To Design an Optimal PV/Diesel/Battery Hybrid Energy System for Havelock Island in India

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Abstract In the case of hybrid model design, the Hybrid Optimization Model for Electric Renewables (HOMER) software is employed for optimization. This work aims to reduce overpriced net present cost (NPC) and cost of energy (COE) at Havelock Island in India and lower the air pollution index by utilizing non-conventional energy sources. Havelock Island's average daily radiation is 5.30 kWh/m^2/day. The HOMER simulates, optimizes, and does sensitivity analysis on the proposed model for thousands of combinations to find the best answer. We are employing diesel generators, solar panels, and battery storage to develop the optimal hybrid system possible for modeling reasons. This model yields the lowest NPC and COE. In this analysis, the sensitivity variables for simulation are diesel generators' run time and fuel cost. The diesel price of Rs. 77/L and the generator run periods of 720 min were used as sensitivity variables for the optimized model. For these values of sensitivity variables, the NPC and COE come out to be Rs. 1.82 B and Rs. 19.87/kWh, respectively. Using an optimal hybrid system instead of an existing diesel-only system at Havelock Island, the pollution will also be reduced by 83.21%.

Keywords Hybrid model · Net present cost (NPC) · Cost of energy (COE) · Renewable energy · HOMER

1 Introduction

The non-renewable fuel source accounts for a large utilization ratio in the world. The development of fossil energy as a fuel is of grave concern for the world in achieving sustainable growth and development, and also, the use of fossil fuel as an

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energy source is a worthy cause of worldwide water contamination, air contamination, desertification, and the worldwide crisis of climate [1]. However, around the previous decagons, a reduction in hydrocarbon deposits is detected worldwide [2]. If the depletion rate of hydrocarbon deposits remains at the same pace, it is being predicted by proper estimation methods that the amount of non-renewable sources will get empty by 2070. There is a strong requirement to bring the world under a transition phase from a non-renewable energy source to a renewable energy source. This process includes proper modeling, analysis, calculating, and simulating the various factors so that the dependence on the hydrocarbon deposits gets reduced, and we can pace toward the upcoming green and clean energy sources [3]. Statistical data shows that there are still 1.8 billion people under the outreach to power. Those occupants need to be provided electricity either through laying transmission lines of a grid network or a remote power generation system in remote areas where laying a grid is difficult due to hilly terrains or in island territories [4]. In the Havelock Island of Andaman & Nicobar, the major providers of power sources are the diesel-based generator. There are two negative impacts of using diesel appliances. The first one is the high generation cost of power due to inflation in diesel prices. The second reason is hurting the ecological system and causing air contamination, noise disturbance, and water contamination. However, this remote region has high substantiality rational source of power, so using those available energy resources can be viable to decrease the power generation cost [5]. Due to the high inflation in the price of distillate fuel oil, there is a solid requirement to increase the supply of energy through renewable and sustainable sources of power. Using this methodology, more and more energy can be harnessed without disturbing the ecological disturbance. The balance of nature can be ensured, and there is a way forward to discover more potential in standalone or hybrid systems [6]. The standalone system includes a single system like PV based, whereas a hybrid amalgamates two or more standalone designs like PV-diesel and many other types. The hybrid system includes two or more combinations of renewable sources that may be standalone or maybe in the form of a grid connection. Renewable sources like solar, biomass, hydro, and wind are examples of these sources [7]. We can use the above sources as standalone or hybrid systems depending upon the geological factors determining the actual combination of these systems. There are some places where we can use a variety of two or maybe more than two. At some other sites, we also use renewable hybrid with non-renewable sources like a hybrid diesel-solar hybrid for Havelock Island [8]. Hybrid Optimization Multiple Energy Resources (HOMER) software is a system that programs the economic-based approach so that a feasible programming methodology can be adopted by inserting the appropriate parameter so that a better scheme of implementation can be achieved [9]. This HOMER model has given appropriate analysis in case of rural electrification in the remote areas of Bangladesh and also in the isolated areas of Algeria and North Africa [10].

