biomass. Within the last 20 years several different gasification technologies were developed and demonstration plants were realized. Based on the experience from these demonstration plants the gasification technologies were further developed. Gasification plants consist of several process steps, which are shown in figure 6. The solid biomass fuel delivered needs to be adjusted (fuel conditioning and handling) to the fuel characteristics (particle size, water content) required for the gasification process. The conditioned fuel enters the gasification process, which produces raw product gas. The raw product gas needs to be cleaned in order to achieve the product gas quality needed for further utilization. The cleaned product gas is used for the production of electric power, heat and fuel based on different technologies.

During the thermo-chemical biomass gasification process solid biomass is cracked by thermal energy and a fumigator and converted into a product gas. The product gas is cleaned and used for the production of heat and power.

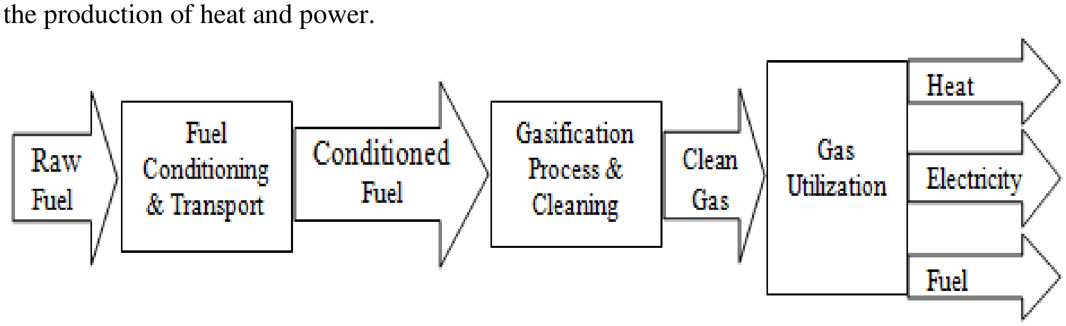

Figure 6. Basic process steps of a biomass gasification plant

3.2.2. Conversion to Electricity

Theoretically, biogas can be converted directly into electricity using a fuel cell. In most cases, biogas is used as fuel for combustion engines, which convert it to mechanical energy, powering an electric generator to produce electricity.

Appropriate electric generators are available in virtually all countries and in all sizes. The technology is well known and maintenance is simple. In most cases, even universally available 3-phase electric motors can be converted into generators.

Gas turbines are occasionally used as biogas engines, especially in the US. They are very small and can meet strict exhaust emissions requirements. Small biogas turbines with power outputs are available on the market, but are rarely used for small-scale applications in developing countries as they are expensive. Furthermore, due to their spinning at very high speeds and the high operating temperatures, the design and manufacturing of gas turbines is challenging and maintenance requires specific skills.

External combustion engines such as Stirling motors have the advantage of being tolerant of fuel composition and quality. They are, however, relatively expensive and characterized by low efficiency. Their use is therefore limited to a number of very specific applications. In most commercially run biogas power plants today, internal combustion motors have become the standard technology either as gas or diesel motors.

3.2.3. Energy Generation by Using Cow Dung

Several types of gasifier e.g. fixed bed updraft and downdraft gasifier, fluidized bed gasifier and bubbling bed gasifier are available in the existing market with different sets of pros and cons. However, the downdraft gasifier is a comparatively cheap and gasification in this type of gasifier can produce a product gas with very low tar current [4].

All the collected cow dung is fed into an anaerobic digester. The digester is built to hold 21 days of farm waste. Bacteria convert the waste into various products, one of which is methane gas. Gas produced by the bacteria builds up the pressure in the concrete vessel, and a pipe delivers the biogas to a modified natural gas engine.

The biogas fuels the engine, which in turn spins an electric generator to create electricity. Waste heat from the engine is used to keep the digester warm and offsets fuel purchase on the farm.
One cow's waste can produce enough electricity to light two 100-watt light bulbs for 24 hours a day. The energy is fed onto the electrical system for distribution to customers. Cow dung gas is 55-65% methane, 30-35% carbon dioxide, with some hydrogen, nitrogen and other traces. Its heating value is around 600 B.T.U. per cubic foot. Cow dung slurry is composed of 1.8-2.4% nitrogen (N_2), 1.0-1.2% phosphorus (P_2O_5), 0.6-0.8% potassium (K_2O) and 50-75% organic humus.

About one cubic foot of gas may be generated from one pound of cow manure at around 28°C. This is enough gas to cook a day’s meals for 4-6 people in Bangladesh. About 1.7 cubic meters of biogas equals one liter of gasoline. The manure produced by one cow in one year can be converted to methane, which is the equivalent of over 200 liters of gasoline.

