DEVELOPMENT OF HYBRID ENERGY SYSTEM FOR OFF-GRID REMOTE AREA

Ankit Bhatt[1], M. P. Sharma[2], Ishan Kaushik[3]

[1]*Assistant Professor, Department of Electrical and Electronics Engineering, G.E.U., Dehradun (India)*

[2]*Associate Professor, Alternate Hydro Energy Center, I.I.T. Roorkee (India)*

[3]*Department of Electrical and Electronics Engineering, G.E.U., Dehradun (India)*

ABSTRACT

Renewable energy can be seen as one of the important prospect of today's research, as it enlightens the lives of millions of people by fulfilling multiple necessities of their daily life and simultaneously overcomes the ill effects caused by the non-renewable sources. Present study is based on the development of a hybrid energy system for supplying the load demand of 5 unelectrified villages of Almora district in Uttarakhand, India with the help of the available resources of the area such as solar, hydro, biomass and biogas with the addition of diesel generator by using HOMER software. HOMER software is used to analyze the best configuration among a set of systems for electricity requirement for 254 households whose total population is 965. The system is designed to fulfill the daily and the peak demand of each day. From the optimization results, it is found that an optimum HES comprising of 5 kW SPV, 20.5 kW hydro turbines, 5 kW biogas generators, 15 kW biomass gasifier, 5kW diesel generators and 10kW of converter with 20 storage batteries, has been found suitable for the study area. The COE and renewable fraction are 0.079 $/kWh as minimum and 81% as maximum respectively.

Keywords: Cost of Energy (COE), Hybrid Energy System (HES), HOMER, Net Present Cost (NPC), Renewable Fraction (RF).

I. INTRODUCTION

Rural electrification plays a vital role in electrifying unelectrified rural households. In India, more than 200 million people in rural areas do not have access to grid electricity. Over 80,000 villages remain to be un-electrified, as it is difficult to electrify them by grid electricity due to high capital cost, poor voltage regulation and low load factor [1]. Therefore the electrification of remote and non-electrified areas is a big challenge which requires cost effective approaches that can supply power to these areas.

The off-grid remote areas are mostly rich in renewable energy resources like hydro, solar, biomass, biogas, wind etc. Several researchers explained the techno economic viability of biogas plants in rural areas [2, 3]. Hybrid Energy System (HES) are found cost effective solutions to energize such areas and can remove the infeasibility related to a single energy source by taking advantages of all the available resources [4]. Due to the intermittent nature of most of the renewable energy sources, conditions may arise, when the demand exceeds the generation. The use of battery, as storage may improve the power quality and can store the excess energy required during the peak time. DG can be an another solution to such problem as it can meet the demand by manipulating the DG operation that can improve battery life and charge it if a lower set point is reached. The system size can also be reduced by effectively selecting suitable combination of generators [5]. A proper tuning of DG and battery storage may also help to reduce the fuel consumption [6, 7].

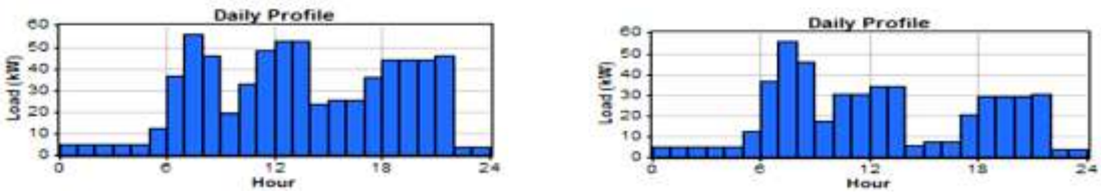
The present paper deals with the development of HES for five unelectrified villages in the Almora District of Uttarakhand, India. The area is rich in renewable resources such as solar, hydro, biomass, biogas etc. The paper covers the assessment of demand and potential of available renewable energy. Optimization of cost effective HES for the area has been carried out using HOMER [8-12]. Based on load following strategy, HOMER found the best combination of components for the development of HES in terms of NPC (Net Present Cost) and COE (Cost of Energy) for the study area.

II. PROFILE OF THE STUDY AREA

Uttarakhand (formerly Uttaranchal), a Northern State of India, has a total area of 53,484 km², of which 93% is mountainous and 65% is covered by forest [13]. There are 13 districts in Uttarakhand grouped into two divisions: Kumaon and Garhwal. Almora a district of Kumaun division is located at 29.62°N 79.67°E and consists of 11 blocks. The block consists of 227 villages with a population of 60,620. Out of 227 villages, 5 un-electrified villages named as: (1) Seli (2) Tapari (3) Sirani (4) Nailpar (5) Chimkholi, are chosen for the present study. These villages have 254 households and 11 hamlets with a population of 965.

