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Comparative Study on different Types of Grid Independent Hybrid Power System

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Abstract: The potentiality of delivering the load of an academic institution in a hilly state of India with solar photovoltaic (PV) arrays, diesel generator (DG), biomass generator (BG) and battery (BAT) as backup source by using the hybrid optimization model for electric renewables (HOMER) software. The HOMER software is used to analyze and find out the optimum configuration among a set of systems configurations. In this study, two hybrid systems (PV-DG-BAT system and PV-DG-BG-BAT system) are evaluated among themselves considering the levelized cost of energy (COE), renewable fraction (RF) and net present cost (NPC). The electrical energy demand is partially covered by diesel and biomass sources. The system must fulfill the annual average load of 854 kWh/day with 75 kW peak load.
Keywords: Biomass generator (BG), hybrid optimization model for electric renewables (HOMER), levelized cost of energy (COE), renewable fraction (RF), net present cost (NPC).

I. INTRODUCTION

Electricity forms the nation's share of the ever increasing total energy consumption of the country. Since the middle of the last century, there has been a remarkable enlargement in the demand for energy globally. As a result, the innovative technology of renewable energy sources has become a theme of cardinal importance all over the world [1]. By global standards the present level of energy consumption in India as compared to other countries is very low. However, India is privileged to have plentiful assets of coal to power economic improvement.

The high ash content of India's coal has come at a cost in terms of sensitive public risk and ecological problems. In several regions of India, huge fraction of population does not get the grid electricity and major part of rural areas still remain outside the reach of national or regional grid [2,3]. It is really impossible to meet by the conventional energy sources because of high capital investment on fuel and transport.

The best way to meet their demand is by the non-conventional energy sources. Non-conventional sources are clean, unlimited and environmental friendly [4].

Hybrid energy systems are the systems where two or more renewable energy sources as wind, hydrogen, solar, etc. have been utilized simultaneously to satisfy the demand. Many renewable sources like solar energy, wind energy, hydro potential, plant and animal waste, tidal energy, and the heat of the earth's core as the resources from which energy is produced, are clean and abundantly available in nature, and are being widely used in cost effective manner [5].

Standalone systems produce power independently of the utility grid. These systems are proper for isolated locality where the grid cannot be accessible and there is no additional source of energy. Standalone systems are mostly consisting of the PV and the wind energy [6].

Photovoltaic (PV), diesel generator (DG), biomass generator (BG) and battery (BAT) are considered as main power sources of the study, where PV and BG as renewable energy source and DG as conventional energy source. Since PV source is not available during 24 hours and it is also depend on climatic conditions, so in addition BAT has been taken as a backup. In order to determine the optimal renewable energy hybrid system design which can cover the load of the studied location HOMER (Hybrid Optimization Model for Electric Renewables) is used. HOMER ranked the system according to the Net Present Cost (NPC) and an optimum system has to be chosen for that location.

II. DESCRIPTION OF MODEL SITE

A. Load Profile

A block of an academic institution in the hilly state of India is considered as the model site for the hybrid renewable energy system. Fig. 1 shows the load profiles of the model site. Measured hourly load profiles are not available, so load data were synthesized by specifying typical daily load profiles and then adding some random variability of daily 5% and hourly 5%. These have scaled up the annual peak load to 75 kW and annual average load to 854 kWh/day.

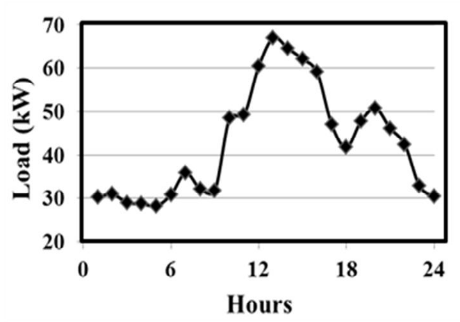

Fig.1 Daily load profile of the model site

B. Photovoltaic Array (PV)

The rated capacity of each PV module used in the study is 205 W, with area of 3.66 m^2. Since the PV module converts the sunlight into electricity, it is impossible to harvest PV energy throughout 24 hour period. In general, the monthly solar radiation of the studied model site varies from 2.85 to 6.22 kWh/m^2/day, with an annual average of 4.7 kWh/m^2/day.

