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Feasibility of Renewable Energy Source as an Electrification Option for a Residential Load in an Under-developed Colony

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ABSTRACT

This article proposes a hybrid renewable energy system for residential loads located in under-developed colonies which are deprived of regular permanent electricity connections from grid and have to take temporary connections for their day to day electrical energy requirements, which have higher energy charges. Here, one such residential load is considered which is presently fed with a temporary domestic connection from grid, in Bhilai, Chhattisgarh, India, the supply from which is also affected by scheduled shutdown for maintenance purposes and unscheduled trippings and breakdowns, and other such supply interruptions. For providing an optimal solution to this costly unreliable system, a comparative study is carried out using Homer Software, among photo voltaic(PV)-battery, photo voltaic(PV)-grid and grid only system. These systems are compared with each other considering net present cost(NPC), levelised cost of energy(COE) and pollutant emissions. The study results show that PV-battery system has the lowest NPC and COE. Moreover, this lowest NPC PV-battery system excludes the emission of pollutants like CO_2, SO_2 and NO_x, altogether.

KEYWORDS

battery; electric grid; hybrid renewable energy system; power convertor; PV

INTRODUCTION

The depleting fossil fuel resources and global warming are two of the most disturbing present day issues, affecting both the economical and environmental health of a region. Thus, it has become the need of the day to harness the renewable energy sources by tapping the power from solar, wind, hydel, biomass, available in nature free of cost. The other problem addressed here, is that faced by the residents of colonies which have been left undeveloped by the colonizer, i.e. the residents are deprived of basic amenities like roads, drainage and most importantly electricity. The residents of such colonies have to depend upon temporary modes of power supply, which are 1.5 times costlier than the regular supply from grid for permanent connections, since they don't receive NOC from competent authorities for permanent connection. Hence, here the focus is on providing a permanent solution to the electrification problem of one such residential premise with the added benefit of power supply reliability and reduction in pollutant emissions by comparing it with conventional grid system using HOMER.

Presently, the solar energy has been considered as the alternative renewable energy source, since the horizontal mean solar radiation of Bhilai is 5.08kwh/m^2/day, which is quite good. The state government is also promoting the use of solar-based systems as much as possible by providing discounts (Chhattisgarh Renewable Energy Development Agency 2015).

The optimization of the hybrid energy system has been done in HOMER, with an objective to find an environmental friendly system having lowest net present cost(NPC), lowest cost of energy(COE) and improved power reliability. Among the various software tools available for designing, optimization and economic planning of such systems, like HOMER, HYBRID2, RETScreen, INSEL, HYBRIDS, HySys, etc, HOMER is the most widely used tool which comprises of several renewable energy sources for selection in the design with various configurations for size optimization and sensitivity analysis.

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Various researchers have worked in the area such as Sen and Bhattacharya (2014) have considered a mix of renewable energy sources to satisfy the electrical needs of an off-grid remote village, Palari, that too in the state of Chhattisgarh, India. Miqdam T Chaichan et al (2016) discussed an optimization solution of a hybrid system of renewable energy for lighting 10km street in Salalah, Oman by using the Homer software and compared results with that of the grid. Satya Prakash Makhija and S.P.Dubey (2016) presented feasibility of application of solar electricity in auxiliaries of a cement manufacturing plant in Jamul, Chhattisgarh.

The significance of this study can be understood by the results which shall open an economical, reliable and environment friendly mode of electrification for residents of underdeveloped colonies.

SYSTEM MODELLING

The modeling of the system has been done using HOMER Software. Homer does the size optimization on the basis of hourly load profile and the climatic conditions of the region under consideration, with the objective of finding a suitable supply system which has the least net present cost.