2 Overview of Havelock Island

2.1 Havelock Profile

Havelock Island is the pioneered Island of Andaman & Nicobar. Havelock belongs to the south administrative district part of the union territory. The Havelock Island, now renamed Swaraj Dweep, is 41 km northeast of the capital city, Port Blair. The area of Havelock Island is 92.2 km^2. It is the major tourist destination in the union territory having beach hotels and is famous for its coral reefs and scuba diving experience. The maximum length of the island is 18 km, and its breadth is 8 km. Island is a sub-group of the Ritchie Archipelago [11].

2.2 Consumption Estimation of Demand Projection for Domestic Consumers

The Havelock Island analytical report suggests that it has an installed potential of 1.6 MW (the fiscal year 2015), but the maximum requirement of the Island is more than 2.5 MW. Being the central tourist spot in the region of Andaman & Nicobar, there is an essential requirement of the continuous supply of electricity for the better economic prospect of the area. Electric energy's present potential is insufficient to fulfill the current demand, especially during the maximum load hours. It is evident from the various reports published that power cut is very much regular during the maximal demand for electricity. There is a requirement for an additional reliable system to avoid this disruption to the electricity, which can lead to a better tourism spot and has a high chance of attracting a large number of tourists so that Havelock Island's economy can be boosted significant factor.

3 Exquisite Hybrid Representation of Havelock Island

3.1 About HOMER

The National Renewable Energy Laboratory in the United States created the HOMER software. HOMER, a computer model, is used in various technologies and applications, including manufacturing, storage, load analysis, and microgrid or off-grid micropower systems [12]. The link can be designed throughout the project cycle and includes several cost-related items, such as the cost of investment, replacement, and operation. It helps us assess and compare different options, technical and economic advantages, and disadvantages of other parts of the projects with HOMER; the design process is simple. Simulation, optimization, and execution were performed in three stages and sensitivity analysis. The first level, which is the most basic, is a simulation, technical analysis, and cost–benefit analysis of the micropower system has been completed. The optimization phase begins following the simulation phase [13].

3.2 Details of Havelock Island

NASA dataset is used here to obtain the insolation data for Havelock Island on a mean of per month basis. The per month mean value of solar insolation is obtained from NASA. Table 1, gives the monthly mean value for the global irradiance value of Havelock Island. Table 1 also depicts the clearness index. It is a dimensionless number between 0 and 1 and is defined as the ratio of surface radiation to terrestrial radiation.

The maximal value of the clearness index is 0.690, and the minimal value of the clearness index is 0.420. The maximal and minimal value of the clearness index is reported in April and December, respectively. The maximal and minimal value of per day irradiation is 4.530 kWh/m^2/day and 0.210 kWh/m^2/day, respectively. The month of minimal and maximal value of solar insolation occurs in December and June, respectively. The value of the mean annual irradiation is 2.32 kWh/m^2/day.

Table 1 Clearness index and per day irradiation index for Havelock Island

Month	Clearness index	Daily irradiation (kWh/m^2/day)
January	0.655	5.65
February	0.69	6.47
March	0.674	6.83
April	0.631	6.65
May	0.482	5.08
June	0.42	4.38
July	0.426	4.45
August	0.425	4.45
September	0.454	4.64
October	0.522	4.99
November	0.555	4.86
December	0.621	5.19
Mean value	0.546	5.3

3.3 Load Profile of Havelock Island

The shape of the load is an essential parameter when performing optimization by the HOMER because the different power sources depending on the load shape. The selected island also works as a significant dependent parameter for the model design by the HOMER, and we get the best optimization of the proposed model. The monthly solar global irradiance (SGI) and load profile of Havelock Island are shown in Figs. 1 and 2 respectively. On Havelock Island, the primary energy use is to meet the residents and businesses. As a result, only these two loads will be required to handle in HOMER. HOMER uses these data for simulation and optimization. The island will be supplied 24 * 7 h per week, and the demand is expected to rise. The island is also a significant tourist destination in Andaman & Nicobar Island, requiring reliable and continuous power.

