Renewable Energy Based Hybrid Power System Design for Hilly Area in Bangladesh

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Abstract – *Access to minimal expense energy has become crucial for the working of contemporary economies. Threats to global energy security include political instability in energy-producing nations, manipulation of energy supplies, competition over energy resources, attacks on supply infrastructure, as well as accidents and natural disasters. The safety of electrical power might be a significant factor in the progression of agricultural nations like Bangladesh. With the event of demand electricity will increase. The use of petroleum derivatives for energy production not only rapidly depletes these finite resources but also significantly impacts the environment. During this situation, taking advantage of environmentally friendly power to plan crossover power frameworks is both expenses upgrading and climate amicable. In this paper, a viability analysis is conducted to examine the potential of green energy for the hilly areas such as Bandarban, Khagrachari, and Rangamati in Bangladesh. Bandarban was chosen for this research. During this paper, an endeavor is taken to design a system with a lower levelized cost of energy (LCOE) with a higher renewable fraction. For the system, the levelized cost of energy (LCOE) is calculated as $0.126, with a net present cost of $259,976. Using HOMER software, an optimal configuration was established for this hybrid power system. This paper may be an ideal example for an effective power solution for hilly areas in Bangladesh.*

Keywords: *Biomass, hybrid system, HOMER, Photovoltaic, renewable energy, wind power*

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I. Introduction

Energy is the main source of all kinds of development for a country. A well-settled and developed country is often raised primarily based solely on their potency in energy rates. It's hard to imagine our lives without electrical energy in today's world. Most of the items go past electricity in our existence like lights, appliances, cooling and heating for home and business. Each and every space of our life is currently absolutely addicted to it however none thinks deeply as long as electricity is accessible. The importance of electricity is only realized when power outages occur within the facility. The government is facing difficulty in coping with urban and industrial demand in the last few years. About 60% of the total inhabitants of Bangladesh live in the countryside [1]. Therefore, it is a major challenge for the administration to meet the overall demand and ensure the availability of electricity to the remaining population who lack access to it. The situation is worse and more severe in the isolated islands and hilly areas like St martin's Island, Kutubdia, Hatiya, Bandarban, Khagrachari etc. Grid connected electricity will be difficult even in the future because of cost and geographic location. These vast hilly areas have a lot of possibilities of industrialization and development but the only hindrance against their prosperity is the need for electricity. Bandarban is one of these hilly areas, which are deprived of grid connected electricity. Because of these causes, off-grid hybrid systems are far more possible with relevance to such reasonably mountainous areas in Bangladesh. There is some research conducted previously for areas like Bhasan char [3], St. Martin's island [4], Nijhum Dwip [5], Sandip para [6], Cox's Bazar [7] and also Bangladesh as a whole [8] [9] [12]. Also, a recent paper on Bandarban Bilchari hill area was published [10] which levelized cost of energy (LCOE) was $0.128. In our research, the levelized cost of energy (LCOE) is $0.126 with lowest NPC (net present cost) and operating cost. Therefore, it is a major challenge for the administration to meet the overall demand and ensure the availability of electricity to the remaining population who lack access to it. In the context of hilly areas, overcoming these energy access barriers is not just a matter of convenience, but a critical step toward uplifting these communities, fostering economic growth, and improving livelihoods for generations to come.

II. Site Selection

Fig. 1. Satellite view of proposed site.

The area of our study is BANDARBAN district. It is part of Chittagong hill tracks [2]. The area of Bandarban is about 4480 km^2. Its geographical position is about 21° 48.0′ N latitude and 92° 24′ E longitude. It is located 87.3 km from Chittagong Airport, 76.8 km by road from Chittagong City, 116.2 km by road from Cox's Bazar town, and 75.9 km from Rangamati city.

The proposed substation is planned to be installed adjacent to Meghla Parjatan Complex, alongside the national highway N108. There are some free spaces which will be easier for the government to acquire. Beside this, the place is only 4.5 km (13 min drive away) from Bandarban city. Additionally, it is a relatively safe location. We can also isolate that place in case of an emergency. The proposed location is situated at 22°11'09.5"N, 92°11'14.4"E. Figure 1 provides a satellite view of the area.