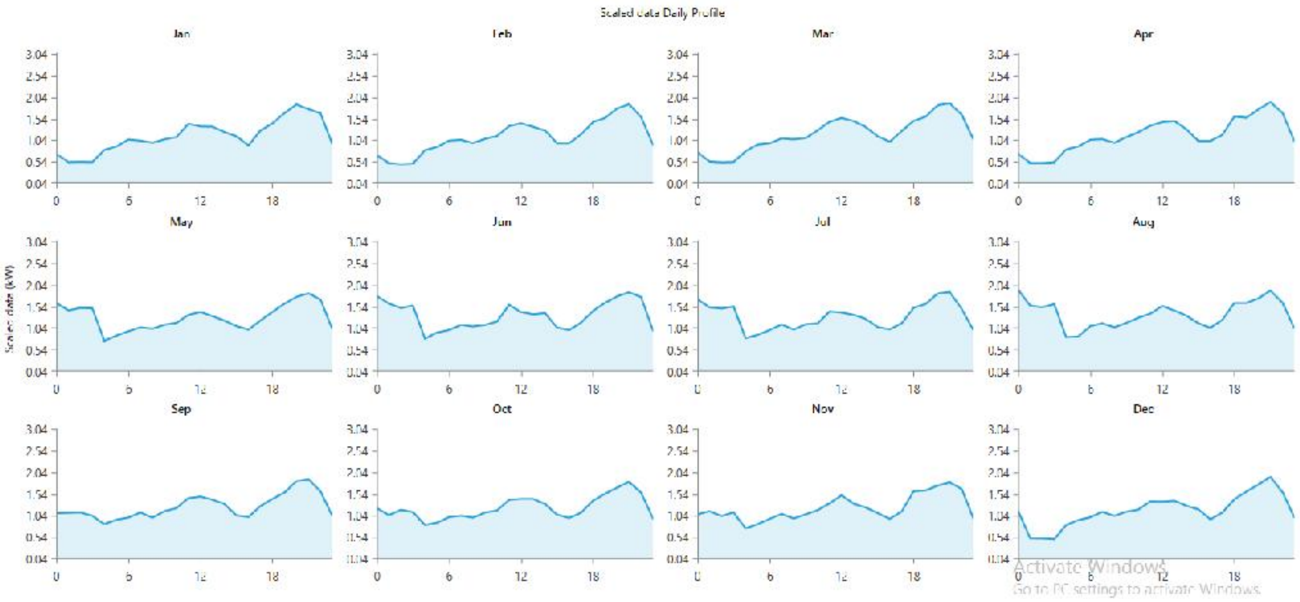

Fig. 1(a) Monthwise Daily Load Profile

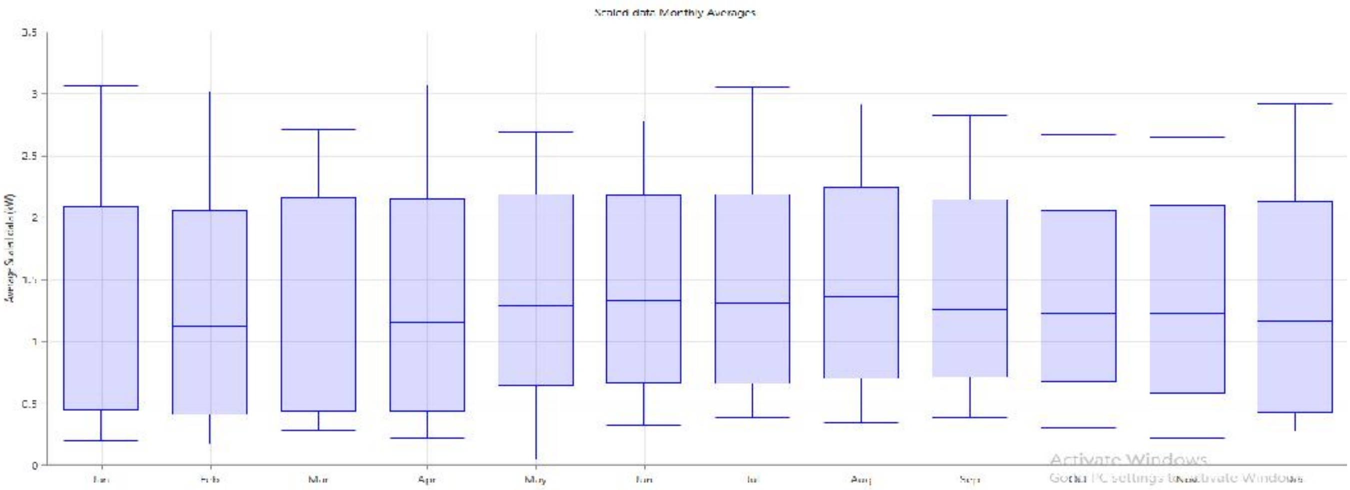

Fig. 1(b) Monthly average Load data

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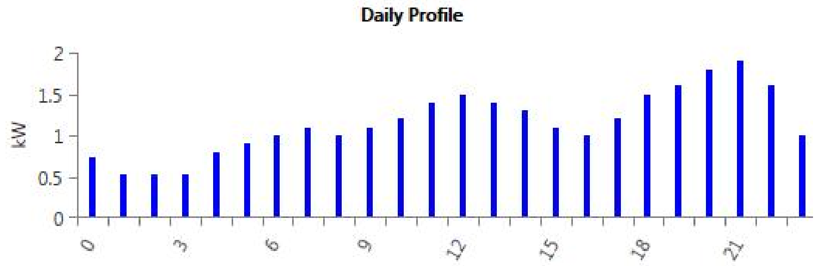

Fig. 1(c) Hourly Load Profile

A. Load Profile

The daily, monthly and hourly domestic load profiles generated by HOMER software, are shown in Figure 1a, 1b and 1c, respectively. The hourly load profile is for the first month of the year, i.e. January. The calculated energy demand is 29.63 kWh/day and the peak demand is 3.08 kW.

B. Renewable Energy Resource Assessment

The solar energy resource is considered in system modeling and simulations. The renewable energy resource assessment is carried out using the data from NASA surface meteorology and solar energy website [14].

The Global Horizontal Solar Radiation data for the region under consideration is shown in Figure 2.

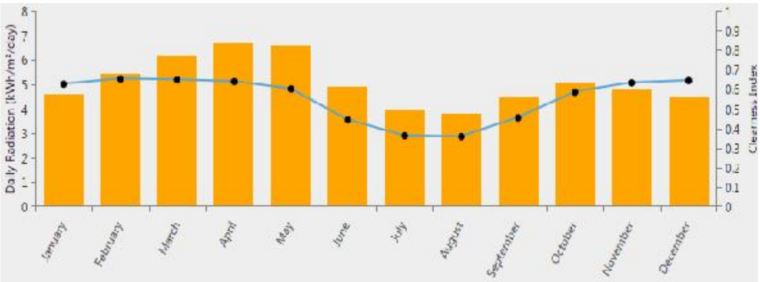

Fig. 2 Monthly average Solar Radiation and clearness index.

The solar radiation in Bhilai (Latitude 21.23 / Longitude 81.35) varies in the range 3.79-6.71 kWh/m^2/day, with the highest and lowest radiations found in the months of April and August, respectively. The annual average of the horizontal solar radiations is 5.08 kWh/m^2/day and the annual clearness index is 0.553.

C. Economics, System Control and Constraints

In regard to economics the project life time is considered to be 25 years and the annual real interest rate is 5.88%. For system control inputs, two power dispatch strategies, i.e. cycle charging and load following can be modeled [15]. The load following strategy is considered in both of the PV-battery and PV-grid systems. In this system, whenever a generator is required to feed the load, it produces only as much power as is needed to meet the demand at that moment and it tends to be optimal, when renewable energy is involved and renewable power sometimes exceeds the load. The constraint put in the grid system is 1% capacity shortage which is considered to be zero for the hybrid renewable system.

D. System Components Description

In the hybrid systems considered, solar PV is considered as a resource of energy apart from the grid. Battery and converter/inverter are for storing and AC-to-DC/DC-to-AC conversion respectively.