C. Diesel Generator (DG)

The cost of a DG depends on its size. For the present study, the DG capacity is varied from 40 kW to 80 kW. The fuel consumption is modeled by a linear relationship characterized by a slope and an intercept of value 0.25 L/h/kW and 0.08 L/h/kW respectively. The fuel cost is considered 0.8 $ per liter.

D. Biomass Generator (BG)

The cost of a BG depends on its size. For the present study, the BG capacity is varied from 35 kW to 65 kW. The fuel consumption of BG is also modeled by a linear relationship characterized by a slope and an intercept of value 1.9 kg/hr/kW and 0.8 kg/hr/kW respectively. The considered price of biomass is 30 $ per tonne.

E. Storage Battery (BAT)

The BAT model Surrette block 40 is chosen as the storage element in this simulation. This model consists of 5 volts of 40 unit battery. Numbers of batteries are varied to meet demand providing storage of excess electricity from PV and/or DG. The considered lifetime of BAT is 10 years. The nominal capacity of battery is 1156 Ah with nominal voltage of 240 volt.

III.ECONOMIC ANALYSIS OF MODEL SITE

A. Levelized Cost of Energy (COE)

The levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system. The equation for the COE is as follows:

$$\mathrm{COE} = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC}} \qquad (1)$$

where, $C_{ann,tot}$ is total annualized cost ($/yr), $E_{prim,AC}$ is AC primary load served (kWh/yr), $E_{prim,DC}$ is DC primary load served (kWh/yr). The total annualized cost is the sum of the annualized costs of each system component, plus the other annualized cost [7-9].

B. Net Present Cost (NPC)

The present value of the cost of installing and operating the system over lifetime of the project is also referred as net present cost (NPC). Project lifetime in this study is considered as 25 yr. The NPC is calculated according to Eq. (2) [7-9],

$$C_{NPC} = \frac{C_{ann,tot}}{\mathrm{CRF}(i, R_{proj})} \qquad (2)$$

where, $C_{ann,tot}$ is the total annualized cost ($/yr), CRF is the capital recovery factor, i is the real interest rate (%), and R_{proj} is the project lifetime (yr).The capital recovery factor is a ratio used to calculate the present value of an annuity. The equation for the capital recovery factor is given in Eq. (3), where, i is real interest rate (%) and N is number of years.

$$\mathrm{CRF}(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \qquad (3)$$

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IV. HYBRID POWER GENERATING SYSTEM COMPONENTS

Two different hybrid systems are considered for the model site comprising of PV, DG, BG, BAT and CONV:

A. PV-DG-BAT system

The schematic diagram of PV-DG-BAT system is shown in Fig. 2. The hybrid power generating system consists of a PV arrays, DG, BAT and power CONV.

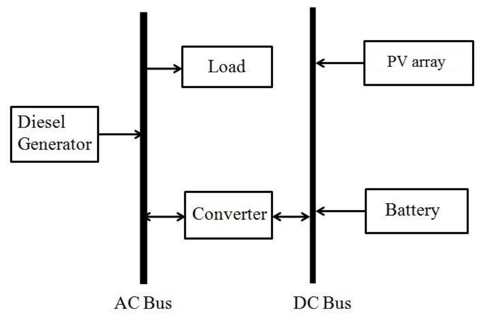

Fig. 2 Configuration of the standalone PV-DG-BAT system

A 1 kW solar energy system capital and replacement costs are taken as $4200 and $3150 respectively. Various sizes of PV array are considered, ranging from 100 to 250 kW in the study. The lifetime of the PV array is taken as 25 yr and there is no tracking system in the PV arrays. The cost of a commercially available DG may vary from $250 to $500 per kW. For larger units per kW cost is lower and for smaller units cost is more. A 45 kW DG is used in this power system as the peak power demand is less than 45 kW. The capital, replacement and operational costs are taken as $500, $400 and $0.50 per hour respectively. Meanwhile, the lifetime is 15000 h. The different sizes of DG ranging from 25 kW to 65 kW were used for HOMER simulation.

