ISSN: 2321-8169
450 – 456

Design of Solar-Biomass-Biogas Based Hybrid System for Rural Electrification with Environmental Benefits

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Abstract:- After so many years of independence, India still has many villages that are not electrified or grid supply is rarely available. However, there is a lot of scope of tapping the renewable energy resources for power generation at these locations. In the present investigation, optimal design of hybrid power system by utilizing locally available renewable energy resources like solar, biomass and biogas has been carried out and presented. Four different configurations have been compared on the basis of techno-economic evaluation.The proposed model has least net present cost (NPC), cost of energy (COE) and negligible green house gas emission.

Keywords—*solar photovoltaic; biomass; biogas; HOMER; green house gas emission.*

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I. INTRODUCTION

Rural electrification plays an essential role in escalation of social and economic status of rural people and ultimately the growth of the nation. In India, most of the population resides in remote rural areas and the majority of them do not have access of grid electricity and extension of the grid is not feasible in such areas. Further, those rural areas are connected to grid get limited supplies of about eight to ten hours daily. Furthermore, access of electricity through diesel generator is not a feasible solution due to its fuel, operation and maintenance cost and greenhouse gas emission etc. Therefore, utilizing locally available renewable energy sources (RES) like solar, wind, biomass, small hydro etc. for power generation might be a good alternative to meet electricity needs of rural people. Moreover, Government of India (GOI) is also making efforts for encouraging renewable energy sources by providing various schemes, incentives, etc. and also fixed a goal of adding up 175 GW power generations through RES by 2022 [1].

However, renewable energy sources are stochastic in nature, so combining two or more sources called hybrid system is more favourable and reliable solution. In order to achieve cost-effective and reliable power system, optimal sizing is an important issue. A lot of work has been done in this direction by using various simulation and optimization software and techniques [2-26].

Keeping in view of all above, the main objective of the present study is to design an optimal hybrid power system via exploiting and utilizing locally available RES viz. Solar, biomass and biogas for rural villages of Sonipat district of Haryana state, India. This hybrid power system will able to provide a continuous supply to rural community and other future requirements. HOMER (Hybrid Optimization Model for Electrical Renewable) software has been employed for selecting most feasible system in terms of least net present cost. In addition, techno-economic analysis with greenhouse gas emission analysis has also been carried out.

II. HYBRID SYSTEM MODELLING METHODOLOGY

A systematized modelling methodology is crucial step for the design and development of an optimal hybrid system for a rural area as it makes sure continuous and reliable electricity to the rural community. In the present investigation, a modeling methodology contains site identification, electrical load estimation, renewable energy sources potential evaluation and optimization method which are illustrated in the subsequent sections

A. Site Identification

A group of four villages Ganwari, Kasanda, Kasandi and Sargathal situated in Gohana Tehsil of Sonipat District, Haryana State in India has been considered in the present work. Based on extensive survey, it has been found that these villages have 105 un-electrified households and no street lights. The general particulars of the study area have been demonstrated in Table I.

Table I: Particulars of study area [27,28]

Description	General particulars			
Country, State	India, Haryana			
District, Sub-division	Sonipat, Gohana			
Village	Ganwari	Kasanda	Kasandi	Sargthal
Latitude	29.135° N	29.126° N	29.139° N	29.00° N
Longitude	76.77° E	76.83° E	76.838° E	77.01° E
Population	3677	2077	2921	3435
Total households	700	399	568	634
Number of unelectrified households	20	43	16	26

B.Estimation of Electrical Load Demand

The electrical load demand has been computed on the basis of present and future load demand of the rural community. The electrical load demand of the considered area has been classified as residential, commercial and community. A residential load involves LED, fan, TV, radio, mobile charger, heater and water pump. The commercial load comprised of shops and flour mill. School, health centre, veterinary hospital and street lights are considered in community load.Further, the description of the electrical load for the selected area alongwith their energy saving appliances and rating is presented in Table II.