PV-GRID SYSTEM

The configuration of this system is as follows in Figure 3

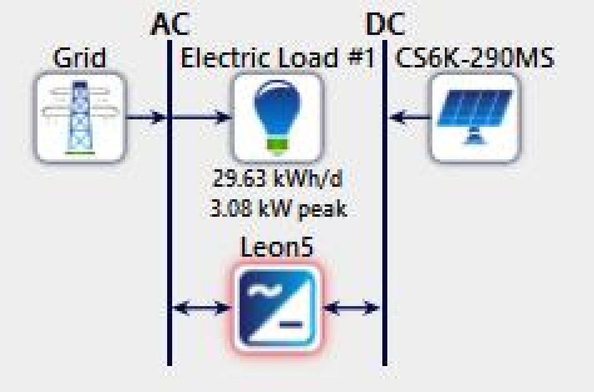

Fig.3 Configuration of PV-Grid System.

Some of the inputs for the PV-Grid system are size (kW), capital cost, replacement cost, O&M cost and lifetime in years.

PV sizes considered (kW): 2, 3, 4, 5, 6, 8

Power converter sizes considered (kW): 1, 2, 3, 4

Efficiency of converter (%): 94

PV-BATTERY SYSTEM

The configuration of this system is as follows in Figure 4

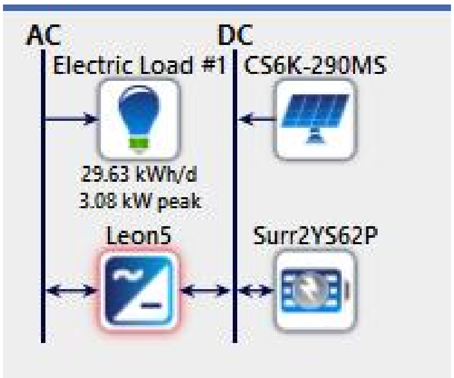

Fig.4 Configuration of PV-Battery System.

Some of the inputs for the PV-Grid system are size (kW), capital cost, replacement cost, O&M cost and lifetime in years.

PV sizes considered (kW): 6, 8, 10, 12

Power converter sizes considered (kW): 2, 3, 4

Efficiency of converter (%): 94

Battery Nominal voltage: 2 V

Battery string size considered: 100

Minimum state of charging (%): 40

GRID-ONLY SYSTEM

The configuration of this system is as follows in Figure 5

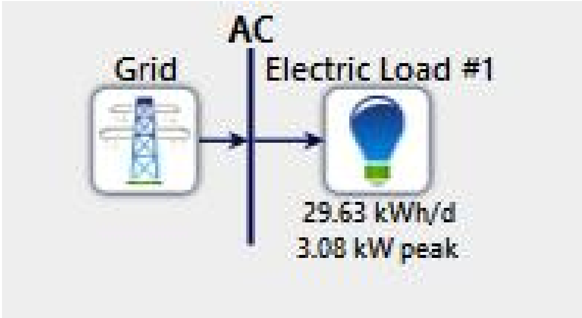

Fig.5 Configuration of Grid only System.

This system already exists in the residence and has been considered in the analysis for comparision purpose only. The results will be compared with the outcome of PV-Grid and PV-Battery systems. It is considered that this system is directly supplying power to the residential load. The system fixed capital cost is considered to be zero.

RESULTS AND DISCUSSIONS

The simulations were carried out for all the three systems, i.e. PV-Grid, PV-Battery and Grid only systems. In this section simulation results of these systems will be discussed to find the best feasible system having lowest Net Present Cost and lowest Cost Of Energy with least pollutant emissions. The simulations were done with all the capacity options mentioned above.

PV-GRID SYSTEM

Based on the meteorological input data for energy resources, technical and cost data for system components, HOMER performed simulations and obtained feasible systems with optimization results as shown in Table 1.As seen, the most feasible system is one with the lowest NPC of Rs.11,51,362.

