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Economic Feasibility Study of an Optimized Hybrid Energy System for Chittagong Hill Tract Region of Bangladesh

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***Abstract*—*The main Objective of this paper is to propose a hybrid energy system containing solar photovoltaic panels, hydro generator, biogas-generator and a diesel generator for electrification in chittagong hill tract regions of Bangladesh. This work also presents a optimized hybrid scheme consisting of the Net Present Cost (NPC) and renewable fraction. A hill tract region called Barkal in Chittagong is considered for this project. All the simulations are carried on HOMER software. Simulation input data are collected from the survey of that region. A 20kW hydro power project is going on by the Ministry of Chittagong Hill Tracts Affairs in this area which is developed by CANMET Energy Diversification Research Laboratory of Canada (CEDRL). Our research can incorporate this project with some more hydro, solar & biomass energy resources to design an optimized system which can motivate other hilly regions also.*

***Keywords*— *Biogas, Feasibility Study, HOMER, Hydro Power, Net Present Cost (NPC), Optimization, Solar Photovoltaic.*

I. INTRODUCTION

Need for energy is growing up day by day all over the world. Bangladesh being a developing country has been suffering from high energy crisis in recent years [1]. Dependence on fossil fuels not only contributes to the global warming but also increases the cost of power generation. Besides, we have to import power from our neighboring country to meet the extra demand otherwise problem of load shedding can reduce the production of industries. But our country has a lot of renewable resources to reduce this energy crisis. Use of these resources is also environment friendly by emitting low amount of greenhouse gases [2].

There are many remote areas where electricity has not reached yet. Among them many of the hill tract regions of Chittagong are still remote and powerless. The reason for this situation is probably the difficulty of power transmission over the hill tracts [1]. The tower poles and the insulators have to withstand high mechanical strength caused by conductor load and wind speed. For these kinds of problems if we can design a stand-alone hybrid system for these areas, it can supply energy with a low cost.

Barkal is one of the remote hill tract regions of Chittagong containing lesser building infrastructure. According to geological structure, the region is covered with hills of 300-500m in height. It has several waterfalls which have the potential to generate 60kW power [3]. Besides, this site is highly suitable for solar radiation. The household waste and waste from animal can also be a source of biogas generation [4]. To design an optimized power system for this area, the HOMER software requires input data of solar radiation, biogas resources, hydro data, electric load, cost, emission, system control and constraints. The solar data for this simulation is taken from the satellite record [5]. Hydro resource data are taken from the survey of the site. The amount of waste material produced from each house is also recorded for biogas generator. Furthermore, the scheme also contains a diesel generator as backup supply. All the input data are given for simulation in HOMER and sensitivity analysis is performed according to the multiple optimizations [14]. In the end, the simulation proposes the most effective design with better cost of energy (COE) and lower greenhouse gas emission.

II. BACKGROUND OF HYBRID ENERGY SYSTEM

A energy system which consists of both conventional and non-conventional sources of energies for supplying the connected loads or feeding into the grid is called a hybrid energy system. Diesel generators use conventional resources while solar photovoltaic, biogas and running water are non-conventional resources [7]. Our research put focus on the design of a economically feasible hybrid power system for the hill tract community. Taking these background concepts in mind, optimization of the hybrid system is done by the sensitivity analysis. The hybrid energy system should be sustainable, cost-effective and reliable.

III. DATA COLLECTION

A survey is carried on in different areas of Barkal sub-district and the surveyed data are listed below:

1) Measured Electrical Loads:

Peak Load: 225kW
Average Energy: 2.4MWh/day
Load Factor: 0.446

Other load data are given in figure 1. The load varies during different hours of the day with a mean value of a 135kW over the season. It is considered for January month working days. The data is identical for the rest of the months of the year.

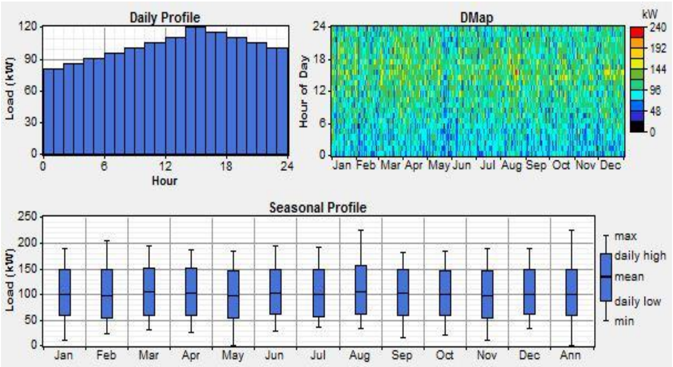

Fig. 1. Daily and seasonal load profile input in HOMER.

