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Techno-Economic Feasibility Analysis of Hybrid Systems for Decentralized Power Generation in India

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Abstract: The main objective of this paper is to find the optimum configuration from amongst the different combination of hybrid energy systems that will fulfill the electrical energy requirement of selected village reliably and economically. The various systems that are considered are solar-grid connected system, solar-diesel system, solar-wind energy system, wind-grid connected system, solar-wind-grid connected system, wind-diesel-grid connected system and solar-diesel-grid connected system. The comparison of these systems is done based on various economic indicators like internal rate of return, net present cost, payback period and cost of energy. From amongst the various systems that have been considered in this study wind-grid connected system is best suited hybrid system for the considered case having lowest cost of energy as Rs. 2.34/kWh. Also the initial cost of this system is less in comparison to other hybrid systems considered.

Keywords: Hybrid Energy Systems, Techno-Economic Analysis, Decentralized Power Generation

1. Introduction

Electricity is one of the driving forces in a growing economy and increasing demand puts incredible pressure on the countries energy infrastructure to match that demand. India as a developing country, where majority of the population lives in rural areas without access to electricity, the problem therefore assumes greater importance. Extension of the central electricity grid to such areas is either financially not viable or practically not feasible as these locations are geographically isolated, sparsely populated and have a very low power demand.

In India, out of 593,732 villages there are 21,318 villages listed under the category of un-electrified villages as per ministry of new and Renewable energy Sources, Government of India. Electrification of the unelectrified villages is a great challenge facing the developing countries including India. The Government of India has taken essential steps towards the implementation and promotion of decentralized electricity generation through Renewable Energy Technology (RET) systems. At present in most of the unelectrified villages in India that are located far away from the central electricity grid and have small loads are supplied traditionally by diesel generators which have high reliability, high running cost, high maintenance and low efficiency. However these locations normally called as remote areas present a significant potential market for renewable energy based systems like solar and wind. Moreover, from an environmental perspective renewable energy system are sustainable and environment friendly.

A.H. Al-Badi et al [1] have done the study to determine the optimum size of systems able to fulfill the electrical energy requirements of remote sites located in the South of Oman. The methodology applied provides a useful and simple approach for sizing and analyzing the hybrid systems which can provide the required electricity reliably and economically. The results of the analysis are a list of feasible power supply systems, classified according to their net present cost. The energy management of hybrid energy systems taking life cycle cost into account is discussed [2-4]. The simulation result of different combinations of hybrid energy systems in grid connected and standalone mode is analyzed to find out the most cost effective system. Photovoltaic panels, wind turbines, diesel generators and grid connection are used as the energy sources in this study. As hybrid system of minimum two and maximum three sources are considered, reliability of the system increased. The combinations used are PV-Wind-Diesel, PV-Grid, Wind-Grid, PV-Wind and PV-Wind-Grid. The possibility of wind alone, PV alone and hybrid wind/PV system for a typical residential load in Montana is discussed [5]. Generation and storage units for different system are properly sized in order to meet the annual load and minimize the total annual cost to the customer. In addition, an economic analysis has been performed for the three different scenarios and is used to justify the use of renewable energy versus constructing a line extension from the nearest existing power line to supply the load with conventional power.

Annual average hourly values for load, wind speed, and insolation have been used. This work takes into account the economic factors for calculation of optimum component size.

An economic analysis is performed for realizing the advantage of the stand-alone system versus constructing a line extension from the nearest existing distribution line for supplying the load with conventional power. The sizing and techno-economic optimization of an autonomous hybrid PV/Wind energy system with battery storage is discussed [5]. The study has considered the various aspects e.g. the level of autonomy i.e. the fraction of time for which the specified load can be met and the cost of the system rather than designing the system for the worst month scenario which lead too costly system as done by few researchers the system cost and performance both are taken into account and a third energy source that is a battery is connected in the system to reduce the cost. Similarly, optimization of unit sizing of various combinations of hybrid energy system is also reported [6-8]. Similarly [9-10] presents the economic analysis of various combinations of hybrid systems under different operating conditions and [11] presents techno-economic comparison of various energy supplying systems. From the literature, it is found that it is very essential to develop an algorithm for optimal operation of hybrid energy system especially for Indian scenario, which can be applied to any type and any number of systems.

In this paper, an optimal operating strategy for hybrid energy system is proposed. the simulation result of different combinations of hybrid energy systems with and without grid is analyzed to find out the most cost effective system. Photovoltaic panels, wind turbines, diesel generators and grid connection are used as the energy sources in this purpose. As hybrid system of minimum two and maximum three sources are considered, reliability of the system increased. The combinations used are PV-Wind-Diesel, PV-Grid, Wind-Grid, PV-Wind and PV- Wind-Grid.

2. Description of the Area Considered for Electrification and Metrological Data

The optimal installation sites for the hybrid systems are characterized by good average renewable energy resource potential. After preliminary study, it was observed that the site selected in this case study has good solar as well as wind potential. Therefore this site is chosen for this case study. For this hybrid system, the meteorological data of Solar Radiation, monthly wind speed are taken for the village Rawra in Udaipur, Rajasthan (latitude and longitude of the site is 26.238^0N & 73.0243^0E respectively). The population of village is about 890 and peak load taken is 51 kW. Daily solar radiation data were imported into HOMER to calculate daily radiation and monthly average values of clearness index. These data were taken from Indian meteorological department. The average clearness index is 0.68 and average daily radiation is 5.53 KWh/m^2/day. Figure 1 shows the variation of solar radiation.

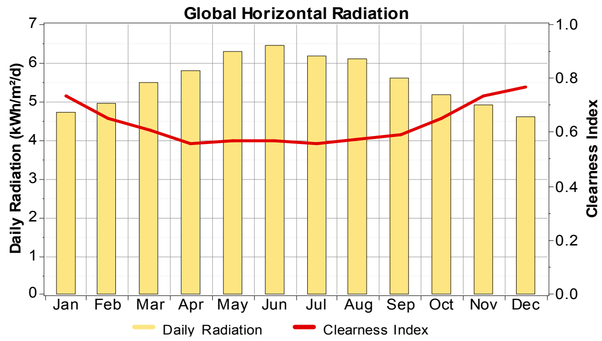


Figure 1. *Daily solar radiation with clearness index.*

Wind speed also varies seasonally. Average wind speed at the selected site is 4.117 ms^{-1}. This data were collected from India Meteorological Department. Figure. 2 shows the monthly wind speed variation.

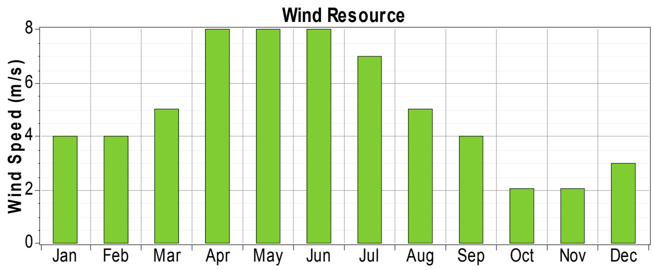
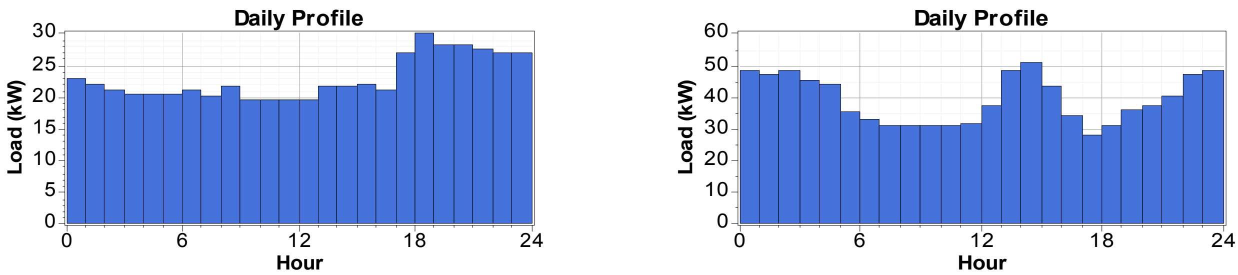


Figure 2. *Monthly wind speed variations.*

The proposed hybrid power system is designed to ensure the reliable and economic electric supply to the village. The village requires a maximum of 51 kW peak demand and it has a base demand of approximately 30 kW. From the load profile, it can be seen that, during night times, the load requirements are the lowest since that is the off working hours of the staffs and students. The maximum demand occurs during daytime from 2 p.m. to 2 a.m. during January and from 2 p.m. to 4 a.m. during July period. The peak demand is about 30 kW in January and peak demand is about 51 kW in July. Figure 4 illustrates the average and the deviation of the monthly load profile for the site. The scaled annual average energy demand of the studied building as simulated by HOMER software is 722 kWh/day.