Table II: Description of different loads alongwith appliances rating

Load	Appliances	Rating (W)	Quantity/household or village
Residential load	LED	12 W	3@ each household
	Fan	45 W	3@ each household
	TV	70 W	1@ each household
	Music system	25 W	1@ each household
	Mobile charger	6 W	1@ each household
	Water pump	500 W	1@ each household
	Heater	1000 W	1@ each household
Commercial load			
Shop	LED	12 W	1@ each village
	Fan	45 W	1@ each village
Flourmill		3750 W	1@ each village
Community load			
Health centre	LED	12 W	2 @ each village
	Fan	45 W	2 @ each village
	Refrigerator	200W	1@ each village
	Water heater	1000W	1@ each village
Veterinary hospital	LED	12W	2 @ each village
	Fan	45 W	2@ each village
	Refrigerator	200 W	1 @ each village
School	LED	12 W	10 @ each village
	Fan	45 W	10 @ each village
Street lights	LED	30 W	40 @ each village

The electrical load demand of given area during summer and winter season has been estimated as 727.7 kWh/day and 453.07 kWh/day respectively. Further, the hourly load profile of summer and winter season has been presented in Fig.1.

ISSN: 2321-8169
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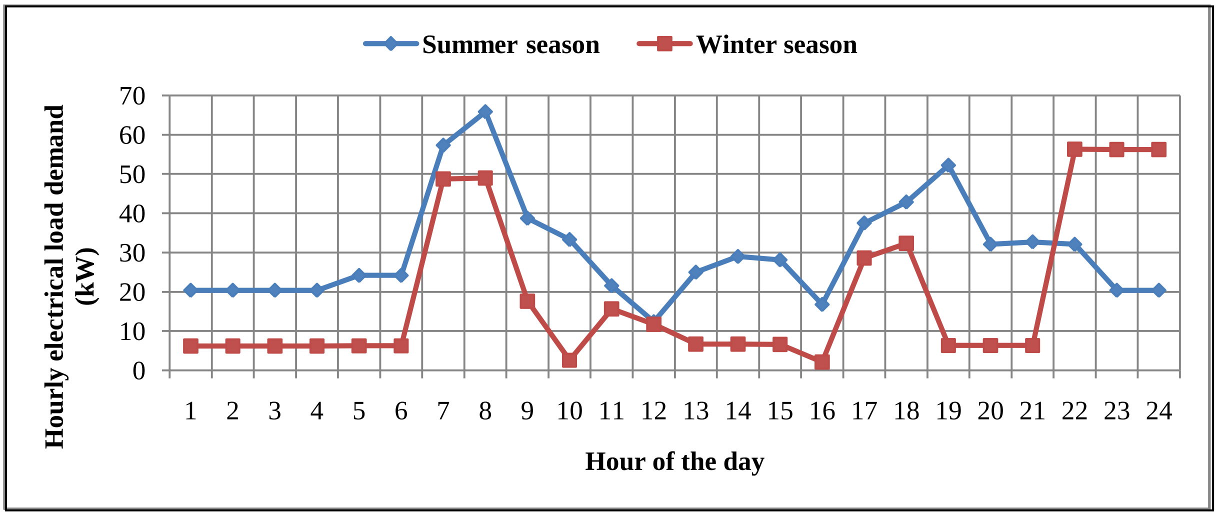

Fig. 1. Hourly load profile during summer and winter season of selected site

C. Potential Assessment of Renewable Energy Resource

Based on extensive survey and collected data, the potential of RES viz. solar, biomass and biogas has been assessed and demonstrated in Table III.