4 Architectonics Structure Representation of Havelock Island

On Havelock Island, the power generation is mainly from the diesel generator. Still, it has a vast potential for transitioning from diesel generators to solar PV panels. Since diesel is a very costly, non-renewable, polluting source, this is a time to focus on a safe and reliable form of solar energy. The proposed model consists of solar PV, diesel generator, converter, and battery, as shown in Fig. 3. The HOMER tells us the best possible combination of the mentioned energy-producing sources. It gives us

Fig. 1 Monthly average SGI for Havelock Island

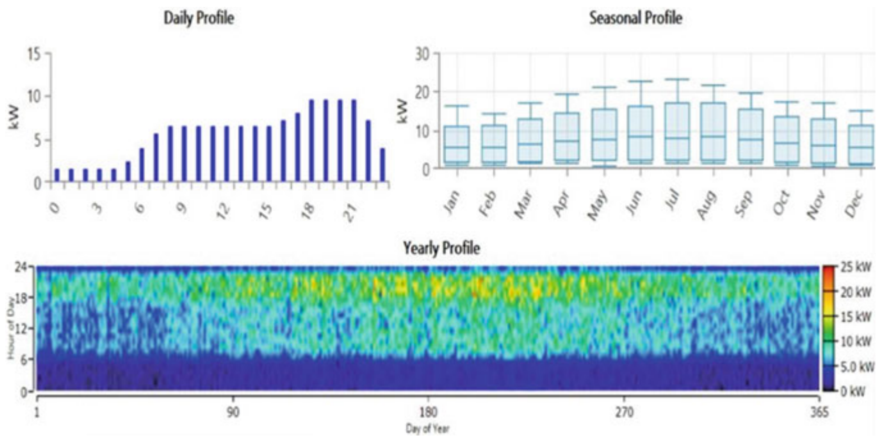

Fig. 2 Load profile of Havelock Island

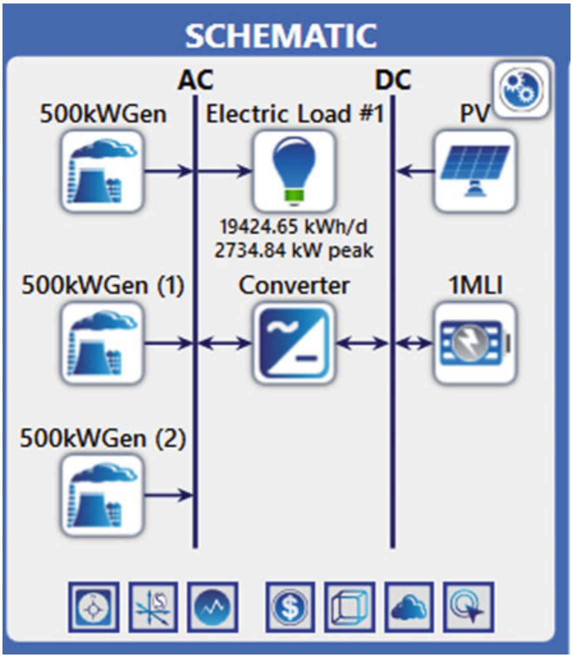

Fig. 3 Schematic diagram of suggested model

the best result by undergoing proper optimization techniques. It requires adequate data insertion for a particular location to retrieve the best-simulated result.

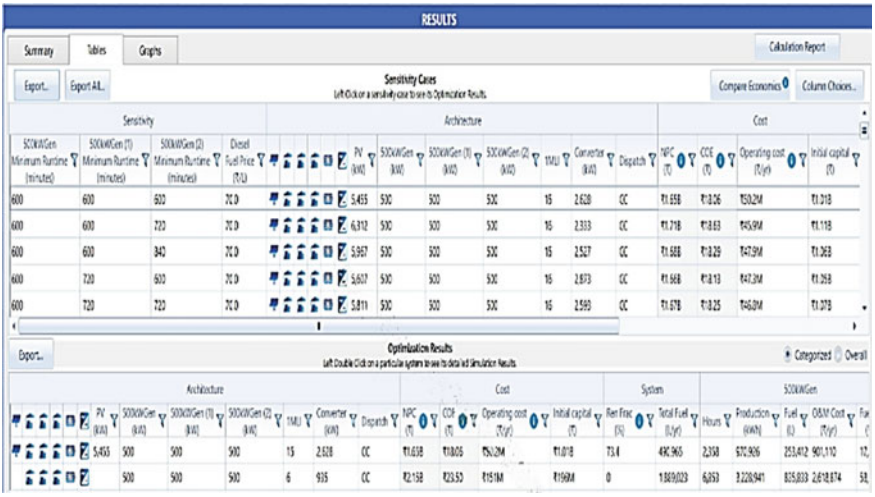

Fig. 4 Optimization and sensitivity results

5 Results Obtained for the Suggested Model at Havelock Island

5.1 Stimulated and Computed Outcome

We have obtained stimulated and computed outcomes from HOMER as presented in Fig. 4.