(a) Hourly Load Profile for January

(b) Hourly Load Profile for July

Figure 3. *Daily Load Profile for (a) January & (b) July.*

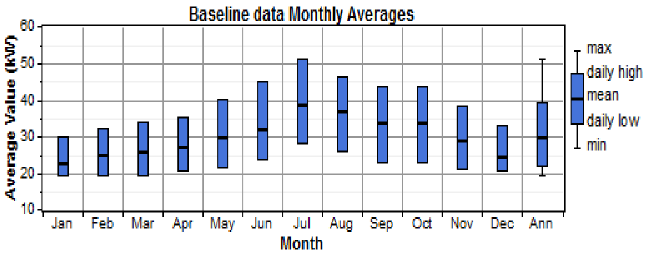


Figure 4. *Monthly load profile.*

3. Hybrid System Design and Analysis

The Hybrid Optimization Model for Electric Renewables (HOMER) is used in this work, it is used to model a power system physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life time.

3.1. Simulation

The simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period of time.

The system can be grid-connected or autonomous and can serve ac and dc electric loads and a thermal load. Systems that contain a battery bank and one or more generators require a dispatch strategy, which is a set of rules governing how the system charges the battery bank. The simulation process serves two purposes. First, it determines whether the system is feasible. The feasible system is one which can adequately serve the electric and thermal loads and satisfy any other constraints imposed by the user. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. The lifecycle cost is a convenient metric for comparing the economics of various system configurations.

3.2. Optimization

The simulation process models a particular system configuration, whereas the optimization process determines the best possible system configuration. The best possible, or optimal, system configuration is the one that satisfies the user-specified constraints at the lowest total net present cost. Finding the optimal system configuration may involve deciding on the mix of components that the system should contain, the size or quantity of each component, and the dispatch strategy the system should use. In the optimization process, many different system configurations are simulated; the infeasible ones are discarded, the feasible ones are ranked according to total net present cost, and the feasible one is presented with the lowest total net present cost as the optimal system configuration.

The goal of the optimization process is to determine the optimal value of each decision variable that interests the modeler. A decision variable is a variable over which the system designer has control and for which multiple possible values can be considered in the optimization process. Pos sible decision variables include: the size of the PV array, the number of wind turbines, the size of each generator, the number of batteries, the size of the dc-ac converter, the dispatch strategy.

3.3. Sensitivity Analysis

In the sensitivity analysis process multiple optimizations are performed, each using a different set of input assumptions. A sensitivity analysis reveals how sensitive the outputs are to changes in the inputs.

In a sensitivity analysis, a range of values for a single input variable are fed to HOMER. A variable for which the user has entered multiple values is called a sensitivity variable. Almost every numerical input variable that is not a decision variable can be a sensitivity variable. Examples include the PV module price, the fuel price, the interest rate, etc.

3.4. Economic Analysis

The economic study is based on a financial evaluation of different configuration of hybrid systems based on renewable energy technologies (T C Kandpal et.al 2003). The different parameters that are calculated for comparing the various systems are payback period, internal rate of return (IRR), net present cost (NPC) and cost of energy (COE),.

3.5. Payback Period

It is the time in which initial investment is expected to recover from the cash inflow generated by the investment. It can be calculate by the expression (1)

$$-IC + \sum_{n=1}^{p} \frac{QN}{((1+i)^n)} \quad (1)$$

Where IC is the initial cost, QN is net cash flow, 'i' is the rate of interest and P is the payback period.

3.5.1. R. R (Internal Rate of Return)

The internal rate of return on an investment or project is the "annualized effective compounded return rate" that makes the net present value (NPV) equal to zero.

$$NPV = \sum_{n=0}^{N} Cn/\ (1+r)^n = 0 \quad (2)$$

Cn is cash flow, r is internal rate of return and n is the positive integer.

3.5.2. Net Present Cost (NPC)

The quantity used to represent the life-cycle cost of the system is the total net present cost (NPC). This single value includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. The total net present cost includes the initial capital cost of the system components, the cost of any component replacements that occur within the project lifetime, the cost of maintenance and fuel.

The net present value of the system can be calculated with the formula

$$NPC = -C_o + (B-C)\sum_{t=1}^{T}\left(\left[1+\left|\frac{d}{100}\right|\right]^{-t} + L_T\left[1+\left(\frac{d}{100}\right)\right]^{-t}\right) \quad (3)$$

Where Co = initial investment, B= annual benefits, C= annual investment, d=discount rate, t=time period. From among the mutually exclusive events the project which has got maximum positive NPC is economically more feasible. Table 1 shows the economic and technical specifications for the components of the proposed hybrid energy system.

3.5.3. Cost of Energy

The unit electrical cost can be calculated using the relation

$$\text{The per unit cost of energy} = \frac{ALCC}{365 \times E_L} \quad (4)$$

Where ALCC is the annualized life cycle cost, EL is the average daily load demand.

3.6. PV and Grid Connected System

Figure 5 shows the PV and grid connected system configuration as designed in Homer simulation software.

Figure 6 shows the HOMER output results ordered from lowest NPC for adding the PV generation system to the simulation. HOMER uses the total NPC as its main selection tool.

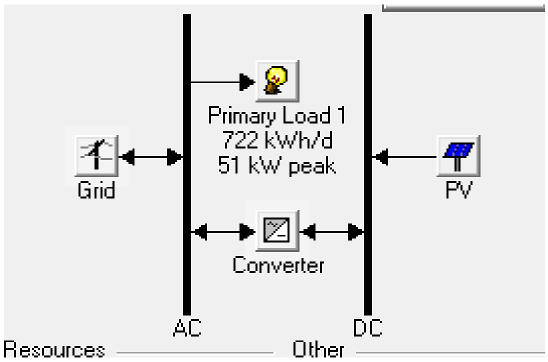


Figure 5. *PV and Grid connected system configuration.*

Table 1. *Economic and technical specification for the components of the proposed hybrid energy system.*

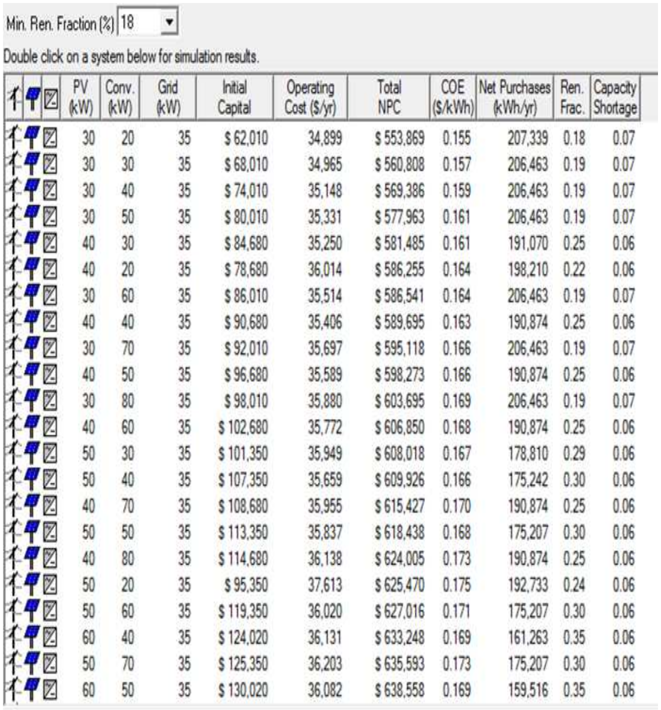
Description	Data
PV	
Capital cost	99,990 Rs/kW
Lifetime	25 years
Operation and maintenance cost	550 Rs/kW/year
Replacement cost	99,990 Rs/kW
Diesel generator	
Capital cost	13,750 Rs/kW
Rated power	Variable (0–500 kW)
Minimum allowed power (min load ratio)	30% of rated power
Operation and maintenance cost	1 Rs/h/kW
Operating hours	15,000 h
Replacement cost	13,750 Rs/kW
Wind turbine	
Capital cost	Rs. 1320000
Lifetime	25 years
Rated power	25 kW AC
Operation and maintenance cost	2706 Rs/kW/year
Replacement cost	Rs 407040
Cut in wind speed	3.5 m/s
High cut-out wind speed	25 m/s
Hub height	25 m
Batteries	
Type of batteries	Surrette 6CS25P
Nominal voltage (V)	6 V
Nominal capacity	1,156 Ah
Nominal energy capacity of each battery	6.94 kWh
Operation and maintenance cost	110 Rs/year
Capital cost	6,875 Rs
Replacement cost	2,750 Rs
Converter	
Capital cost	36,025 Rs/kW
Operation and maintenance cost	110 Rs/year/kW
Lifetime	15 years
Replacement cost	36,025 Rs/kW
Efficiency	95%
Project life time	25 years

3.6.1. Sensitivity Analysis of PV and Grid Connected System

Figure 6 shows the sensitivity results of PV and grid connected system given by the HOMER. We can see that there is only one optimal system with a PV system. This system has a PV fraction of 4% with a grid fraction of 96%. For the optimal alternative system, the PV system and inverter size are 5 KW

Details of this configuration are shown in Table 2 The total NPC, Initial Capital cost and COE for such a hybrid system are Rs 30588300, Rs 2609520 and Rs 8.22/kWh, respectively.

