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Ecological and Economical Friendly Analysis of a Hybrid Solar Grid Diesel Connected Power Generation System

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ABSTRACT

This paper presents Importance of hybrid power system. This paper depicts model and simulation of a renewable energy based hybrid power system for improving power quality because optimal utilization of primary energy sources will increase the level of supply reliability. The combination of grid, photo voltaic (PV) array system, and diesel generator systems are used for power generation. Due to variation in output power of solar panel, diesel engine is also coupled to ensure reliable supply under all conditions. the results shows that the proposed hybrid power system can effectively manage the optimal utilization of primary energy sources and improves the power quality in an islanding as well as grid connected mode.

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1. INTRODUCTION

1.1. Grid

Grid exists as the main power component in this hybrid system. Moreover, grid has the functions as a storage system, so a grid power system does not need a battery [1].

Diesel generator is one of the elements of hybrid system described in this thesis. A diesel generator is an engine which use diesel as the prime mover to generate electric energy. It supplies the load when there is less supply from renewable energy sources than demand for an efficient, continuous, and reliable customers' energy demand. The following figure, Figure 1, shows the schematic of a diesel generator [2-3].

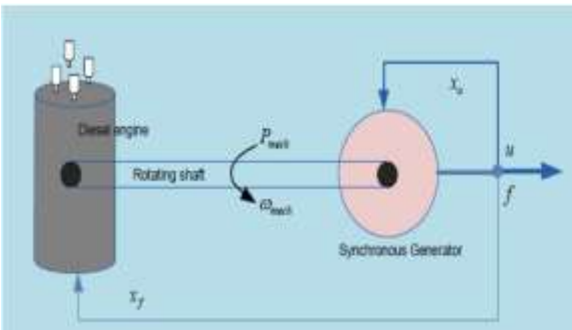


Figure 1. Schematic of diesel generator with constant engine speed

1.2. Battery

A battery is a device that stores direct current (DC) electrical energy in electrochemical form for later use. The amount of energy that will be stored or delivered from the battery is managed by the battery charge controller. Electrical energy is stored in a battery in electrochemical form and is the most widely used device for energy store in a variety of application. The conversion efficiency of batteries is not perfect. Energy is lost as heat and in the chemical reaction, during charging or recharging. Because not all batteries can be recharged they are divided in two groups. The first group is the primary batteries which only converts chemical energy to electrical energy and cannot be recharged. The second group is rechargeable batteries. Rechargeable batteries are used in hybrid power generation system [4-5].

1.3. Power conditioning unit

An inverter converts the direct current (DC) electricity from sources such as batteries, PV modules, or wind turbine to alternative current (AC) electricity. The electricity can then be used to operate ac equipment like the ones that are plugged in to most house hold electrical outlets. The normal output ac waveform of inverters is a sine wave with a frequency of 50 Hz [6].

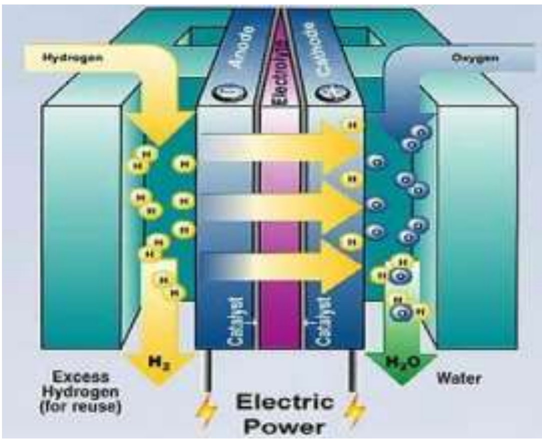


Figure 2. Schematic of fuel cell

Inverters are available in three different categories based on where they are applied: grid-tied battery less, grid tied with battery back-up and stand-alone. The grid tied battery less are the most popular inverters today. These inverters connect directly to the public utility, using the utility power as a storage battery. The grid-tied with battery backup are more complex than battery less grid-tied inverters because they need to sell power to the grid, supply power to backed-up loads during outages, and charge batteries from the grid, PV or wind turbine after an outage. The stand-alone inverters are designed for independent utility-free power system and are appropriated for remote hybrid system installation [7].

In the other hand, based on their output waveforms there are three kinds of inverters; square wave, modified sine-wave, and pure sine wave inverters. Of the three, the square wave type is the simplest and least expensive, but with the poorest quality output signal. The modified sine wave type is suitable for many load types and is the most popular low-cost inverter. Pure sine wave inverters produce the highest quality signal and are used for sensitive devices such as medical equipment, laser printers, stereos, etc. The efficiency of converting the direct current to alternative current of most inverters today is 90 percent or more. Many inverters claim to have higher efficiencies but for this report the efficiency that was used is 90% [8].

