Optimization of Hybrid Renewable Resources using HOMER

Rachit Srivastava*‡, Vinod Kumar Giri**

*Department of Electrical Engineering, Madan Mohan Malaviya University of Technology, Gorakhpur, India

**Department of Electrical Engineering, Madan Mohan Malaviya University of Technology, Gorakhpur, India

(srivastava.rachit94@gmail.com, girivkmmm@gmail.com)

‡ Corresponding Author; Rachit Srivastava, Madan Mohan Malaviya University of Technology, Gorakhpur, India

srivastava.rachit94@gmail.com

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Abstract- The demand of electricity is increasing day by day throughout the world. Due to limited amount of fossil fuel it is important to design some new non-renewable energy systems that are able to decrease the dependence on conventional energy resources. A hybrid off-grid renewable energy system may be used to decrease dependency on the conventional energy resources. Optimization of hybrid system is a process to select the best combination of component and there cost that are able to provide cheap, reliable and effective alternative energy resource. In this paper photovoltaic system, wind turbine, diesel generator, battery backup and converter have been simulated and optimized for Measurement & Instrument Laboratory in Electrical Engineering Department of Madan Mohan Malaviya University of Technology at Gorakhpur, India. In this system, primary source of power is solar photovoltaic system and wind turbine whereas diesel and batteries are used as backup supply. HOMER software has been used to simulate off-grid system and it checks the technical and economical criteria of this integrated system. The performance of each component of this system is analyzed and finally sensitive analysis has been performing to optimize the hybrid system at different conditions. Based on the simulation result it is found that 5kW PV pannel, 4kW Gentator, 10 batteries and 4.5 kW Inverter is the optimal solution for this system. This hybrid system will reduce the emmision of CO_2 of about 25,472 Kg/year.

Keywords-HOMER, Optimization, Renewable Resources, Hybrid System, Techno-Economical Analysis.

1. Introduction

Solar and wind energy can play a very important role as non conventional resource in India [1].For the off grid system single technologies such as solar photovoltaic system and wind turbine are unable work reliable and effectively due to their variability of resources. Reliance on the single technology creates over sizing of the system [2]. Hybrid system is the combination of renewable energy resources along with conventional energy resources [3]. Hybrid system is able to overcome intermittent nature of non conventional energy resources. But hybrid system increases complexity in the system hence optimization of hybrid system is required. Many studies have been done on the optimization of hybrid energy resources in India, considering different configuration and conditions.

Deepak Kumar Lal et al. [4] present a hybrid system containing PV, Wind, Micro-hydro and Diesel Generator for Sundargarh district of Orissa in India. Two simulations have been done in this study with the HOMER software, first arrangement consist of Wind, PV and Diesel Generator whereas second arrangement consist of Wind, PV, small hydro and Diesel Generator. Author suggests that wind power fluctuation and demand variation are the constraints of the system.

Munuswamy et al. [5] compares the cost of electricity from the fuel cell for the health center in rural area in India using HOMER software. The result shows that off grid source is cheaper than the grid at distance of 44 Km.

J.B. Fulzele et al. [6] present a hybrid system for Yavatmal distich in Maharastra, India. The hybrid system consists of PV Panel, Wind Turbine, Generator, Inverter and Storage Batteries. These systems are optimized by the HOMER software.

Abbas Babaei et al. [7] present a techno-economical analysis for powering residential building Sari city in Iran. Hybrid system is optimized using HOMER software using PV system, Generator, Inverter and Batteries.

As hybrid system is very usefull for the off-grid loads, this study will be helpfull for the villages which are near by the gorakhpur, that are remote to grid and istill not powered. In this paper a hybrid system consist of PV Panel, Wind Turbine, Convertor, Battery and Diesel Generator is designed for Measurement Laboratory in Electrical Engineering Department of Madan Mohan Malaviya University of Technology at Gorakhpur in India. HOMER legacy 2.68 beta version is used for the optimization of the system. At the last some sensitive analysis are also done for exact result.

