Optimization of Renewable Energy Efficiency using HOMER

Kenneth E. Okedu*‡, Roland Uhunmwangho*

* Department of Electrical Engineering, College of Engineering, University of Port Harcourt, Nigeria

‡ Corresponding Author; e-mail: kenokedu@yahoo.com or Kenneth.okedu@uniport.edu.ng

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Abstract- Hybrid Optimization Model for Electrical Renewable (HOMER), is a micro power optimization model, that simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. The HOMER Hybrid Optimization Modeling Software is used for designing and analyzing hybrid power systems, which contain a mix of conventional generators, cogeneration, wind turbines, solar photovoltaic, hydropower, batteries, fuel cells, biomass and other inputs. This paper is divided basically into two sections. The first section investigates the energy efficiency of renewable energy system considering an isolated AC diesel generator. A model system consisting of a PV, three batteries and a converter system was considered. HOMER was able to calculate the best option that would give the best energy efficiency. In the second section, a further investigation was carried out considering two cases with two different load profiles to show that the load profiles affects the responses of the renewable energy system and the cash flow summary of some of the system equipments. In this section, a wind turbine is integrated into the PV, battery, converter and AC diesel generator system.

Keywords: HOMER, Network, Renewable energy, Optimization, Efficiency, Cash flow.

1. Introduction

The large number of technology options and the variation in technology costs and availability of energy resources make project design decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations [1]. HOMER allows the user to input an hourly power consumption profile and match renewable energy generation to the required load. It allows a user to analyze micro-grid potential, peak renewables penetration, ratio of renewable sources to total energy, and grid stability, particularly for medium to large scale projects. Additionally, HOMER contains a powerful optimizing function that is useful in determining the cost of various energy project scenarios. This functionality allows for minimization of cost and optimization of scenarios based on various factors [1, 2].

To use HOMER, the model with inputs must be provided, which describe technology options, component costs, and resource availability [2]. HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that can be viewed as a list of feasible configurations sorted by net present cost. HOMER also displays simulation results in a wide variety of tables and graphs that help to compare configurations and evaluate them on their economic and technical merits [3, 4]. The use of HOMER for renewable energy has been reported in the literature [4-11]; but the use of different load profiles was not taken into account. However, in [12, 13], the use of different load scenarios in determining the levelized cost of electricity considering the integration of only wind and solar energy was analyzed.

This paper is basically in two sections. The first section shows how HOMER can be used to optimize renewable energy system based on the net present cost of the system from a list of different possible configuration. The second section tends to investigate the effects of different load profiles, considering two scenarios. Also, in order to get an accurate comparison, the model system considered and its parameters were kept constant. The results display that the higher the load profile, the higher the cash flow summary, with increased capital, fuel consumption, operating and replacement cost and higher salvage value of the project. However, the load profiles do not affect the converter system.

2. Advantages and Disadvantages of HOMER

Table 1 shows some of the merits and limitations of using the HOMER software.

Table 1: Merits and Limitations of HOMER

Merits	Limitations
Simulates a list of real technologies, as a catalogue of available technologies and components	Quality input data needed (sources)
Very detailed results for analysis and evaluation.	Detailed input data (and time) needed
Determines the possible combinations of a list of different technologies and its size.	An experienced criterion is needed to converge to the good solutions
It is fast to run many combinations.	HOMER will not guess key values or sizes if there are missed.
Results could be helpful to learn a system configuration and optimization.	Could be time consuming and onerous

3. Considered System Model and Load Profiles

Section 1: The first model system considered in this study in section 1 is shown in Fig. 1, where a PV system and three batteries are connected to the DC terminal and a converter is connected between the AC and DC bus bars.

An isolated diesel generator that is not loaded depending on the load profile and the required time that is necessary to come on stream is also shown in the model system. The details of the equipment considered for the model system are given in the HOMER summary input shown in the Appendix.