Gas engines require about 0.5 m^3 of methane per horsepower per hour. Some care must be taken with the lubrication of engines using solely biogas due to the “dry” nature of the fuel and some residual hydrogen sulphide; otherwise these are a simple conversion of a gasoline engine.

Power generation by using cow dung consist of several process steps, which are shown in figure 7. First, cow dung is stored in biogas digester and produced gas in gasification process in cleaned and supplied it to syngas engine to produce electricity.

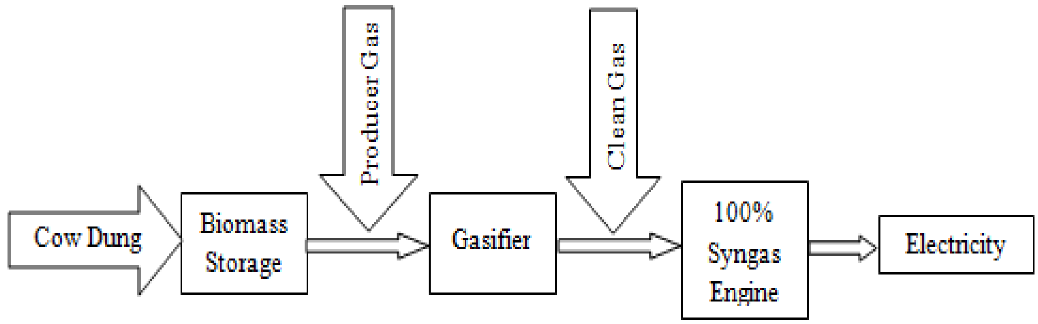

Figure 7. Electricity Generation by cow dung gasification

3.3. Wind Resource

In HOMER Weibull factor (k) is taken as 2, autocorrelation factor is taken as 0.78, the diurnal pattern strength 0.30 is used and the hour of peak wind speed is taken as 14 [5][6][1]. Table-II shows the monthly averaged measured wind speed at 30m height [Research has measured wind speed by Bangladesh Council for Scientific and Industrial Research (BCSIR) for the period of 1999 to 2001] and NASA measured the values for the same location at 10m height.

Table 1. Monthly average wind speed data for Saint Martin Island

Months	NASA(10m)	Measured	V_{max}
January	3.27	5.03	23.32
February	3.39	4.70	19.78
March	3.57	4.24	18.94
April	3.67	3.79	20.03
May	3.89	5.07	26.30
June	6.27	6.17	29.80
July	6.35	5.56	24.20
August	5.64	5.78	20.40
September	4.05	4.47	17.70
October	3.27	4.11	15.90
November	3.24	3.53	14.50
December	3.1	4.11	15.20

4. SYSTEM COMPONENTS

In this analysis, the major components are PV panels, biogas disaster, bio fuel generators, batteries, and converters. For economic analysis, the number of units to be used, capital cost, replacement and O&M costs and operating hours to be defined in HOMER in order to simulate the system.

4.1. Solar Photovoltaic

Sun rays are available with prosperity in Barisal, Bangladesh. Lots of solar home system has been installed. But, there is no set up yet established for off grid networking. In this research, solar photovoltaic is used with biogas generation for the establishment of a hybrid system. Solar system cost consists of cost with cables and charge controllers. It's known to me by analysing present market; cost of PV panel with set up cost Tk. 75000 for 1 kW generation. Various costs are represented in Table 2 and cost is considered in BDT. Life time has been taken 25 years and 25 kW PV modules are considered.

Table 2. PV cost assumption and technical parameters

Parameter	Unit	Value
Capital Cost	BDT/W	75
Replacement Cost	BDT/W	66
Operating & Maintenance Cost	BDT/Yr	100
Lifetime	Years	25
Derating factor	Percent	80
Slope	Degree	22.566
Tracking System	No tracking System	0.05

*1 BDT (Bangladeshi taka) =0.013 $ (USD)

4.2. Biomass Generator

In this research, two set of 10 kW biomass generators are considered to find out the most cost effective system. The main reason of using to fulfil the energy demand in peak hour both for winter and summer season and also meet the terms of backup requirements. As biomass resource is available in prosperity, fuel cost is considered zero. The main cost is considered for biogas generation procedure and biogas power generator. . To produce 1KW electricity from biomass, $1200 is required including plant cost and generator cost, i.e. about BDT 9600000 is required in this purpose [7]. Digester lifetime is considered for 8 years and fuel curve slope and intercept are taken as 0.05 and 0.33 respectively [8]. Different costs and parameters are given in Table 3.