2. HOMER Software

HOMER software has been developed by National Renewable Energy Laboratory, USA in 1993[8]. It is used to evaluate the performance of the grid connected system as well as off grid system. HOMER performers three tanks, firstly simulation than optimization and at the last sensitive analysis. In simulation process, HOMER simulates the hybrid system for each hour for the year and determines its technical feasibility and its life cycle cost. In optimization process, HOMER simulates many configurations to find the best combination that fulfill the criteria of technical feasibility along with minimum life cycle cost. In sensitive analysis process HOMER perform many optimizations with some input assumptions to determine the effect of uncertainty and variation in model input [9]. Figure 1 shows the basic working of the HOMER software.

In this experiment, HOMER software is basically used because it is freely available on internet and in the literature it is found that this software gives better result then other software available.

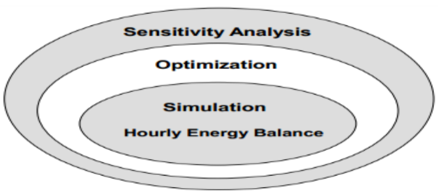

Fig. 1. Interactions between Simulation, Optimization and Sensitivity Analysis

3. Site Location and Load Profile

The proposed system designed used to power the Measurement & Instrument Laboratory in Electrical Department of Madan Mohan Malaviya University of Technology (MMMUT), Gorakhpur. MMMUT is a reputed state university of Utter Pradesh situated in India. The University is situated at Latitude of 26^{0}43'50.41" North and Longitude of 83^{0}26'2.8" North. The altitude of site is 59 meter above the sea. In this study, the Measurement & Instrument Laboratory electrical load requirement is carefully estimated considering existing load profile. The demand has been estimated separately for all the months for one year considering the appliance holding and use patterns for laboratory instrument. Table 1 show the total appliances used in laboratory.

Table 1. Various Load Appliances

Name of Instrument	Number of Instrument	Energy Consumption in Watt	Total Energy Consumption in Watt
Air Condition	1	1500	1500
Fan	5	150	750
Tube Light	18	40	720
Laboratory Apparatus	10	-	1000

In this study we consider the fallowing profile of load:

- Two tubes light is glow throughout the night period in whole year.
- Air Condition is used during the summer session.
- Laboratory practical time is 10AM to 12 AM and 2 PM to 4 PM in the first semester.
- Laboratory practical time is 11 AM to 1PM and 3 PM to 5 Pm in second semester.
- First semester is run from January to May and second semester is run from July to November.
- During the semester break no apparatus is used except the night lightning instrument.

Figure 2 shows the load profile for the laboratory. It is found that average energy required is 11KWh per day. Average load is 0.45 KW. Peak load is 6.1 KW during the August month. Minimum load is in June and December period.

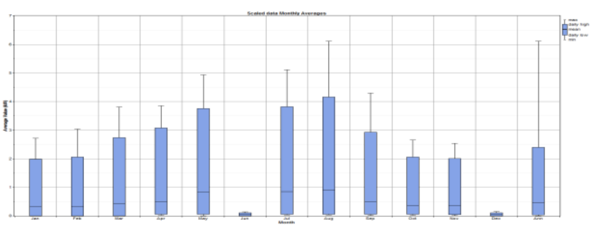

Fig. 2. Load per Month for this Site

4. System Components

We have considered following technologies, namely small wind turbines, solar PV (SPV) systems, batteries, and a diesel generator for back-up. Figure 3 shows schematic system configuration diagram. In the hybrid system the electrical demand of the Laboratory is AC-coupled, the diesel generator is connected to the AC side of the network and the solar panel, wind turbine and the batteries are connected to its DC side. The conventional back-up diesel generator (DG) is used to supplement the renewable energy system for peak loads and during poor resource periods neutral system. Table 2 shows the cost of various components used in this study.