2) Solar data:

Location: Barkal, Rangamati, Chittagong, Bangladesh.
Latitude and Longitude: 22.5°N, 92.22°E

Annual solar radiation data for Chittagong is collected from online found from different Research Center Satellites is given in figure 2 and figure 3:

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.627	4.500
February	0.596	4.900
March	0.570	5.400
April	0.525	5.500
May	0.465	5.100
June	0.379	4.200
July	0.364	4.000
August	0.396	4.200
September	0.409	4.000
October	0.514	4.400
November	0.596	4.400
December	0.645	4.400
Average:	0.492	4.581

Fig. 2. Tabular representation of daily solar radiation for HOMER input.

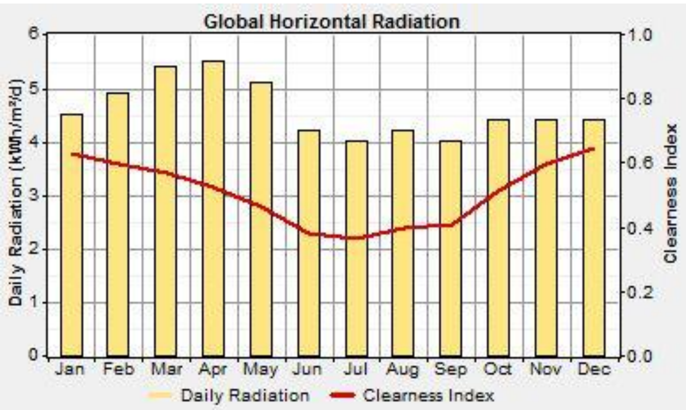

Fig. 3. Graphical representation of daily solar radiation in HOMER.

3) Hydro data:

Ongoing micro-hydro Project by the Ministry of Chittagong Hill Tracts Affairs can generate 20kW power. There is a canal named Hnara Khal that has the potential to generate 40kW power [3]. If we can establish a run-off river scheme in this canal by creating a dam, it will provide power to the system during good flow conditions and supply the peak demands. The total sectional area of the canal is 45m^2. During high flood or low loads the water should be controlled by the spillways. The complete hydro resource data for different months of the year is shown in table I. This data can be changed from year to year depending on the weather condition.

TABLE I. Collected complete hydro resource data.

Month	Stream Flow(L/s)
January	24
February	24
March	24
April	25
May	25
June	25
July	25
August	24
September	25
October	23
November	23
December	23

4) Biomass Data:

The total waste produced from the household and other resources like animal waste and poultry waste are given in figure 4. The carbon content within the biomass is considered as 5% and the gasification ratio is 0.7.

Month	Available Biomass (tonnes/day)
January	50.000
February	45.000
March	45.000
April	30.000
May	30.000
June	50.000
July	30.000
August	45.000
September	45.000
October	50.000
November	50.000
December	50.000
Annual average:	43.313

Fig. 4. Surveyed biomass data from Barkal Sub-district for HOMER input.

IV. PROPOSED HYBRID ENERGY SYSTEM

Keeping in mind all the information above, we can design a hybrid energy model as shown in figure 5. Hydro generator, Diesel generator and Biogas generator are connected to AC grid. Solar panels and batteries are connected to DC grid. Primary Load is connected to AC grid which will consume power from these resources. Converters are connected to both AC and DC grid to convert DC power from solar panels into AC and supply the power to primary load or batteries. Diesel generator works as a backup power supply during the unavailability of power.

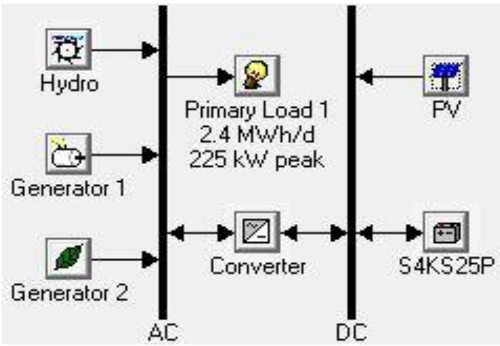

Fig. 5. Proposed renewable hybrid model for Barkal.

V. COST DATA OF THE SYSTEM EQUIPMENTS

The collected cost data for the different system components are given below:

TABLE II. Estimated cost for the system components.

Components	Capital Cost($)	Replacement Cost($)
1) Hydro Generator (60KW)	200$ for 25 years of lifetime	100$
2) Diesel Generator (130kW)	13000$	6500$
3) Biogas Generator (20kW)	800$	400$
4) Solar PV(50kW)	20000$	10000$
5) Converters(50kW)	2700$	1350$
6) Batteries(2/string)	100$	50$

The costs of the equipments are assumed as the recent market prices. The batteries used in the simulation, has a nominal voltage 4V and nominal capacity of 1900 Ah. Moreover, the battery lifetime is assumed to be 4 years. The cost of the hydro power plant installation is not considered here because it depends on the site specific hydrograph and height of the dam. The proposed hydro generator has a monthly average flow rate of 24 L/s. However, all the system components are operated with a considerable efficiency.