Table 3. Cost and parameter of Biogas generator

Parameter	Unit	Value
Capital Cost	BDT/kW	96000
Replacement Cost	BDT/kW	67200
Operating & Maintenance Cost	BDT/Yr	50
Lifetime	Hours	35000
Load factor	Percent	15

4.3. Diesel Generator

To meet the peak load, diesel generator is used with renewable resources. We mainly scheduled the diesel generator for the time 6 PM to 12 midnight. In HOMER 10 kW diesel generators is considered with 10 kW biogas generators to meet the peak load demand. Diesel generator price is considered by analysing present market price. Fuel curve slope and intercept are 0.05 and 0.33 respectively [9]. Fuel price is considered here Tk. 68 instead of Tk. 56 which was considered in [1].

Table 4. Diesel generator cost assumption and technical parameters

Parameter	Unit	Value
Capital Cost	BDT/kW	10000
Replacement Cost	BDT/kW	8000
Operating & Maintenance Cost	BDT/hr	30
Operating Lifetime	Hours	30000
Minimum load ratio	Percent	10

Fuel Curve Intercept	1/h/kWrated	0.05
Fuel Curve Slope	1/h/kWrated	0.33
Fuel Price	Tk	68

4.4. Wind Turbine

Cost and wind turbine depends on the tower height and technology used. In this analysis, A Generic 3kW wind turbine is considered for the hybrid system. Technical and economic parameters [10] of the wind turbine are furnished in Table 5.

Table 5. Wind turbines cost assumption and technical parameters

Parameter	Unit	Value
Weibull (k)		2
Autocorrelation factor		0.78
Diurnal pattern strength		0.3
Hour of peak wind speed	m/s	14
Capital Cost per set	BDT	600000
Replacement Cost per set	BDT	450000
Operating & Maintenance Cost	BDT/Yr	10000
Lifetime	Years	25

4.5. Battery

Batteries are used to store the solar photovoltaic output. In rural area like our proposed are, where most of the power is used after day time. So, main target of our system is to store energy at day time and discharge the stored energy after evening. So, batteries are used following through charge controller. Also, a dump load is used for the purpose of removing excess charge and preventing system damage. In this system, the Surrette 4KS25P storage batteries are utilized [11]. The specifications and different costs of batteries are shown in Table 6.

Table 6. Battery cost assumption and technical parameters

Parameter	Unit	Value
Nominal Voltage	volt	2
Nominal Capacity	Ah(kWh)	800(1.6)
Maximum Charge Current	A	162
Round-trip efficiency	Percent	86
Minimum State of Charge	Percent	30
Capital Cost	BDT/kWh	7000
Replacement cost	BDT/kWh	6000
Operating & maintenance Charge	BDT/kWh/yr	50

4.6. Converter

Converter converts the dc power to ac power. As, most of the home appliances are operated in ac, dc generation from the PV array is converted to ac following through a controller. In this proposed system, 25 kW converters are considered for optimum solution. The details of converter cost assumption and different parameters are given in Table 7.

Table 7. Converter cost assumption and technical parameters

Parameter	Unit	Value
Capital Cost	BDT/kW	15000
Replacement Cost	BDT/kW	10000
Life time	Years	15
Efficiency	Percent	90
Rectifier Capacity	Percent	95
Rectifier Efficiency	Percent	85

4.7. System Control Parameters

We have tried to design an off grid system in remote location. Bangladesh government declare target to cover all areas in between 2030. So, with considering caution factor, we have considered the project life time 25 years. Other consideration and parameters like System control parameters and various constraints are given in Table 8.

Table 8. System control parameters and constraints

Parameter	Value
Percent of annual peak load	0
Percent of hourly load	10
Percent of hourly solar output	0
Maximum Unreserved energy	0 (%)
Maximum renewable fraction	0 to 100%
Maximum battery life	N/A
Maximum annual capacity shortage	0 to 1%

5. RESULTS AND DISCUSSION

The optimal systems performance analysis has been carried out by using HOMER software. The optimized result is analyzed for specific wind speed 4.72 m/s, solar irradiation 4.55kWh/m2/d and diesel price 68 taka. The hybrid system analyzed for 35 kW PV array, one 3kW Generic wind turbine, 10 kW diesel generator, 10 kW biogas generator and 135 no of storage batteries with 40 kW converters. Simulated result shows that the minimum COE [12] is tk.14.351/kWh that was tk. 26.54 in [1] and a minimum NPC of Tk. 19,330,286 represented in Figure 8.

Net Present Costs

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	2,450,000	0	1,409	0	0	2,451,410
Generic 3kW	200,000	56,533	140,940	0	-33,222	364,251
Biogas	960,000	1,470,994	4,354,326	0	-121,222	6,664,098
Diesel Generator	100,000	32,806	1,157,113	4,920,803	-14,923	6,195,799
Hoppecke 8 OPzS 800	1,512,000	1,417,258	705	0	-28,267	2,901,696
Converter	600,000	192,407	0	0	-39,374	753,033
System	5,822,000	3,169,998	5,654,494	4,920,803	-237,007	19,330,286

*All the currency values are considered in terms of Tk. (Taka, Bangladeshi Currency) instead of $(USD).