2. DESIGNING AND MODELING OF HYBRID SYSTEM WITH HOMER

The hybrid optimization model for electric renewable (HOMER), which is copyrighted by Midwest Research Institute (MRI) is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist the design of power systems and facilitate the comparison of power generation technologies across a wide range of applications. HOMER is used to model a power system’s physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life time. HOMER allows the modeler to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs.

HOMER software is used as a tool to accomplish this report. As mentioned earlier, the main objective of the study is to design and model hybrid PV–Wind–diesel–battery based standalone power generation systems to meet the load requirements of the specified load.

The power conditioning units are dc-dc and ac-dc converters, with the sole purpose of matching the PV, batteries and wind turbine voltages to that of the bus voltage at the dc bus. The primary load is an electric demand that must be served according to a particular schedule whereas deferrable load is electric demand that can be served at certain period of time, the exact timing is not important.

HOMER performs three major tasks: simulation, optimization, and sensitivity analysis based on the raw input data given by user. The performance of a particular power system configuration for each hour of the year is modeled by simulation process to determine its technical feasibility and life-cycle cost. Many different system configurations are simulated in the optimization process in search of the one that satisfies the technical constraints at the lowest life-cycle cost. During the sensitivity analysis process multiple optimizations are performed under a range of input assumptions for judging the effects of uncertainty or changes in the model inputs. Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each. The effects of uncertainty or changes in the variables can be assessed by Sensitivity analysis, over which the designer has no control, such as the average wind speed or the future fuel price.

3. SIMULATION AND RESULTS

3.1 Simulation of hybrid system on HOMER

HOMER performs the simulation for a number of prospective designed configurations. After examining every design, it selects the one that meets the load with the system constraints at the least Life Cycle Cost (LCC). HOMER performs its optimization and sensitivity analysis across all mentioned components and their resources, technical and cost parameters, and system constraints and sensitivity data over a range of exogenous variables.

3.2 Modeling of electric load using HOMER

The electric loads are usually the largest single influence on the size and cost of hybrid system components. So, one of the most important steps in the design of the hybrid system is deciding on the load. The term loads refers to a demand for electric or thermal energy. In this study, electrical load of Faculty of Engineering and Technology, AZAD TECHNICAL CAMPUS, Lucknow is selected to carry out the economic analysis. A typical sample of the daily load profile during working day of the building is shown in Figure 3.

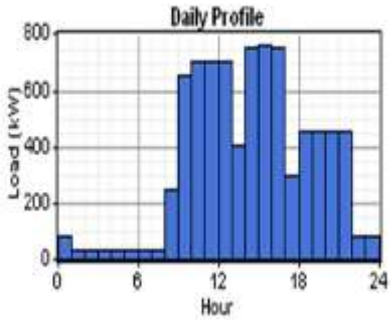


Figure 3. Daily load profile

The building requires a maximum of 758 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 8 a.m. to 5 p.m. as this is the working hour period. The peak demand is about 62 kW from 8 a.m. to 11 a.m. and 2 p.m. to 5 p.m. where it is the time for students to conduct experiments in the laboratory. The load demand drops to about 420 kW in the afternoon when there are no experiments in the laboratory and therefore the computers and other laboratory equipment were turned off. Usually, some replacement lectures and classes are conducted after working hours, 5 p.m.–10 p.m. which it results in the load demand of about 450 kW. Figure 4 illustrates the average and the deviation of the monthly load profile for the studied building. The scaled annual average energy demand of the studied building as simulated by HOMER software is 5484 kWh/day.

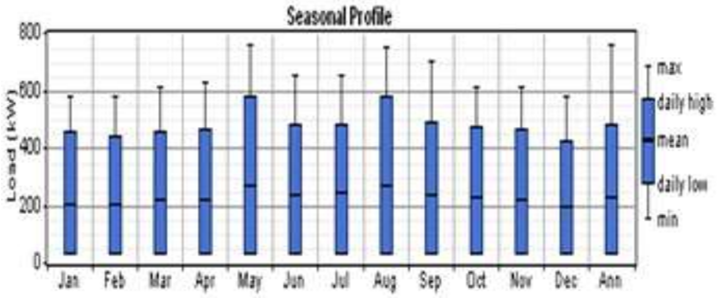


Figure 4. Monthly load profile

3.3 Results and discussion

This section represents the results obtained using the homer software for different configuration of hybrid system as designed in Homer simulation software to calculate total net present cost (NPC) & cost of energy (COE).