The outcome of the different stimulated parameters is obtained from the upper part of the figure and the calculated result for a stimulated variable from the lower part. The sensitivity factors for diesel pricing are Rs. 70/L, Rs. 77/L, and Rs. 84/L. The sensitivity variable for minimum runtime of diesel generator has been taken as 600 min, 720 min, and 840 min.

5.2 Net Present Cost (NPC)

Net present cost is depicted in a bar graph and tabular forms, as shown in Table 2. Net present cost includes the cost of operation, cost of capital, cost of replacement, cost of salvage, and cost of resource that comes out to be for the proposed model. The cost of operation, cost of capital, cost of replacement, cost of salvage, and cost of the resource is for the proposed model Rs. 18,23,97,815.31, Rs. 1,29,34,75,781.06, Rs. 3,83,31,784.37, Rs. 86,78,701.81, and Rs. 31,48,37,708.05, respectively.

Table 2 Net present cost of the proposed system at Havelock Island

Equipment	Capital cost (Rs.)	Operating cost (Rs.)	Replacement cost (Rs.)	Salvage value (Rs.)	Resource cost (Rs.)	Total cost (Rs.)
Generic 500 kW fixed capacity genset-1	99,30,095.76	71,53,482.65	68,90,722.91	−11,27,200.58	15,45,24,699.54	17,73,71,800.29
Generic 500 kW fixed capacity genset-2	99,30,095.76	42,63,436.14	29,69,853.37	−10,79,166.46	9,38,42,376.21	10,99,26,595.02
Generic 500 kW fixed capacity genset-3	99,30,095.76	29,24,030.77	19,30,507.75	−19,14,960.08	6,64,70,632.29	7,93,90,306.50
Generic 100 kWh Li-ion	43,26,12,260.34	16,79,69,183.36	53,76,632.09	−5,74,083.45	0	60,53,83,992.34
Generic flat plate PV	77,60,63,649.15	37,682.40	0	0	0	77,61,01,331.55
System converter	5,50,09,584.29	0	2,11,64,068.25	−39,83,291.24	0	7,21,90,361.30
System	1,29,34,75,781.06	18,23,97,815.31	3,83,31,784.37	−86,78,701.81	31,48,37,708.05	1,82,03,64,386.99

Total NPC includes Rs. 1.29 B as cost of capital, Rs 182.3 M as cost of operation, Rs 38 M as cost of replacement, Rs 8.6 M as cost of salvage, and Rs. 314 M as cost of the resource. Out of these expenses, the system capital cost is maximum, around Rs. 1.29 B. This system's capital cost includes the capital cost of generator sets, which comes out to be Rs. 29.8 M; PV cost of capital is Rs. 776 M, and the capital cost in case of the converter is Rs. 55 M, and capital cost of the battery is Rs. 432 M. The cost of operation is Rs. 182 M; the total cost of replacement is Rs. 38 M; the total cost of salvage is Rs. −8.67 M, and the total cost of the resource is Rs. 314 M.

6 Emission Due to Distinct Contaminating Particles at Havelock Island

The emission due to various kinds of contaminating particles because of only the diesel and hybrid system is given in Table 3. This table presents the emission of carbon dioxide, carbon monoxide, and hydrocarbon without complete combustion. From Table 3, it is also observed that a hybrid system can reduce a considerable amount of pollution. The CO_2 emission in the diesel-only system is 4940254 kg/year, while the CO_2 emission in the hybrid system is 829375 kg/year. If the hybrid system is adopted, a large amount of cut in CO_2, i.e., 4,110,879 kg per year, can be seen. Cut in the emission of other contaminating particles such as CO, SO2, and NO_2 is also presented in Table 3.

