Economic Management of Alternative Energy Sources For Electric Power Generation

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Abstract— **This paper gives information about the economic analysis of a hybrid energy system comprising solar PV(1kw, 2channel), wind turbine(1.5kw), Batteries(12v, 200Ahr, 10 no.) and Hydrogen Fuel Cell(500W, PEM Type). The simulation is performed in HOMER(hybrid optimization of multiple energy resources) software. The simulation studies give information about the different economic and technical parameters of a given hybrid system which is used to access its technical and economical feasibility. For this hybrid system, the metrological data of Solar Radiation, and hourly wind speed for the given location are taken from NASA. The given system is grid connected system. The load for the system is 46.01kWh/day, with a peak load of 9.58kw. The objective of this study is to evaluate the optimal system configuration that would minimize the cost of energy.**

Keywords— System Optimization, Net Present Cost (NPC), Levelized Cost of Energy (LCOE).

I. Introduction

The use of renewable energy sources for electric power generation is increasing as the world is concerned about global warming due to conventional electric power generation plants. India is one of the world's fastest-developing nations. In India, too, the energy demand is mostly met by non-renewable sources, which contributes to its carbon emissions, making the Indian government more inclined to produce clean energy. The development of the renewable energy sector in India has been important. The only one source of Renewable energy is not capable of continuously supplying power to the load, so hybrid energy systems become an important option to maintain feasibility between power and load.

The efforts in using renewable energies have often focused on single technologies. But single renewable energy source often unable to cater to consumers' needs adequately and reliably due to the intermittent nature of renewable energy sources. Reliance on a single source generally results in an oversizing of the system, thereby increasing the initial costs. Hybrid systems comprising different renewable energy sources can overcome the intermittent nature of renewable energy sources, and the oversizing issue and enhance the reliability of supply. Different authors around the world have carried out several studies on power generation using different hybrid system. However, only a few studies are reported in India on power generation using a hybrid system.

The purpose of this simulation analysis is to find the best combination of Renewable energy technologies from the available resources in a given location that can meet the electricity demand in a reliable and sustainable manner and to analyse whether such a hybrid option is a cost-effective solution or not. To achieve this objective, we collected Load data(daily load curve), Metrological data of Solar Radiation and hourly wind speed data for We performed the simulation for the given system parameters in HOMER. Here we have analysed Grid connected hybrid system comprising Solar PV (1 Kw), Wind turbine (1.5kw), and Batteries (12V, 200A, 10nos).

II. HOMER SOFTWARE DESCRIPTION

The United States National Renewable Energy Laboratory developed a programme called Hybrid Optimisation of Multiple Energy Resources (HOMER) [7]. In 1993, the first HOMER was developed. Fundamentally, HOMER is a simulation system. For any possible equipment combination you'd like to find, the HOMER will attempt to model a workable system. Depending on how your query is constructed, HOMER can simulate hundreds or even thousands of systems. The step of optimisation comes after every simulation. You can examine the best fits by filtering and sorting the simulated structures according to the parameters you choose. Despite the fact that HOMER is primarily an economic optimisation system [7].