3.3.1 Only grid connected system

HOMER generated a simulated option with an optimal system being one without an alternative source, which means the factory load supplied electricity 100% from the grid as shown in Figure 5. The total NPC of this grid-only method came solely from the grid since the grid was the only supply. The output shows that a total energy of 2,001,655kWh/year was purchased from the grid and no power supply came from the PV system as illustrated in Table 1. It can be noted there is no capital cost because no alternative system needed to be purchased or installed in this phase of the analysis.

Table 2 shows the HOMER output results for grid only system. The optimal result for HOMER depending on the NPC is to use a grid-only method as the first choice. This means that any alternative system will not be considered an optimal solution. The reason for this is the grid-only system is assumed to carry no capital or maintenance cost.

Table 1. Optimization Results for Grid Only System

Grid	Total Initial Capital Cost	Total NPC	Operating Cost	COE	Rene wable Fraction
kW	Rs	Rs	Rs/yr	Rs/kWh	-
850	0	182953320	14311825	7.15	0

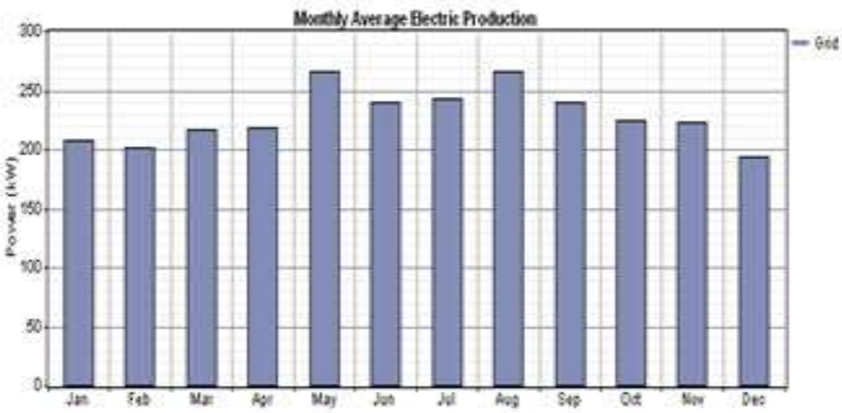


Figure 5. The monthly average electricity production

Table 2. Grid Only System Electricity Consumption

		kWh/yr	Fraction %
Production	Grid purchases	2,001,655	100
Consumption	AC primary load	2,001,585	100

3.3.2 PV and grid connected system

Figure 6 shows the PV and grid connected system configuration as designed in Homer simulation software. Figure 7 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.

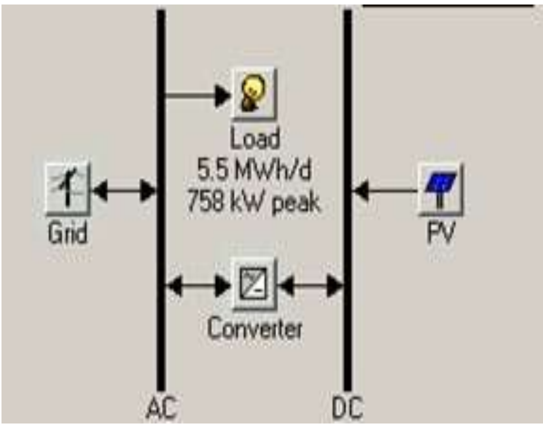
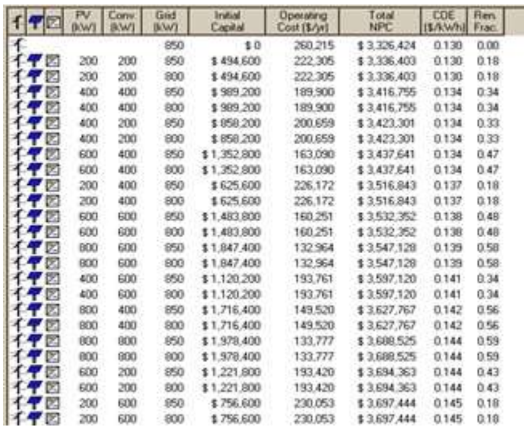


