Optimisation of a Hybrid PV-Diesel System for Rural Application: The Case of Oluundje Village, Namibia

E. Hamatwi[1]*, C.N. Nyirenda[2], I.E. Davidson[3]

[1]Department of Electrical Engineering, University of Namibia, Ongwediva, Namibia

[2]Department of Computer and Electronics Engineering, University of Namibia, Ongwediva, Namibia

[3]Department of Electric Power Engineering, Durban University of Technology
Durban 4001, Republic of South Africa

Received: 24th July, 2016. Accepted: 14th October, 2016. Published: 23rd October, 2016

Abstract

The absence of electricity in remote and rural areas is one of the major challenges faced by many poor and developing countries. Hybrid energy systems (HES) based on photovoltaics (PV) are considered to be an effective option to electrify remote and isolated areas, which are far from conventional grids. This is true for areas that receive high averages of solar radiation annually. This research investigation involves the modelling, simulation and optimization of a PV-Diesel hybrid system for Oluundje village in Namibia. A site survey was conducted in a form of questionnaires and interviews for the purpose of load forecasting and system modelling. HOMER software was used to design and model the proposed hybrid energy system. Costs of different components, hourly solar radiation, and rating parameters are inputs of the simulation program. Sensitivity analysis was carried out using Homer. The optimal PV-Diesel hybrid system and diesel-generator-only system were compared both technically and economically. Based on simulation results, it was found that electrifying a remote village using a PV-diesel hybrid system is more advantageous when compared to the diesel-generator-only system as it has lower operating costs and emissions. This system may be used as a preliminary design to guide in the planning and modelling of similar systems for other remote villages.

Keywords: Photovoltaics, PV-diesel hybrid system, Optimisation, HOMER software,

*Corresponding author - E. Hamatwi (e-mail: ehamatwi@unam.na)

ISSN: 2026-7673

diesel-generator only system, net present cost

ISTJN 2017; 9:9-25.

1 Introduction

A large segment of the world's population lives in rural areas that are geographically isolated, remote and sparsely populated (Lal et al. 2011). According to the 2010 population statistics, approximately 58% of the Namibian people stay in remote villages with no conventional power grids (Hungamo, 2011). Extending grid access to these villages will increase the system load and require an increase in the generation capacity which is costly (Sen et al. 2014). Currently, various types of renewable energy (RE) sources are used to supply different applications in rural areas (Bhandari et al. 2011).

Increased reliability and energy security issues are some of the benefits that can be achieved by using hybrid renewable systems (Kamalapur et al. 2011; Daud et al. 2012). A hybrid renewable energy system incorporates two or more electricity generation options based on renewable energy sources (Sinha et al. 2014; Nema et al. 2009). Hybrid energy systems that depend on PV systems are considered the most popular among other types of RE systems. The main advantages of these technologies are their low maintenance costs and low pollutant emissions (Twaha et al. 2012).

A hybrid combination of renewable energy generators at an off-grid location can be a cost-effective alternative to grid extension and it is sustainable, techno-economically viable and environmentally sound (Sen et al. 2014). Khatib (2011) has concluded that a PV-diesel generator hybrid system is a more feasible system compared to a diesel generator system or standalone PV system for the Malaysian case and other remote villages. Hrayshat (2009) used HOMER software to optimize a PV-diesel hybrid system in Jordan and concluded that the most optimal configuration is the scenario that involves PV and diesel.

Optimizing different component sizes in the hybrid system is one of the important issues that are considered when designing hybrid systems. In this study, a PV-diesel hybrid system was modelled and analysed to be a source of electric energy for a remote village situated in Oshikoto region, Namibia. A survey was conducted in a form of interviews and questionnaires to carry out load demand forecasting and enable system modelling. The solar radiation data for the proposed remote village was also obtained from NASA database. HOMER software package was then used for PV-Diesel hybrid system modelling. A financial optimization, sensitivity and cost analysis of different system configurations have been carried out with the main aim of identifying the cost efficient and environmental friendliest configuration well suited for the proposed study area.

2 Load Forecasting and Assessment

2.1 Load Forecasting

To obtain the average load and energy consumption data for a particular remote village, it is required that load forecasting should be carried out for the proposed village. The load forecasting is necessary for obtaining the information regarding the load demand and the total population under consideration. In this study, load forecasting was carried out in a form of a survey which was conducted through interviews and questionnaires. A breakdown of the loads identified includes a total number of eighty (80) households; fifteen (15) commercial shops; one (1) church; a school, and clinic undergoing planning.

The relevant load forecasting information gathered during the survey were based on the following survey questions:

- The current sources of power used in households and commercial shops
- The number of people in each household
- The types of electrical appliances that are most likely to be used should electricity be made available

Currently, most households and commercial shops make use of candles and kerosene lamps for lighting purposes which most of the times lead to accidental fires and loss and damage of properties. Furthermore, some of the households make use of the diesel operated generator during social events and gatherings.