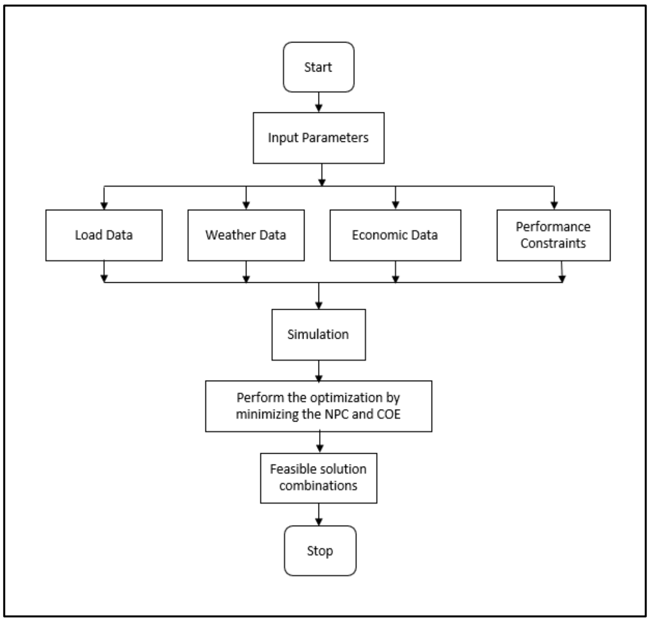

Figure 1: HOMER Algorithm

III. METHEDOLOGY

The methodology for this paper involves software based apprach. First the Electric Load data is obtained including average daily consumption(in KWh) and peak load (Kw) and daily load profile is ploted with time frame of 60 minutes. Here the average daily consumption is 46.01 KwH with a peak of 9.58kw. The type of load is residential load. The cost of one unit(KwH) is 11.86(including all taxes). The simulation is performed on Homer by giving inputs such as component rating and costing. The simulation is done for given system component ratings and then homer optimization analysis is done.

A. *Metrological Data Collection*

Climate details including wind velocity and PV radiation used for this study have been collected from the National Aeronautics and Space Administration (NASA). According to NASA, monthly averaged global solar radiations for sites were collected over 22 years. Figure 2 shows the Solar Data for given location.

The wind speed data are recorded for 30 years. Table.1 shows the Monthly Average Solar Irradiance Data (KWh/m^2/day) and Clearness Index data at a given location. Table.2 shows the data of the Monthly Average Wind Speed (m/sec). The figure 3 shows the wind speed data which is collected from NASA.

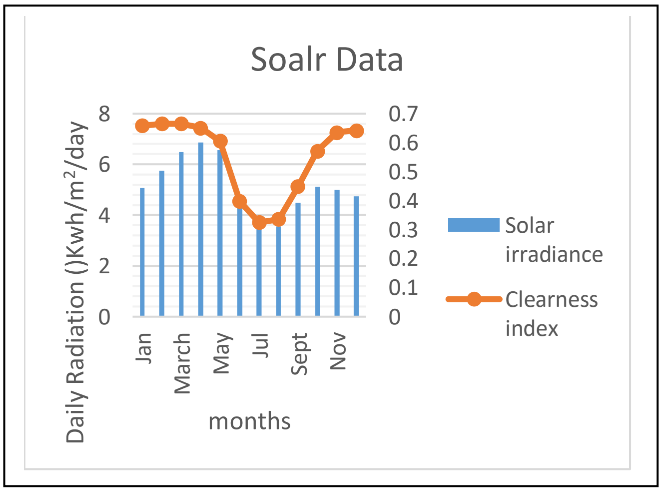

Figure 2: Solar radiation

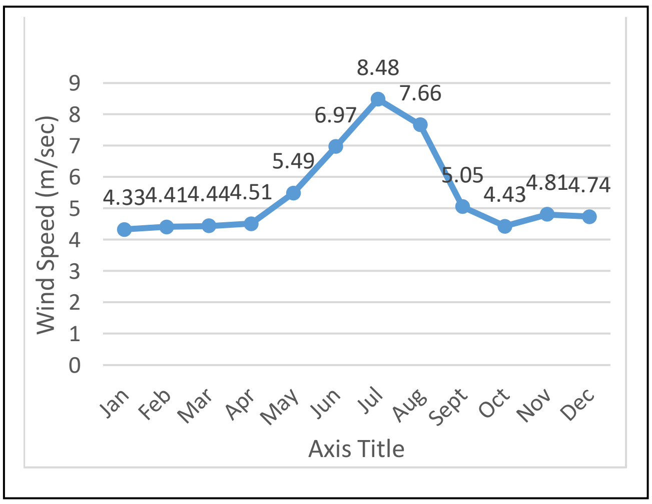

Figure 3: Wind Speed Data

B. *Electrical Load Data*

The load connected to the system is 46.01 kW/day, with a peak load of 9.58 kW. For this simulation analysis, the daily load profile is calculated for a time interval of 60min for a single day in all months. Below is the daily, seasonal and yearly load profile of the given load