Figure 6. PV and grid connected system configuration



PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
		850	$ 0	260,215	$ 3,326,424	0.130	0.00
200	200	850	$ 494,600	222,305	$ 3,336,403	0.130	0.18
200	200	800	$ 494,600	222,305	$ 3,336,403	0.130	0.18
400	400	850	$ 989,200	189,900	$ 3,416,755	0.134	0.34
400	400	800	$ 989,200	189,900	$ 3,416,755	0.134	0.34
400	200	850	$ 858,200	200,659	$ 3,423,301	0.134	0.33
400	200	800	$ 858,200	200,659	$ 3,423,301	0.134	0.33
600	400	850	$ 1,352,800	163,090	$ 3,437,641	0.134	0.47
600	400	800	$ 1,352,800	163,090	$ 3,437,641	0.134	0.47
200	400	850	$ 625,600	226,172	$ 3,516,843	0.137	0.18
200	400	800	$ 625,600	226,172	$ 3,516,843	0.137	0.18
600	600	850	$ 1,483,800	160,251	$ 3,532,352	0.138	0.48
600	600	800	$ 1,483,800	160,251	$ 3,532,352	0.138	0.48
800	600	850	$ 1,847,400	132,964	$ 3,547,128	0.139	0.58
800	600	800	$ 1,847,400	132,964	$ 3,547,128	0.139	0.58
400	600	850	$ 1,120,200	193,761	$ 3,597,120	0.141	0.34
400	600	800	$ 1,120,200	193,761	$ 3,597,120	0.141	0.34
800	400	850	$ 1,716,400	149,520	$ 3,627,767	0.142	0.56
800	400	800	$ 1,716,400	149,520	$ 3,627,767	0.142	0.56
800	800	850	$ 1,978,400	133,777	$ 3,688,525	0.144	0.59
800	800	800	$ 1,978,400	133,777	$ 3,688,525	0.144	0.59
600	200	850	$ 1,221,800	193,420	$ 3,694,363	0.144	0.43
600	200	800	$ 1,221,800	193,420	$ 3,694,363	0.144	0.43
200	600	850	$ 756,600	230,053	$ 3,697,444	0.145	0.18
200	600	800	$ 756,600	230,053	$ 3,697,444	0.145	0.18

Figure 7. The overall optimization results from homer

All the possible hybrid system configurations are listed in ascending order of their total NPC in the figure shown in Figure 8-9. The optimal result for HOMER depending on the NPC is to use a grid-only method as the first choice. It can be deduced that the most cost effective option is to use the supply from the grid only system without a PV generator. This option has a total net present cost (NPC) of $ 3326424 (Rs 182953320) and the lowest cost of energy (COE) of $ 0.13 (Rs 7.15) /kWh. This option also results in an operating cost of Rs 14311825/year. The operating cost was generated by multiplying the total energy purchased by the purchase prices. The initial capital cost in this case is zero due to the lack of a PV generator and inverter.

3.3.2.1 Sensitivity analysis of PV and grid connected system

Figure 8 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 18% with a grid fraction of 82%. For the optimal alternative system, the PV system and inverter size are 200 KW. The total NPC, initial capital cost and cost of energy (COE) for such a hybrid system are $ 3336403 (Rs 183502165), $ 494600 (Rs 27203000) and $0.130 (Rs 7.15)/kWh, respectively.

Figure 8 also showed the results given by the HOMER for different rate of per unit cost of energy purchased by the grid. It can be concluded that in future if the grid electricity price increases, integration of PV system with grid would be optimum as the cost of energy decreases. 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.

Rate 1 Price ($/kWh)	Min. RF (%)				PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
0.130	0						850	$ 0	280,215	$ 3,326,424	0.130	0.00
0.130	18				200	200	850	$ 494,600	222,305	$ 3,336,403	0.130	0.18
0.130	33				400	400	850	$ 989,200	189,900	$ 3,416,755	0.134	0.34
0.170	0				600	400	850	$1,352,800	213,515	$ 4,082,242	0.160	0.47
0.170	18				600	400	850	$1,352,800	213,515	$ 4,082,242	0.160	0.47
0.170	33				600	400	850	$1,352,800	213,515	$ 4,082,242	0.160	0.47
0.200	0				800	600	850	$1,847,400	207,131	$ 4,495,226	0.176	0.58
0.200	18				800	600	850	$1,847,400	207,131	$ 4,495,226	0.176	0.58
0.200	33				800	600	850	$1,847,400	207,131	$ 4,495,226	0.176	0.58
0.250	0				800	600	850	$1,847,400	280,107	$ 5,172,437	0.202	0.58
0.250	18				800	600	850	$1,847,400	280,107	$ 5,172,437	0.202	0.58
0.250	33				800	600	850	$1,847,400	280,107	$ 5,172,437	0.202	0.58