Figure 7 shows the monthly distribution of the electricity produced in kW by the Solar PV and Grid. The effect of SPV penetration reduces the energy consumption from grid.



Min. Ren. Fraction (%) 18

Double click on a system below for simulation results.

PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Net Purchases (kWh/yr)	Ren. Frac.	Capacity Shortage
30	20	35	$ 62,010	34,899	$ 553,869	0.155	207,339	0.18	0.07
30	30	35	$ 68,010	34,965	$ 560,808	0.157	206,463	0.19	0.07
30	40	35	$ 74,010	35,148	$ 569,386	0.159	206,463	0.19	0.07
30	50	35	$ 80,010	35,331	$ 577,963	0.161	206,463	0.19	0.07
40	30	35	$ 84,680	35,250	$ 581,485	0.161	191,070	0.25	0.06
40	20	35	$ 78,680	36,014	$ 586,255	0.164	198,210	0.22	0.06
30	60	35	$ 86,010	35,514	$ 586,541	0.164	206,463	0.19	0.07
40	40	35	$ 90,680	35,406	$ 589,695	0.163	190,874	0.25	0.06
30	70	35	$ 92,010	35,697	$ 595,118	0.166	206,463	0.19	0.07
40	50	35	$ 96,680	35,589	$ 598,273	0.166	190,874	0.25	0.06
30	80	35	$ 98,010	35,880	$ 603,695	0.169	206,463	0.19	0.07
40	60	35	$ 102,680	35,772	$ 606,850	0.168	190,874	0.25	0.06
50	30	35	$ 101,350	35,949	$ 608,018	0.167	178,810	0.29	0.06
50	40	35	$ 107,350	35,659	$ 609,926	0.166	175,242	0.30	0.06
40	70	35	$ 108,680	35,955	$ 615,427	0.170	190,874	0.25	0.06
50	50	35	$ 113,350	35,837	$ 618,438	0.168	175,207	0.30	0.06
40	80	35	$ 114,680	36,138	$ 624,005	0.173	190,874	0.25	0.06
50	20	35	$ 95,350	37,613	$ 625,470	0.175	192,733	0.24	0.06
50	60	35	$ 119,350	36,020	$ 627,016	0.171	175,207	0.30	0.06
60	40	35	$ 124,020	36,131	$ 633,248	0.169	161,263	0.35	0.06
50	70	35	$ 125,350	36,203	$ 635,593	0.173	175,207	0.30	0.06
60	50	35	$ 130,020	36,082	$ 638,558	0.169	159,516	0.35	0.06

Figure 6. *The overall optimization results from HOMER.*

3.6.2. Emissions for PV and Grid Connected System

In India, the main source of power generation is coal based power plants. As a consequence in 2010-2012, its emission factor for the electricity sector was 0.81 kg CO_2/kWh.

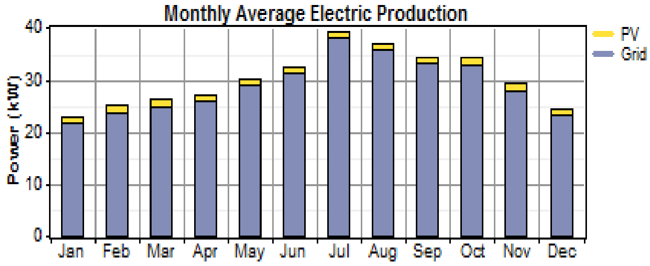


Figure 7. *Monthly average electricity production from PV and grid connected system.*

Table 2. *Technical & Cost details of the best suited PV and Grid configuration for hybrid system.*

Cost summary		**System Architecture**		**Electrical**		
Total net present cost	Rs 30588300	PV Array	5kW	Component	Production (kWh/yr)	Fraction
Levelized cost of energy	Rs 8.22/kWh	Grid	51kW			
Operating cost	Rs 2114940/yr	Inverter	5kW	PV Array	10,500	4%
Reliability	93%	Rectifier	5kW	Grid	254,081	96%
		Dispatch Strategy	Load Following	Total	264,581	100%

Table 3 shows the types of GHG and other emission and their quantity given out by the PV and grid connected system over one year in operation when PV penetration is 4% and 20% respectively. We can see that the emissions are reduces significantly as the PV penetration increases.

Table 3. *GHG & emissions recorded from the HOMER analysis for PV and grid connected system when PV penetration is 4% and 20% respectively.*

Pollutant	**Emissions (kg/yr)**	**Pollutant**	**Emissions (kg/yr)**
Carbon dioxide	1,60,579	Carbon dioxide	1,31,039
Carbon monoxide	0	Carbon monoxide	0
Unburned hydrocarbons	0	Unburned hydrocarbons	0
Particulate matter	0	Particulate matter	0
Sulfur dioxide	696	Sulfur dioxide	568
Nitrogen oxides	2,208	Nitrogen oxides	278

3.7. PV, Diesel and Grid Based System

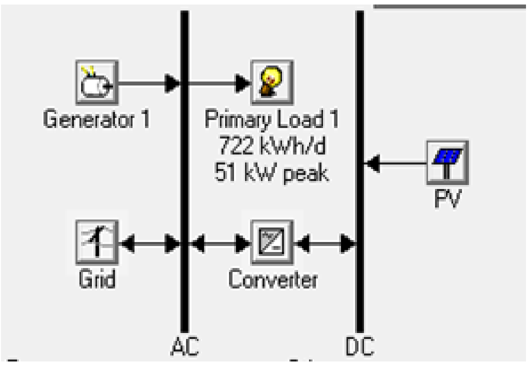


Figure 8. *PV, Diesel and Grid based system configuration.*

Figure 8 shows the PV and diesel based system configuration as designed in Homer simulation software. For the off-grid electrification, various combinations have been obtained of hybrid systems with SPV, diesel generator, batteries and convertors from the HOMER Optimization simulation software.

All the possible hybrid system configurations are listed in ascending order of their total NPC in the figure shown below. The technical and economical details of all the configurations of the hybrid systems from the optimization process are shown in detail in Figure 9, where the best possible combination of SPV, a diesel generator and Grid is on top of the Figure. The upper most combination is able to fully meet the load demands at the lowest possible total NPC.

PV (kW)	Label (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Net Purchases (kWh/yr)	Ren. Frac.	Diesel (L)	Label (hrs)
20	30	10	25	$ 46,240	63,397	$ 939,754	0.253	159,722	0.11	36,001	7,086
20	30	20	25	$ 52,240	63,084	$ 941,338	0.253	156,174	0.12	35,971	7,086
20	30	30	25	$ 58,240	63,267	$ 949,915	0.256	156,174	0.12	35,971	7,086
30	30	20	25	$ 68,910	63,395	$ 962,397	0.258	141,821	0.18	35,841	7,086
30	30	30	25	$ 74,910	63,462	$ 969,336	0.260	140,945	0.18	35,841	7,086
30	30	10	25	$ 62,910	65,072	$ 980,038	0.264	155,344	0.12	35,919	7,086
40	30	30	25	$ 91,580	63,707	$ 989,461	0.260	125,615	0.23	35,785	7,086
40	30	20	25	$ 85,580	64,471	$ 994,230	0.266	132,755	0.21	35,785	7,086
40	30	10	25	$ 79,580	67,069	$ 1,024,844	0.276	153,080	0.13	35,884	7,086
20	40	10	25	$ 48,540	71,745	$ 1,059,704	0.285	143,534	0.11	45,714	7,086
20	40	20	25	$ 54,540	71,438	$ 1,061,387	0.286	139,899	0.12	45,706	7,086
20	40	30	25	$ 60,540	71,621	$ 1,069,964	0.288	139,899	0.12	45,706	7,086
30	40	20	25	$ 71,210	71,773	$ 1,082,770	0.290	125,259	0.17	45,647	7,086
30	40	30	25	$ 77,210	71,839	$ 1,089,710	0.291	124,383	0.18	45,647	7,086
30	40	10	25	$ 65,210	73,434	$ 1,100,182	0.296	138,986	0.12	45,674	7,086
40	40	30	25	$ 93,880	72,096	$ 1,109,992	0.289	108,914	0.23	45,626	7,086
40	40	20	25	$ 87,880	72,860	$ 1,114,762	0.296	116,054	0.21	45,626	7,086
40	40	10	25	$ 81,880	75,437	$ 1,145,081	0.308	136,641	0.13	45,660	7,086

