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RESEARCH ARTICLE:

Comparative Study of Hybrid Solar Photovoltaic - Diesel Power Supply System

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Abstract

In an environment with unstable power supply, incessant load shedding and inconsistent energy availability remains a major challenge. Hence, there is a need for an urgent alternative source of energy to mitigate this challenge. Over the years, fossil fuel-based energy sources have been considered as an effective solution, however the greenhouse gases emissions from these sources contribute largely to the rise in the depletion of the ozone layer which eventually leads to pollution and global warming. This work contributes to efforts in curbing this menace by reducing the use of diesel generators and focus more on a hybrid renewable energy system. This study, used selected residential buildings as a case study. A photovoltaic system and a diesel generator were incorporated as hybrid energy system, and the data gathered was processed using the HOMER software. The output of the simulation provided two optimal systems (PV-Diesel Generator, Battery coupled with the complete Hybrid system) and (PV- Diesel generator). The optimal and cost-effective system from the analysis is the PV-diesel hybrid system. This consists of a 10kW solar PV, 45kW Diesel generator, a 10kW converter and six 6FM200D batteries. This study provides a synergy of individual subsystems as analyzed in the result to enhanced the reliability of the system.

Keywords: *energy storage; hybrid renewable energy systems; fuel cell; HOMER software*

Introduction

A crucial driver for economic growth and development of any country lies in its energy generation capacity for various applications. Moreover, energy sources facilitate increase in productivity and income as well as fostering of employment creation. Hence, it is imperative to build a better energy supply system for various sectors of the economy, such as industry, transportation, households, and service industries. For this reason, energy will continue to be one of the major facilitators of sustainable economic development. Albeit, while the reliance on fossil fuel energy sources such as gas, coal and oil to meet energy demands is very high, there is a need to keep in mind that they may run out in the nearest future. Furthermore, fossil fuels are major contributors to greenhouse gas (GHG) emissions, which are the primary cause of both air pollution and global warming. Carbon dioxide emissions from fossil fuel-based energy generating systems, such as coal-fired power plants, are predicted to increase by 20% globally above other energy generation methods by 2030 (Ramli *et al*., 2016). Additionally, the growing use of renewable energy combined with the short supply of conventional energy sources has inspired the desire to minimize fossil fuel dependence. Renewable energy technology is gradually proofing to be the future of power generation as it is replicable and eco-friendly (Adebisi *et al*., 2022; Nag and Sarkar, 2018). Recently, the world has witnessed an increase in the use of renewable energy

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resources. This initiative will ensure that about 26.5% of the world's energy requirements are supplied by renewables by 2030.

Renewable energy has been identified as an alternative to traditional energy generation, some of these include solar and wind energy which has been demonstrated to be cost effective and reliable especially in rural area electrification. Renewable energies are from naturally regenerated sources commonly referred to as "clean energy." Although renewable energy is considered a comparable substitute for conventional energy sources, they are intermittent in nature. This necessitated the need for backup with regards to storage and conventional diesel generator. Interestingly, the developed technologies to harvest and save wind and solar energy have advanced to become both less expensive and more creative. Thus, renewables are becoming an increasingly vital part of the energy market, accounting for more than one-eighth of global energy supply (Adebisi *et al*., 2023). Rooftop solar panels and large-scale offshore wind farms are examples of renewable expansion taking place at different scales: from modest residential to massive industrial. Some households rely on rely on renewable energy for heating and lighting, whether within a village or entire metropolis. Hence, with the increasing growth of renewable power consumption, the goal is to develop a hybridized renewable power supply system that offers a smarter, secure, and the capacity to interconnect different regions. Importantly, to ensure the cost of technical and environmental effectiveness of hybridized renewable energy technology, it is essential to compare it to the traditional source of energy such as diesel engine.

In this work a hybrid system which uses Photovoltaic, battery, and generator was examined and compared to diesel generator with regards to cost, technical and environmental effectiveness. Hybrid Optimization Model for Electric Renewable (HOMER) application was utilized for simulation of the system's maximum net present cost (NPC) and cost of energy (COE). The choice of HOMER is due to its allowance for a better blend of RES (Renewable Energy System) options. These options are based on a number of factors, including various energy sources, generation capacity, solar irradiation data, and diesel generator fuel prices. A good design of the hybrid system allows for running costs to be lowered by maximizing the design's usage of different forms of energy. Subsequently, this research tends to establish a framework that will utilize Photovoltaic (PV) -battery-diesel generator components for a long-term efficient hybrid system. Hybrid systems can be used for domestic electrical systems in isolated areas, and to pumping water in places with no access to clean water. This system will use fuel more efficiently, lower maintenance cost, lessen emissions, and employs a techno-economic analysis of a hybrid system. The PV–battery–diesel system is thus a more viable solution than typical standalone diesel generators, as proven by the benefits that it offers economically and environmentally.