The estimated load demand and power consumption for one out of 80 households are shown in Table 1.

Different households had different load and power consumption demands, hence, the total load demand and power consumption for 80 households are as follow:

- Total load for 80 houses = 110674W
- Total energy consumption for 80 houses = 448 742Wh

Table 1: Load forecasting for one household.

Appliance	Power rating (W)	Qty	Total Load (W)	Hours of Use	Total Power Consumption (Wh)
Plasma TV	180	1	180	6	1 080
Fridge/freezer	180	1	180	24	4 320
Electric Kettle	1 200	1	1 200	1	1 200
LED Lights	11	6	66	5	330
Phone Charging	4	2	8	3	24
Radio	15	1	15	6	90
Microwave	700	1	700	3	2 100
TOTAL			2 349		9 144

The estimated load demand and power consumption for one out of 15 commercial shops are shown in Table 2.

Table 2: Load forecasting for one commercial shop

Appliance	Power rating (W)	Qty	Total Load (W)	Hours of Use	Total Power Consumption (Wh)
Plasma TV	180	1	180	3	540
Fridge/freezer	180	1	180	24	4 320
LED Lights	11	4	44	3	132
Phone charging	4	5	20	6	120
Radio	15	1	15	3	45
Portable fan	70	1	70	2	140
TOTAL			509		5 297

Different commercial shops had different load and power consumption demands, hence, the total load demand and power consumption for 15 commercial shops are as follow:

- Total load demand for 15 shops = 5268W
- Total power consumption for 15 shops = 72 775Wh

The estimated load demand and power consumption for the church and school (kindergarten) are shown in Table 3.

The estimated load demand and power consumption for the clinic are shown in Table 4.

2.2 Load Assessment

Through the process of load assessment, the average load demand and average power consumption are determined using the data obtained during the load forecasting process. This

Table 3: Load forecasting for the church and school

Appliance	Power rating (W)	Qty	Total Load (W)	Hours of Use	Total Power Consumption (Wh)
LED Lights	11	10	110	7	770
Computer	150	2	300	4	1 200
Printer/copier	120	1	120	3	360
Telephone	25	1	25	3	75
TOTAL			555		2 405

Table 4: Load forecasting for the clinic

Appliance	Power rating (W)	Qty	Total Load (W)	Hours of Use	Total Power Consumption (Wh)
Plasma TV	180	1	180	5	900
Fridge/freezer	180	1	180	24	4 320
LED Lights	11	6	66	3	198
Computer	150	2	300	3	900
Printer/copier	120	1	120	3	360
Telephone	25	1	25	5	125
Portable fan	70	1	70	2	140
Electric Kettle	1 200	1	1 200	2	2 400
Washing Machine	555	1	555	2	1 110
Phone Charging	4	5	20	3	60
Radio	15	1	15	2	30
Microwave	700	1	700	1	700
TOTAL			3 431		11 243

is necessary for accurate power system sizing and modelling to ensure continuous power supply to the village residents. A load assessment was carried out to determine the estimated load demand and the estimated power consumption for Oluundje village.

The average load demand and power consumption per household were determined as follow:

$$\text{Average load demand per household (kW)} = \frac{\text{(Total load demand for all households (W))}}{\text{(No. of households)} \times \frac{1000W}{kW}}$$

$$= \frac{(110674W)}{(80 \times 1000)} = 1.68kW/\text{house}$$

$$\text{Average power consumption per household (kWh)} = \frac{\text{(Total energy for all households (Wh))}}{\text{(No. of households)} \times \frac{1000W}{kW}}$$

$$= \frac{(448742Wh)}{(80 \times 1000)} = 6.79kWh/\text{house}$$

The average load demand and power consumption per commercial shop were determined as follow:

$$\text{Average load demand per shop (kW)} = \frac{\text{Total load demand for 15 shops (W)}}{\text{(No. of shops)}} \times \frac{1000W}{kW}$$

$$= \frac{5268W}{15 \times 1000} = 0.3512kW/\text{shop}$$

$$\text{Average power consumption per shop (kWh)} = \frac{\text{Total energy for 15 shops(Wh)}}{\text{(No. of shops)}} \times \frac{1000W}{kW}$$

The average load demand and power consumption for the school and church are as follow:

$$\text{Total Load(kW)} = \frac{555W}{1000} = 0.555kW,$$

and

$$\text{Total Power consumption(kWh)} = \frac{2405W}{1000} = 2.405kW$$

The average load demand and power consumption for the clinic are as follow:

$$\text{Total Load(kW)} = \frac{3431W}{1000} = 3.431kW,$$

and

$$\text{Total Energy(kWh)} = \frac{11243W}{1000} = 11.243kW$$

Table 5 and Table 6 illustrate the estimated load demand and estimated power consumption for Oluundje village, respectively.