Figure 9. *Optimization results for PV, Diesel and Grid based system.*

According to the optimization results, the optimal combination of hybrid system components are a 20kW PV-Array, 30kW Diesel Generator, 25kW from grid, 20kW Inverter and a 20kW Rectifier with a dispatch strategy of load following. Details of this configuration are shown in Table 4. The total NPC, operating cost and Levelized cost of energy (COE) for such a hybrid system are Rs 56385240, 3803820 and Rs 15.18/kWh, respectively.

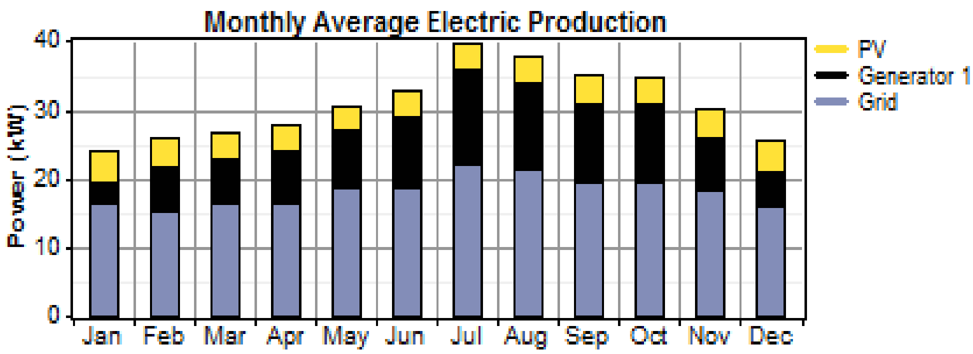


Figure 10. *Monthly average electricity production for PV, diesel and Grid based system.*

Figure 10 shows the monthly distribution of the electricity produced in kW by the SPV, Diesel generator and grid. The effect of SPV penetration reduces the diesel fuel consumption. As the output from the PV increases, the generator's operation hours decrease.

Table 4. *Technical & Cost details of the best suited configuration for PV, Diesel and Grid based system.*

Cost summary		System Architecture		Electrical		
Total net present cost	Rs56385240	PV Array	20kW	Component	Production (kWh/yr)	Fraction
Levelized cost of energy	Rs15.18/kWh	Diesel Generator	30kW			
Operating cost	Rs3803820/yr	Grid	25kW	Grid	159,722	59%
Reliability	100%	Inverter	20kW	PV Array	35,000	13%
		Rectifier	20kW	Diesel Generator	75,976	28%
				Total	270,698	100%

Table 5. *Annualized Cost of the PV, Diesel and Grid based system.*

Component	Capital (Rs/yr)	Replacement (Rs/yr)	O&M (Rs /yr)	Fuel (Rs /yr)	Salvage (Rs/yr)	Total(Rs /yr)
PV	2,366	758	4,340	0	-445	7,018
Generator	490	3,055	3,614	28,801	-27	35,932
Grid	0	0	19,205	0	0	19,205
Converter	426	205	20	0	-42	609
Other	0	0	3,915	0	0	3,915
System	3,281	4,018	31,093	28,801	-515	66,678

Table 5 shows the annualized cost of the proposed system's components. It can be seen that the costs for the DG and SPV are distributed completely oppositely over both components' lifespan: The capital cost of the Diesel generator makes up only 5% of the system's total capital cost, whereas almost 60% of the initial investment go to the SPV arrays. Once installed, however, SPV is cheap to maintain and operate compared to DG, which in the end is responsible for 59.5% of the system's total annual cost of Rs 29425110.

Emissions for PV, Diesel and Grid Based System

Table 6 shows the types of GHG and other emission and their quantity given out by the PV and diesel based system over one year in operation.

Table 6. *GHG & emissions recorded from the HOMER analysis for PV, diesel and Grid based system.*

Pollutant	Emissions (kg/yr)
Carbon dioxide	195,747
Carbon monoxide	234
Unburned hydrocarbons	25.9
Particulate matter	17.6
Sulfur dioxide	628
Nitrogen oxides	2,302

3.8. PV, Wind and Diesel Connected System with Batteries

Figure 11 shows the PV, Wind and diesel based system configuration as designed in Homer simulation software.

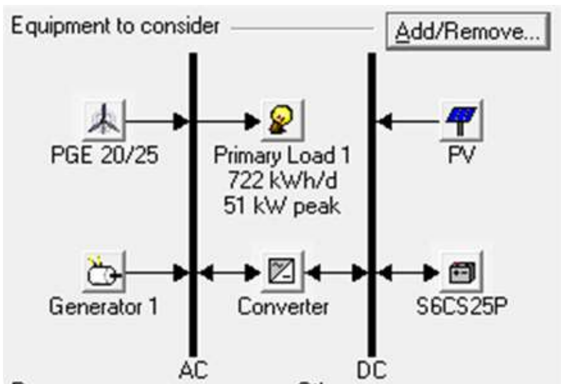


Figure 11. *PV, Diesel and Grid connected system configuration.*

The optimization results of PV, diesel and Wind based system with batteries are shown in Figure 12. All the possible hybrid system configurations are listed in ascending order of their total NPC in the figure shown below.

Double click on a system below for simulation results.

PV (kW)	PGE25	Label (kW)	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Batt. Lf. (yr)
5	3	50	25	20	$ 129,085	46,227	$ 780,605	0.210	0.63	37,519	3,307	12.0
6	3	50	25	20	$ 130,752	46,207	$ 781,994	0.211	0.63	37,258	3,289	12.0
5	3	50	20	20	$ 122,835	46,856	$ 783,219	0.211	0.63	38,277	3,446	12.0
6	3	50	20	20	$ 124,502	46,822	$ 784,404	0.211	0.63	38,008	3,423	12.0
5	3	50	30	20	$ 135,335	46,103	$ 785,112	0.211	0.63	37,208	3,245	12.0
5	3	51	25	20	$ 129,315	46,552	$ 785,419	0.211	0.63	37,788	3,306	12.0
6	3	51	25	20	$ 130,982	46,538	$ 786,892	0.212	0.63	37,532	3,289	12.0
6	3	50	30	20	$ 137,002	46,134	$ 787,208	0.212	0.63	36,990	3,235	12.0
5	3	51	20	20	$ 123,065	47,209	$ 788,421	0.212	0.63	38,571	3,446	12.0
5	3	50	35	20	$ 141,585	45,912	$ 788,672	0.212	0.63	36,825	3,180	12.0
6	3	51	20	20	$ 124,732	47,146	$ 789,211	0.212	0.63	38,275	3,420	12.0
9	3	50	25	20	$ 135,753	46,374	$ 789,344	0.213	0.64	36,681	3,265	12.0
9	3	50	20	20	$ 129,503	46,832	$ 789,546	0.213	0.64	37,302	3,370	12.0
5	3	51	30	20	$ 135,565	46,407	$ 789,618	0.213	0.63	37,458	3,242	12.0
5	3	50	10	20	$ 110,335	48,272	$ 790,679	0.213	0.62	39,870	3,779	12.0
6	3	50	35	20	$ 143,252	45,942	$ 790,757	0.213	0.64	36,605	3,171	12.0
6	3	51	30	20	$ 137,232	46,427	$ 791,573	0.213	0.64	37,230	3,231	12.0
5	3	50	35	30	$ 147,585	45,742	$ 792,266	0.213	0.62	36,734	2,910	11.5
6	3	50	10	20	$ 112,002	48,312	$ 792,908	0.213	0.63	39,671	3,765	12.0
10	3	50	25	20	$ 137,420	46,521	$ 793,082	0.214	0.64	36,576	3,267	12.0
5	3	51	35	20	$ 141,815	46,212	$ 793,128	0.214	0.63	37,071	3,178	12.0
10	3	50	20	20	$ 131,170	46,970	$ 793,167	0.214	0.64	37,189	3,371	12.0
5	3	50	40	20	$ 147,835	45,851	$ 794,052	0.214	0.64	36,556	3,135	12.0
9	3	51	25	20	$ 135,983	46,713	$ 794,347	0.214	0.64	36,963	3,266	12.0