Literature Review

Due to breakthroughs in renewable energy technology and rising fuel prices, HRES are becoming attractive in the market for providing energy to isolated locations (Babatunde *et al*., 2020). Most renewable energy resources are based on solar energy (Akinyele *et al*., 2020). Energy systems combining multiple forms of generation increases reliability and ensures energy security especially with the addition of a storage system or backup generator to store excess energy and guarantee supply reliability and security. Hybrid systems can be constructed from a variety of system configurations (Akinyele, 2016; Abdulsalam *et al*., 2023), which include PV-Wind, PV-Fuel cell, PV-Wind –Fuel cell, PV-Wind Battery, and more. Benefits of these aforementioned systems include cheaper energy cost, more dependability, lower maintenance, flexibility, extended equipment life, and an elevated utility potential (Sovacool *et al*., 2022).

The application of HRES has been extensively considered in the literature. For instance, Vaičys, (2020) evaluated PV systems against diesel generator system for 4.7kWh/day average load with a peak load of 520W, using intuitive and numerical techniques. For the intuitive technique, the optimal system comprises of a 1.7kW PV module, six batteries and 1.5kW inverter. The Net Present Cost (NPC) was $8,012 with operation cost and Cost of Energy (COE) of 197$/year and 0.31$/kWh respectively. From the numerical technique and using HOMER, the optimal result is achieved when the system is composed of 1.54kW PV module, five batteries and 1kW inverter. The total NPC for this system was $7,364 with operation cost and cost of energy of 168$/year and 0.22$/kWh respectively. Therefore, the numerical technique gave a more accurate design than intuitive technique. Similarly, (Al-Asadi and Kazem, 2013) designed a hybrid PV/Wind/Battery system in Oman for loads which included street lights, billboards, traffic lights and telephones, for a distance of 880km. For this load, 4500kW PV modules, 20,000 batteries, 5000kW inverter and 100 wind turbines were selected as the optimum system size by HOMER. The NPC and COE of the 7000kW diesel generator system chosen was $503,669,504 and 3.164$/kWh. The hybrid system was therefore chosen to be more technically and economically suited for the load than the diesel generator system.

Zhang *et al.* (2022) proposed a hybrid PV/Diesel/Wind system to generate power for an off-grid village in Comilla. Results showed that for a daily average load of 86kWh and 10kW peak load, a 10kW wind turbine, 10kW PV array, 15kW diesel generator, 32 batteries and six converters provided the best performance in terms of reduction in cost and emissions. An investigation by (Nfah *et al*., 2007) led to the conclusion that a hybrid power system including a 1440Wp solar PV array and a 5kW diesel generator could adequately supply the demand of a typical rural household region. The study was performed by Saheb-Koussa *et al*. (2009) to find a cost-effective solution for supplying power to isolated sites in Algeria using hybrid systems composed of wind, PV, and diesel generators, with a battery backup to store generated energy. According to the findings, the hybrid system was the optimal solution for each location. It also offered improved system performance compared to standalone systems using PV or wind. And depending on renewable energy potential, the cost of electricity was closely linked to system reliability.

Singh *et al*. (2018) developed a control system for a hybrid system composed of PV, DEG, and FC generators, all of which are connected to the electric grid. Researchers looked at the influence of frequency control in the electric grid caused by implementing Variable Speed Control (VSC). Fuel cell systems have a fuel cell generator, electrolyzer, and a hydrogen storage facility built into them. Moreover, the constraints placed on hydrogen volume due to restricted storage space were included. Modeling of photovoltaic has been offered and the study investigated fluctuating solar radiation and temperature over a period of 24 hours. The simulations revealed that, when the load on the network grows, the frequency of operation in the FC system will contribute to stabilizing it with inverse. Operating this feature with a hybrid Wind-PV system is beneficial (Shailendra, 2019). Soe *et al*. (2019) designed an Off-Grid PV-Diesel Hybrid system. The authors found an optimal balance between energy production, consumption, and cost while reducing waste by finding the best possible system component sizes. Data was obtained from weather stations located at an engineering college to collect real solar radiation and wind speed information, as well as information regarding the total electrical demand for a campus (case study) in order to create a solar power project. In determining optimal component sizes, the resulting simulations analyzed peak load, and the loads used for sizing have variable influences on their decisions.