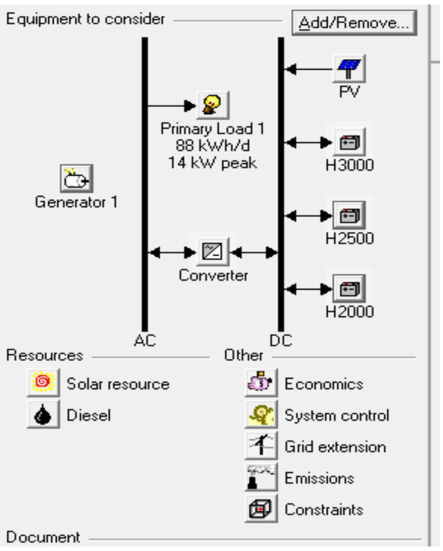


Fig. 1. Model System 1 with no Wind Turbine and Diesel Generator

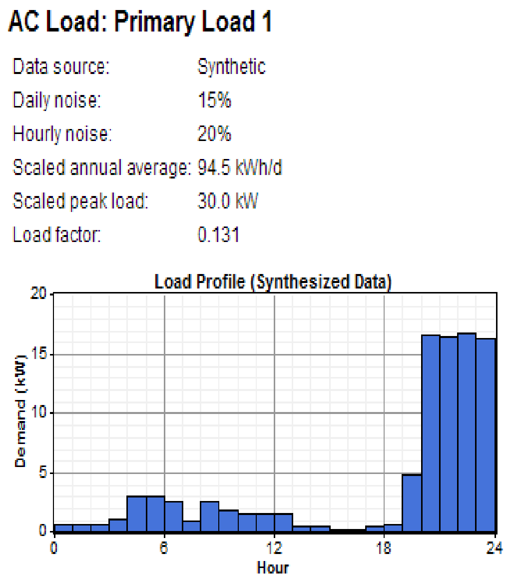


Fig. 2. Load Profile for case 1

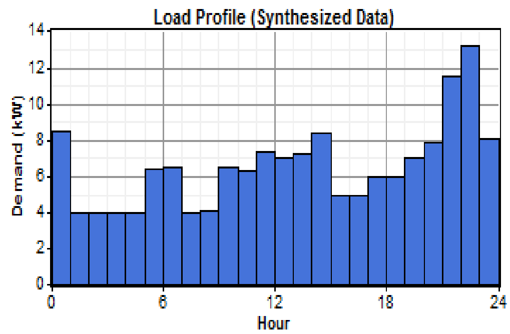


Fig. 3. Load Profile for case 2

The load profile in case 1 is skewed towards the right where a maximum load of about 17kW is used towards the late hour of the evenings, while the load profile of case 2 is roughly and evenly distributed with a peak load of 13kW observed also in the late evenings.

These two load profile forms the basis of the HOMER simulation in this paper. HOMER simulates the annual performance of each of the system combination possibilities in the model system for a specified set of energy sources and calculates also the system and operating costs over the given period. The load profiles and operation of the system is simulated by HOMER by making energy balance calculations for each of the 8,760 hours in a year. In Section 1, the load profile in Fig. 2 is used to determine the energy efficiency of model system 1.

Section 2: Two cases using two load profiles shown in Figs 2 and 3 respectively are also considered with another model system, named model system 2. Section 2 uses the load profile in Fig. 3 to make a comparison with case 1 load profile and investigate the effects of the load profile on the equipments in the model system. The model system 2 used in Section 2 has a wind turbine and a diesel generator connected to the AC bus as shown in Fig. 4, where an ENAIR wind turbine and a diesel generator are connected to the AC bus bars to investigate the effects of the load profiles on the power system. The details of the wind turbine and the diesel generator are shown also in the Appendix.