Figure 12. *Optimization results for PV, diesel and Wind based system.*

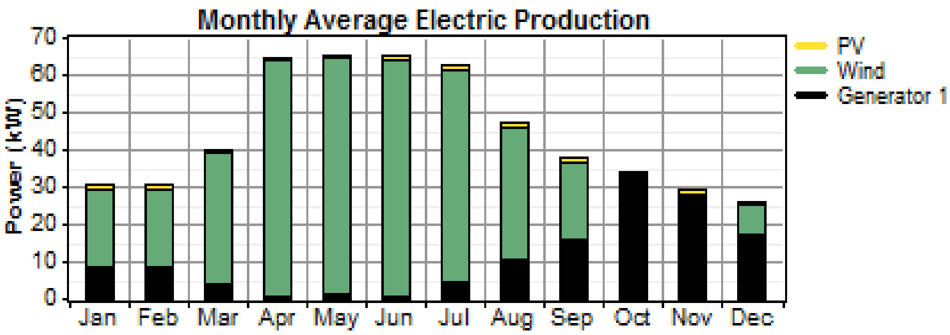


Figure 13. *Monthly electricity productions for PV, Wind and Generator based system.*

According to the optimization results, the optimal combination of the PV, diesel and Wind system have a 5kW PV-Array, 25 Surrette 6CS25P Batteries, 20kW Inverter and a 20kW Rectifier with a dispatch strategy of load following. Details of this configuration are shown in Table 7. The total NPC, operating cost and COE for such a system are Rs 43836300, Rs 2773620 and Rs 12.6/kWh, respectively.

As we know that for PV, diesel and Grid based system, Generator and batteries have a very important role as it is the only backup power component. Technical details of the battery for best suited configuration are shown in Table 7.

Table 7. *Technical & Cost details of the best suited configuration for PV, diesel and Grid based system with batteries.*

Cost summary		System Architecture		Electrical		
Total net present cost	Rs 43836300	PV Array	5 kW	Component	Production (kWh/yr)	Fraction
Levelized cost of energy	Rs 12.6/kWh	Battery	25 Surrette 6CS25P			
Operating cost	Rs 2773620/yr	Wind	75 kW	PV Array	8,750	2%
Reliability	100%	Generator	50 kW	Diesel	97,164	25%
		Inverter	20 kW	Wind turbine	284,212	73%
		Rectifier	20 kW	Total	390,126	100%

From Table 7 we can see that the total amount of generation of electricity for this configuration is 126581kWh/yr more than the requirement which is i.e. extra electricity will able to sell to grid.

Emissions for PV, Diesel and Wind Turbine Connected System

As PV, diesel and Wind based system with batteries is used for the power generation, there will be pollutant emissions for this system configuration only from the generator which is less in compare to the only generated connected system.

Table 8. *GHG & emissions recorded from the HOMER analysis for PV, Wind and diesel based system.*

Pollutant	Emissions (kg/yr)
Carbon dioxide	98,800
Carbon monoxide	244
Unburned hydrocarbons	27
Particulate matter	18.4
Sulfur dioxide	198
Nitrogen oxides	2,176

3.9. Wind and Grid Connected System

Figure 5.12 shows the Wind and grid connected system configuration as designed in Homer simulation software.

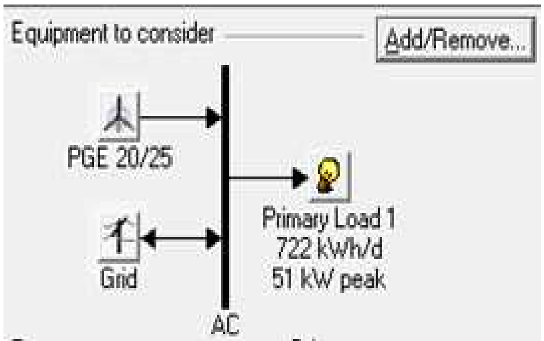


Figure 14. *Wind and Grid connected system configuration.*

Figure 14 shows the HOMER output results ordered from lowest NPC for adding the PV generation system to the simulation. HOMER uses the total NPC as its main selection tools.

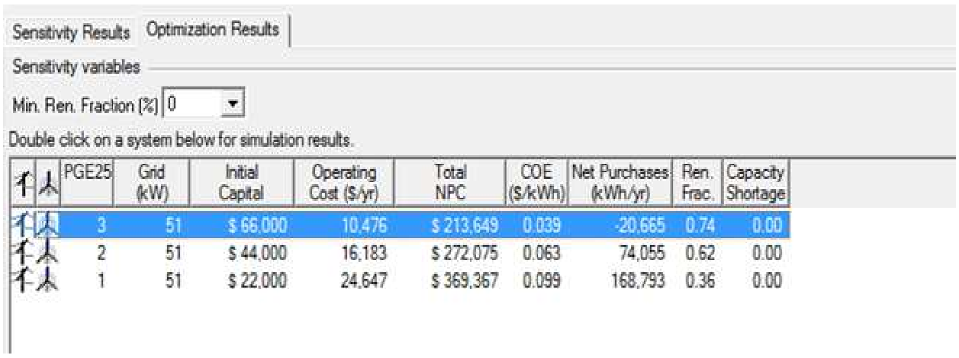


Figure 15. *Optimization results for Wind and Grid based system.*

Figure 15 shows the optimization results of Wind and grid connected system given by the HOMER. This system has a Wind fraction of 74% with a grid fraction of 26%. For the optimal alternative system, the Wind turbine size is 75 kW and Grid is 51kW. Details of this configuration are shown in Table 9 The total NPC, Initial Capital cost and COE for such a hybrid system are Rs 30588300, Rs 2609520 and Rs 8.22/kWh, respectively.

Table 9. *Technical & Cost details of the best suited configuration for Wind and Grid based system.*

Cost	summary	System	Architecture		Electrical	
Total net present cost	Rs 12818640	Wind	75 kW	Component	Production	Fraction
Levelized cost of energy	Rs 2.34/kWh	Grid	51 kW		kWh/yr	
Operating cost	Rs 628560/yr	Dispatch Strategy	Load Following	Wind turbine	284,212	74%
		Reliability	100%	Grid	100,359	26%
				Total	384,572	100%

From Table 9 we can see that the total amount of generation of electricity for this configuration is more than the requirement which is 121,025kWh/yr i.e. extra electricity will able to sell to grid and also there is no capacity shortage.

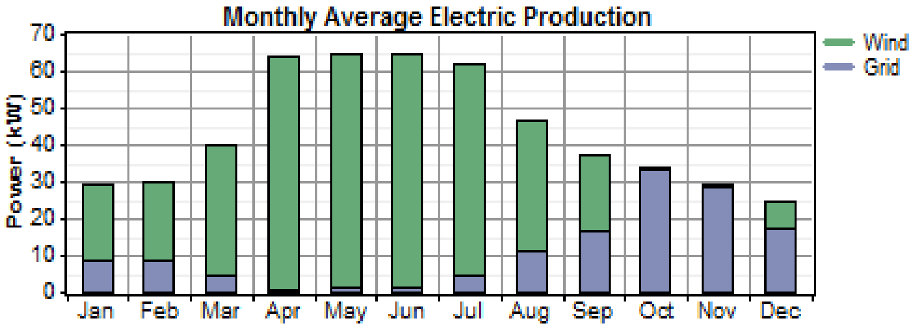


Figure 16. *Monthly electricity production for Wind and Grid based system.*

Figure 16 shows the monthly distribution of the electricity produced in kW by the Wind turbine and grid. There is excess electricity production but capacity shortage is also in this configuration.

Emissions for Wind and Grid Connected System

As Wind and Grid based system is used for the power generation, there will be no pollutant emissions for this system configuration from Wind system and the emission is only because of the Grid connection.