III. Load Estimation

The load was estimated based on 100 households from the rural population. We considered 400 CFLs and 300 ceiling fans, 200 charging points for telephone or small electronic devices such as charger lamp, fan and 19 inch 100-piece color TV & 100 refrigerator. The total average power consumed here is 436.9 kWh/day. In table 1 we can see the tabular representation of the considered load calculation.

TABLE I.
CONSIDERED LOAD CALCULATION TO PREPARE THE LOAD PROFILE

Appliances	No. of Unit	Power consumption by each unit (W)	Power Consumption per hour (Wh)	Maximum power consumption (kWh/day)	Working time per day (hour)	Average power consumption (kWh/day)
CFL Bulb	400	15	6000	144	8	48
Ceiling Fan	300	50	15000	360	10.5	157.5
TV 19" color	100	70	7000	168	5.5	38.5
Charging point	200	3	600	14.4	1.5	0.9
Refrigerator	100	80	8000	192	24	192
Total average power consumed (kWh/day)						436.9

IV. Renewable Energy Resources

The site is mainly blessed with solar, wind, and biomass resources [14] – [17]. This area gets enough sunlight and the hilly forest is a very good source of biomass.

A. Solar Energy

Fig.2 represents the graphical formation of the clarity index and daily Bandarban radiation. The average solar GHI [13] is 4.89 kWh/m^2/day. The maximum solar GHI is found from March to May.

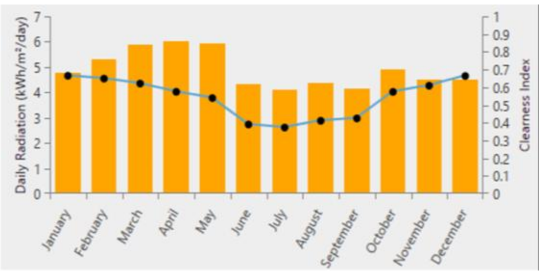


Fig. 2. Daily Clearness Index and Radiation.

B. Abstract and Keywords

Fig. 3 represents breeze speed for a year. Yearly mean breeze speed is 3.65 m/s with the maximum breeze speed during the months of June, July and August.

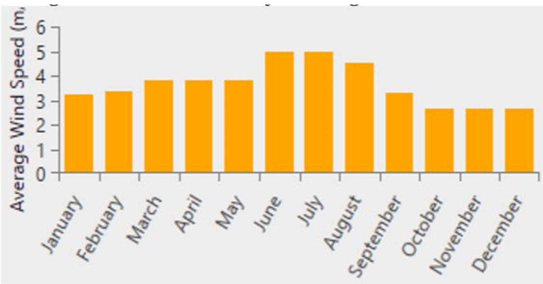


Fig. 3. Normal breeze speed (m/s) for different months.

C. Biomass Resource

Fig. 4 represents the biomass resources of our site. The annual average biomass is 3.36 t/d with gasification ratio of 0.70 [10].

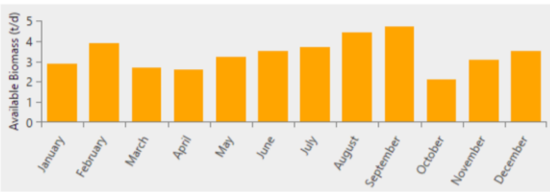


Fig. 4. Available biomass for different months

V. Components of Hybrid System

A schematic diagram of our proposed system is given below at fig. 5. The main components we have used here are biogas genset, wind turbine and PV system. We have also used a converter for the AC-DC conversion batteries to store the charge produced by the PV module.

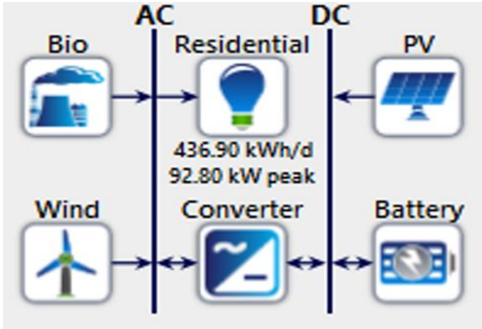


Fig. 5. Schematic diagram of proposed system

A. PV Module

We have used CanadianSolar MaxPower CS6X-325P [18] PV module with 0.325 kW rated capacity. It has efficiency of 16.94 % with temperature coefficient of -0.41.