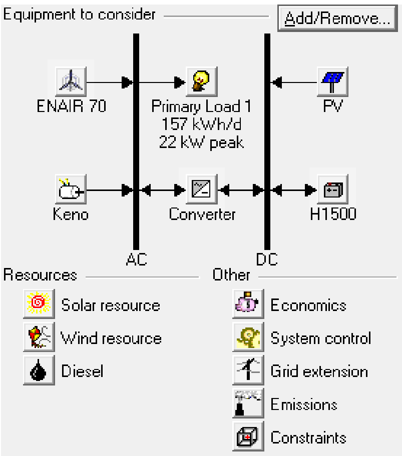


Fig. 4. Model System 2 with Wind Turbine and Diesel Generator

4. Simulation Results and Analyses

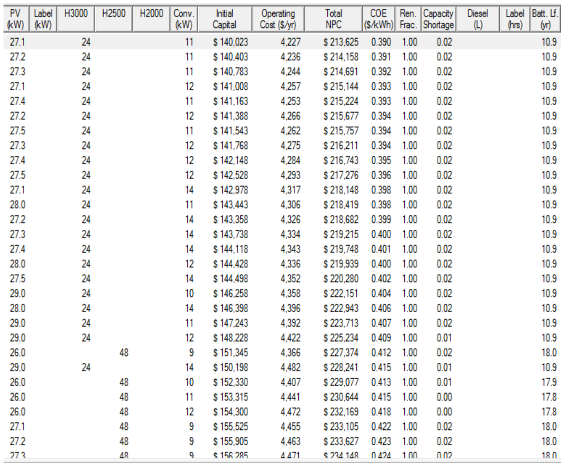
Some of the simulation results for this study are shown the figures below for the two sections considered. Figs 5 to 15 show the results for section 1. Possible range of results obtained for case 1 using the combination of the energy sources in the model system, arranged in order of the most energy efficient in terms of the net present cost of the system is shown in Fig. 5, where the optimized result with the lowest net present cost is in the first array.

Further analyses of the best result are in section 1, are as follows. Fig. 6 shows the state of charge of the battery bank, with an initial state of charge of 30%, while Fig. 7 shows the cash flow of the system. The initial capital cost is high that is the reason for the negative sign, however, this is eased-off after some time with the positive salvage value of the system. Also, since the diesel generator is not connected in the course of the study, the effect could be clearly seen in the zero fuel cost in Fig. 7. The inverter and rectifier outputs are shown in Fig. 8, with high oscillations in the inverter output compared to the rectifier.

Fig. 9 shows the cash flow summary, with the PV system having the highest cost while the converter has the lowest cost. This could be explained with the high PV array production of 48,757kW/yr shown in the monthly average electric production, high frequency PV output, high global and incident solar and high frequency change in global solar over 1 hr as shown in Figs 10 to 13 respectively.

The hourly data capture for the month of December for the global solar, incident solar, AC primary load, PV power, AC primary served and the excess electricity are shown in Fig. 14. It could be observed that the excess electricity is fairly much because of the low load profile used in the study, as compared to the much PV output due to high global solar.

The electrification cost of the system based on the grid extension criterion of comparing the grid system to the stand alone system is shown in Fig. 15, where a breakeven distance of 1.07km is required for the grid system to be more expensive than the stand alone system.