III. LOAD ASSESSMENT

The energy demand was estimated by considering the household loads (light, TV, fan, radio), commercial load (light and fan for shops, flour mill), industry load (saw mill or paddy huller) and community load (post office, gram panchayat office, hospital, school, street light and water pumping). The total energy requirement of the area based on summer (April-September) and winter (October-March) seasons is 675.78kWh/day with peak load of 55.49 kW and 486.18kWh/day with peak load of 55.49 kW respectively. "Fig. 1" shows daily profile of load for summer and winter season respectively.



(a) summer season (b) winter season

Fig. 1: Daily Profile of Load of the Area

IV. RESOURCE ASSESSMENTS

In this area, solar, hydro and biomass are the major resources and wind as a minor. The estimation of potential of available renewable energy resources as well as the energy demand of the study area is carried out as follow:

4.1 Micro Hydro Power (MHP)

Micro Hydro Power (MHP) up to 100 kW is selected, as it plays an important role in meeting the energy needs of domestic, commercial, industrial and community through mechanical power generated by hydro turbines. Annual energy from hydro in kWh is determined by (1)

$$MHP = 9.81 \times Q \times \rho \times H \times 8760 \ (kWh / year) \quad (1)$$

where Q is discharge of water, ρ is water density and H is required head.

Tapari is considered as one of the feasible site selected due to the presence of significant amount of hydro potential. For this site, the average discharge (Q) of 0.116 m^3/sec and head (H) of 22m is considered. The total annual potential is about 208MWh/yr. "Fig. 2" shows the hydro resource availability throughout the year with minimum stream flow of 97 L/s in the month of January and December and the maximum flow of 146 L/s in the month of July.

4.2 Solar Energy

Solar radiation data are taken from HOMER software for the study area having 29.34$^{/}$ 34.09$^{//}$ N Latitude and 79.54$^{/}$ 01.36$^{//}$ E Longitude. "Table 1" shows daily and monthly global solar radiations [14], from which it is clear that May has the maximum solar radiation of about 229kWh/m^2 whereas December has minimum of about 111kWh/m^2. Average solar radiation of the year is about 162kWh/m^2. Total solar energy potential of the area is found about 1948 kWh/m^2/year.

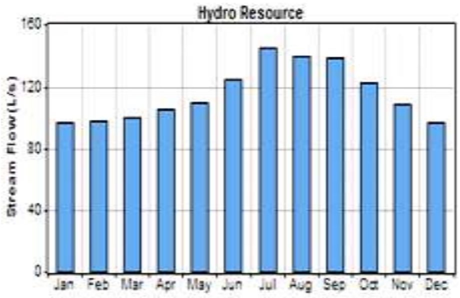


Fig. 2: Hydro Resource Availability

Table 1: Daily and Monthly Global Solar Radiation Data

Month	Clearness index	Daily Total Radiation (kWh/m^2)	Monthly Total Radiation (kWh/m^2)
January	0.662	3.966	122.95
February	0.651	4.694	131.43
March	0.662	5.827	180.64
April	0.669	6.848	205.44
May	0.665	7.38	228.78
June	0.586	6.684	200.52
July	0.463	5.201	161.23
August	0.471	4.952	153.51
September	0.566	5.242	157.26
October	0.7	5.364	166.28
November	0.687	4.292	128.76
December	0.641	3.587	111.19
Annual			1948

4.3 Biogas Energy

To assess the biogas potential, cows, buffalos, goat, horses and mules are considered. Based upon the survey, the total population of cattle from 5 villages is found as 1920. The total biogas potential was calculated on the basis of dung collection efficiency of 70%, biogas yield per kg of wet dung as 0.036 m^3/kg, calorific value of biogas as 4700 kcal/m^3, conversion factor of 860 [15], generator efficiency 95% and engine efficiency as 28%. The gas production is based on the production of biogas/kg cattle dung as 0.036m^3/kg while the energy available/day is calculated by the (2):

$$\text{Energy available (kWh/day)} = (\text{Total Gas Yield } (m^3) * 4700 * 0.28 * 0.95)/860 \quad (2)$$

The biogas production from the dung is evaluated based on the assumption that 10 kg/day dung will be available from cow/horse/mule, 15 kg/day from buffaloes and 1kg/day from goat. The available cattle dung from the study area is about 10481 kg/day. Therefore, the biogas availability in the study area is about 265m^3/day; from which about 385 kWh/day of energy can be produced. About 232m^3/day is proposed to be made available for cooking while the balance 47 kWh/day generated by using DG set for 8hrs/day can be converted for electricity. Biogas for cooking is based on gas requirement of $0.24m^3$/person/day [16]. This comes out as $232m^3$/day.