The operational results are as shown below,

PV array

Rated Capacity 4 kW

Mean Output 6,502 kWh/yr

Grid

Energy Purchased 7,986 kWh/yr

Energy Sold 1,422 kWh/yr

Pollutant Emissions

Carbon Dioxide 5047 kg/yr

Sulfur Dioxide 21.9 kg/yr

Nitrogen Oxides 10.7 kg/yr

TABLE 1. OPTIMIZATION RESULTS FOR PV-GRID SYSTEM

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture				Cost				System		CS6K-290MS		Leon5		Grid	
CS6K (	Grid (kW)	Leon5 (kW)	Disp	COE (₹)	NPC (₹)	Operating (₹/yr	Initial ca (₹)	Ren Fr (%)		Capital (₹	Productio (kWh/yr	Rectifier	Inverte	Energy Pur (kWh	Energy Sold (kWh)
4.00	999,999	2.00	LF	₹7.28	₹1.15M	₹67,895	₹273,644	34.7	0	202,644	6,502	0	0.485	7,986	1,422
5.00	999,999	2.00	LF	₹7.15	₹1.16M	₹64,673	₹324,305	39.4	0	253,305	8,128	0	0.564	7,607	1,733
3.00	999,999	2.00	LF	₹7.71	₹1.17M	₹73,314	₹222,983	26.8	0	151,983	4,877	0	0.360	8,588	924
5.00	999,999	3.00	LF	₹6.54	₹1.18M	₹63,247	₹359,805	46.0	0	253,305	8,128	0	0.731	7,532	3,122
4.00	999,999	3.00	LF	₹7.02	₹1.19M	₹67,781	₹309,144	39.3	0	202,644	6,502	0	0.586	7,926	2,243
6.00	999,999	2.00	LF	₹7.19	₹1.19M	₹62,835	₹374,966	42.3	0	303,966	9,753	0	0.617	7,379	1,965
6.00	999,999	3.00	LF	₹6.35	₹1.19M	₹60,581	₹410,466	49.8	0	303,966	9,753	0	0.827	7,299	3,731

TABLE 2. OPTIMIZATION RESULTS FOR PV-BATTERY SYSTEM

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture				Cost				System		CS6K-290MS		Surr2YS62P				Leon5	
CS6K	Surr	Leon5 (kW)	Dispat	COE (₹)	NPC (₹)	Operating (₹/yr)	Initial c (₹	Ren F (%		Capital Cost (₹)	Productio (kWh/yr)	Au	Annu	Non	Usa	Re	Inver
10.0	100	3.00	LF	₹7.06	₹987,629	₹17,368	₹763,110	100	0	506,610	16,256	676	7,188	1,390	834	0	1.23
10.0	100	4.00	LF	₹7.51	₹1.05M	₹19,465	₹798,610	100	0	506,610	16,256	676	7,188	1,390	834	0	1.23
12.0	100	3.00	LF	₹7.88	₹1.10M	₹18,368	₹864,432	100	0	607,932	19,507	676	7,074	1,390	834	0	1.23
12.0	100	3.00	LF	₹7.88	₹1.10M	₹18,368	₹864,432	100	0	607,932	19,507	676	7,074	1,390	834	0	1.23
12.0	100	3.00	LF	₹7.88	₹1.10M	₹18,368	₹864,432	100	0	607,932	19,507	676	7,074	1,390	834	0	1.23
8.00	200	3.00	LF	₹7.88	₹1.10M	₹22,444	₹811,708	100	0	405,288	13,005	1,351	7,340	2,701	1,668	0	1.23
12.0	100	4.00	LF	₹8.33	₹1.16M	₹20,465	₹899,932	100	0	607,932	19,507	676	7,075	1,390	834	0	1.23

The total electrical production is 14,488 kWh/yr where the percentage of electricity produced by the component PV is 44.9% and that from the grid is 55.1%. The total pollutant emissions comes out to be 5,079.6 kg/yr.

PV-BATTERY SYSTEM

The optimization results obtained from simulations carried out for PV-Battery system are shown in Table 2. The system with the lowest NPC is the first entry in the table.