Table 5: Estimated load demand for Oluundje village

Type of load	Per Unit (kW)	Quantity	Total load (kW)
Household	1.68	80	134.4
Shops	0.35	15	5.25
School and church	0.55	1	0.55
Clinic	3.43	1	3.43
Total			143.63

Based on Electric Control Board (ECB) standards (Shilamba, 2013), a minimum capacity reserve margin of 10%-14% of supply is to be considered on top of the current demand. In this study, the reserve margin is taken to be 12%. Therefore, the new load demand is the given by adding 12% of 143.63kW to the current load demand, adding up to 160.87kW.

Table 6: Estimated power consumption for Oluundje village

Type of load	Per Unit (kWh)	Quantity	Total Power Consumption (kWh)
Household	6.79	80	543.2
Shops	4.85	15	72.75
School and church	2.41	1	2.41
Clinic	11.24	1	11.24
Total			629.6

3 System Implementation

3.1 Geographical Site Location and Climate Database

Namibia is an arid country with clear skies most of the time throughout the year, and hence it has a very good solar radiation potential. This makes it a suitable place to implement solar power plants to provide off-grid electricity access to the energy-deprived, remote and scarcely populated rural areas.

Oluundje village is located at 18°1'1.17"S and 16°42'52.76"E, in the northern part of Namibia, Oshikoto region. The latitude and longitude coordinates of the study area are mainly used to obtain the annual solar radiation data from the Surface Solar Energy website of National Aeronautics and Space Administration (NASA) (Ajao et al. 2011). According to NASA, Oluundje village has an annual solar radiation of 5.94kWh/m^2/d. Figure 1 shows the average values of solar radiation in Namibia as well as the geographical location of the study area (Oluundje village).

3.2 Homer Code Implementation

Hybrid Optimization Model for Electric Renewables (HOMER) is micro-power optimization software developed by Mistaya Engineering, Canada for the National Renewable Energy Laboratory (NREL) USA (Lilienthal 1995; Lilienthal et al. 2005). HOMER is mainly used to carry out optimization studies and system analysis for hybrid energy systems for both off-grid and grid-connected power systems. HOMER's flexibility makes it useful for rural electrification projects through its three principal tasks: simulation, optimization, and sensitivity analysis.