VI. OPTIMIZATION OF THE SYSTEM

Optimization in HOMER, means to evaluate the system against different decision variables and pick up the economically feasible system whose components result in the lowest Net Present Cost. In our system, we have five decision variables. They can be written as the PV array size, the size of diesel generator, the size of biogas generator, the number of batteries in each string and the converter size [14]. We enter the values of each decision variable according to the figure 6.

	PV Array (kW)	Label (kW)	Label (kW)	S4KS25P (Strings)	Converter (kW)
1	25.000	0.00	0.00	1	1.00
2	50.000	65.00	10.00	2	2.00
3	75.000	130.00	20.00	3	50.00

Fig. 6. Search space consisting of 243 system configurations (3 X 3 X 3 X 3 X 3 = 243) in HOMER.

The total optimization results includes total initial cost, total net present cost, total cost of energy, fuel consumed annually and the generator operating hours. These data are processed to determine the sensitive result.

VII. SENSITIVITY RESULTS

According to the fuel price, interest rate and lifetime of the project, the most economic and optimized sensitive configuration is shown in figure 7 and figure 8.

						PV (kW)	Hydro (kW)	Label (kW)	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital
						75	61.2	130	20	2	50	$ 46,800

Fig. 7. The most economic design components with their total initial capital cost in HOMER.

Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Biomass (t)	Label (hrs)	Label (hrs)
65,823	$ 888,236	0.079	0.30	0.01	77,275	161	8,729	8,416

Fig. 8. Cost analysis data of the optimized system in HOMER.

The system has a 30% renewable fraction and only 1% capacity shortage. The total cost of energy (COE) is 0.079$/kWh which is slightly higher than the recent updated grid connected cost 0.060$/kWh. But this cost will be reduced within the payback period. Furthermore, the CO_2 emission penalty is taken into account, which is approximately 0.03$/ton. If we investigate the cost data, the initial capital cost is 46800$, the operating cost per year is 65823$ and total net present cost is 888236$. All the costs are plotted in figure-9.

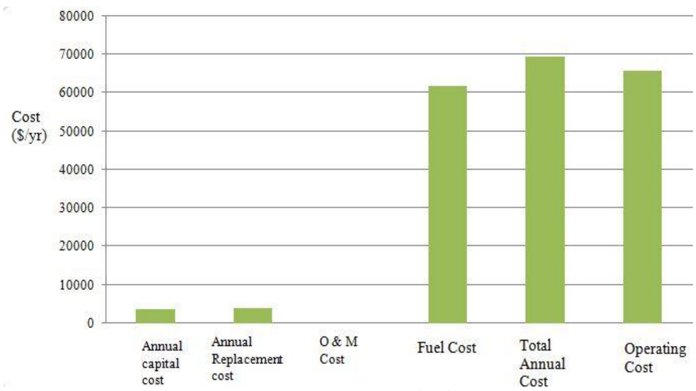

Fig. 9. Graphical representation of different costs.

The payback period can be calculated as follows:
Total Electricity Production (TEP) = 893183 kWh/yr
Cash inflow per year = TEP*COE = 893183 X 0. 079
= 70562$
Annual cost of the project = 69484$
Net Cash Inflow = 70562 – 69484 = 1078$
Initial cost (IC) = 46800$
Payback period = IC/1078 = 43 years

The greenhouse gases emitted from the hybrid system is presented in table III.

TABLE III. Estimation of greenhouse gas emissions from the proposed hybrid energy model.

Greenhouse Gases	Emissions(kg/yr)
CO_2	203517
CO	503
UHC	56
PM	38
SO_2	409
NO_x	4491
Total	209014

CO_2 emission from an equivalent diesel generator only system is 228936kg/yr. In our proposed system, there is about 11% decrease in CO_2 emission. Therefore, it must meet the emission penalties and decline the dependency on fossil-fuels. In addition, after serving the AC primary load there is about 5580kWh/yr excess energy. The system owner can sell this energy to grid to make money and to ensure the power security also.

VIII. Conclusion

The proposed hybrid energy system shows how the non-conventional energy resources in hill tract areas like Barkal can be utilized to serve the local community. This kind of model can also be implemented in other hill tract areas of Chittagong like Khagrachori and Bandarban. This model indicates that the people in hill tract areas can build stand alone system to meet their local demand without depending on the grid. Although the cost of energy is slightly high, the additional cost can be recovered through 43 years payback period. Operational cost is also negligible. However, the most important fact is, there is approximately 11% decrease in GHG emission which indicates that the model is environment friendly. It can motivate the investigation of other models of similar kinds which can produce GHG emission free energy.

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