Figure 8. Sensitivity results for PV and grid connected system from homer

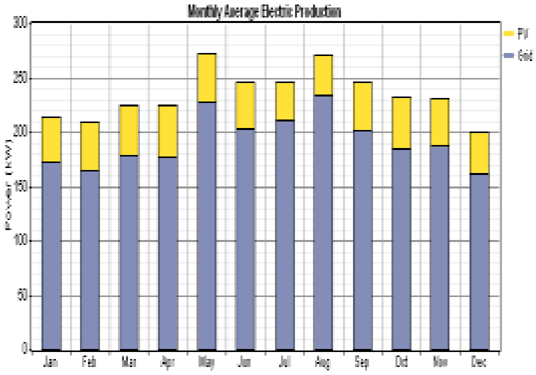


Figure 9. Monthly average electricity production from PV and grid connected system

3.3.2.2. Emissions for PV and grid connected system

In India, the main source of power generation is coal based power plants. As a consequence in 2009-2010, its emission factor for the electricity sector was 0.81 kg CO_2/kWh. 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 18% and 33% 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 Zero

Pollutant	Emissions (kg/yr)
Carbon dioxide	1,265,046
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	5,485
Nitrogen oxides	2,682

3.3.3 PV and diesel based system

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.

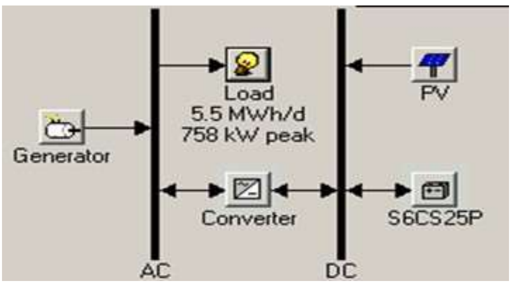


Figure 10. PV and diesel based system configuration

All the possible hybrid system configurations are listed in ascending order of their total NPC in the figure shown in Figure 11-12.

Figure 11. Optimization results for PV and diesel based system

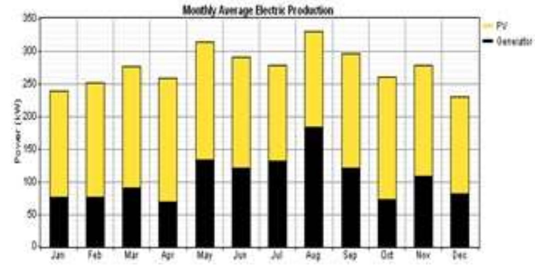


Figure 12. Monthly average electricity production for PV and diesel based system

According to the optimization results, the optimal combination of hybrid system components are a 800kW PV-Array, 500kW Diesel Generator, 3000 Surrette 6CS25P Batteries, 800kW Inverter and a 800kW 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 376151490, 18761875and Rs 14.685/kWh, respectively Figure 12 shows the monthly distribution of the electricity produced in kW by the SPV and Diesel generator. The effect of SPV penetration reduces the diesel fuel consumption. As the output from the PV increases, the generator's operation hours decrease.

Table 3 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.

Table 4. Technical & Cost Details of the Best Suited Configuration for PV and Generator Based System

Component	Capital (Rs/yr)	Replacement (Rs/yr)	O&M (Rs /yr)	Fuel (Rs /yr)	Salvage (Rs/yr)	Total (Rs /yr)
PV	6257515	0	264000	0	0	6521515
Generator	537790	719730	995445	15338015	-81235	17509745
Surrette 6CS25P	1613425	480095	330000	0	-137830	2285690
Converter	2254505	940720	88000	0	-175120	3108105
System	10663235	2140545	1677445	15338015	-394185	29425110

Table 5. Annualized Cost of the PV and Diesel Based System

Cost Summary		System Architecture		Electrical		
Total net present cost	Rs456809375	PV array	800kW	Component	Production (kWh/yr)	Fraction
Levelized cost of energy	Rs17.875/kWh	Diesel generator	500kW			
Operating cost	Rs18937875/yr	Inverter	800kW	PV array	1,491,700	62%
		Rectifier	800kW	Diesel generator	917,676	38%
		Battery	3000 Surrette 6CS25P	Total	2,409,376	100%