PV (kW)	Label (kW)	H3000	H2500	H2000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)	Batt. Lf. (yr)
27.1		24			11	$ 140,023	4,227	$ 213,625	0.390	1.00	0.02			10.9
27.2		24			11	$ 140,403	4,236	$ 214,158	0.391	1.00	0.02			10.9
27.3		24			11	$ 140,783	4,244	$ 214,691	0.392	1.00	0.02			10.9
27.1		24			12	$ 141,008	4,257	$ 215,144	0.393	1.00	0.02			10.9
27.4		24			11	$ 141,163	4,253	$ 215,224	0.393	1.00	0.02			10.9
27.2		24			12	$ 141,388	4,266	$ 215,677	0.394	1.00	0.02			10.9
27.5		24			11	$ 141,543	4,262	$ 215,757	0.394	1.00	0.02			10.9
27.3		24			12	$ 141,768	4,275	$ 216,211	0.394	1.00	0.02			10.9
27.4		24			12	$ 142,148	4,284	$ 216,743	0.395	1.00	0.02			10.9
27.5		24			12	$ 142,528	4,293	$ 217,276	0.396	1.00	0.02			10.9
27.1		24			14	$ 142,978	4,317	$ 218,148	0.398	1.00	0.02			10.9
28.0		24			11	$ 143,443	4,306	$ 218,419	0.398	1.00	0.02			10.9
27.2		24			14	$ 143,358	4,326	$ 218,682	0.399	1.00	0.02			10.9
27.3		24			14	$ 143,738	4,334	$ 219,215	0.400	1.00	0.02			10.9
27.4		24			14	$ 144,118	4,343	$ 219,748	0.401	1.00	0.02			10.9
28.0		24			12	$ 144,428	4,336	$ 219,939	0.400	1.00	0.02			10.9
27.5		24			14	$ 144,498	4,352	$ 220,280	0.402	1.00	0.02			10.9
29.0		24			10	$ 146,258	4,358	$ 222,151	0.404	1.00	0.02			10.9
28.0		24			14	$ 146,398	4,396	$ 222,943	0.406	1.00	0.02			10.9
29.0		24			11	$ 147,243	4,392	$ 223,713	0.407	1.00	0.02			10.9
29.0		24			12	$ 148,228	4,422	$ 225,234	0.409	1.00	0.01			10.9
26.0			48		9	$ 151,345	4,366	$ 227,374	0.412	1.00	0.02			18.0
29.0		24			14	$ 150,198	4,482	$ 228,241	0.415	1.00	0.01			10.9
26.0			48		10	$ 152,330	4,407	$ 229,077	0.413	1.00	0.01			17.9
26.0			48		11	$ 153,315	4,441	$ 230,644	0.415	1.00	0.00			17.8
26.0			48		12	$ 154,300	4,472	$ 232,169	0.418	1.00	0.00			17.8
27.1			48		9	$ 155,525	4,455	$ 233,105	0.422	1.00	0.02			18.0
27.2			48		9	$ 155,905	4,463	$ 233,627	0.423	1.00	0.02			18.0
27.3			48		9	$ 156,285	4,471	$ 234,148	0.424	1.00	0.02			18.0