The estimated lifetime of the battery is 10 year and the cost of one battery is $3000 with a replacement cost of $2500, while the operation and maintenance cost is $14 per year. Meanwhile, the number of units for the BAT stacks is in the range of 120–1600 units.

A power electronic converter maintains flow of energy between the ac and dc components. For a 1 kW system the installation and replacement costs are taken as $750 and $502 respectively. 80 kW CONV is sufficient for the conversion of power. Meanwhile, lifetime of the power converter is considered to be 15 year with an efficiency of 92%.

B. PV-DG-BG-BAT system

All the meteorological data used here is the same as the previous simulation. The components of this hybrid system are PV array, DG, BG, BAT and power electronic CONV and shown in Fig. 3. In order to determine optimum combination of equipment dimensions, different sizes of the BAT are selected. Standalone PV-DG-BG-BAT system components are described more detail below:

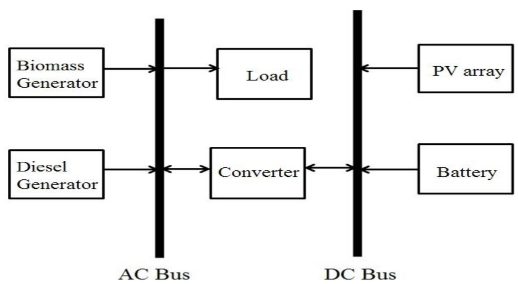

Fig. 3. Configuration of the standalone PV-DG-BG-BAT system

For this hybrid system, the capital, replacement, and operation and maintenance costs, as well as lifetime of the PV array are the same as those in section IV.A. The considered sizes of the PV array are in the range of 100–200 kW.

For this hybrid system, the capital, replacement, and operation and maintenance costs, as well as lifetime of DG are the same as those in section IV.A. The considered sizes of the DG are in the range of 30–50 kW. The cost of BG varies greatly depending on the type of biomass resources, gasification system. Here, the per kW capital, replacement and operational costs are taken as $1000, $833 and $0.016 per hour respectively. The BG sizes are considered from 35 to 65 kW. Meanwhile, lifetime is taken as 150000 h.

For this hybrid system, the capital, replacement, and operation and maintenance costs, as well as lifetime of the BAT are the same as those in section IV.A. The considered sizes of the BAT are in the range of 200–1200 units.
Power electronic converter in this hybrid system has similar properties with one in the previous system. For a 1 kW system, the installation and replacement costs are taken as $800 and $750 respectively.

V. RESULT AND DISCUSSIONS

Two standalone hybrid power systems are considered and analyzed in this study using the HOMER software to determine the optimum hybrid systems for the model site. The optimum configurations obtained for these hybrid systems are presented in detail in Table I. For both the configurations CONV size was considered 80 kW. Furthermore, all outputs about the economic and environmental parameters of these hybrid systems that were simulated by means of the HOMER software are given in Table II.

TABLE I
OPTIMUM CONFIGURATION FOR THE CONSIDERED HYBRID SYSTEMS

Systems	PV (kW)	DG (kW)	BG (kW)	BAT (units)	Operating cost ($*1000/yr)	NPC ($*1000)	COE ($/kWh)	RF
PV-DG-BAT	160	45	-	800	11.4	1037	0.188	0.95
PV-DG-BG-BAT	150	30	45	600	11.8	1003	0.182	1

TABLE III
SOME ECONOMICAL AND ENVIRONMENTAL PARAMETERS FOR THE CONSIDERED HYBRID SYSTEMS

Systems	COE ($/kWh)	Total cost ($*1000)	Renewable (%)	Fuel		Emission (kg/yr)	
				Diesel (lt/yr)	Bio. Feedstock (t/yr)	CO_2	CO
PV-DG-BAT	0.188	1074.9	95	7116	-	18738	46.3
PV-DG-BG-BAT	0.182	1048.8	100	964	154	2566	7.27