Table III: Potential of different renewable energy sources at selected site

Sr. No.	**Village name**	**Biomass (tons/year)**	**Biogas (m^3/day)**	**Solar radiation (kWh/m^2/day)**
1	Ganwari	2454.99	1023.84	5.146
2	Kasanda	3210.03	287.22	5.216
3	Kasandi	5143.77	558.24	5.22
4	Sargthal	4811.31	1009.58	5.142
Total		15620.1	2878.88	5.22

A biomass of 15620.1 tons/year from crop residues and biogas of 2878.88 m^3/day from cattle dung has been computed in the selected area. The annual daily average solar radiation of 5.22 kWh/m^2/day is available in the study area. It has been observed that a large amount of renewable energy is available in the study area that can be used to fulfil the energy needs. In addition, biogas can also be utilized to meet the cooking energy needs of the given area.

D. Simulation and Optimization Technique

In the present work, Hybrid Optimization Model for Electrical Renewable (HOMER) software has been employed for simulation and optimization purpose. It simulates various feasible system configurations of considered system in order to find out best possible configurations and ranks them on the basis of least net present cost (NPC) [29]. Further, the technical and economical input parameters like capital cost, replacement cost, operation and maintenance (O &M) cost, size, lifetime etc. of hybrid system components are given in Table IV.

Table IV: Technical and economical input parameters of proposed hybrid system components [24]

Parameters	**SPV System**	**Biomass generator**	**Biogas generator**	**Battery**	**Converter**
Capital cost	950 $/kW	901 $/kW	751 $/kW	235 $/kW	171 $/kW
Replacement cost	900 $/ kW	750 $/kW	550 $/kW	190 $/kW	171 $/kW
Operation and maintenance cost	1 $/kW/year	0.01 $/kW/hour	0.01 $/kW/hour	2 $/kW/year	4 $/kW/year
Lifetime	25 years	15000 hours	20000 hours	4 years	20 years
Fuel cost	--	$ 15/ tone	3 $/litre	--	--
Size to be considered	0-100	0-100	0-100	0-100	0-100
Project life	25 years				
Annual rate of interest	10 %				
Operating reserve as % of hourly load	10%				
Operating reserve as % of solar power	25%				
Dispatch strategy	Cycle charging with 80% setpoint state of charge				

III.SIMULATION RESULTS AND DISCUSSIONS

Based on the locally available RES in the selected area and numerous input parameters, constraints, etc. a hybrid model has been developed using HOMER software. After hourly simulation for a year, four feasible configurations has been obtained and their results are given in Table V.

The most feasible hybrid system has been selected on the basis of least NPC and COE. The schematic diagram of hybrid SPV/biomass/biogas along with battery system has been shown in Fig.2.

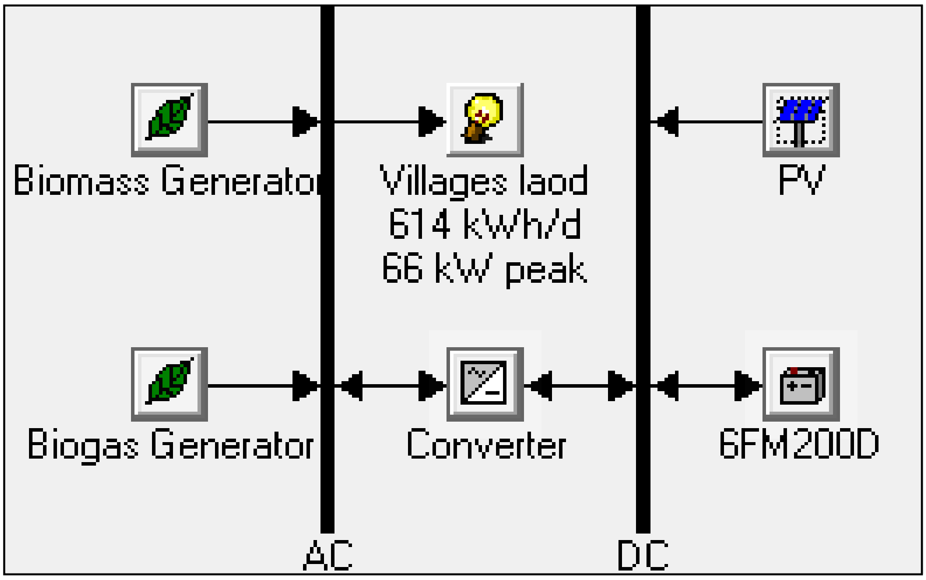

Fig.2. Schematic diagram of proposed hybrid SPV/biomass/biogas with battery system