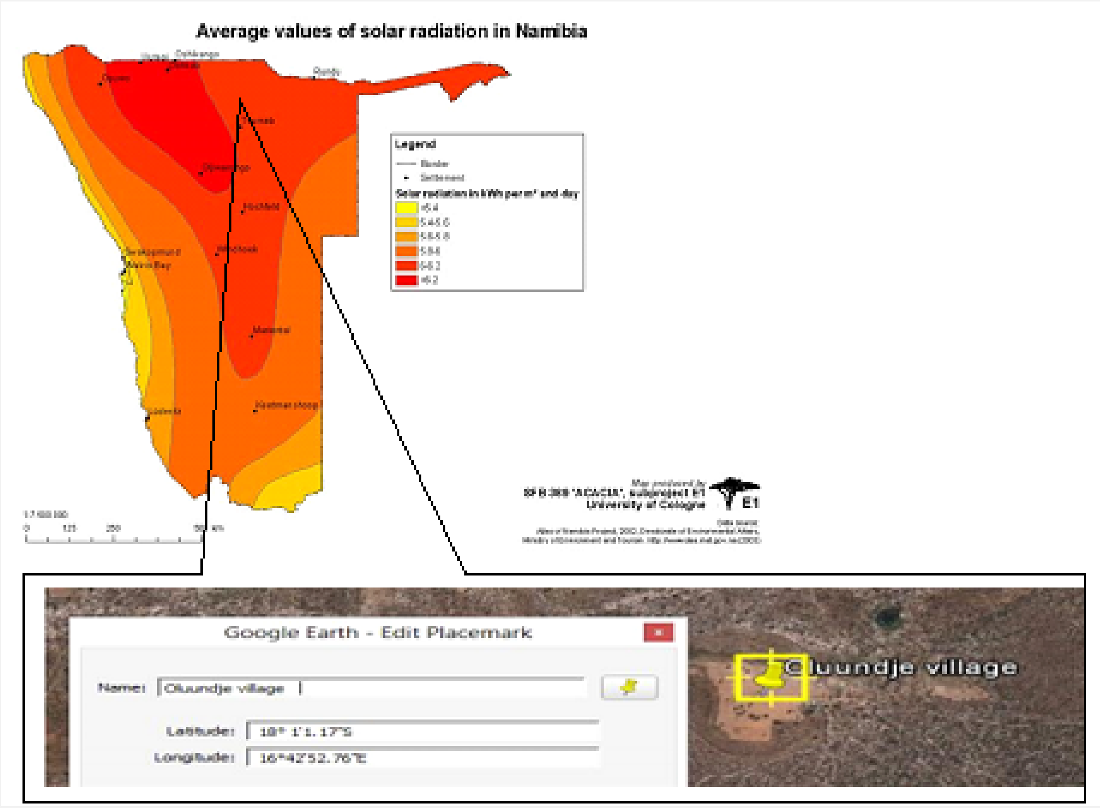


Figure 1: Namibia's Solar Radiation Distribution and Geographical Location of Oluundje Village

3.2.1 Solar Radiation Profile and Load Profile

Figure 2 presents the annual solar resource profile and the daily load profile for Oluundje village.

The solar radiation profile is obtained from the monthly average solar radiation data for the study area provided by NASA. It has been observed that the solar intensity ranges from 4.58 kWh/m^2/d to 7.09 kWh/m^2/d. The daily solar radiation is lowest in winter months and highest in summer months. The daily load profile is obtained from the estimated hour of use for the electrical appliances. There is a base load of 16.16kW. Small peak loads of 89.68kW occur from 7am-8am and from 13pm to 14pm. The daily peak load of Oluundje is 144 kW with the scaled annual average energy consumption of 632 kWh/day.

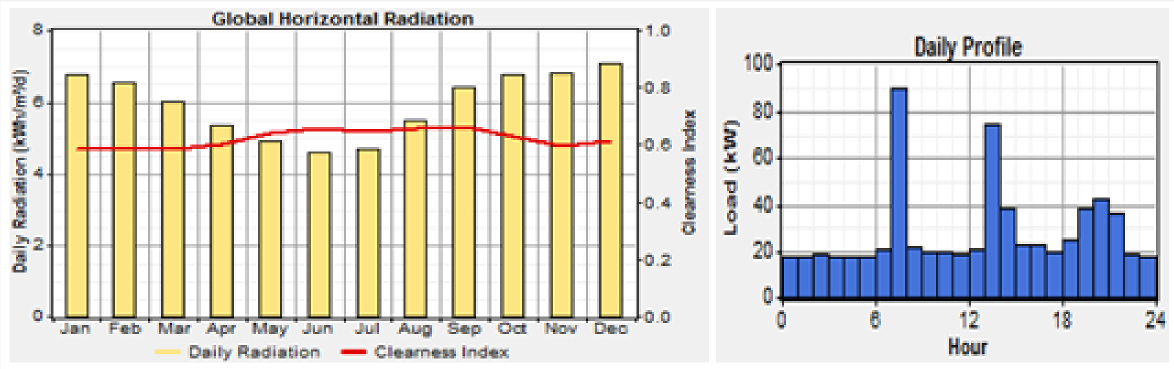


Figure 2: Oluundje Solar radiation and load profiles

3.2.2 Economic Analysis

An annual interest rate of 10% was used, which is common in many developing countries (Kassam, 2010); a project lifetime was taken as 20 years. All calculations were performed at an exchange rate of US$1=N$10.68. Sensitivity analysis assesses the behaviour of the system when certain parameters change their values, such as diesel fuel cost, maximum annual capacity shortage (MAC) and solar radiation. These are the sensitivity variables.

3.2.3 System Equipment Configuration

The input data into the HOMER software include sizes of the components under consideration, acquisition cost, replacement cost, operation cost, maintenance cost and the expected lifetime. Table 7 shows the data used, which were obtained from two Namibian solar energy companies, Solar Age Namibia and Light Systems Namibia (Light Systems Namibia, 2014, Solar Age Namibia, 1989). These companies are approved and registered installers and suppliers of solar energy equipment in Namibia.

3.2.4 System Performance and Sizing

3.2.4.1 PV System

In solar photovoltaic applications, the solar radiation is directly converted into electricity through the use of silicon solar cells which are electrically linked to a base plate to form a power generating unit called a solar panel/array. As an input to the simulation program, the photovoltaic system has to be accurately sized. According to standard practices, the

Table 7: System Components

Component	Size	Capital cost ($)	Replacement cost ($)	O&M Cost ($)	Lifetime (Years)
PV Panels	0-300 kW	$2223/kW	$1710/kW	$10/yr	20
Surrette 4KS25P 4-V deep cycle battery	1900Ah/4 volts	$1450/battery	$1370/battery	$2.00/yr.	10
Inverter	0-160kW	$171600/kW	$15600/kW	$20/year	5
Diesel Generator	50-150 kW	$124.44/kW	$123.33/kW	$0.01/hr.	25000 operating hours.

solar panels are to be sized 10-30% above the load size for the security of supply (Vanek, 2012). In this study, the solar panels are sized to be 20% above load size. A derating factor of 80% and 20 years lifetime was used. If no sun trackers are used, stationary solar panels generate more power when they are placed at an angle equal to the latitude of that site location (Vanek, 2012). The latitude angle of the study area is equal to 18.017°, and hence, the slope angle for the panels was chosen to be 18.017°.