4.4 Biomass Energy

The biomass potential assessment is based on agriculture and forest waste available in the area. "Table 2" gives the total forest area of all the 5 villages with annual energy from biomass i.e. crop and forest practices. About 202.39 Ton/yr of biomass waste and 11.76 Ton/yr of foliage is available with a total of 214.15 Ton/yr equivalent to 157.59kWh/day.

For the above table, it is assumed that from the total foliage, only 60% is used for biomass and the electricity generated can be calculated by (3).

Total available energy for electricity (kWh/yr) = (Total fuelwood available (T/yr) × 1000 × CV_{BM} × η_{BM})/(365×860×(operating-hrs/day))[17] (3)

Table 2: Village wise Forest Area and available Energy

Village name	Forest Area (ha)	Total Foliage available @(160 kg/ha/yr)	60% of foliage available for use as biomass (T/yr)	Total Available biomass (Crop + Forest) (T/yr)	Total available energy for electricity (kWh/day)
Nailpar	9.37	1499.2	0.9		
Seli	29.55	4728	2.84		
Tapari	9.35	1496	0.9		
Sirani	47.37	7579.2	4.55		
Chimkholi	26.83	4292.8	2.58		
Total	122.47	19595.2	11.76	214.15	157.59

From the above "Table 2", it is clear that crop and forest provide about 202 T/yr and 12T/yr biomass respectively. For calculating biomass available from forest, it is assumed that more than 160kg/ha/yr foliage is available from the forest [18]. Total available biomass from crop and forest, is about 214 T/yr. To calculate total energy available for electricity, the calorific value (CV_{BM}) is considered as 1100, conversion efficiency (η_{BM}) as 21% and operating hours/day as 10 hrs. So the total electricity generated is about 158kWh/day.

V. CONFIGURATION OF THE PROPOSED HYBRID ENERGY SYSTEM COMPONENTS

The major components of hybrid energy system are SPV, MHP, biogas generator, gasifier based diesel generator, batteries and converters. For economic analysis, capital costs, replacement and O&M costs of each unit is defined in HOMER software in order to simulate the system. "Table 3" shows different economic parameters of system components used for the development of HES.

The sizes of SPV module are considered as 0, 5, 10, 15, 20 and 30 kW. Life of 20 years and derating factor of 90% are considered with no tracking system. For micro hydro turbine, head of 22m and design flow of 100 lps, turbine efficiency as 95% and life 25 years, are considered. Size of biogas generator is considered as 5 kW and gasifier as 15 kW. Operating hours for biogas generator is taken as 15000 hrs and minimum load ratio as 30%. Sizes of diesel generator are considered as 0, 5, 10, 15, 20, 25, 30, 40 and 50kW. Surrette 6CS25P battery is considered whose manufacturer is Rolls/Surrette.

VI. RESULT AND DISCUSSION

The HES given by HOMER is shown in "Fig. 3". "Table 4" shows the optimized results of hybrid energy system. It is found that several configurations are possible on the basis of minimum net present cost (N.P.C.) and cost of energy (C.O.E.).Result shows that the total cost of first configuration i.e. MHP-Diesel-Biogas-Gasifier comes out as 210,779 $ with COE of 0.078$/kWh, renewable fraction as 78% and emissions as 263,472 kg/yr (carbon dioxide) whereas in second configuration i.e. PV-MHP-Diesel-Biogas-Gasifier, NPC is 215,181 $ with COE 0.079 $/kWh, renewable fraction as 81% and emissions as 247,787 kg/yr (carbon dioxide). This shows that both the configurations have almost same COE but second configuration has greater renewable fraction and less carbon emissions. So second configuration is considered as the best configuration having system specifications as 5 kW SPV, 20.5 kW MHP, 5 kW diesel generator, 5 kW biogas generator, 15 kW gasifier and 20 storage batteries in addition to 10 kW capacity converter.

