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Design and Development of Solar Photovoltaic based Hybrid System for Remote Applications

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Abstract: **In today's scenario, renewable energy based applications are increasing due to the global warming issue and increase in the prices of fossil fuels. Renewable energy sources (RES) like sun, biomass, air, water etc. are environmental friendly and have plenty of potential that can be utilized in power generation. However, RES have a problem of intermittent in nature that can be conquered presently by combining RES known as hybrid system that can provide the reliable, economic and environment friendly electricity. One of the major concerns in this hybrid system is to optimize the size of components of hybrid system in order to fulfill the load requirements in minimum cost. Keeping in view of the above constraints, a RES based hybrid system for the rural location of Haryana state in India have been developed and economically compared in this paper. Out of different configurations, solar/biomass with biogas based hybrid system has been found most economical in view of least net present cost (NPC) and cost of energy (COE).**

Keywords: Solar Photovoltaic, Biogas, Biomass, Off grid, HOMER.

I. INTRODUCTION

In today's scenario, the world is facing four major challenges viz. 'Energy security', 'Climate change' 'Drinking water', and 'poverty'. India, a highly populated nation in the world and therefore its energy requirement is increasing with time. In addition, large portion of energy of the nation is fulfilled by conventional energy sources owed to greenhouse gas (GHG) emission. These issues can be conquering by using renewable energy sources (RES) that offers environmental friendly energy. Also, Government of India (GOI) is promoting RES based energy generation by initiating several schemes like providing subsidies on green and clean energy, Jawaharlal Nehru solar mission etc. [1]. The contribution of RES and conventional sources in the total installed capacity (349288MW) in India as of 31.12.2018 has been demonstrated in Figure-1.

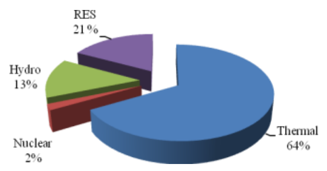

Figure-1: Distribution of different energy sources to the total installed capacity in India [2]

II. METHODOLOGY

The methodology used in this paper involves brief description of selected site, evaluation of the potential of RES, estimation of hourly load demand, and simulation and optimization, which are illustrated in the forthcoming sections.

i) Study area

Khanpur-Kalan, a village (latitude of 29.15° N and longitude of 76.75° E) placed in Gohana Tehsil in Haryana state, India included for the proposed study. Based on census 2011, this region has total population of 12544 with total households of 2014. Presently, a health centre situated in this village is not connected to the grid supply. Hence it is necessary to evolve an optimal hybrid system in order to provide regular supply of electricity. Further, the general information of the given area is mentioned in Table-1[23].

Table-1: Study Area Illustration

Description	General Information
Country, State, District, Block	India, Haryana, Sonipat, Gohana
Village	Khanpur-Kalan
Occupants	12544
Households	2014
Latitude	29.15° N
Longitude	76.75° E

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Hybrid system combining two or more than two RES may provide the economical electrical energy due to intermittent nature of RES. Several analyses have been reported in literature that hybrid system is more attractive than single energy system in view of economy, reliability, sizing etc. [3-7]. Additionally, the capital cost of renewable energy based system is relatively higher than traditional energy system. Therefore, optimal sizing is also topmost requirements in order to meet the energy requirements in economic manner. In this direction, several investigations have been carried out by utilizing various simulation software and methods [8-22].

The objective of the present work is to develop a hybrid system including solar photovoltaic (SPV)/biomass generator (BMG) along with biogas generator (BG) system for the health centre of rural location of Haryana state in India. Utilizing HOMER (Hybrid Optimization Model for Electrical Renewable), different types of renewable energy based off grid/grid connected hybrid system have been developed and compared in view of least NPC and COE.

ii) Evaluation of Potential of RES

In order to compute the potential, an extensive survey is carried out and data related to different RES involves solar radiation from sun, biogas from cattle dung and biomass from crop residues is obtained. The potential of RES of the given area is illustrated in Table 2.

Table-2: RES Potential at Study Area

RES	Potential
Daily Solar irradiance	5.26 kWh/m^2/day
Biomass (Crop Residue)	1418.41935 tonne/year
Biogas	1152.0828 m^3/day

From Table-2, it has been found that the study area has huge potential of RES that can be used to fulfill the energy needs of the study area.