Fig. 5. Combination of Results for Case 1

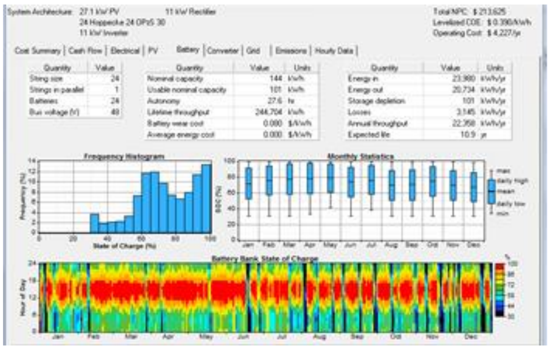


Fig. 6. Battery Bank State of Charge

Fig. 7. Cash Flow of the System

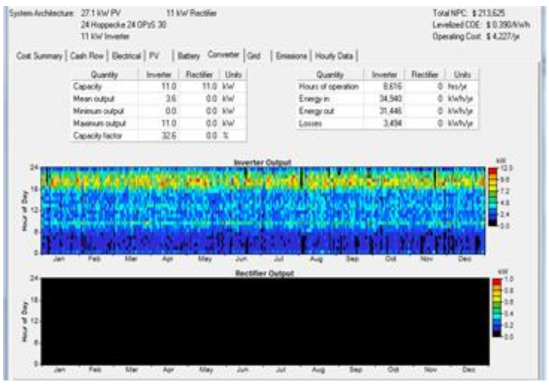


Fig. 8. Inverter and Rectifier Outputs

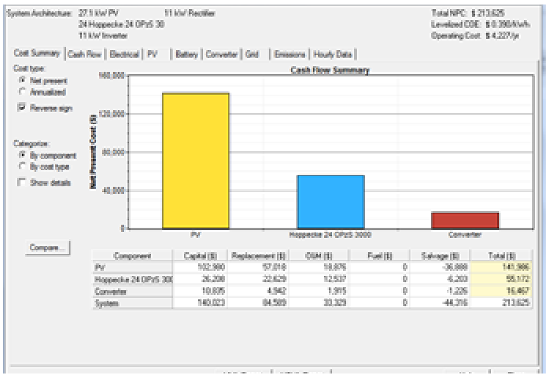


Fig. 9. Cash Flow Summary

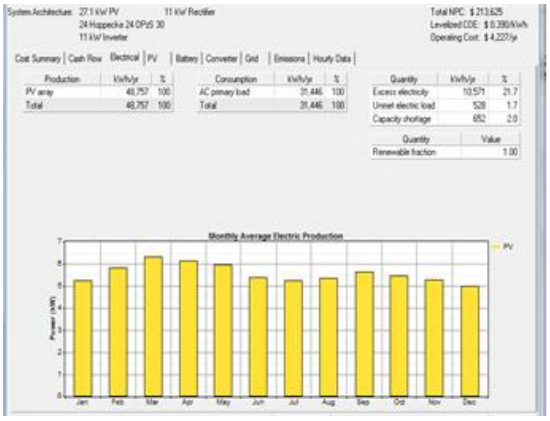


Fig. 10. Monthly Average Electric Production

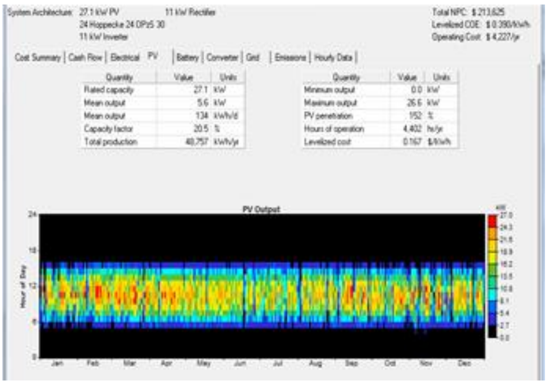


Fig. 11. PV Output

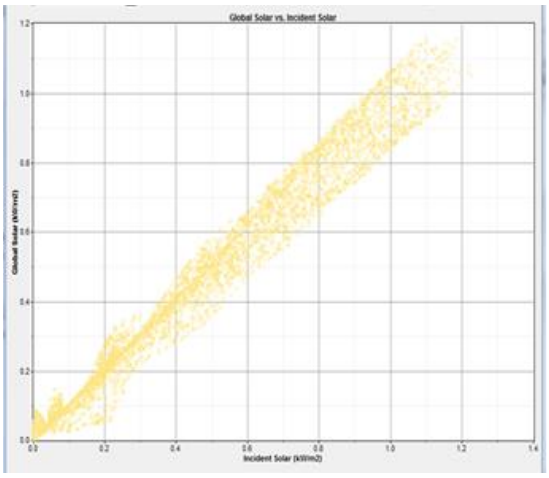


Fig. 12. Global and Incident Solar

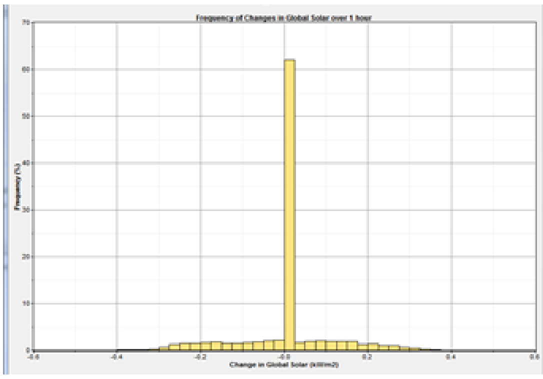


Fig. 13. Frequency Change in Global Solar

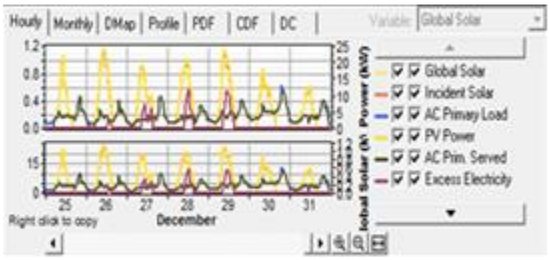


Fig. 14. Hourly Data Capture

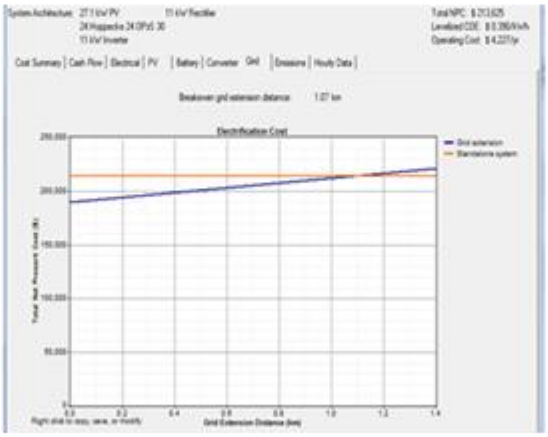


Fig. 15. Grid Extension

The responses of the system for section 2 are as follows. From Figs 16 and 17, it is seen that the load profile has a great influence in the cash flow summary of the system. Lower load profile 1 requires lower capital, replacement, and operating, fuel and salvage value of the project for the PV, wind turbine, diesel and battery system as compared to higher load profile 2. However, the cost of operating the converter system remains the same despite the variation in the load profiles.

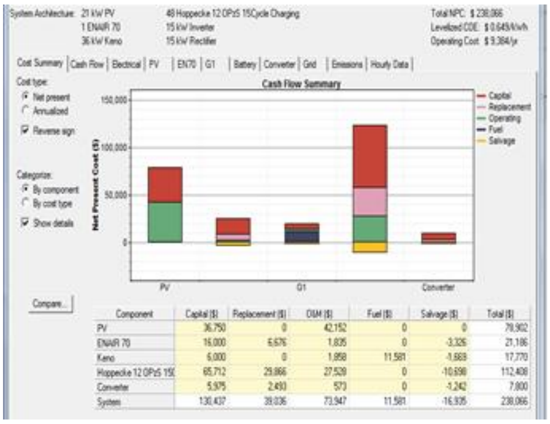


Fig. 16. Cash Flow Summary using Load Profile of Case 1

Fig. 17. Cash Flow Summary using Load Profile of Case 2

5. Levelized Cost of Electricity and Demand Side Management Loading Scheme

The Levelized cost of electricity (LCOE) is also the levelized cost of energy (LCOE) or the levelized energy cost (LEC). It is a common metric for comparing power generating technologies as used in the model system of this study. The full life-cycle costs (fixed and variable) of a power generating technology per unit of electricity (MWh) are often called levelized costs of electricity. In contrast to the tendency of increasing energy prices for conventional power sources, like the AC diesel generator used in this study, the levelized cost of electricity of all renewable energy technologies (the PV and wind turbine) have been falling continuously for decades. This development is driven by technological innovations such as the use of less expensive and better performing materials, reduced material consumption, more-efficient production processes, increasing efficiencies as well as automated mass production of components. It can be defined with the following equation [12, 14].