3.2.4.2 Battery Storage

Deep-cycle storage batteries are used to store the energy generated by the PV panels for backup purpose when the total system generation is lower that the load demand. Surrette 4KS25P 4-volt deep cycle battery type was used due to its favorable characteristics designed suitable for remote area application and its favorable price (Girma, 2013). Each battery has a nominal capacity of 1900Ah at 100-hour rate and battery lifetime throughput is 10569kWh.

3.2.4.3 Inverter

An inverter converts Direct Current (DC) from the solar panels to Alternative Current (AC) suitable for supplying power to AC loads. The selection of the suitable inverter for a particular application depends on the waveform requirements of the load and on the efficiency of the inverter (Messenger, 2010). Hybrid renewable energy system requires an inverter with a sinusoidal waveform that has a predictable amplitude and frequency (Messenger, 2010). In this study, a sine wave inverter will be employed. Based on standard practices, the inverter size is to be 20-30% above the peak load to cater for losses experienced during rectification (Vanek, 2012). In this study, the inverter efficiency was assumed to be 90% of all sizes considered.

3.2.4.4 Diesel generator

The diesel generator acts as a backup power supply in hybrid systems. In this study, the diesel generator is designed in such a way that it only gets switched on when the battery is discharged to its minimum allowable level and the solar radiation is very low at that instant. To ensure better performance and improved efficiency, a diesel generator will always operate between 80 and 100% of its power rating (Lal, 2011). In this study, a Perkins diesel generator rated at 150kW was chosen. Diesel fuel price has a significant impact on the running cost of the equipped diesel generator (Kassam, 2010). The prevailing diesel price was US$ 1.26/L and this was taken as the reference price for the diesel fuel in this investigation (Ministry of Mines and Energy, 2014).

4 Results and Discussion

4.1 Model of the PV-Diesel Hybrid System

Figure 3 shows the model of the proposed hybrid system and its components. As indicated, the scaled annual energy consumption and the peak power are 632kWh/day and 144kW, respectively.

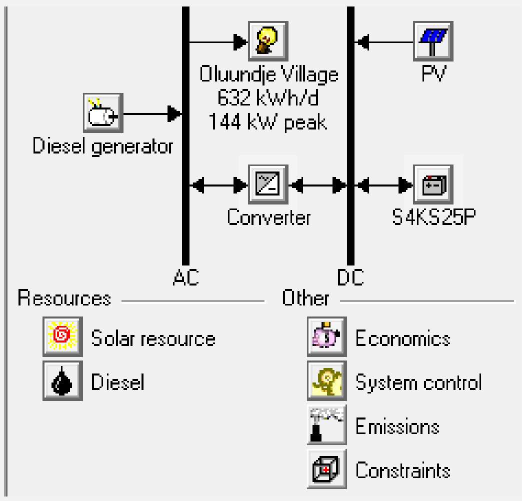


Figure 3: Schematic diagram of Hybrid PV-diesel power system

The main electrical generator in Figure 3 is the PV generator which converts the solar radiation directly into DC electricity that is then fed to the DC bus. The PV panels have priority to supply the load. The access energy is stored in the battery bank to be supplied to the load when there is no or less power generated from the PV system. A decision to operate the diesel generator is taken when the battery is discharged to its depth of discharge level and there is no sufficient energy generated by PV system to supply the load. This is done by the battery charge controller which in HOMER is incorporated in the battery block. The bi-directional converter converts AC power to DC power when required and vice versa.

4.2 Sensitivity Results

In this investigation, solar radiation, diesel fuel price and maximum annual capacity (MAC) shortage were taken as sensitivity variables to take into accounts the effect of varying these variables on the entire system's performance. From the simulations, it is shown that the solar-diesel hybrid system is optimal for the specified range of solar radiation and diesel fuel price. That is, the system is less sensitive to the changes in these two variables.

Table 8 shows the economic performance summary for different MACs. For this study, the 2% MAC was considered because it is associated with the highest renewable fraction and with less operation and maintenance costs.