Table 10. *GHG & emissions recorded from the HOMER analysis for Wind and Grid based system.*

Pollutant	Emissions (kg/yr)
Carbon dioxide	-13,061
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	-56.6
Nitrogen oxides	-27.7

3.10. PV and Wind Connected System

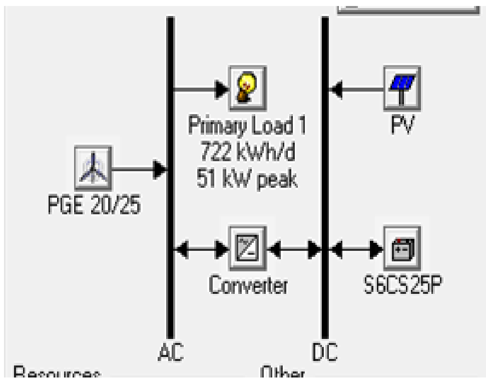


Figure 17. *PV and Wind connected system configuration.*

Figure 17 shows the PV and Wind connected system configuration as designed in Homer simulation software.

Figure 18 shows the HOMER output results ordered from lowest NPC for adding the PV generation system to the simulation. HOMER uses the total NPC as its main selection tool.

PV (kW)	PGE25	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Batt. Lf. (yr)
50	3	120	40	$ 323,350	24,782	$ 672,628	0.220	1.00	0.20	12.0
50	4	100	30	$ 314,350	25,827	$ 678,356	0.218	1.00	0.19	12.0
50	3	120	50	$ 329,350	24,965	$ 681,205	0.222	1.00	0.20	12.0
50	4	100	40	$ 320,350	26,010	$ 686,933	0.221	1.00	0.18	12.0
50	4	100	50	$ 326,350	26,193	$ 695,510	0.223	1.00	0.18	12.0
50	4	120	30	$ 339,350	26,798	$ 717,036	0.229	1.00	0.18	12.0
50	3	150	30	$ 354,850	26,055	$ 722,071	0.235	1.00	0.20	12.0
50	4	120	40	$ 345,350	26,981	$ 725,613	0.231	1.00	0.18	12.0
50	3	150	40	$ 360,850	26,238	$ 730,649	0.237	1.00	0.19	12.0
50	4	120	50	$ 351,350	27,163	$ 734,191	0.234	1.00	0.17	12.0
50	3	150	50	$ 366,850	26,421	$ 739,226	0.239	1.00	0.19	12.0
50	4	150	20	$ 370,850	28,071	$ 766,479	0.248	1.00	0.20	12.0
50	4	150	30	$ 376,850	28,254	$ 775,057	0.246	1.00	0.18	12.0
50	4	150	40	$ 382,850	28,437	$ 783,634	0.248	1.00	0.17	12.0
50	4	150	50	$ 388,850	28,619	$ 792,211	0.250	1.00	0.17	12.0
50	3	200	30	$ 417,350	28,482	$ 818,772	0.265	1.00	0.19	12.0
50	3	200	40	$ 423,350	28,665	$ 827,350	0.266	1.00	0.19	12.0
50	3	200	50	$ 429,350	28,848	$ 835,927	0.269	1.00	0.18	12.0
50	4	200	20	$ 433,350	30,498	$ 863,180	0.278	1.00	0.20	12.0
50	4	200	30	$ 439,350	30,680	$ 871,758	0.276	1.00	0.17	12.0
50	4	200	40	$ 445,350	30,863	$ 880,335	0.277	1.00	0.16	12.0
50	4	200	50	$ 451,350	31,046	$ 888,912	0.279	1.00	0.16	12.0

Figure 18. *Optimization results for PV and Wind based system.*

Figure 18 shows the optimization results of PV and Wind connected system with batteries backup given by the HOMER. This system has a PV fraction of 19% and Wind fraction of 81%. For the optimal alternative system, the PV array size is 50 kW and Wind turbine size is 100 kW and there is 100 no. of batteries for backup. There is capacity shortage of about 20% however the optimization result shows the excess electricity production due to the variation in climate in different seasons which is 230937 kWh/yr. And the unmet load is 43240kWh/yr. The excess electricity will be able to sell to grid.

Details of this configuration are shown in Table 11. The total NPC, operating cost and Levelized cost of energy (COE) for such a hybrid system are Rs12818640, 628560 and Rs 2.34/kWh, respectively.

Table 11. *Technical & Cost details of the best suited configuration for PV and Wind based system.*

Cost	summary	System	Architecture		Electrical	
Total net present cost	Rs 40701360	PV array	50 kW	Component	Production	Fraction
Levelized cost of energy	Rs 13.8/kWh	Wind	100 kW		kWh/yr	
Operating cost	Rs 1549620/yr	Dispatch Strategy	Load Following	PV array	87,500	19%
Reliability	80%	Inverter	40 kW	Wind turbine	378,950	81%
		Rectifier	40 kW	Total	466,449	100%

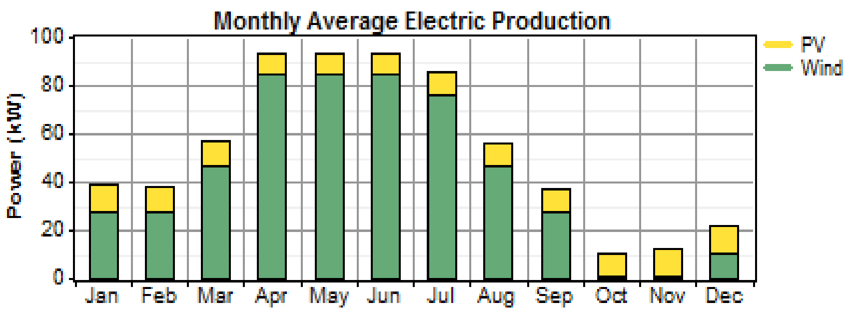


Figure 19. *Monthly average electricity production for PV and Wind based system.*

Figure 19 shows the monthly distribution of the electricity produced in kW by the SPV and Wind turbine. There is excess electricity production but capacity shortage is also in this configuration.

Emissions for PV and Wind turbine connected system

As Solar and Wind based system is used for the power generation, there will be no pollutant emissions for this system configuration because there is no use of diesel or coal Wind and Grid connected system which is good for the environment.

Table 12. *GHG & emissions recorded from the HOMER analysis for PV and Wind based system.*

Pollutant	Emissions (kg/yr)
Carbon dioxide	0
Carbon monoxide	0
Nitrogen oxides	0

3.11. PV, Wind and Grid Connected System

Figure 20 shows the PV, Wind and grid connected system configuration as designed in Homer simulation software.

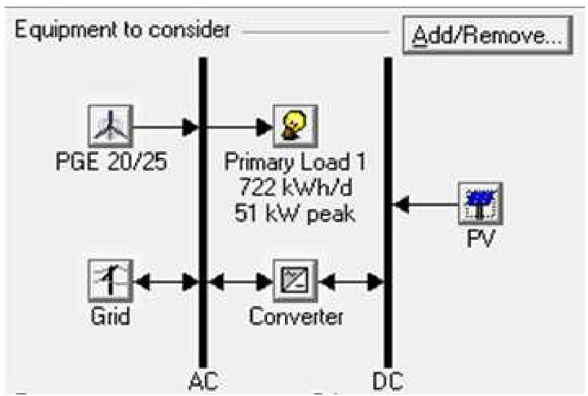


Figure 20. *PV, Wind and Grid connected system configuration.*

Figure 21 shows the HOMER output results ordered from lowest NPC for adding the PV generation system and Wind generation system to the simulation. HOMER uses the total NPC as its main selection tool.

Figure 21 shows the optimization results of PV, Wind and Grid connected system given by the HOMER. This system has a PV fraction of 14% and Wind fraction of 37% and Grid fraction of 49%. For the optimal alternative system, the PV array size is 20 kW and Wind turbine size is 25 kW and Grid size is 25 kW. There is capacity shortage of 10% which is about 26,467kWh/yr. And the unmet load is 17,847kWh/yr.

Details of this configuration are shown in Table 13.The total NPC, operating cost and Levelized cost of energy (COE) for such a hybrid system are Rs23573760, 1385940 and Rs 6.6/kWh, respectively.

Double click on a system below for simulation results.