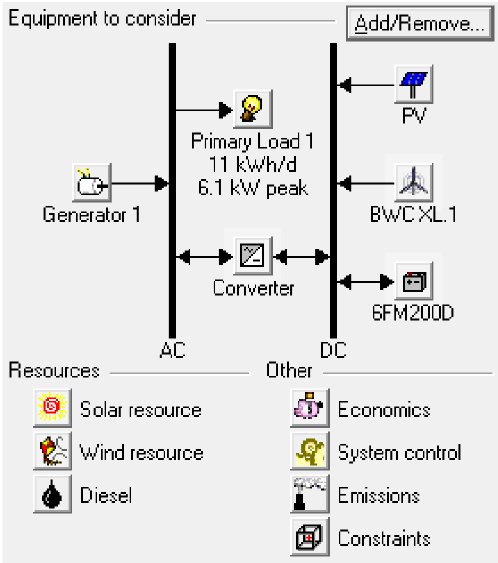

Fig. 3. HOMER Diagram for Hybrid System Set up

Table 2. System Component Considered in this Study*

*1US $ = 65 Indian Rs

Component	Size (kW)	Capital Cost ($)	Replacement Cost ($)	O&M Cost ($/year)	Life Time	References
PV Panel	0.1	98	74	1	25 year	[11]
	0.15	138	110	1	25 year	[11]
	0.25	238	190	1	25 year	[11]
Wind Turbine	1	2307	1845	10	20 year	[13]
Diesel Generator	4	2739	2215	0.1 $/h	15000 hr.	[15]
Battery		80	56	1	719 kWh	
Convertor	1.5	542	433	5	15 year	[11]
	3	664	531	10	15 year	[11]
	7.5	1003	802	20	15 year	[11]

4.1. Photovoltaic Panels

After surveying different products focusing on the cost provided the following panel was chosen. The reason for choosing the product from the stated company is due to its low cost delivered as long as efficiency is not a big concern here. We considered 100W, 150W and 250 W solar panels from Su-Kam Company. The selected panel was poly-crystalline silicon made which is known as SU100, SU150 and SU250 model with an efficiency of 14 to 15 % [10]. We considered the current installation cost for 100W 150W and 250W is 93$, 138$ and 238$ respectively [11]. In this paper the installation cost is taken as 80% of the PV price and the operation and maintenance cost would be 1% per year. The following parameters have been considered like; the de-rating factor was taken as 85%, ground reflectance was also considered as 20%, slope 26.98 (latitude of the location) and azimuth 0 (south orientation). PV Panels are studied at 0, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9 and 9.5 kW.

4.2. Wind Turbine

The wind turbine taken for this project work is 1kW power rating. The wind turbine was manufactured by the Bergey wind power, USA [12].The model no of the selected turbine is XL1. In this project installed cost was taken about $2307/kW [13]. Replacement cost of the wind turbine considered in this case is about 80% of capital cost after 20 year service life. Hub height is considered 25m. 0, 1, 2, 3 and 4 wind turbines are studied for simulation.

4.3. *Diesel Generator*

Diesel generators do not allow running at less than the minimum load ratio of 30%. In this study, after surveying of various diesel generator suppliers, the selected one is from Cummins, supplied by Mahindra Powerol [14]. Generator size is among the input sizes to consider working with wind and solar PV to meet the load requirement in the case of no wind flows and no sunshine times. Power rating is 4kW of selected diesel generator. The cost of diesel generators available in the market is about 2769$ [15]. Lifetime operation of generation is about 15000 hr. 0, 4, 8 and 12 kW Diesel Generators are studied.

4.4. Battery

The storage battery chosen is Vision 6FM200D from the manufacturer Vision Battery, which is given in HOMER tool library. The selected battery has the following characteristics obtained from the modeling tool. The nominal capacity of the selected battery is 200Ah (2.4kWh) with nominal voltage of 12V for single battery and the amount of energy stored in a single battery is 2.4kWh, maximum charge current is 60A, lifetime throughput of 917 kWh was considered, minimum state of charge is accounted for 40%, round-trip battery efficiency is taken as 80%. Replacement cost for battery is assumed about 70% of its capital cost. Battery is studied at quantities of 0, 10, 20, 50, 100 and 150.

4.5. Converter

A converter needs to maintain flow of energy between AC and DC power system components. The rated power of the inverter should be equal to or larger than the peak load but since the load will supply both from the renewable and non-renewable, even below the peak would be installed. . Converter sizes considered are: 1.5, 3 and 7.5 kW. The converter is selected for this project is manufactured by SuKam [10]. Replacement cost is taken 80% of the capital cost, efficiency of converter is around 90% and the lifetime of the converter will end for 15 years. Converter size is considered 0, 1.5, 3, 4.5, 6, 7.5 kW.