Figure 8. Net present cost of the proposed system

The overview of electrical parameters in our analysis is represented in Figure 9. The figure shows that the ac primary load demand is 95% and deferrable load demand is 5%. And demand is achieved with 42% PV generation, 2% from wind generation, 45% from biogas and rest 12% from diesel generator. It's possible to consider a smaller diesel generator. But, we considered here a 10 kW generator in case of biogas generator failure. In this analysis, renewable fraction is obtained 0.884 percent and annual capacity shortage is 0.3 percent only. The software also simulates the sensitive analysis that represents the forecasting of unit generation cost with the increase or decrease of diesel price.

System Architecture:

35 kW PV	10 kW Diesel Generator	40 kW Rectifier	Total NPC: $ 19,330,282
1 Generic 3kW	135 Hoppecke 8 OPzS 800	Cycle Charging	Levelized COE: $ 14.351/kWh
10 kW Biogas	40 kW Inverter		Operating Cost: $ 958,446/yr

Electrical

Production	kWh/yr	%
PV array	54,775	42
Wind turbine	2,696	2
Biogas	58,611	45
Diesel Generator	15,283	12
Total	131,365	100

Consumption	kWh/yr	%
AC primary load	91,123	95
Deferrable load	4,445	5
Total	95,569	100

Quantity	kWh/yr	%
Excess electricity	20,916	15.9
Unmet electric load	154	0.2
Capacity shortage	295	0.3

Quantity	Value
Renewable fraction	0.884

Figure 9. Energy generated by diesel generator, PV system and wind Turbine

6. SENSITIVE ANALYSIS

In this paper sensitive analysis has been embark on study the effects of variation in solar radiation and diesel price for Levelized Cost of Energy (COE) [1]. This sensitive analysis is done for the future forecasting of price for unit generation with the increase and decrease of diesel price. In Figure 10, we find COE is Tk. 14.4/kWh at the point of solar irradiation 4.55kWh/m2/d and diesel price Tk. 68. If diesel price increases, COE will be increased. As for example, at 4.55kWh/m2/d solar irradiation and diesel price Tk. 70, COE will be 15 taka. The Levelized cost of energy is signified in Fig. 6.

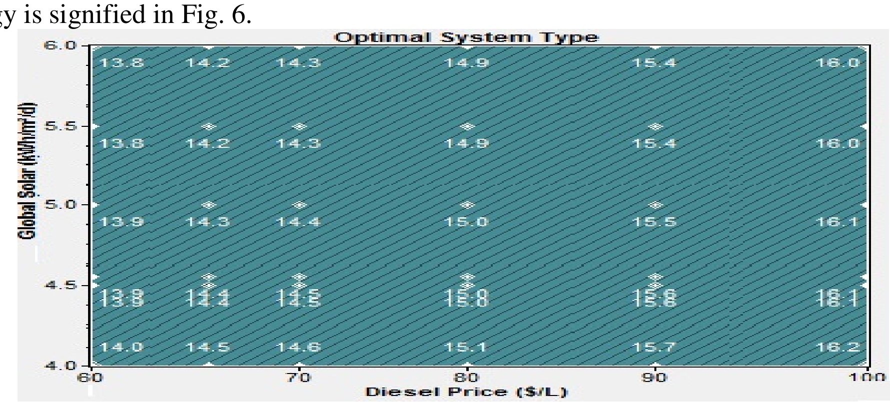

Figure 10. Optimal system in terms of diesel price and solar radiation

7. CONCLUSION

In our country most eclectic generation is dependent on natural gas. The reserve of natural gas is running off, other fossil fuels have to import from abroad. The price of fuel is increasing throughout the world. Though, Government has set up his goal to go under coverage of electricity of the whole country within 2030 and already taken few initiatives to solve the power crisis. However, that's not enough to fulfill the present crying need. Nevertheless, it may not possible to fulfill the target within that time because now nearly 60% people in rural area have no access to the national grid and around 75% Bangladesh's 161 million citizens live in rural areas. Therefore, this type of proposed system can be a solution for rural area in addition to the isolated island. The feasible system is considered 35 kW PV array with one 3kW Generic wind turbine, a 10kW diesel generator, a 10 kW biogas generator and 135 storage batteries among 40kW converter. The cost of energy of the proposed model is found 14.351 BDT, which is around 20 to 25 taka at present solar home system generation cost. As the net present cost is high, a large capital is needed for the feasibility of this research. But, it is possible to make up the establishment cost within 10 years. So, this project can be profitable though the preliminary set up cost is high. The integrated of the proposed model with the grid connection is also possible. The use of hybrid power system not only reduces the unit price of electricity generation but also generate environmental friendly energy.

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