Table 3 Comparison of emission of the hybrid system and diesel-only system

Contamination causing particles	Diesel generator emission (kg/year)	Emission by diesel, PV, battery for the diesel price of Rs77/L (kg/year)	Decrease in emission value (kg/year)
Carbon dioxide	4,940,254	829,375	4,110,879
Carbon monoxide	25,558	4291	21,267
Unburned hydrocarbons	1356	228	1128
Particulate matter	219	36.7	182.3
Sulfur dioxide	12,076	2027	10,049
Nitrogen oxides	4898	822	4076

7 Comparative Analysis of Diesel-Only System and Optimal Hybrid System

Comparing the economic estimation of the two given systems is depicted in Table 4. The NPC of Rs. 1.65 B and COE of Rs. 18.06 /kWh are minimum for a hybrid system, including all the possible sources at a diesel cost of Rs. 70/L, and the minimum runtime of all three generators is 720 min. In today's scenario, the actual cost of diesel is Rs. 77/L on Havelock Island. Because of this, the diesel price of Rs. 77/L and minimum run time of all three generators are taken as 720 min as standard, which has resulted in the NPC and COE of Rs. 1.82 B and Rs 19.87 /kWh, respectively, for the system consisting of diesel-PV-battery. Table 4 here depicts that the mere-diesel generator system for the standard value of diesel price Rs. 77/L, and minimum runtime of 720 min for all three generators has the NPC and COE for the stimulated varying values Rs. 2.29 B and Rs. 24.97/kWh, respectively. If we observe both the system values for hybrid and the mere-diesel generator set system at diesel price, i.e., Rs. 77/L, we can clarify that NPC has decreased from Rs. 2.29 B to 1.82 B, and COE has decreased from 24.97/kWh to 19.87/kWh. It says that if a hybrid system is used instead of a diesel-only system, there will be a significant reduction in NPC and COE. If we use a hybrid approach in place of only a diesel system, CO_2 emission will be reduced from 4,940,254 kg per year to 829,375 kg per year, which is a significant reduction.

8 Conclusions

Optimization and sensitivity results are depicted in Fig. 4 for a given set of parameters. The optimal system includes diesel generators, PV, battery storage, and converters. The optimized value of NPC and COE is Rs. 1.82 B and Rs. 19.87/kWh, respectively. The NPC and COE have been calculated for diesel rates of Rs. 70/L, Rs. 77/L, Rs. 84/L, and the minimum runtime of generators as 600 min, 720 min, 840 min, respectively. For optimal solution, the actual rate of diesel, i.e., Rs. 77/L, and 720 min of the minimum runtime of each diesel generator are considered. If we use diesel-only system, the CO_2 emission is 4940254 kg/year; if we use a hybrid approach, the CO_2 emission is 829375 kg/year. From the above, it is seen that if we use the optimal hybrid system, there will be a significant reduction in CO_2 emissions.

Table 4 Comparative analysis of diesel-only system and optimal hybrid system

Sensitivity variables				Diesel-only system (base system)				Optimal hybrid system			
Diesel price (Rs./L)	Running time of DG sets (min)										
	500 kW	500 kW	500 kW	NPC (Rs.)	COE (Rs.)	Ren fraction %	CO_2 emission (kg/year)	NPC (Rs)	COE (Rs)	Ren fraction %	CO_2 emission (kg/year)
70	600	600	600	2.15B	23.5	0	12,87,422	1.65B	18.06	73.4	12,87,422
	720	720	720	2.12B	23.14	0	49,48,076	1.80B	19.63	74.3	12,47,850
	840	840	840	2.12B	23.11	0	49,35,782	1.71B	18.75	72.8	13,21,712
77	600	600	600	2.29B	24.98	0	49,46,031	1.70B	18.61	72.9	1,311,06
	720	720	720	2.29B	24.97	0	49,40,254	1.82B	19.87	82.9	8,29,375
	840	840	840	2.29B	24.98	0	49,34,101	1.75B	19.13	74.4	12,41,848
84	600	600	600	2.46B	26.82	0	49,41,961	1.75B	19.05	78	10,64,265
	720	720	720	2.46B	26.83	0	49,39,450	1.85B	20.2	83	8,25,890
	840	840	840	2.46B	26.79	0	4,928,67	1.80B	19.6	74.4	1,241,84

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