A. The PV-DG-BAT system

The optimum COE of this system is 0.188 $/kWh and results from the combination of 160 kW PV, 45 kW DG, 800 units of BAT and 80 kW CONV. The RF of this hybrid system is 0.95. Diesel fuel consumption in this configuration is only 7,116 lt. Simulation results show that the consumption of diesel fuel and amounts of emission gases (CO_2, CO) per year are reduced about 95% by the introduction of 160 kW PV panels into the system when compared with the standalone diesel system using only DG as power supplier. The distribution of annualized cost for each component of the standalone hybrid PV-DG-BAT system is presented in Table III. The capital cost, total NPC and COE for this optimal hybrid system are $835,500, $1,037,230 and 0.188 $/kWh, respectively. The most expensive cost, $693,000 comes from the PV panels. It is followed by DG, BAT and CONV costs. From simulation results, the PV-DG-BAT hybrid system has a total annual electrical energy production of 410,782 kWh/yr.

TABLE IIIII
ANNUALIZED COST OF HYBRID PV-DG-BAT SYSTEM

Component	Capital ($*1000)	Repalcement ($*1000)	O&M ($*1000)	Fuel ($*1000)	Total ($*1000)
PV	693.0	0	29.2	0	722.2
DG	22.5	0	4.2	100.8	127.5
BAT	60.0	62.4	4.9	0	127.3
CONV	60.0	26.4	11.5	0	97.9
System	835.5	88.7	49.9	100.8	1074.9

B. The PV-DG-BG-BAT system

The optimum COE of this system is 0.182 $/kWh and results from the combination of 150 kW PV, 30 kW DG, 45 kW BG, 600 units of BAT and 80 kW CONV. The RF of this hybrid system is 1. Diesel fuel consumption in this hybrid system is only 964 lt. Biomass feed stock consumption is 154 tonne. The distribution of annualized cost for each component of the standalone hybrid PV-DG-BG-BAT system is presented in Table IV. The capital cost, total NPC and COE for this optimal hybrid system are $795,000, $1,003,965 and 0.182 $/kWh, respectively. RF of the optimum hybrid system is 1 because there is no electricity production from DG. Regarding environmental effects of the hybrid system with the least COE, emission rates of CO_2 and CO are negligible as compared to PV-DG-BAT system. According to the simulation results, the PV-DG-BG-BAT hybrid system generates total electrical energy production 393,264 kWh/yr, almost all of this value is generated by the PV panel.

TABLE IVV
ANNUALIZED COST OF HYBRID PV-DG-BG-BAT SYSTEM

Component	Capital ($*1000)	Repalcement ($*1000)	O&M ($*1000)	Fuel ($*1000)	Total ($*1000)
PV	630.0	0	26.6	0	89.6
DG	45.0	0	14.9	109.3	169.3
BG	15.0	0	908.0	13.7	29.6
BAT	45.0	46.8	3.8	0	95.5
CONV	60.0	26.4	11.5	0	97.9
System	795.0	73.2	57.7	122.9	1048.8

VI. CONCLUSION

The study investigates the economic feasibility of the use of two different hybrid energy systems in different configurations consisting of PV, diesel, biomass, BAT for energy requirement of an academic institution located at hilly state of India. The price of diesel fuel is increasing very rapidly. So using only DG will not be feasible in near future. Experimental result shows that the COE of the optimized system is 0.182 $/kWh with 100% renewable fraction. NPC and operating cost for the optimized system are $1,003,965 and 11,801 $/yr respectively. This hybrid energy system reduces the emission of CO_2 and CO significantly which reduces global warming which is a matter of annoyance all over the world. Here, BG is chosen as a major source of power in the rural areas due to its high efficiency and cost effectiveness. It is found that PV-DG-BG-BAT reduces COE in small quantity but the reduction in emission is 86% as compared to PV-DG-BAT system. As solar and biomass resources are abundantly present in India, therefore considering the economic and environmental aspects it is found that this type of hybrid energy system is feasible for rural electrification in the country.

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