5. Solar and Wind Resources

The solar and wind resource used for MMMUT, Gorakhpur at a location of 26^0 43'50.41"N latitude and 83^0 26' 2.8" E longitudes was taken from NASA Surface Meteorology and Solar Energy website [16]. Figure 4 shows the graph of annual radiation at MMMUT, Gorakhpur. The annual average solar radiation was 5.17kWh/m^2/Day and the average clearness index was found to be 0.5312. Solar radiation is maximum on the May of 7.260KWh/m^2/day whereas minimum on December of 4.010 KWh/m^2/day. The solar radiation is available throughout the year; therefore a considerable amount of PV power output can be obtained. The annual average wind speed for the location is 3.13 m/sec with the anemometer height at 50 meters. Figure 5 presents graph of the average wind speed at our study site.

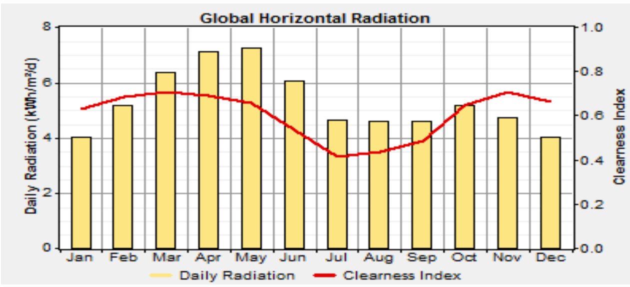

Fig. 4. Graph of Solar Radiation

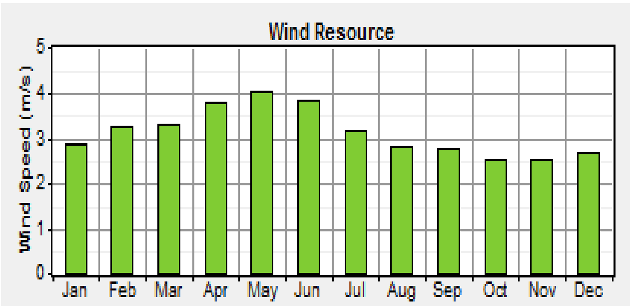

Fig. 5. Graph of Wind Speed

6. Result and Discussion

6.1. Optimization Result

A total of 12240 simulations with 27 sensitivities were performend by the HOMER software.From the simulation it is found that 5kW pv pannel, 4kW generator 10 Battery and 5kW converter is the optimal solution for over system. In this system innetial cost is 9334$ and operating cost is 320$year where as cost of electricity is 0.262$. For more accurate result simulation run into three value of solar radiation, wind speed and fuel price, the values are rage of minimum to maximum value. By these vales three cases are form. In case 1 solar radiation and wind speed are at their maximum value where as fuel price at their minimum value. In this case PV, diesel generator and battery are best solution economically shown in table 3. While PV, Wind turbine, diesel generator and battery system is a good alternative having litter higher cost of energy, listed in second position.

Table 3. Optimization Results for Maximum non-conventional Resources and Minimum Fuel Price

Sensitivity variables

Global Solar (kWh/m²/d) 6 Wind Speed (m/s) 4.5 Diesel Price ($/L) 0.5

Double click on a system below for simulation results.

PV (kW)	XL1	Gen (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
4.0		4	10	4.5	$ 8,334	242	$ 11,432	0.223	0.91	250	212
3.0	1	4	10	4.5	$ 9,641	246	$ 12,784	0.249	0.92	231	200
7.5			50	6.0	$ 12,378	291	$ 16,096	0.314	1.00		
6.0	1		50	6.0	$ 13,185	308	$ 17,120	0.334	1.00		
	1	4	10	3.0	$ 6,540	856	$ 17,487	0.341	0.37	1,123	879
		4	10	1.5	$ 4,111	1,125	$ 18,489	0.360	0.00	1,594	1,452
9.5	3	4		4.5	$ 19,955	1,549	$ 39,750	0.775	0.89	1,604	2,566
	4	8		3.0	$ 15,430	4,618	$ 74,463	1.451	0.44	5,183	4,149
8.0		8		4.5	$ 14,303	5,563	$ 85,417	1.664	0.56	6,259	5,043
		8			$ 5,538	8,735	$ 117,207	2.284	0.00	9,916	7,911

In case 2 solar radiation, wind speed and fuel price are at their actual average value. In this case PV, diesel generator and battery is also economically best solution listed in table 4. The second listed system is also a good alternative having litter big net present cost. Renewable fraction for both first and second system is same.