In Nigeria similar works have been done concerning hybrid renewable energy systems. A summary of other related works on size, optimization model, emission reduction output and energy sources are presented in Table 1.

Table 1: Literature survey summary

S/N	AUTHORS	SFT	GC/OG	FAC	ES	ERO
1	(Babayomi *et al.*, 2023)	HOMER	OG	Review	PV	N/A
2	(Adebisi *et al.*, 2023)	HOMER	OG/GC	Generic Framework	PV	N/A
3	(Babatunde *et al.*, 2022)	HOMER	OG	Community	PV/Wind/DG/Batt	CO_2
4	(Yakub *et al.*, 2022)	HOMER	OG	Health Care	PV – Diesel and Wind	N/A
5	(ADEBISI *et al.*, 2022)	HOMER	OG/GC	Community	PV/Wind	N/A
6	(Babatunde *et al.*, 2020)	HOMER	OG	Community	PV/Wind/DG/Batt	CO_2
7	(Sanni *et al.*, 2021)	HOMER	GC	Abattoir	Grid/PV/Biogas/Batt	CO_2
8	(Oladigbolu *et al.*,2021)	HOMER	OG	Community	PV/Wind/DG/Batt	CO_2, CO, SO_2, UHC, PM
9	(Aghenta and Iqbal, 2019)	HOMER Pro, Simulink, BEopt		Residential	PV/DG	N/A
10	(Adesanya and Pearce, 2019)	HOMER	OG	Production, Hospital and Banking Sectors	PV/DG/Batt	CO_2
11	(Oladigbolu *et al.*, 2020)	HOMER	OG	Community	Hydro/PV/Wind/DG/Batt	CO_2
12	(Nosakhale *et al.*, 2019)	HOMER	GC, OG	Community	PV/Wind/Batt/Grid	CO_2, SO_2, NO_2
13	(Muhammad *et al.*, 2017)	HOMER	OG	Educational Institute	PV/Wind/Batt	N/A
14	(Olatomiwa *et al.*, 2014)	HOMER	OG	Health Care	PV/Wind/DG/Batt	CO_2, CO, NO_x, PM, UHC, SO_2
15	(Yimen *et al.*, 2020)	MATLAB	OG	Community	PV/Wind/DG/Batt	CO_2
16	(Olatomiwa *et al.*, 2016)	HOMER	OG	Community	PV/Wind/DG/Batt	CO_2, CO, NOx, PM, UHC, SO_2
17	(Ariyo *et al.*, 2018)	HOMER	OG	Educational Institute	PV/DG/Batt	CO_2
18	(Okundamiya and Ojieabu, 2017)	HOMER	OG	Community	PV/Wind/Batt	CO_2
19	(Esan *et al.*, 2019)	HOMER, MATLAB	GC	Community	PV/DG/Batt	CO_2
20	(Okundamiya, 2020)	HOMER	GC	Educational Institute	PV/FC/Hydrogen	CO_2, O, NOx, PM, UHC, SO_2
21	(Obuah and Alalibo, 2017)	HOMER	OG	Industrial Setting	PV/DG/Batt	CO_2
22	(Bashir *et al.*, 2018)	HOMER	OG	Community	PV/DG/Batt	CO_2
23	(Adesanya and Pearce, 2019)	HOMER Pro	GC	Industrial Outfits	PV/DG	CO_2
24	(Manjor *et al.*, 2021)	PVSYST, Microsoft Excel,	GC	Educational Institute	PV/DG	CO_2
25	(Owolabi *et al.*, 2019)	RETScreen Expert	GC	Community	PV/Utility Grid	CO_2
26	(Dioha and Kumar, 2018)	PVSYST	N/A	Community	PV	N/A
27	(Anayochukwu and Onyeka, 2014)	HOMER	OG	Residential Outfit	PV/DG/Batt	CO_2
28	(Uwaoma *et al.*, 2021)	DigSILENT	GC	Community	PV/Hydro	N/A

Abbreviations:

SFT-Software, **GC**-Grid connected, **OG**-Off Grid, FAC-Facility, **ES**-Energy Sources, **ERO**-Emission Reduction output, **CSP**-Concentrated Solar Power