$$LEC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (1)$$

Where

- LEC is the average lifetime levelized electricity generation cost
- It is the investment expenditures in the year t
- Mt is the operations and maintenance expenditures in the year t
- Ft is the fuel expenditures in the year t
- Et is the electricity generation in the year t
- r is discount rate
- n is life of the system

The LCOE for section 1 of this study, for the best HOMER configuration option is shown in Figs 5 to 15 with a value of \$0.390/kWh. For section 2 the LCOE, as shown in Figs. 16 and 17 respectively are \$0.649/kWh and \$0.596kWh. It could be observed that the lower load profile of case 1 gives a higher LCOE, lower net present cost of \$238.066, and lower operating cost of \$9,384/yr compared to results obtained in load profile of case 2, with higher net present cost and operating cost.

Moreover, the costs of constructing and operating a new capacity generation unit are increasing everyday as well as transmission and distribution and land issues for new generation plants. This leads to the utilities to search for another alternative without any additional constraints on customers comfort level or quality of delivered product. Demand side management (DSM) therefore encompasses load reduction strategies as well as load growth strategies and flexible energy service options. This can be defined as the selection, planning, and implementation of measures intended to have an influence on the demand or customer-side of the electric meter, either caused directly or stimulated indirectly by the utility. DSM programs are peak clipping, valley filling, load shifting, load building, energy conservation and flexible load shape [15, 16]. Considering the model system of study, with respect to the two load profiles scenarios, load profile for case 1 is said to have a better demand side management compared to load profile of case 2. Thus, more energy would be saved in the first case, with less pressure on the renewable energy sources based on effective load or energy management system in load profile 1.