Table 8: Economic performance summary for different MACS

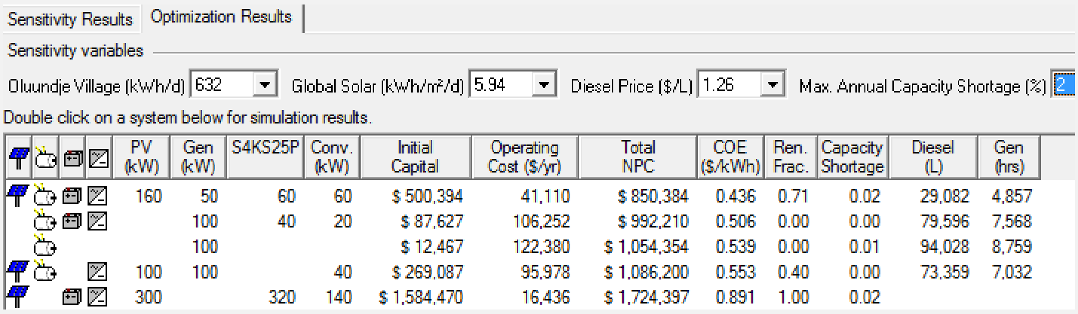
MACS value	0%	2%	3%	5%
NPC ($)	881 732	850 384	787 317	738 170
COE ($/kWh)	0.52	0.436	0.406	0.384
O&M cost ($/yr.)	61 742	41 110	47 553	52 424
Renewable fraction	0.52	0.71	0.6	0.52
Diesel generator's operating hours. (hrs.)	4 331	4 857	5 713	6 349
Fuel consumption (L)	29 082	34 732	39 407	44 937

4.3 Optimization Results

HOMER software simulates every combination of the system configurations in search space and the feasible configurations are then sorted based on the total Net Present Cost (NPC). These configurations are arranged in the descending order from the most cost effective (lowest NPC) to the least cost effective (highest NPC) as shown in Figure 4. The optimal system configuration comprises of 160kW solar array, a 50kW diesel generator, a 60kW inverter and 60 batteries. The Net Present Cost (NPC) of the system is $850 384 and the Cost of Energy (CoE) is $0.436/kWh.

4.4 Electricity Production Analysis

Figure 5 shows the contribution of electrical energy production by various sources in the hybrid system. The PV array generated 71% of the total energy, while the diesel generator contributed the remaining 29%. Therefore, the system's renewable fraction is 71%.



Sensitivity Results | Optimization Results

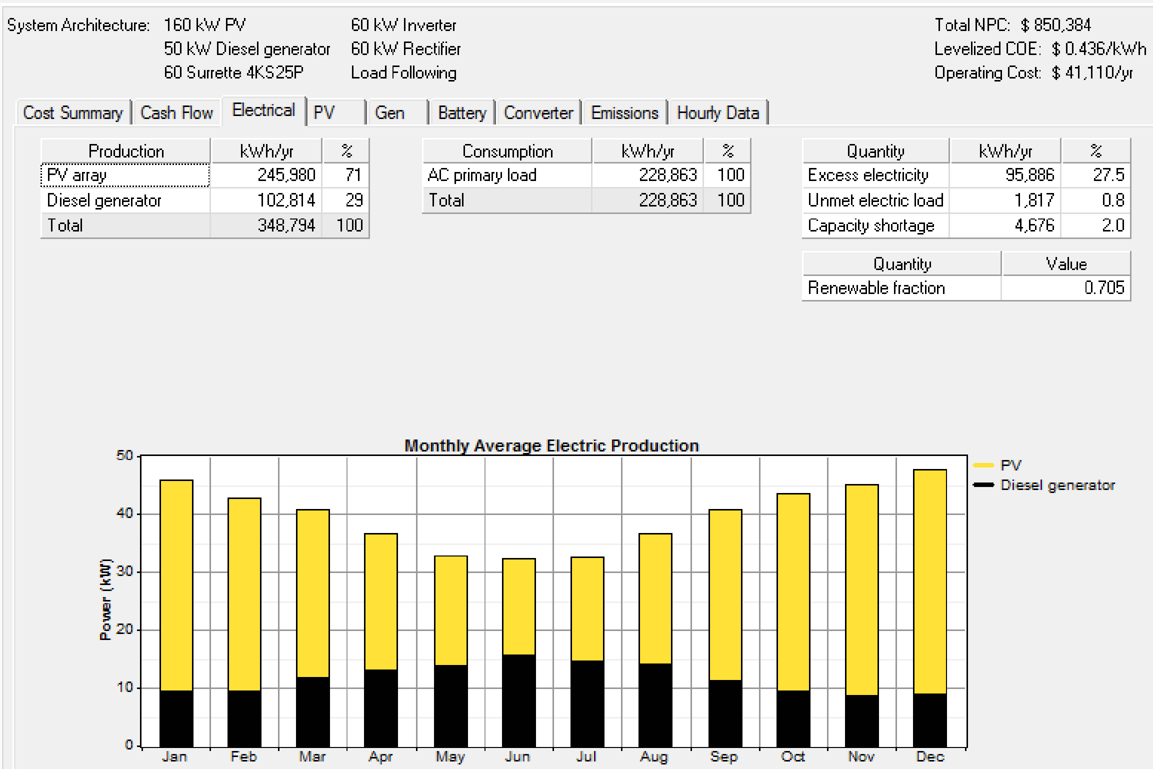
Sensitivity variables

Oluundje Village (kWh/d) 632 | Global Solar (kWh/m²/d) 5.94 | Diesel Price ($/L) 1.26 | Max. Annual Capacity Shortage (%) 2

Double click on a system below for simulation results.