Methodology

In this work, HOMER software is used to determine the optimal sizing by minimizing cost for hybrid power systems that are matched to specific load demands. This allows for performance evaluation of individual components, various other project details, and establishing the most efficient components. In addition, we determine design alternatives for distant, isolated, and distributed generation (DG) applications by analyzing possibilities for off-grid and grid connected power systems. This tool helps facilitate renewable energy hybrid system design, allowing for a variety of power generators, energy storage, and load alternatives to be integrated into the system. The simulation of off-grid and grid-connected systems with several power sources, including wind, solar, hydro, biomass, and traditional energy generation are can be achieved with HOMER. The solution is also capable of modeling both renewable and conventional power generation techniques. This model can assess the PV-wind-fuel cell system as a separate unit. The schematic diagram in Figure 1 is used to illustrate the integration of the various components used and detailed explanation of each sub-system:

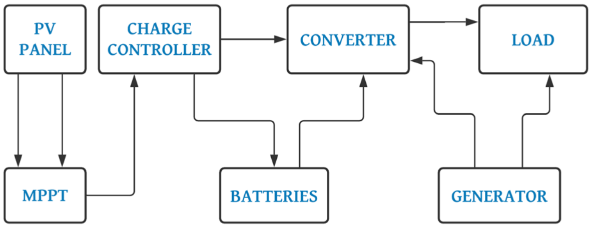


Figure 1: Graphical representation of Hybrid Solar PV- Diesel System

The PV array's DC electricity is converted to AC, before being transmitted to the AC Bus. In the event of insufficient energy production from wind or solar power, the extra power stored in the battery bank is consumed by the load. HOMER provides a framework for evaluating and integrating the numerous technological possibilities and the potential variance in costs and energy resource availability. The overall approach employed in this work is presented in figure 2.

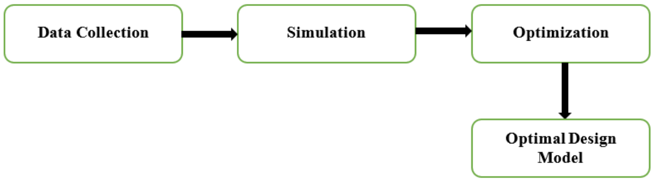


Figure 2: Flow of methodology

The study uses HOMER for simulation activities in this research. HOMER mimics a system's functioning by calculating energy balance for each of the year's 8760 hours. Then it estimates the energy flows to-and-fro from each system component for every hour. Within an hour, it decides how to run the batteries or fuel-powered generators and how to charge or discharge the batteries. The energy balance of the system is calculated and configured based on the study objective and reviewed designs. The cost of installation and operation during implementation is based on the case study including capital replacement, operation and maintenance, fuel, and interest was simulated.

Following the simulation of various system design and comparison, a list of all configurations, organized by net present cost (NPC, which sometimes refers to lifespan cost), is generated. The HOMER then sorts the configurations according to NPC and is used to simulate every possible system configuration. The optimization procedure was also achieved using the sensitivity variable specified by adding them as inputs to examine system stability for a range of value.

The basic system components of a micro grid PV-diesel hybrid system include diesel generators, PV, batteries, and a converter that connects the AC and DC bus. Deciding on which components will be used is a vital stage in getting the most out of PV-diesel hybrid system design. For this scenario, the PV-diesel hybrid system is adequately provided. The expenses of a hybrid system encompass component costs (first and second-hand), fixed costs (maintenance and fuel, for example), and total system costs (salvage revenues or salvage costs). Purchase of necessary components (including labor) was made from inception. Costs include: solar panels, batteries, diesel generators, management units, and accessories needed for installation. The inputs to HOMER are the data fed into the software to enable it perform simulations from which an optimal system can be developed. The system design is shown in Figure 3.

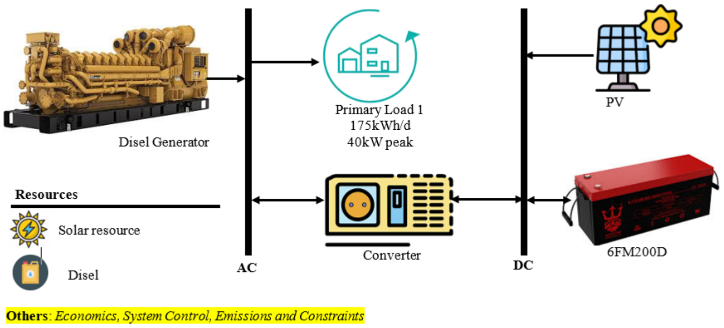


Figure 3: A typical solar diesel hybrid system used in HOMER software

Load profile

The load under consideration for the building with rated appliances as well as the time of use each day is presented in Table 2.