TABLE II
PARAMETERS OF PV MODULE

Parameter	Unit	Value
Rated capacity	watt	325
Capital cost	$	185
Replacement cost	$	185
O&M cost	$	0
Lifetime	yr	25
Derating factor	%	92

B. Wind Turbine

AWS HC 5.1kW Wind Turbine [19] with 5.1kW rated capacity. It has a hub height of 12.00 m and very low cut-off wind speed which is very effective for our proposed area.

TABLE III
PARAMETERS OF WIND TURBINE

Parameter	Unit	Value
Rated capacity	kW	5.1
Capital cost	$	3900
Replacement cost	$	3500

O&M cost	$	15
Lifetime	yr	20
Hub Height	M	
Cut-Off wind speed	m/s	2.2
Rotor diameter	m	5.24

C. Biogas Genset

We have used Generic 500kW Biogas Genset [20]. We have considered 20,000.00 hr of lifetime with a decent CO emission of 2 g/kg fuel.

TABLE IV
PARAMETERS OF BIOGAS GENSET

Parameter	Unit	Value
Rated capacity	kW	500
Capital cost	$	12,000
Replacement cost	$	12,000
O&M cost	$/op.hour	0.400
Fuel	type	Biogas
Fuel density	Kg/m^3	0.720
Lower heating value	MJ/Kg	5.5
Minimum load ratio	%	50

D. Converter

A Generic System Converter has been used with 1kW of capacity. It has good efficiency with a decent cost.

TABLE V
PARAMETERS OF BIOGAS TURBINE

Parameter	Unit	Value
Rated capacity	kW	1
Capital cost	$	236
Replacement cost	$	212
Efficiency	Inverter(%)	90
	Rectifier(%)	95

E. Battery

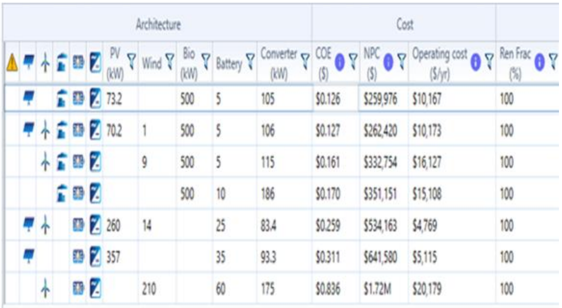
Gildemeister 20kW-40kWh CELLCUBE® FB 20-40 has been used as our battery. It is a vanadium redox flow battery. We have specified a string size of 5 batteries which results in 240V. The capital cost of the battery is $10,000.

TABLE VI
PARAMETERS OF BATTERY

Parameter	Unit	Value
Nominal voltage	V	48
Nominal capacity	kWh	40
Capital cost	$	10000
Replacement cost	$	8000
O&M cost	$	0
Lifetime	yr	20
Throughput	kWh	1,752,000

VI. Optimization Result and Discussion

The Hybrid system comprises biogas genset, wind and PV has been stimulated to utilize HOMER to get a feasible structure. HOMER displays the effective architecture in downward sequence with parameters such as Net present cost (NPC) and Cost of Energy (COE).



PV (kW)	Wind	Bio (kW)	Battery	Converter (kW)	COE ($)	NPC ($)	Operating cost ($/yr)	Ren Frac (%)
73.2		500	5	105	$0.126	$259,976	$10,167	100
70.2	1	500	5	106	$0.127	$262,420	$10,173	100
	9	500	5	115	$0.161	$332,754	$16,127	100
		500	10	186	$0.170	$351,151	$15,108	100
260	14		25	83.4	$0.259	$534,163	$4,769	100
357			35	93.3	$0.311	$641,580	$5,115	100
	210		60	175	$0.836	$1.72M	$20,179	100

Fig. 6. Optimized result of proposed system.

Fig. 6 displays the most economically friendly solution as a collection of simulated data. All system configurations were compared while the constraint values were kept constant. The best energy system was chosen because it had a low net present cost (NPC), a low cost of energy (COE), a high renewable fraction, a low capacity shortage, a low amount of excess power, and a low amount of fuel usage.

It can be observed from table VII that the electrical production of our system has been 343,704 kWh per year. The maximum electricity we get from biogas-genset is 221,500 kWh/yr.

The replacement, fuel, operating, and capital costs of our proposed system have been shown in Table VIII. The capital cost of our proposed system has been $128,538 and replacement cost has been $35,240. In our system the assets expected resale value at the end of its useful life has been $12,000.