PV (kW)	PGE25	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Net Purchases (kWh/yr)	Ren. Frac.	Capacity Shortage
20	1	20	25	$ 67,340	23,099	$ 392,896	0.111	119,445	0.50	0.10
20	1	30	25	$ 73,340	23,282	$ 401,473	0.114	119,445	0.50	0.10
25	1	20	25	$ 75,675	23,263	$ 403,543	0.113	111,913	0.53	0.10
20	1	40	25	$ 79,340	23,465	$ 410,050	0.116	119,445	0.50	0.10
25	1	10	25	$ 69,675	24,188	$ 410,573	0.117	120,262	0.50	0.10
25	1	30	25	$ 81,675	23,444	$ 412,088	0.115	111,896	0.53	0.10
30	1	20	25	$ 84,010	23,524	$ 415,558	0.115	105,113	0.55	0.10
20	1	50	25	$ 85,340	23,648	$ 418,628	0.119	119,445	0.50	0.10
25	1	40	25	$ 87,675	23,626	$ 420,665	0.118	111,896	0.53	0.10
30	1	30	25	$ 90,010	23,591	$ 422,500	0.116	104,238	0.55	0.10
20	1	60	25	$ 91,340	23,830	$ 427,205	0.121	119,445	0.50	0.10
25	1	50	25	$ 93,675	23,809	$ 429,242	0.120	111,896	0.53	0.10
30	1	40	25	$ 96,010	23,774	$ 431,078	0.119	104,238	0.55	0.10
30	1	10	25	$ 78,010	25,104	$ 431,824	0.122	118,402	0.51	0.10
20	1	70	25	$ 97,340	24,013	$ 435,782	0.123	119,445	0.50	0.10
25	1	60	25	$ 99,675	23,992	$ 437,820	0.122	111,896	0.53	0.10
30	1	50	25	$ 102,010	23,957	$ 439,655	0.121	104,238	0.55	0.10
20	1	80	25	$ 103,340	24,196	$ 444,360	0.126	119,445	0.50	0.10
25	1	70	25	$ 105,675	24,175	$ 446,397	0.125	111,896	0.53	0.10
30	1	60	25	$ 108,010	24,140	$ 448,232	0.123	104,238	0.55	0.10
25	1	80	25	$ 111,675	24,358	$ 454,974	0.127	111,896	0.53	0.10
30	1	70	25	$ 114,010	24,322	$ 456,810	0.126	104,238	0.55	0.10
30	1	80	25	$ 120,010	24,505	$ 465,387	0.128	104,238	0.55	0.10

Figure 21. *Optimization results for PV, Wind and Grid based system.*

Table 13. *Technical & Cost details of the best suited configuration for PV, Wind and Grid based system.*

Cost summary		**System Architecture**		**Electrical**		
Total net present cost	Rs 23573760	PV Array	20kW	Component	Production (kWh/yr)	Fraction
Levelized cost of energy	Rs 6.6/kWh	Wind turbine	25kW			
		Grid	25kW	PV array	35,000	14%
Operating cost	Rs 1385940/yr	Inverter	20kW	Wind turbine	94,737	37%
		Rectifier	20kW	Grid purchases	124,366	49%
		Reliability	90%	Total	254,104	100%

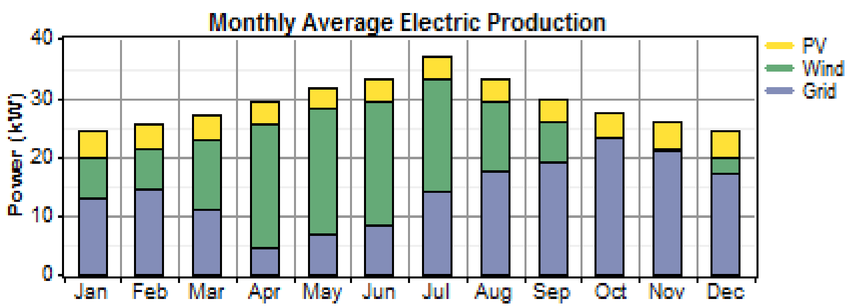


Figure 22. *Monthly average electricity production for PV, Wind and Grid based system.*

Figure 22 shows the monthly distribution of the electricity produced in kW by the SPV, Wind turbine and grid. There is excess electricity production but capacity shortage is also in this configuration.

Emissions for PV, Wind turbine and Grid connected system

As Solar and Wind based system is used for the power generation, there will be no pollutant emissions from the PV and Wind turbine in this system configuration but there is use of diesel or coal in Grid electricity generation which emits green house gases this is shown in Table 14.

Table 14. *GHG & emissions recorded from the HOMER analysis for PV, Wind and Grid based system.*

Pollutant	**Emissions (kg/yr)**
Carbon dioxide	75,490
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	327
Nitrogen oxides	160

3.12. Wind, Diesel and Grid Connected System

Figure 23 shows the Wind, Diesel and grid connected system configuration as designed in Homer simulation software.

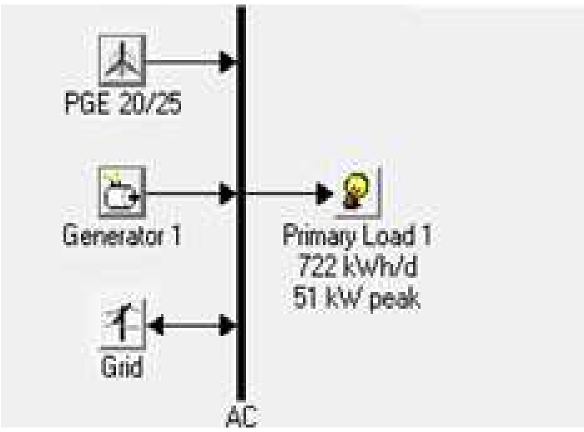
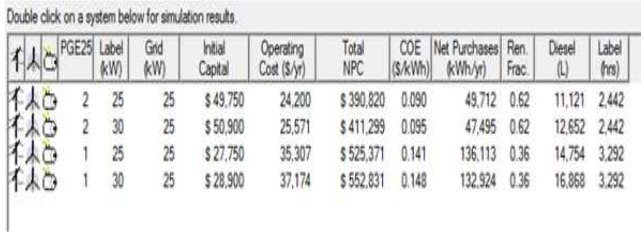


Figure 23. *Wind, Diesel and Grid connected system configuration.*

Figure 24 shows the HOMER output results ordered from lowest NPC for adding the Wind generation system and Diesel generator to the simulation. HOMER uses the total NPC as its main selection tool.


Double click on a system below for simulation results.

	PGE25	Label (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Net Purchases (kWh/yr)	Ren. Frac.	Diesel (L)	Label (hrs)
	2	25	25	$ 49,750	24,200	$ 390,820	0.090	49,712	0.62	11,121	2,442
	2	30	25	$ 50,900	25,571	$ 411,299	0.095	47,495	0.62	12,652	2,442
	1	25	25	$ 27,750	35,307	$ 525,371	0.141	136,113	0.36	14,754	3,292
	1	30	25	$ 28,900	37,174	$ 552,831	0.148	132,924	0.36	16,868	3,292

Figure 24. *Optimization results for Wind, Diesel and Grid based system.*

Figure 24 shows the optimization results of Wind, Diesel and Grid connected system given by the HOMER. This system has a Wind turbine fraction of 62%, Diesel fraction of 8%and Grid purchases fraction of 30%. For the optimal alternative system, Wind turbine size is 50 kW, generator size is 25 kW and Grid size is 25 kW. There is almost no capacity shortage.

Details of this configuration are shown in Table 15. The total NPC, operating cost and Levelized cost of energy (COE) for such a hybrid system are Rs23449200, 1542000 and Rs 5.4/kWh, respectively.

Table 15. *Technical & Cost details of the best suited configuration for Wind, Diesel and Grid based system.*

Cost summary		System Architecture		Electrical		
Total net present cost	Rs 23449200	Wind turbine	50kW	Component	Production (kWh/yr)	Fraction
Levelized cost of energy	Rs 5.4/kWh	Diesel	25kW			
				Wind turbine	189,475	62%
Operating cost	Rs 1542000/yr	Grid	25kW	Diesel	24,949	8%
		Reliability	100%	Grid purchases	92,957	30%
				Total	307,381	100%

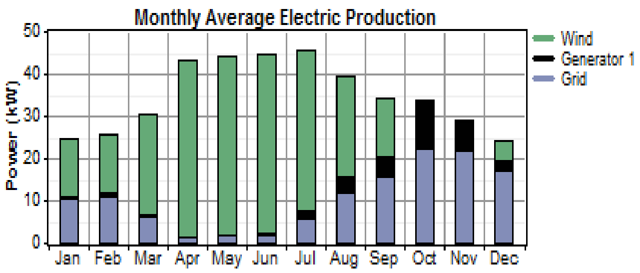


Figure 25. *Monthly average electricity productions for Wind, Diesel and Grid based system.*

Figure 25 shows the monthly distribution of the electricity produced in kW by the Wind turbine generator, Diesel and grid. There is excess electricity production of about 43,245kWh/yr which will be able to sell to Grid and no capacity shortage in this configuration.