Table 2: Load profile of the residential building

Appliance	Rating (Watts)	Number of Appliances	Total Rating (Watts)	Duration of Use (Hours)	Energy Per Day (Watts-hour)
Fan	60	10	600	8	4800
Air conditioner	1120	3	3360	8	26880
Desktop Computer	160	3	480	4	1920
Laptops	65	5	325	4	1300
Fridge	200	1	200	4	800
Printer	50	1	50	0.75	37.5
Light	20	12	240	8	1920
Security Light	60	2	120	16	1920
Television	50	1	50	8	400
Photocopier	1200	1	1200	0.5	600
	TOTAL		**6625**		**40557.5**

The data in Table 2 was entered into HOMER with corresponding values therefore calculating the average load using equations 1 and 2:

$$Average\ load = \frac{Total\ Demand(Watts)}{Hours} \qquad \text{(eq. 1)}$$

$$Average\ Load = \frac{40557.5}{61.25} = 662.16\ W/h \qquad \text{(eq. 2)}$$

Table 3: Average solar global horizontal irradiance per month

Month	Clearness Index	Monthly Radiation
Jan	0.566	5.33
Feb	0.555	5.30
Mar	0.527	5.19
Apr	0.499	5.05
May	0.476	4.55
Jun	0.405	3.75
Jul	0.394	3.30

Aug	0.389	3.80
Sep	0.396	3.65
Oct	0.456	4.26
Nov	0.526	4.97
Dec	0.568	5.13
Annual Average		4.52

Source: National Aeronautics and Space Administrations (NASA)

the highest demand of load on it is the peak load with the load factor is given by equations 3 and 4 and load profile presented in figure 4:

$$LoadFactor = \frac{AverageLoad}{PeakLoad} \qquad \text{(eq. 3)}$$

$$Load\ Factor = \frac{662.16}{40557.5} = 0.0163 \qquad \text{(eq. 4)}$$

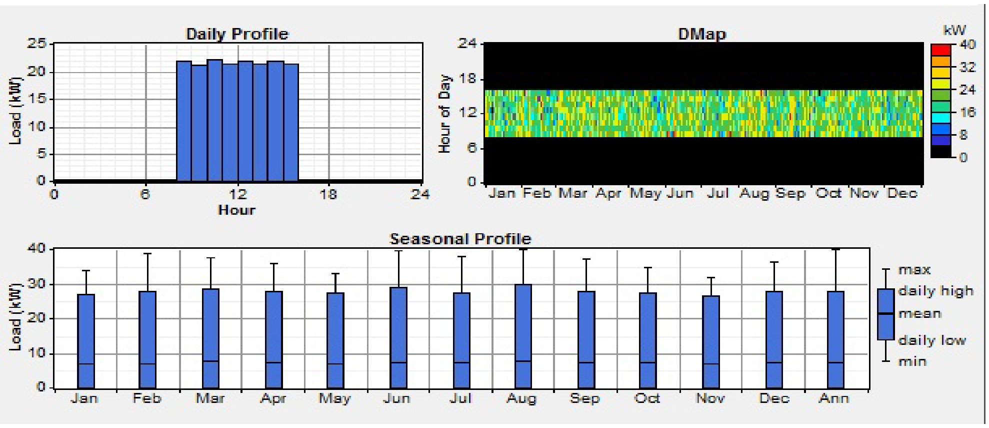


Figure 4: Load profile

Photovoltaic System

The solar PV module, was setup and coupled in series-parallel with the computation of rated power, the PV using equations 5 – 12

$$Total\ Watt\ Hour\ Per\ Day = Average\ Load\ Demand \times 1.3 \qquad \text{(eq. 5)}$$

$$Total\ Watt\ Hour\ Per\ day = 40557.5 \times 1.3 = 52{,}724.75Wh/day \qquad \text{(eq. 6)}$$

Where the value 1.3 takes care of losses in the wiring and battery discharge

$$PV_{size} = \frac{Total\ Watt\ Hour(\frac{kWh}{day})}{Panel\ Generation\ Factor(PGF)} \qquad \text{(eq. 7)}$$

$$PV_{SIZE} = \frac{52{,}724.75}{4.52} = 11{,}664.76W_{Peak} = 11.7kW_{Peak} \qquad \text{(eq. 8)}$$

$$Number\ of\ PV\ Panel = \frac{PV_{Size}}{PV(Watt\ Peak)\ Module\ Chosen\ for\ the\ work} \qquad \text{(eq. 9)}$$

$$No\ of\ PV\ Panel = \frac{11664.76}{110} = 106.04\ Modules \qquad \text{(eq. 10)}$$