Table3: Economic Analysis of System Components

S. No.	Components	Capital Cost	Replacement Cost	O & M Cost
1	Solar Photovoltaic (per kW)	6000 $	5000 $	10 $/yr
2	Micro Hydro Turbine (per kW)	1400 $	1200 $	135 $/yr
3	Biogas Generator (per kW)	650 $	600 $	0.025 $/hr
4	Gasifier (per kW)	215 $	210 $	0.05 $/hr
5	Diesel Generator (per kW)	1000 $	900 $	0.02 $/hr
6	Battery	1000 $	800 $	30 $/yr
7	Converter	700 $	550 $	100 /yr

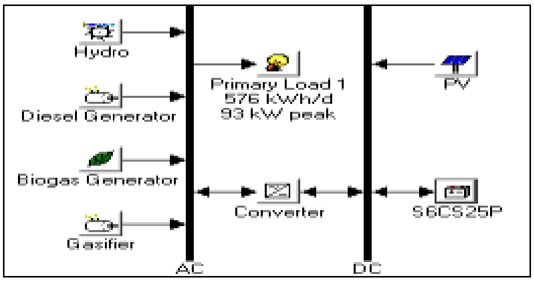


Fig 3: complete hybrid energy system

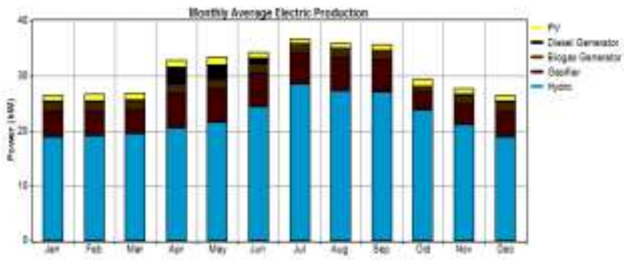


Fig. 4: electricity production by different components of HES

Table 4: Results of Optimization of Hybrid Energy System for Study Area

	PV (kW)	Hydro (kW)	Diese (kW)	Bio (kW)	Gasi (kW)	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	'roducer Ga (kg)	Biomass (t)	Diese (hrs)	Bio (hrs)	Gasi (hrs)
		20.5	10	5	15	20	5	$ 52,340	12,394	$ 210,779	0.078	0.78	4,577	172,703	386	1,975	2,920	3,650
	5	20.5	5	5	15	20	10	$ 80,840	10,509	$ 215,181	0.079	0.81	2,259	166,122	381	1,993	2,920	3,650
		20.5	15	5	15			$ 33,840	15,166	$ 227,716	0.084	0.78	8,012	153,282	381	2,615	2,920	3,650
	5	20.5	15	5	15		5	$ 67,340	14,784	$ 256,334	0.095	0.80	6,939	145,456	367	2,405	2,920	3,650
	10	20.5		5	15	40	20	$ 132,840	10,502	$ 267,093	0.099	0.84		159,200	367		2,920	3,650
	30		25	5	15	40	20	$ 276,440	53,654	$ 962,322	0.355	0.32	35,142	198,949	398	4,911	2,920	3,650
			30	5	15	40	10	$ 94,440	70,452	$ 995,049	0.367	0.06	52,495	203,790	398	5,622	2,920	3,650
			40	5	15			$ 57,440	97,361	$ 1,302,035	0.480	0.06	69,684	196,264	398	8,760	2,920	3,650
	5		40	5	15		5	$ 90,940	96,675	$ 1,326,769	0.489	0.10	68,007	192,184	398	8,760	2,920	3,650

From "Fig. 4" it is observed that the share of electricity from SPV is 9,899 kWh/yr (4%), 197,930 kWh/yr from MHP (73%), 5,846kWh/yr from diesel generator (2%), 13,992kWh/yr from biogas generator (5%) and 44,625kWh/yr from gasifier(16% of the total). Monthly average electricity production from different resources is shown in "Fig. 4". Minimum average production months are December, January, February and March with 26 kW and maximum average production month is July with 37 kW.

The paper signifies the involvement of various available energy resources and their role in the development of HES for a remote area. An optimum HES consisting of 5 kW SPV, 20.5 kW hydro turbines, 5 kW biogas generators, 15 kW biomass gasifier, 5 kW diesel generators and 10 kW of converter with 20 storage batteries, has been taken for electrification of 5 villages. Optimization and simulation has been done using HOMER software. The results indicate that the proposed HES offer the most economically feasible solution for the study area. The COE of the optimal HES comes around 0.079$/kWh with NPC 215,181$ as minimum and the renewable energy fraction accounts for about 81% of the total generation with carbon emissions of 247,787kg/yr which is found to be the most economical solution.

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