6. Conclusion

This paper presented the use of the hybrid optimization model for electric renewable (HOMER) for designing renewable system considering energy efficiency. A combination of different energy technologies was simulated by the HOMER system and a combination of different configurations were achieved, with the best result which gives the least net present cost selected as the most optimized outcome of the different technologies.

Also, a model system consisting of wind turbine, PV system, diesel ac generator, battery and converter system was investigated using different load profiles. The cash flow summary results demonstrates that increase load profile leads to more capital, operating, replacement, increase fuel, and salvage value of the project for the wind turbine, PV, diesel and battery systems. However, the converter system was found to be independent of the load profiles.

Appendix

PV

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
0.230	94,000	94,000	9,400

Sizes to consider: 10, 11, 12, 13, 15, 16, 17, 19, 20, 24, 25, 27, 30 kW
Lifetime: 20 yr
Derating factor: 80%
Tracking system: No Tracking
Slope: 15, 10, 6 deg
Azimuth: 0 deg
Ground reflectance: 20%

AC Wind Turbine: ENAIR 70

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	16,000	16,000	160

Quantities to consider: 1, 2, 3
Lifetime: 15 yr
Hub height: 15 m

Battery: Vision 6FM200D

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	100,000	100,000	0.00

Quantities to consider: 3, 4, 5, 6, 10, 12, 15, 18
Voltage: 12 V
Nominal capacity: 200 Ah
Lifetime throughput: 917 kWh

Converter

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
15.000	710,000	710,000	7,100

Sizes to consider: 15, 20, 25, 30, 45, 50 kW
Lifetime: 15 yr
Inverter efficiency: 90%
Inverter can parallel with AC generator: Yes
Rectifier relative capacity: 100%
Rectifier efficiency: 85%

Fuel: Diesel

Price: $ 1.6/L
Consumption limit: 5,000 L
Lower heating value: 43.2 MJ/kg
Density: 820 kg/m3
Carbon content: 88.0%
Sulfur content: 0.330%

Economics

Annual real interest rate: 6%
Project lifetime: 25 yr
Capacity shortage penalty: $ 0/kWh
System fixed capital cost: $ 0
System fixed O&M cost: $ 0/yr

Generator control

Check load following: No
Check cycle charging: Yes
Setpoint state of charge: 80%

Allow systems with multiple generators: Yes
Allow multiple generators to operate simultaneously: Yes
Allow systems with generator capacity less than peak load: Yes

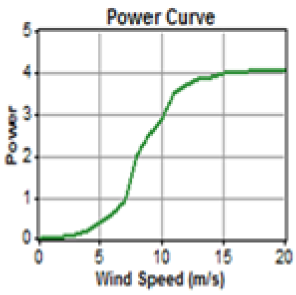
Emissions

Carbon dioxide penalty: $ 0/t
Carbon monoxide penalty: $ 0/t
Unburned hydrocarbons penalty: $ 0/t
Particulate matter penalty: $ 0/t
Sulfur dioxide penalty: $ 0/t
Nitrogen oxides penalty: $ 0/t

Constraints

Maximum annual capacity shortage: 10%
Minimum renewable fraction: 100%

Operating reserve as percentage of hourly load: 10%
Operating reserve as percentage of peak load: 0%
Operating reserve as percentage of solar power output: 10%
Operating reserve as percentage of wind power output: 15%



AC Generator: Keno

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
36.000	6,000	6,000	2.000

Sizes to consider:	36 kW
Lifetime:	15,000 hrs
Min. load ratio:	30%
Heat recovery ratio:	0%
Fuel used:	Diesel
Fuel curve intercept:	0.08 L/hr/kW
Fuel curve slope:	0.25 L/hr/kW

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