Table 4. Optimization Results for Actual Average Values

Sensitivity variables

Global Solar (kWh/m²/d) 4.97 Wind Speed (m/s) 3.13 Diesel Price ($/L) 0.79

Double click on a system below for simulation results.

PV (kW)	XL1	Gen (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
5.0		4	10	4.5	$ 9,334	320	$ 13,422	0.262	0.92	243	221
4.5	1	4	10	4.5	$ 11,141	340	$ 15,486	0.302	0.92	243	223
9.0			50	6.0	$ 13,878	304	$ 17,761	0.346	1.00		
8.0	1		50	6.0	$ 15,185	325	$ 19,339	0.377	1.00		
		4	10	1.5	$ 4,111	1,588	$ 24,411	0.476	0.00	1,594	1,454
	1	4	10	1.5	$ 6,418	1,440	$ 24,827	0.484	0.16	1,399	1,380
9.5	4	8		4.5	$ 25,031	5,383	$ 93,840	1.828	0.68	4,481	3,610
9.5		8		4.5	$ 15,803	7,352	$ 109,792	2.139	0.56	6,227	5,017
	4	8		1.5	$ 15,308	8,561	$ 124,741	2.430	0.17	7,239	5,783
		8			$ 5,538	11,611	$ 153,967	3.000	0.00	9,916	7,911

In case 3 solar radiation, wind speed and diesel price are at their minimum value and fuel cost is maximum. In this case PV, Diesel Generator and battery is still economically best solution, listed in first position is the table 5. The second hybrid system having PV, Wind Turbine, Diesel Generator and battery is still best alternative solution. Renewable fraction of alternative system is litter more than best solution.

Table 5. Optimization Results for Minimum non-conventional Resources and Minimum Fuel Cost

Sensitivity variables

Global Solar (kWh/m²/d) 3 Wind Speed (m/s) 2 Diesel Price ($/L) 1

Double click on a system below for simulation results.

PV (kW)	XL1	Gen (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
7.0		4	10	4.5	$ 11,334	480	$ 17,469	0.340	0.87	310	275
7.0	1	4	10	4.5	$ 13,641	492	$ 19,936	0.388	0.88	298	265
		4	10	1.5	$ 4,111	1,923	$ 28,691	0.559	0.00	1,594	1,454
	1	4	10	1.5	$ 6,418	1,889	$ 30,560	0.596	0.03	1,541	1,428
9.5		8		3.0	$ 15,690	9,809	$ 141,082	2.749	0.38	7,050	5,676
9.5	1	8		3.0	$ 17,997	9,776	$ 142,964	2.785	0.39	7,005	5,640
	4	8		1.5	$ 15,308	12,908	$ 180,314	3.513	0.03	9,257	7,389
		8			$ 5,538	13,693	$ 180,587	3.518	0.00	9,916	7,911

6.2. Sensitive Result

The graphical sensitivity results provide a different view of results; it shows solar radiation and wind speed varies from minimum to maximum with the different values of diesel prices as shown in figure 6 to 8 respectively.

The surface plot for the levelized cost of energy with total net present cost superimposed is presented in Figure 6. The fuel price is fixed at $0.5/L the solar radiation is depicted on the x-axis and wind speed on the y-axis. This shows that cost of energy is lower when the solar radiation is higher. From the figure 6 to 8 it is found that at the higher value of fuel cost the cost of energy is higher and with the lower value of fuel cost the cost of energy is lower.