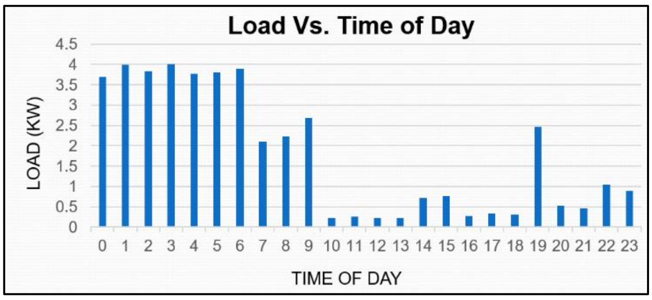

Figure 4: Daily Load Curve

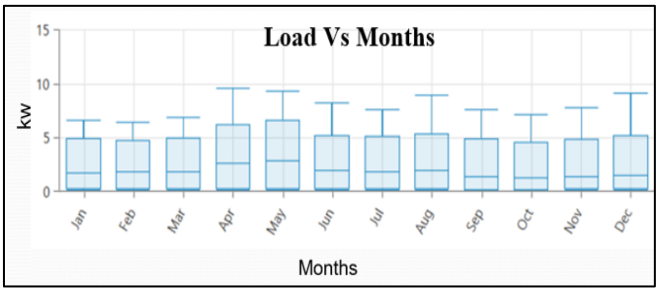

Figure 5: Annual and Seasonal Load

C. *System Components and Configuration*

Below Table 1 shows the ratings and costing of components of the system. Figure 6 is a schematic diagram of the system in HOMER software.

Table 1: Component ratings and costing

Component Name	Rating (Kw)	Cost (Rs.)
Solar PV+ other required components	1 Kw (4no. 250w solar panels)	32000
Wind Turbine	1.5	260000
Single phase inverter	7.5	125000
Batteries (Lead Acid)	12 v, 200A (10 no.)	110000

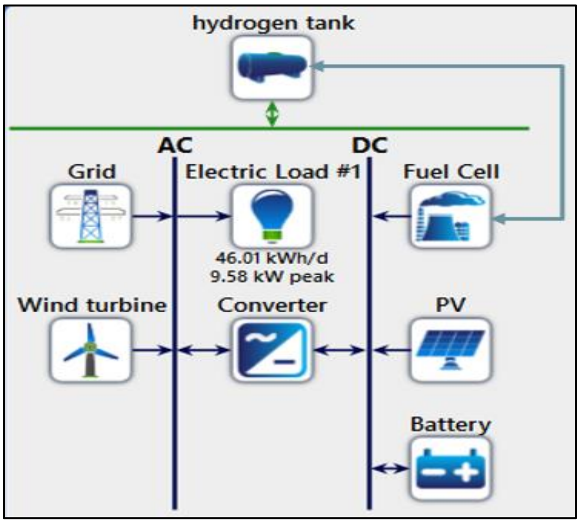

Figure 6: Schematic Diagram of the system

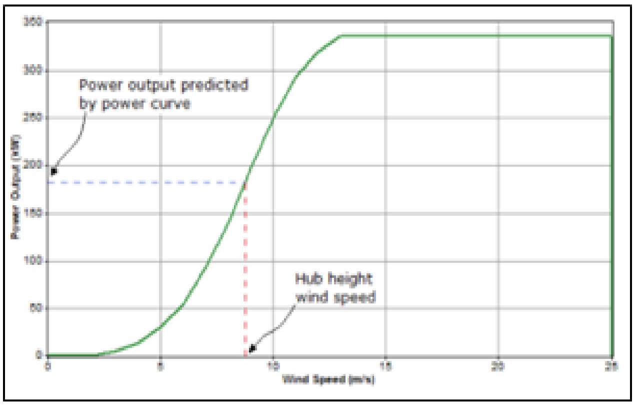

Figure 7: Power Curve of Wind Turbine

IV. Mathematical Modeling of Components

a) Solar PV System:

The following equation (1) is used to calculate the solar PV power output in the system. The

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}} \right) \left[1 + \alpha_P \left(T_c - T_{c,STC} \right) \right] \quad \ldots\ldots\ldots(1)$$

Where,

Y_{PV} = the rated capacity of the PV array, meaning its power output under standard test conditions [kW]

f_{PV} = the PV derating factor [%]

$\bar{G}_T$ = the solar radiation incident on the PV array in the current time step [kW/m^2]

$\bar{G}_{T,STC}$ = the incident radiation at standard test conditions [1 kW/m^2]

α_P = the temperature coefficient of power [%/°C]

T_c = the PV cell temperature in the current time step [°C]