Solar energy can be used to generate electricity via SPV technology and the formula for computing power of SPV system (P_{PV} (t) is as follows [24]:

$$P_{PV}(t) = R_{PV} \times DF \times \frac{Q_{PV}(t)}{Q_{PV,STC}} \quad (1)$$

Where, R_{PV} is rated capacity of SPV array at standard test condition (STC); $Q_{PV}(t)$ is solar radiation incident on SPV array in kW/m^2;$Q_{PV,STC}$ denotes the solar radiation at STC (1 kW/m^2). DF stands derating factor of SPV array.

Further, the power from biomass generator (BMG) system (P_M (t)) is calculated as:

$$P_M(t) = \frac{Q_{AM} \times CV_M \times \eta_M \times 1000}{365 \times 860 \times H_M} \quad (2)$$

Where, Q_{AM} stands yearly potential of biomass (tons/year), CV_M denotes biomass calorific value (kcal/kg), η_M denotes conversion efficiency and H_M denotes operating hours in a day of BMG system.

The output power generated by BG system (P_G (t))is computed as [25]:

$$P_G(t) = \frac{A \times C \times \eta}{860 \times O_H} \quad (3)$$

Where, A stands for biogas availability/day (m^3/day); C defines biogas calorific value (kcal/m^3);η denotes conversion efficiency from biogas to electricity; O_H stands operating hours of BG system/day.

iii) Hourly Load Demand Estimation

The hourly load demand of the specified study region is established on the facts provided by local personnel. In this study, two seasons viz. summer season and winter season have been taken into consideration the variation of temperature on energy consumption pattern. Summer season includes April to September and winter season involves October to March. Moreover, the daily load profile of both the seasons on everyday basis is depicted in Figure- 2.

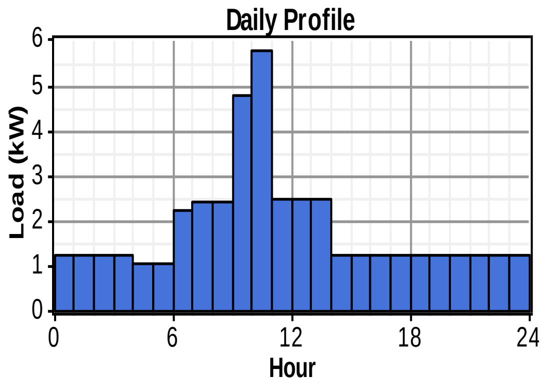

Figure-2(i): Load demand of study area on daily basis in summer

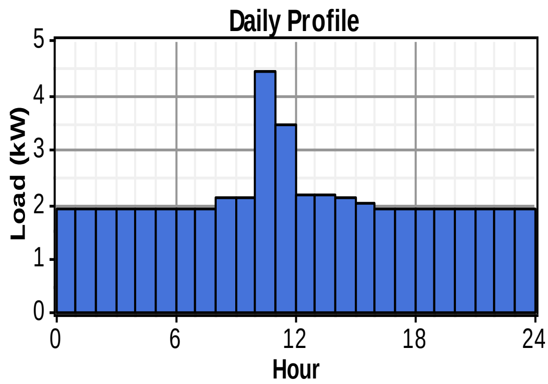

Figure-2 (ii): Load demand of study area on daily basis in winter season

iv) Optimization Methodology

In this study, for simulation and optimization purpose, HOMER software is employed. It simulates various realistic configurations and ranked them in view of least NPC [26].

In the present work, different generators such as SPV system, BMG and BG system along with battery and converter have been considered and their techno-economic inputs such as size, cost, lifetime etc. are illustrated in Table-3.

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III. RESULTS AND DISCUSSION

Based on the availability of RES, different configurations of RES in off grid mode have been identified for the selected site is as under.

1. Configuration I: SPV/Biomass/Battery
2. Configuration II: SPV/Biogas/Battery
3. Configuration III: SPV/Biomass/ Biogas/Battery

Further, some configurations in grid connected mode have also been selected are as follows:

4. Configuration IV: SPV/Biomass/Biogas
5. Configuration V: SPV/Biomass/Biogas/Battery

Among all configurations, most feasible combination in view of techno-economic analysis has been selected. The techno-economic results of the chosen configurations are demonstrated in Table-4.

From Table-4, it is concluded that the grid connected hybrid SPV/BMG/BG together with battery system has minimum NPC and COE. The proposed hybrid system is demonstrated in Figure-4.