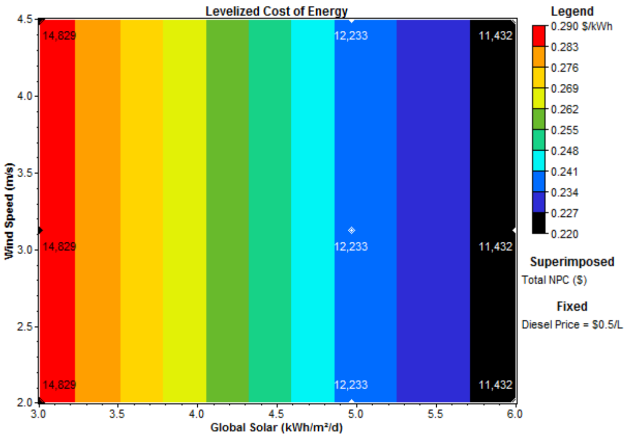

Fig. 6. Surface Plot of Cost of Electricity with Diesel Price of $ 0.5/L.

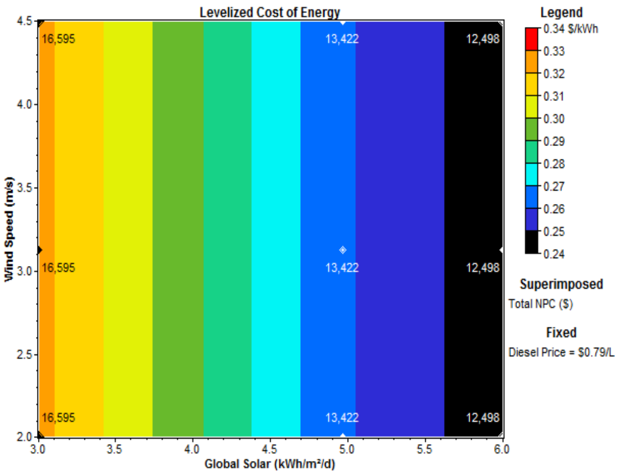

Fig. 7. Surface Plot of Cost of Electricity with Diesel Price of $ 0.79/L

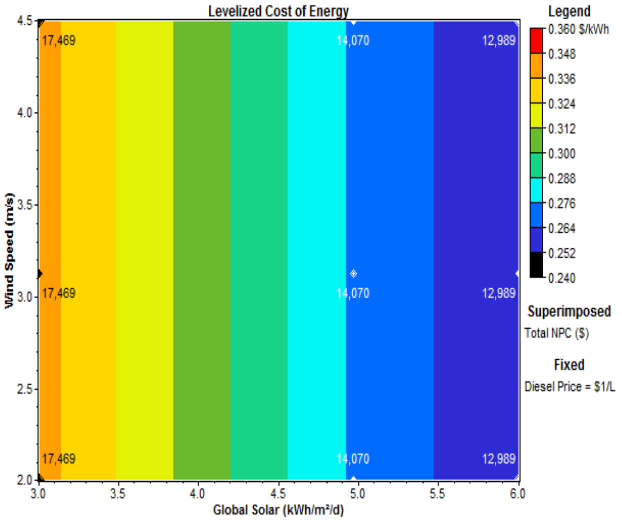

Fig. 8. Surface Plot of Cost of Electricity with Diesel Price of $1/L

6.3. Emmision

The hybrid renewable system would save about 25,472 kg/yr of CO_2 in one year in operation compared to a stand-alone diesel generator system. Emission of other toxic gases such as carbon monoxide and sulphar dioxide will be reduced mentioned in table 6.

Table 6 Emission by Hybrid and Stand-alone system

Pollutant	Emissions By Hybrid System (kg/yr)	Emissions by Diesel Generator (kg/yr)	Emission Reduction (kg/yr)
Carbon dioxide	640	26,112	25,472
Carbon monoxide	1.58	64.5	62.92
Unburned hydrocarbons	0.175	7.14	6.965
Particulate matter	0.119	4.86	4.741
Sulphur dioxide	1.29	52.4	51.11
Nitrogen oxides	14.1	575	560.9

7. Conclusion

The result from the HOMER shows that PV, Diesel Generator with battery and inverter is most economical solution for all three cases for the load of laboratory of MMMUT. PV, Wind Turbine, Diesel Generator with battery and inverter system is also a very good alternative solution having little higher cost of electricity and net present cost. Although the cost of electricity from the proposed system is higher than the cost grid electricity but due the necessity of environmental protection and farseeing the current living standard of rural communities such hybrid system will play a very good role for the country like India having deficit electricity.

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