$T_{c,STC}$ = the PV cell temperature under standard test conditions [25°C]

b) Wind Turbine System:

The following equation (2) is used for calculating the electric power output of a wind turbine. Referring to the Figure 5, the wind turbine's power curve to calculate the expected power output from the wind turbine at that wind speed under standard conditions of temperature and pressure

$$P_{WTG} = \left(\frac{\rho}{\rho_0} \right) \cdot P_{WTG,STP} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where,

P_{WTG} = the wind turbine power output [kW]

$P_{WTG,STP}$ = the wind turbine power output at standard temperature and pressure [kW]

ρ = the actual air density [kg/m^3]

ρ_0 = the air density at standard temperature and pressure (1.225 kg/m^3)

c) Hydrogen Fuel Cell (PEM Type):

The following equation (3) is used to calculate the hydrogen consumption at the rated power of the Fuel cell.

$$HY_{FC} = \frac{Pfc*3600}{2*Vfc*F} \text{ (mol/h}^{-1}\text{)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The main components of the hydrogen fuel cell are Electrolyzer and Hydrogen fuel tank.

V. Economic Terms

1) *Net Present Cost (NPC):*

The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each Component in the system, and of the system.

2) *Levelized Cost of Energy (LCOE):*

It is an output variable. HOMER defines the levelized cost of energy as the average cost per kWh of useful electrical energy produced by the system. The symbol of this parameter is COE. And the unit is Rs./kWh. To calculate the COE, HOMER divides the annualized cost of producing electricity by the total electric load served.

3) *Return on Investment (ROI):*

The Return on Investment (ROI) is the yearly cost savings relative to the initial investment.
The ROI is the average yearly difference in nominal cash flows over the project lifetime divided by the difference in capital cost.

4) *Payback Period:*

HOMER calculates the payback period by comparing one system with another. In general, It tells you how many years it takes to recover an investment. You invest a certain amount of money initially, then earn income from that investment. The payback period is the number of years it takes for the cumulative income to equal the value of the initial investment.

5) *Operating Cost:*

It is the annualized value of all costs and revenues other than initial capital costs.

VI. SIMULATION RESULTS

A) Results without performing HOMER optimization

For the given residential load, the yearly operating cost is 1,99,172Rs. The aim of our system is to reduce this cost effectively. The simulation study for 5 cases is done. The HOMER optimization is turned off during this simulation. Table 2 shows the parameter comparison of these 5 cases.

Table 2: Comparison of performance parameters different combination

Economic and Technical Parameters	CASE I (Grid)	CASE II (G +PV)	CASE III (G+PV+W)	CASE IV (G+P+W+F)	CASE V (G+P+W+F+B)
Initial Cost (Rs.)	0	1,57,000	1,80,000	637000	747000
Energy purchased (KwH)	16,794 kwh	15,603 kwh	13,538 kwh	12,915 kwh	12,907 kwh
Operating Cost (Rs.)	1,99,172	1,78,621	1,44,901	1,45,115	1,50,200
Total NPC (Rs.)	25,74,808	24,66,131	22,10,210	21,20,496	26,88,712
Energy Sold back (KwH)	0	542 kwh	1,742 kwh	1,101 kwh	1,107 kwh
Renewable %	0	10%	27%	27.8	27.9%
COE (Rs.)	11.86	11	9.22	10.86	11.60

G = Grid (220V, 50Hz, Single phase, Residencial)
W = Wind (1.5 Kw).
PV = Solar (1 Kw).
F = Fuel Cell (500 watts)
B = Battery (10 battery , 12V , 200 Amp-hr.)

Table 3: Yearly Production by each component of Actual System (CASE V)

Production	kWh/year	%
1 kW Solar PV	1,589	8.24
Fuel Cell	1,299	6.74
1.5 kW Wind Turbine	3,488	18.1
Grid Purchase	12,907	66.9
Total	19,284	100

Table 3 shows the yearly electric power production by each component of the actual system (CASE V). In Table 2 different economic parameters are compared. From this comparison, it is observed that the Cost of Energy(COE) for case III (Grid + 1kW Solar + 1.5kW wind turbine) is 9.22Rs, Which is low as compared to other cases

B) Simulation results by performing homer optimization

For performing the optimization analysis, the range of solar pv system is taken between 1 to 3kw, the wind turbine range is taken between 0 to 1.5kw, Batteries (0 to 10no.), and the range of hydrogen fuel cell is between 0 to 500 watt. Table 3 gives a detailed comparison of the parameters of the optimized combination of the system obtained by performing HOMER optimization.