TABLE VII.
ELECTRICITY PRODUCTION

Production	kWh/yr	%
PV Module	122,204	35.6
Biogas Genset	221,500	64.4
Total	343,704	100

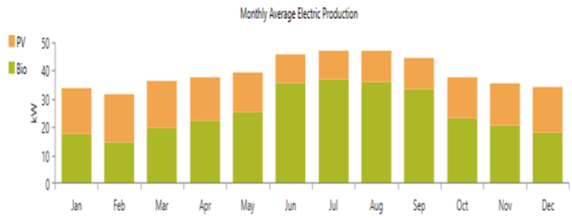
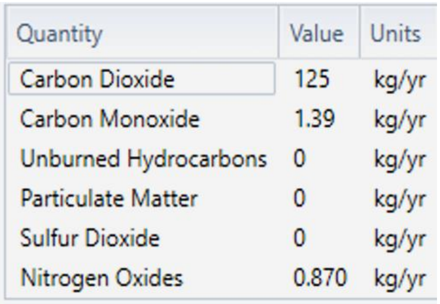


Fig. 7. Energy yield for the proposed system.

TABLE VIII.
COST ANALYSIS OF OUR PROPOSED SYSTEM

Component	Capital($)	Replacement($)	O&M($)	Fuel($)	Salvage($)	Total($)
PV System	41,668.76	0.00	0.00	0.00	0.00	41,668.76
Biogas Genset	12,000.00	2,752.00	4,581.51	89,993.98	2,138.05	10,7189.44
Battery	50,000.00	12,752.29	0.00	0.00	7,186.74	55,565.56
Converter	24,869.43	19,736.29	13,622.88	0.00	2,675.90	55,552.70
System	128,538.19	35,240.59	18,204.39	89,993.9	12,000.90	259,976.46

Fig. 8 displays the yearly GHG emission for our proposed system. From the figure we can see that the CO emission has been comparatively lower so that the system has been feasible for the area.



Quantity	Value	Units
Carbon Dioxide	125	kg/yr
Carbon Monoxide	1.39	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0.870	kg/yr

Fig. 8. Annual GHG emission for the hybrid system

The result we get has been compared with other research works and favorable in economic and technical perspective simultaneously. The optimized result of our system COE has been $0.126. Earlier publications like [7] [10] [11] in this specific region of hybrid systems had COE greater than our research work.

VII. Comparison Between Proposed Hybrid System & National Grid

The price of various transmission lines in Bangladesh [11]:

33 kV line/km is $49,597
11 kV line/km is $30,998
400 V line/km is $22,319
11 KV & 400V Line/km is $43,397

There has been an existing overhead line of 132 kV in Chittagong district. In Chittagong there's an existing substation of 132/33 kV. This 33 KV is extended up to Rangunia which is at a distance of 29 km from Bakalia. In Rangunia there's a substation of 33/11 kV. This 11 kV has been extended up to Fatehabad which has been at a distance of 18 km from Rangunia but the project location has been beside meghla projection complex which has been about 57 km away from Rangunia substation and no existing grid is available.

Capital Cost for extension of 33 kV line up to project location:

$ (57*49597) = $ 2827029

Capital Cost for extension of 11 kV line up to project location:

$ (57* 30998) = $1766886

Capital cost of our Hybrid System: $ 128,538

TABLE IX.
COMPARISON BETWEEN PROPOSED HYBRID SYSTEM AND NATIONAL GRID

System		Cost($)
National grid	33 KV	2827029
	11 KV	1766886
Hybrid system		128,538

The analysis given from the above table shows that our given proposed hybrid system has been more money-saving and also feasible than the 33 kV and 11 kV line extension.

VIII. Conclusion

Bandarban has been one of the south-eastern districts of Bangladesh and a part of the Chittagong division. A bio-genset. A PV based hybrid system has been proposed for this area. The COE of the proposed hybrid system has been $0.126 per Kwh. The operational expense of our proposed system has been $10,167 with the capital of $128,538. Also, we can see that our system has been far cheaper than grid connection. The proposed hybrid system can be integrated with 100% green energy for electricity production, which lessens the significant quantity of CO_2 discharge yearly that has been obligatory for a secure environment.

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Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

Author Contributions

Author 1: Supervision, analysis, writing–original draft preparation, draft review; Author 2: draft review and editing, investigation; Author 3: Conceptualization, review; Author 4: Analysis, writing, review.

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