The operational results show that the system with the least NPC and levelized COE of Rs.9,87,629 and Rs.7.06, respectively is the system having 10 kW PV array and 3kW convertor with 100 batteries

PV array

Rated Capacity 10 kW

Mean Output 16,256 kWh/yr

Battery

Energy In 8,006 kWh/yr

Energy Out 6,429 kWh/yr

Storage Depletion 26.7 kWh/yr

Pollutant Emissions

Carbon Dioxide 0 kg/yr

Sulfur Dioxide 0 kg/yr

Nitrogen Oxides 0 kg/yr

The total energy production is 16256 kWh/yr with zero pollutant emissions.

GRID-ONLY SYSTEM

TABLE 3. OPTIMIZATION RESULTS FOR GRID-ONLY SYSTEM

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture		Cost				System		Grid	
Grid (kW)	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹/yr)	Initial capital (₹)	Ren Frac (%)	Total Fuel (L/yr)	Energy Purchased (kWh)	Energy Sold (kWh)
999,999	LF	₹8.10	₹1.13M	₹87,602	₹0.00	0	0	10,815	0
999,999	CC	₹8.10	₹1.13M	₹87,602	₹0.00	0	0	10,815	0

The optimization results obtained from simulations carried out for Grid-only system are shown in Table 3. The simulation results of grid-only system reveal that the grid supplies 100% power to the load with total NPC and levelized cost of Rs.11,32,480 and Rs.8.10, respectively. The total pollutant emissions comes out to be 6,879.1 kg/yr (CO_2:6,835 kg/yr, SO_2:29.6 kg/yr, NO_x:14.5 kg/yr). Here the pollutant emission factor is predominant as the major portion of the electricity provided by grid is through burning of coal.

Thus, the grid-only system has the highest total NPC, levelized cost and pollutant emissions.

A comparision of all the three power supply systems, tabulated in table 3, with respect to variables NPC, COE and operating costs, shows that the PV-Battery system, which has the lowest NPC and COE with zero pollutant emissions is the best among the three. The NPC and COE of PV-grid system is 16.58% and 3.11% higher than that in case of PV-battery system, respectively. The same quantities in case of grid-only system are 14.67% and 14.73% higher than that in PV-battery system, respectively. Also, the operating costs are exceptionally lower in case of PV-battery system as compared to the other two systems considered here.

TABLE 3. COMPARISION OF SYSTEM COSTS

Cost/System	PV-GRID	PV-BATTERY	GRID-ONLY
Operating Cost (Rs./yr)	67,895	17,368	87,602
NPC (Rs.)	11,51,362	9,87,629	11,32,480
COE (Rs./kWh)	7.28	7.06	8.10

The reduction in Pollutant emissions in PV-battery system as compared to the present grid-only system is as follows,

Carbon Dioxide 6,835 kg/yr

Sulfur Dioxide 29.6 kg/yr

Nitrogen Oxides 14.5 kg/yr

That means a total of 6879.1 kg/yr of pollutant emissions are reduced after using the hybrid PV-battery system.

PAYBACK PERIOD

The payback period is calculated by comparing cost incurred in one system with another. Payback period is the number of years it takes to recover an investment. The simple payback period of the additional investment in proposed PV-battery system is calculated by comparing it with the existing grid-only system.

Simple payback period = difference in capital costs/difference in operating costs

The grid-only system,s capital cost is considered to be zero, as it is already existing and its operating cost is Rs.87,602 per year. The proposed system's corresponding costs are Rs.7,63,110 and Rs.17,368, respectively. Based on these cost figures, the simple payback period is calculated to be 10.8 yrs.

CONCLUSIONS

In the present study, the comparative analysis was done among PV-grid, PV-battery and Grid-only systems. The comparison was based on the parameters, total NPC, levelized COE and pollutant emissions. The techno-economic analysis of the simulation results obtained from Homer software reveals that the optimal PV-battery system, which comprises of 10 kW PV array, 100 batteries and 3 kW power convertor, is most suitable for supplying continuous power to the residential load which is presently fed by temporary connection from grid. The optimal PV-grid system which has 4 kW PV array, 2 kW power convertor and grid supply is not suggested due to higher NPC, COE and operating costs. The Grid-only system was found to be the most costly and most pollution emitting system.

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