According simulation study performed, it is observed that the optimum system satisfying the load and economic parameters is of a configuration comprising 3kw solar pv, 1kw wind turbine system and 2.46 kw inverter. The initial capital of this configuration is Rs. 317000, with an operating cost of Rs. 109220.

Table 4: Optimized combination parameters comparison

Sr No.	Solar PV (KW)	Wind Turbine (kW)	Batteries	inverter (kW)	NPC (RS.)	COE (Rs.)	Operating cost (Rs.)	Initial capital (Rs.)	Ren Frac (%)	PV Production (kWh/yr)	Wind Turbine Production (kWh/yr)	Wind Turbine O&M Cost (Rs.)	Energy Purchased (kWh)	Energy Sold (kWh)
1	3	1		2.4594911	1728936	6.43666	109220.1	316991.5	38.53175	4768.324	3487.64	5000	12771.86	3984.332
2	3	1		2.4594911	1728936	6.43666	109220.1	316991.5	38.53175	4768.324	3487.64	5000	12771.86	3984.332
3	3	1	1	2.4922951	1746601	6.50172	109693.4	328538.3	38.54885	4768.324	3487.64	5000	12769.68	3986.567
4	3	1	1	2.4922951	1746601	6.50172	109693.4	328538.3	38.54885	4768.324	3487.64	5000	12769.68	3986.567
5	3	1		2.0489331	1929159	7.67786	125237.5	310148.9	34.2431	4768.324	3487.64	5000	12780.69	2642.617

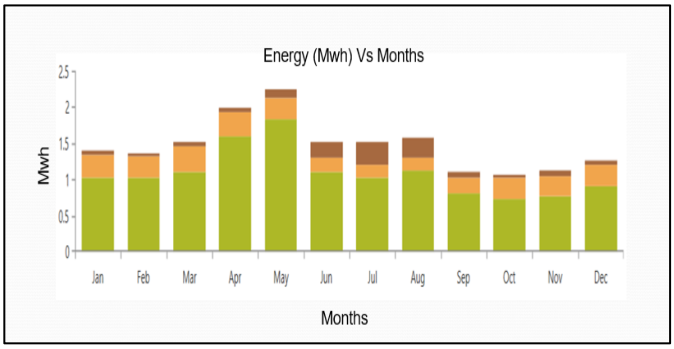

Figure 8: Monthly electric production data of optimized system

VII. CONCLUSION

The simulation study of a hybrid energy system comprising alternative energy sources is carried out in this paper. By comparing the different cases of simulation results without HOMER optimization we find that case III has the lowest operating cost (Rs. 1,44,901) with a COE of Rs. 9.22. The initial cost of case III configuration is Rs. 3,37,000.

The case V is an actual system that is going to install, the initial cost of this system is 7,47,000Rs. With an operating cost of 1,50,200 Rs the annual saving, in this case, is Rs. 48,972. The payback period for this case V is of 15 years (operating cost/annual saving). The system is cost-saving but not that economically good.

HOMER optimization simulation is performed to get an optimized system configuration for this configuration we give several limits to Homer for a rating of sources which is feasible for us to install. This is the case VI system. HOMER simulated 19444 feasible cases for system configuration and give the system comprising 3kw solar PV, 1kw wind and an inverter of 2.46kw as the optimum system with an initial capital requirement of Rs. 3,16,992. The yearly operating cost of this system is Rs. 109220, and the annual saving in the energy bill, in this case, is Rs. 89995. The payback period for this system is of 3.5 years. The share of renewable sources in this system is 38.5 %. The NPC (Net Present Cost) of this optimized system is Rs. 17,28,936.

Therefore, from simulation study and comparing results it is observed that the HOMER-optimized system is more economical than our actual system(Case V) in terms of cost of energy (COE) and NPC. Hence, it is good to perform the HOMER simulation to check the system's feasibility economically and technically before making an investment in hybrid system projects. Below is a chart of the cash flow of the base system and lowest cost system (HOMER optimized system) plotted across the project lifetime.

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