3.3.3.1. Emissions for PV and diesel 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 and Diesel Based System

Pollutant	Emissions (kg/yr)
Carbon dioxide	815,961
Carbon monoxide	2,014
Unburned hydrocarbons	223
Particulate matter	152
Sulfur dioxide	1,639
Nitrogen oxides	17,972

3.3.4. Only PV system with batteries

Figure 13 shows the PV and diesel based system configuration as designed in Homer simulation software. The optimization results of only PV system with batteries are shown in Figure 14. All the possible hybrid system configurations are listed in ascending order of their total NPC in the figure shown below. According to the optimization results, the optimal combination of the only PV system have a 1600kW PV-Array, 8000 Surrette 6CS25P Batteries, 1000kW Inverter and a 1000kW 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 294316220, Rs 3387780 and Rs11.495/kWh, respectively.

As we know that for only PV system, 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 8.

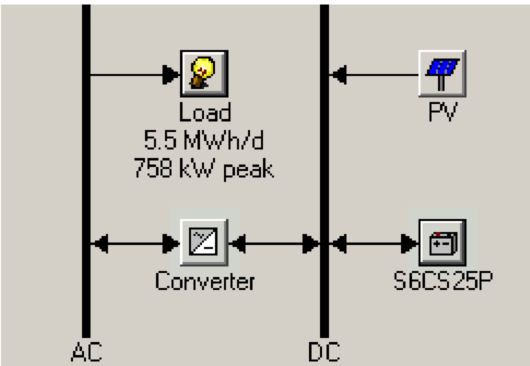


Figure 12. Only PV system configuration

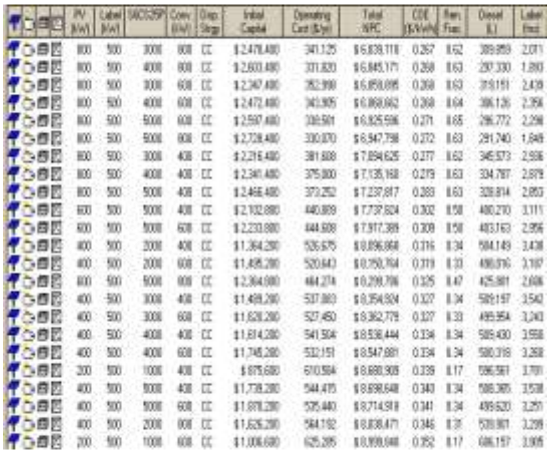


Figure 13. Optimization results for only PV based system

Table 7. Technical Details of the Battery for Best Suited Configuration

Quantity	Value	Unit
Nominal capacity	55,488	kWh
Usable nominal capacity	33,293	kWh
Autonomy	146	Hr
Lifetime throughput	77,238,224	kWh
Average energy cost	0	Rs/kWh
Bus voltage	60	V
Energy in	986,585	kWh/yr
Energy out	792,555	kWh/yr

Table 8. Technical & Cost Details of the Best Suited Configuration for only PV System with Batteries

Cost Summary		System Architecture		Electrical		
Total net present cost	Rs 294316220	PV Array	1600kW	Component	Production	Fraction
Levelized cost of energy	Rs 11.495/kWh	Battery	8000 Surrette 6CS25P	-	(kWh/yr)	-
Operating cost	Rs 3387780/yr	Inverter	1000kW	PV Array	2,983,399	100%
		Rectifier	1000kW	Total	2,983,399	100%

3.3.4.1. Emissions for only PV system

As only PV system with batteries is used for the power generation, there will be no emissions for this system configuration i.e. no green house gases (GHG) will be produced by this system.

4 CONCLUSION

After analyzing all the system models, PV and grid connected system is found to be more economical with lowest cost of energy of Rs 7.15/kWh. At present time the cost of energy for the grid connected system is Rs 7.15/kWh, which is expected to increase with time. At the same time the CO2 emissions are maximum for the grid connected system which can be reduced by adding the PV with the grid connected system without much influenced on the cost of energy. By adding the alternative sources, one can overcome the scheduled power cut too. Table 9 shows the economical comparison between different combinations of hybrid system. Calculated in the preceding of previous section.

Table 9. Economical Comparison between Different Combinations of Hybrid System

System Combination	Total NPC	Operating Cost	Cost of Energy	Renewable Fraction (%)
Grid only	182953320	14311825	7.15	0
PV and grid	183502165	12226775	7.15	18
	187921525	10444500	7.37	34
PV and diesel	376151490	18761875	14.685	62
PV with batteries	294316220	3387780	11.495	100

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