Emissions for PV, diesel and Grid connected system

As Wind and Grid based system is used for the power generation, there will be no pollutant emissions for this system configuration from PV system and the emission is only because of the Grid connection and is shown in Table 16.

Table 16. *GHG & emissions recorded from the HOMER analysis for Wind, Diesel and Grid based system.*

Pollutant	Emissions (kg/yr)
Carbon dioxide	60,704
Carbon monoxide	72.3
Unburned hydrocarbons	8.01
Particulate matter	5.45
Sulfur dioxide	195
Nitrogen oxides	712

4. Results and Discussion

After analyzing all the system models, Wind and Grid connected system is found to be more economical with lowest cost of energy of Rs 2.34/kWh and 100% reliable for the selected site. At present the cost of energy for the grid connected system is Rs 7.5/kWh in India, which it is expected to increase with time. At the same time the CO_2 emissions is maximum for the grid connected system which can be reduced by adding the wind energy with the grid connected system with much influenced in the cost of energy. By adding the alternative sources, we can overcome the scheduled power cut too. Internal rate of return of wind and Grid connected system is 4.5% and NPC for wind and grid connected system is Rs.12818640. and payback period is about 5 years, which attract the investors and is also good from economical point of view. However the cost of energy of other systems is high. For PV and Grid connected system, the total NPC, initial capital cost and COE for such a hybrid system are Rs 30588300, Rs 2609520 and Rs 8.22/kWh, respectively. Internal rate of return is 10.35% and payback period is about 1.2 years. For PV, Diesel and Grid connected system, the total NPC, operating cost and Levelized cost of energy (COE) for such a hybrid system are Rs 56385240, 3803820 and Rs 15.18/kWh respectively, internal rate of return is 11.2% and payback period is about 2 years. For PV, Wind and Diesel connected system, The total NPC, operating cost and COE for such a system are Rs 43836300, Rs 2773620 and Rs 12.6/kWh, respectively Internal rate of return 7.2% and payback period is about 2.3 years. For PV and Wind connected system, the total NPC, operating cost and Levelized cost of energy (COE) for such a hybrid system are Rs12818640, 628560 and Rs 2.34/kWh respectively, internal rate of return 3.15% and payback period is about 6.5 years. For PV, Wind and Grid connected system, The total NPC, operating cost and Levelized cost of energy (COE) for such a hybrid system are Rs23573760, 1385940 and Rs 6.6/kWh respectively. Internal rate of return is 6.4% and payback period is about 3 years. For Wind, Diesel and Grid connected system, the total NPC, operating cost and Levelized cost of energy (COE) for such a hybrid system are Rs 23449200, 1542000 and Rs 5.4/kWh, respectively Internal rate of return 8% and payback period is about 2 years. Carbon emission is also more in other systems which causes green house effect. Table 17 shows the economical comparison between different combinations of hybrid system.

Table 17. *Techno-Economical comparison between different combinations of hybrid system.*

S. No	**Total system size = 51 kW**		**SYSTEMS**		
	(Pv+w+d)	**(Pv+g)**	**(w+g)**	**(Pv+w)**	**(Pv+w+g)**
System fraction	PV= 2% W=73% D= 25%	PV = 4% G= 96%	W= 74% G= 26%	PV = 19% W= 81%	PV =14% W=37% G=49
System Architecture	PV=5kw WT=75kw Gen=50kw	PV=5kw G=51kw	WT=75kw G=51kw	PV =50kw WT=100kw	PV =20kw WT=25kw G=25kw
C.O.E(Rs.)	12.6	8.22	2.34	13.8	6.6
I.R.R (%)	7.2	10.35	4.5	3.15	6.4
N.P.C (Rs.)	43836300	30588300	12818640	40701360	23573760
Annual Cost (Rs)	3323160	2170320	909540	2887860	1672620
Payback Period (years)	2.3	1.2	5	6.5	3
Operating cost (Rs./yr)	2773620	2114940	628560	1549620	1385940
Reliability (%)	100	93	100	80	90

5. Conclusion

This study presents the techno-economic feasibility analysis of hybrid systems for decentralized power generation in India. The results of the study shows that the remote sites of the type considered in this work are prospective locations for the installation of hybrid renewable energy systems based on solar and wind energy. HOMER was used for the analysis, and viability was determined on the basis of internal rate of return, net present cost and cost of energy. The simulation results shows that Wind and Grid connected system is found to be more economical amongst all the configurations considered in this study with the cost of energy of Rs 2.34/kWh with 100% reliability. At present time the cost of energy for the grid connected system is Rs 7.5/kWh, which is expected to increase with time. At the same time the CO_2 emissions is maximum for the grid connected system which can be reduced by adding the Wind energy with the grid connected system with much influenced in the cost of energy. By adding the alternative sources, we can overcome the scheduled power cut too.

Successful implementation of large scale hybrid renewable energy systems requires devising suitable policy measures after considerations of local support, institutional barriers and other social factors. This necessitates joint efforts from policy makers and modeling experts for clear representation of the energy problem and effective implementation of the solutions as there are certain hindrances for the implementation of hybrid renewable energy systems in countries like India for example lack of technical support in case of repair and maintenance, lack of finances and subsidies for creation of projects in rural areas, lack of policy and regulations for the promotion of both off grid and grid connected hybrid renewable energy systems. This calls for the need to promote hybrid renewable energy systems, which can cater to local communities in much effective manner. Apart from providing better quality of life to rural communities, it could have significant effect in the improvement of rural economy.

In view of the above, this work promotes hybrid renewable energy systems for remote places of the type considered in this work as the most cost effective solution. This would involve accelerating the overall development of the under developed areas with a number of programs like providing electricity, entrepreneurship development and employment generation opportunities.

References

[1] Al-Badi A. H. , AL-Toobi M., AL-Harthy S., Al-Hosni Z. and AL-Harthy A. "Hybrid systems for decentralized power generation in Oman". International Journal of sustainable energy, Vol. 31(6), pp. 411–421, 2012.

[2] Balamurugan, P., S. Ashok, and T.L. Jose. "Optimal operation of biomass /wind/ PV hybrid energy system for rural areas" International Journal of Green Energy, Vol. 6(1), pp. 104–16, 2009.

[3] Kumaravel, S. and S. Ashok. "An optimal stand-alone biomass/solar-PV/pico-hydel hybrid energy system for remote rural area electrification of isolated village in western-ghats region of India" International Journal of Green Energy, Vol. 9(5), pp. 398–408, 2012.

[4] W. D. Kellogg, M. H. Nehrir, G. Venkataramanan and V. Gerez, "Generation Unit Sizing and Cost Analysis for Stand-Alone Wind, Photovoltaic, and Hybrid Wind/PV System" IEEE Transactions on Energy Conversion Vol. 13, pp.70-76, 1998.

[5] Ali Naci Celik, "Techno-economic analysis of autonomous PV-wind hybrid energy systems using different sizing methods" Energy Conversion and Management. Vol. 44, pp. 1951–1968, 2003.

[6] Ngan MS, Tan CW, "Assessment of Economic Viability for PV/Wind/Diesel Hybrid Energy System in Southern Peninsular Malaysia", Renewable and Sustainable Energy Reviews, Vol. 16, pp. 634– 647, 2011.

[7] Karakoulidis, K. et al., Techno-Economic Analysis of A Stand-Alone Hybrid Photovoltaic-Diesel-Battery-Fuel Cell Power System, Renewable Energy, Vol. 36, pp. 2238-2244, 2011.

[8] Bahtiyar Dursun, Cihan Gokcol, Ilhan Umut[3], Erdem Ucar[3] and Sureyya Kocabey, 2013, Techno-Economic Evaluation of a Hybrid PV-WIND Power Generation System,, taylor and francis International Journal of Green Energy, 10: 117–136.

[9] J.Dekker, M. Nthontho, S. Chawdhury, S.P. Chawdhury,2012, Economic analysis of PV/diesel hybrid systems in different climate zones of South Africa, Elsevier,

[10] Eyad S. Hrayshat, 2013, Techno-economic analysis of autonomous hybrid photovoltaic-diesel-battery system", Energy for Sustainable Development: 13,143-150.

[11] Majid Jamil, Sheeraz Kirmani and Himanshu Chatterjee, "Techno-economic viability of three different energy-supplying options for remote area electrification in India," international journal of sustainable energy, Vol. 33, No. 2, pp. 470-482.