Table-3: Techno-Economic Input Database [27]

S. No.	Renewable energy technology	Capacity considered	Capital Cost ($/kW)	Replacement cost ($/kW)	Operation and maintenance (O&M) cost	Lifespan
1	SPV system	1kW	1333	1333	$ 26/year	25 years
2	BG system	1kW	660	450	$ 0.01/kW /hour	20000 hours
3	BMG system	1kW	1033	750	$ 0.01//kW/ hour	15000 hours
4	Battery (VISION 6FM200D)	12V, 200 Ah	284	220	$6/battery/year	5 years/battery
5	Converter	1kW	117	117	$3/kW /year	10 years

Table-4: Technical and Economic parameters of selected configurations

Description	Parameter	Configuration I	Configuration II	Configuration III	Configuration IV	Configuration V
System rating	SPV (kW)	5	5	4	3	3
	Biogas generator (kW)	-	2	2	2	2
	Biomass generator (kW)	2	-	1	3	2
	Battery (No.)	7	7	4	-	1
	Converter (kW)	6	6	5	2	3
	Grid (kW)	-	-	-	1	1
	NPC ($)	37273	28133	26717	23855	23238
Economic parameters	Total annualized capital cost ($)	835	893	736	677	627
	Total annual replacement cost ($)	504	915	455	301	310
	Total O & M cost ($)	331	324	295	161	286
	Total fuel cost ($)	553	829	618	741	629
	TAC ($)	2201	2916	2090	1866	1818
	COE ($/kWh)	0.168	0.127	0.120	0.107	0.105

From Table-4, it is concluded that the grid connected hybrid SPV/BMG/BG together with battery system has minimum NPC and COE. The proposed hybrid system is demonstrated in Figure-4.

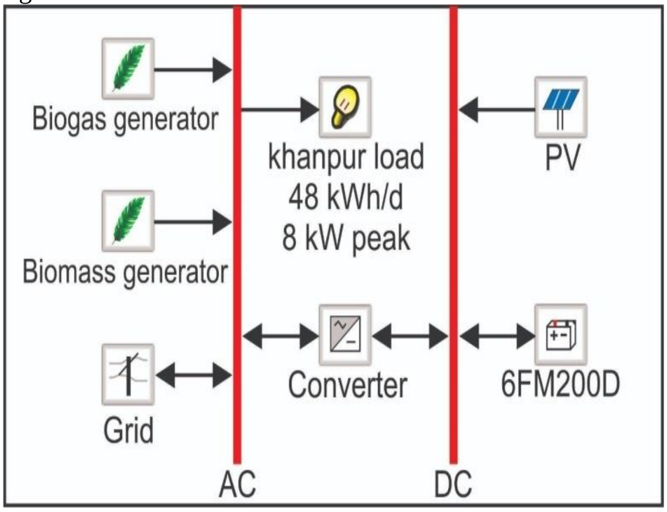

Figure-4: SPV/BMG/BG/Battery/Hybrid System

Further, the monthly average energy generation by the proposed system is mention in Figure-5.

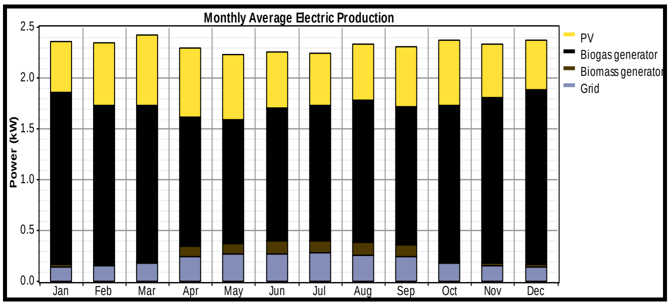

Figure-5: Monthly average energy generation of hybrid SPV/BMG/BG/ battery system

I. CONCLUSION

In this study, design of hybrid system consisting of SPV/BMG/BG with battery system is carried out for providing reliable electrical supply to health centre of the rural location of Haryana state, India. In this context, five configurations have been developed and compared in view of least NPC and COE. The proposed hybrid system comprises of 3 kW SPV; 2 kW BG system; 2 kW BMG generator with 1 no. of battery and 3 kW converter. The COE of the proposed system is $ 0.105 (i.e. INR 7.20 per unit), which is quiet economical.

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