PV (kW)	Gen (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen (hrs)
160	50	60	60	$ 500,394	41,110	$ 850,384	0.436	0.71	0.02	29,082	4,857
	100	40	20	$ 87,627	106,252	$ 992,210	0.506	0.00	0.00	79,596	7,568
	100			$ 12,467	122,380	$ 1,054,354	0.539	0.00	0.01	94,028	8,759
100	100		40	$ 269,087	95,978	$ 1,086,200	0.553	0.40	0.00	73,359	7,032
300		320	140	$ 1,584,470	16,436	$ 1,724,397	0.891	1.00	0.02		

Figure 4: Optimized results by categories



System Architecture: 160 kW PV, 50 kW Diesel generator, 60 Surrette 4KS25P, 60 kW Inverter, 60 kW Rectifier, Load Following

Total NPC: $ 850,384
Levelized COE: $ 0.436/kWh
Operating Cost: $ 41,110/yr

Cost Summary | Cash Flow | Electrical | PV | Gen | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	245,980	71
Diesel generator	102,814	29
Total	348,794	100

Consumption	kWh/yr	%
AC primary load	228,863	100
Total	228,863	100

Quantity	kWh/yr	%
Excess electricity	95,886	27.5
Unmet electric load	1,817	0.8
Capacity shortage	4,676	2.0

Quantity	Value
Renewable fraction	0.705

Figure 5: Contribution of electrical energy production by the sources in the hybrid system

4.5 Economic Comparison of Diesel-Generator-Only System and PV-Diesel Hybrid System

The economic comparison of the two systems is performed based on the cash flow summary obtained from HOMER simulation software. Table 9 shows the cash flow analysis of the two systems.

Table 9: Cash flow summary for both hybrid system and diesel-generator-only system

Hybrid system's cash flow summary						
Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	355 680	0	150	0	0	355 830
Diesel generator	6 234	6 234	414	311 962	-105	324 739
Surrette 4KS25P	87 000	26 191	1 022	0	-4 073	110 140
Converter	51 480	11 204	511	0	-4 638	58 557
Total	500 394	43 629	2 097	311 962	-8 815	849 266
Diesel-generator-only system's cash flow summary						
Diesel generator	12 467	12 467	1 491	1 008 642 (including transportation)	-1 820	1 033 247

From the cash flow summary shown in Table 9, it is shown that, although the capital cost of the hybrid system is high as compared to the one for the diesel-generator-only system, its replacement, maintenance and fuel costs are very low. Whereas for the diesel-generator-only system, the initial capital cost is very low but the replacement, operating and fuel cost are very high. This means that hybrid systems are more cost effective in the long run, unlike diesel-generator-only systems.

4.6 Environmental Impact Analysis

The HOMER software allows an environmental impact analysis to be carried out. This is done by generating results showing the amount in kg/year of Green House Gases (GHG) emitted by the system modeled. In this investigation, the amount of the GHG emitted by both the PV-diesel hybrid system and the diesel generator only system were compared to identify the system that was more environmentally friendly. It is clearly illustrated in Table 10 that the hybrid system significantly reduces the amount of GHG compared to the diesel-generator-only system.

Table 10: GHGs emission and GHGs reduction

GHGs	Diesel gen-only	PV/Diesel hybrid	GHGs reduction
Carbon dioxide (kg/yr.)	247 606	76 582	171 024
Carbon monoxide (kg/yr.)	611	189	422
Unburned hydrocarbons (kg/yr.)	67.70	20.90	46.80
Particulate matter (kg/yr.)	46.10	14.30	31.80
Sulfur dioxide (kg/yr.)	497	154	343
Nitrogen oxides (kg/yr.)	5 454	1 687	3 767
Total (kg/yr.)	254 281.80	78 647.20	175 634.60

5 Conclusion

A large proportion of the Namibian population lives in remote rural areas that are geographically isolated and sparsely populated. Oluundje village is among these villages. With the current power demand outstripping the available supply, the probability of grid extensions to these villages is very low and as a result, they will remain energy-deprived in the future. Therefore, off-grid renewable energy sources, particularly hybrid power generation systems, are proposed as suitable for such remote area application.