Table V: Results of feasible system configurations

Description	Parameter	SPV/biomass/ biogas generator with battery	Biomass/ biogas generator with battery	Biomass/ biogas generator without battery	SPV/biomass/ biogas generator without battery
System rating	SPV (kW)	18	--	--	1
	Biomass generator (kW)	20	20	25	25
	Biogas generator (kW)	35	40	50	50
	Battery (kWh)	48	45.6	--	--
	Converter (kW)	17	16	--	1
Economic	Total capital cost ($)	68094	54397	60075	61142
	Total NPC ($)	202178	204857	237213	238165
	Total annualized capital cost ($)	7502	5993	6618	6736
	Total annual replacement cost ($)	9549	10724	12786	12788
	Total O & M cost ($)	2506	2882	3606	3607
	Total fuel cost ($)	2923	3280	3395	3380
	Total annualized cost ($)	22274	22569	26133	26238
	Cost of energy ($/kWh)	0.099	0.101	0.117	0.117
Electrical power production	SPV array (kWh/year)	29962 (13%)	--	--	1665 (1%)
	Biomass generator (kWh/year)	86948 (38%)	83814 (37%)	94560 (42%)	94068 (41%)
	Biogas generator (kWh/year)	114736 (50%)	142115 (63%)	133206 (58%)	132555 (58 %)
	Total electrical power production (kWh/year)	231647 (100%)	225929 (100 %)	227765 (100%)	228287 (100%)
	Renewable fraction (%)	100	100	100	100
	Unmet electric load (kWh/year)	0.000126 (0%)	0.00 (0%)	0.00 (0%)	0.00232 (0%)
	Excess electricity (kWh/year)	3591 (1.15 %)	0.00165 (0%)	3658 (1.61%)	4052 (1.78%)
	Capacity shortage (kWh/year)	85 (0.04%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
Green house gas emission	Carbon dioxide (CO_2) emission (tonnes/year)	0.0337	0.0378	0.0392	0.039
	Carbon monoxide (CO) emission (tonnes/year)	0.00127	0.00142	0.00147	0.00146
	Unburned hydrocarbons (UHC)	0.00014	0.000157	0.000163	0.000162
	Particular matter (PM) (tonnes/year)	0.0000955	0.000107	0.000111	0.00011
	Sulphur oxide (SO_x) (tonnes/year)	0	0	0	0
	Nitrogen oxide (NO_x) (tonnes/year)	0.0113	0.0127	0.0131	0.0131

From Table V, it has been revealed that Hybrid SPV/biomass/biogas with battery storage model has least net present cost, cost of energy and greenhouse gas emission.

IV. CONCLUSION

In the present investigation, optimal design of standalone hybrid solar photovoltaic/biomass/biogas generator along with battery system has been carried out for electrification of un-electrified households with future needs of the rural areas of Sonipat district of Haryana state of India. Further, techno-economic and greenhouse gas emissions analysis of different configurations of hybrid system for the study area has also been presented and compared.The hybrid system comprising of 18 kW SPV, 20 kW biomass gasifier, 35 kW biogas generator alongwith 48 kWh of battery has been proposed among all considered configurations at the study area due to least net present cost of $ 202178. The cost of energy of the proposed system is 0.099 $/kWh with negligible greenhouse gas emissions. The proposed model would be very supportive in fulfilling the mission of “Power to all” and rural electrification in India.

ACKNOWLEDGMENT

The first author duly acknowledged the I. K. Gujral Punjab Technical University, Kapurthala (Punjab) for providing research facilities for pursuing research work.

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