In this research investigation, a PV-diesel hybrid system model was designed to provide off-grid electricity access to Oluundje village. HOMER software tool was used to carry out system modelling. Furthermore, a financial optimization, sensitivity and cost analysis of different system configurations were carried out with the main aim of identifying the cost efficient and environmental friendliest configuration well suited for the proposed study area.

The optimal system configuration determined comprises of a 150kW solar array, a 50kW diesel generator, a 60kW inverter and 60 batteries rated 1900Ah. The Net Present Cost (NPC) of the system is $850 384, the Cost of Energy (CoE) is $0.436/kWh with a payback period of 6 years.

Based on cash flow analysis and environmental friendliness comparison results, it has been found that the PV-diesel hybrid system would be a feasible solution for distribution of electric power to remote and distant locations rather than the diesel-generator-only system. This is because; it was shown that using the PV-diesel hybrid system for power supply is more cost effective in a long run and more environmentally friendly.

References

[1] Ajao KR, Oladosu OA, Popoola OT. Using HOMER power optimization software for cost-benefit analysis of hybrid solar power generation relative to utility cost in Nigeria. International Journal of Research and Reviews in Applied Sciences Vol. 7, Issue. 1, (2011)

[2] Bhandari R, Stadler I. Electrification using solar photovoltaic systems in Nepal. Applied Energy Vol.88, No.2, 458-465 (2011).

[3] Daud AK, Ismail MS. Design of isolated hybrid systems minimizing costs and pollutant emissions. Renewable Energy, Vol.44, No. , 215-224 (2012)

[4] Girma Z. Technical and Economic Assessment of solar PV/ Diesel hybrid power system for

Rural School Electrification in Ethiopia. International Journal of Renewable Energy Research Vol. 3, No.3 (2013)

[5] Hrayshat ES. Techno-economic analysis of autonomous hybrid photovoltaic-diesel-battery system. Energy for Sustainable Development Vol. 13, No. 3, 143-150 (2009)

[6] Hungamo A, Namibia 2011 population and housing census preliminary results. Windhoek, (2012)

[7] Kamalapur GD, Udaykumar RY. Rural electrification in India and feasibility of photovoltaic solar home systems. International Journal of Electrical Power & Amp: Energy Systems Vol.33, No.3, 594-599 (2011)

[8] Kassam A. HOMER Software Training Guide for Renewable Energy Base Station Design. (2010)

[9] Khatib T, Mohamed A, Sopian K, Mahmoud M. Optimal sizing of building integrated PV/diesel generator system for zero load rejection for Malaysia. Energy and Buildings Vol. 43, No. 12, 3430-3435 (2011)

[10] Lal DK, Dash BB, Akella AK. Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER for the Study Area. International Journal on Electrical Engineering and Informatics Vol. 3, No.3 (2013)

[11] Light Systems Namibia, 2014. Light Systems Namibia. [Online]. Available: http://www.lsn.com.na/.

[12] Lilienthal P, Flowers L, HOMER: The Hybrid Optimization Model for Electric Renewable, in Proc. Windpower '95, American Wind Energy Association, Washington, DC, pp. 475-480, (27-30 March 1995)

[13] Lilienthal P, Lambert T, Gilmann P, Getting Started guide for HOMER Version 2.1, National Renewable Energy Laboratory, Colorado (April 2005)

[14] Menaldi J L, Estimates and sample sizes, Pearson Education, Inc, (2010)

[15] Ministry of Mines and Energy, 2014. Fuel Prices. GRN Windhoek, Namibia

[16] Nema P, Nema R K, Rangnekar S, A current and future state of art development of hybrid energy system using wind and PV-solar, Renewable and Sustainable Energy reviews, India (2009)

[17] Sen R, Bhattacharyya S C, off-grid electricity generation with renewable energy technologies in India: an application of HOMER, Renewable Energy, India (2014)

[18] Shilamba P, Nampower electricity update, Nampower, Windhoek, and (August 6, 2013)

[19] Sinha A, Chandel S, Review of software tools for hybrid renewable energy systems, Renewable and Sustainable Energy Reviews, India (2014)

[20] Solar Age Namibia, 1989. Solar Age Namibia [Online]. Available: http://www.solarage.com/.

[21] Twaha S, Idris MH, Anwari M, Kairuddin A. Applying grid-connected photovoltaic system as an alternative source of electricity to supplement hydropower instead of using diesel in Uganda. Energy Vol. 37, No. 1, 185-194 (2012)

[22] Vanek FM, Albright LD, Angenent LT. Energy Systems Engineering: Evaluation and Implementation. 2nd edition, Mc Graw-Hill, New York (2012)