Hence, the approximate value is 106 modules of 110-Watt peak (W_P) PV modules were enough to fulfil the objective of this research project

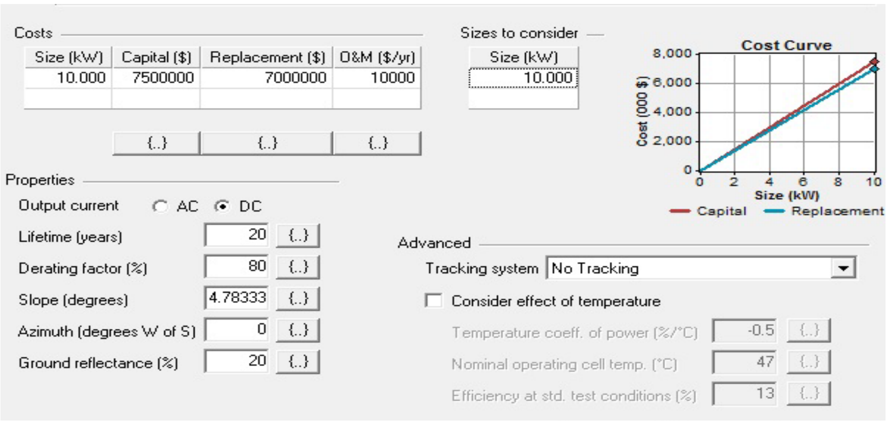
$$P_{PV} = P_{R-PV} \times (G/G_{ref}) \times [1 + K_T(T_c - T_{ref})] \qquad \text{(eq. 11)}$$

$P_{R\text{-}PV}$ is rated using the reference factors and $P_{PV\text{-}out}$ is the power being generated by the Photovoltaic system. The solar radiation (W/m²) is denoted by G while G_{ref} is the value at the reference condition (Gref =1000 W/ m. T_{ref} is the cell temperature at reference conditions (T_{ref}=25°C), K_T is temperature coefficient of the PV panel ($K_T = -3.7 \times 10^{-3}$ (1/°C)) for mono and poly crystalline silicon. The cell temperature $T_{c,}$ is calculated using equation 4.1 such that;

$$T_c = T_{amb} + (0.0256 \times G) \qquad \text{(eq. 12)}$$

Where T_{amb} is the ambient temperature in °C

The cost of a installing a 10kW PV module is $7,500,000 (Figure 5). The replacement cost is $7,000,000. Since the operation and maintenance cost is minimal, HOMER assumes it to be done once a year, which amounts to $10,000/year for each kW installed. This is shown in figure 5.



Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
10.000	7500000	7000000	10000

Sizes to consider

Size (kW)
10.000

Properties

Output current ○ AC ● DC

Lifetime (years) 20

Derating factor (%) 80

Slope (degrees) 4.78333

Azimuth (degrees W of S) 0

Ground reflectance (%) 20

Advanced

Tracking system No Tracking

☐ Consider effect of temperature

Temperature coeff. of power (%/°C) -0.5

Nominal operating cell temp. (°C) 47

Efficiency at std. test conditions (%) 13

Figure 5: PV simulation details

Battery Bank System Calculation

The importance of batteries at different levels of usage cannot be overemphasized however within the context of energy storage, Nickel batteries are now commonly utilized alongside lead-acid batteries Hadjipaschalis et al., (2009). Findings revealed that the round-trip efficiency of a lead-acid battery ranges from 85-90%, a nickel-based battery has an efficiency of 65-83%, and a lithium-based battery has a potential efficiency of 95%. Lead acid batteries, with their inexpensive cost and rather good energy efficiency, have been widely adopted in renewable energy power systems. The battery chosen is a Vision 6FM200D deep cycle type because it is a lead-acid battery designed to be regularly deeply discharged using most of its capacity, whilst ensuring quicker recharge time. The storage capacity of the battery (C_{Wh}) as given by Khatib *et al.* (2011) and calculated using equations 13.

$$C_{Wh} = (E_L \times AD)/ (\eta_V \times \eta_B \times DOD), \qquad \text{(eq. 13)}$$

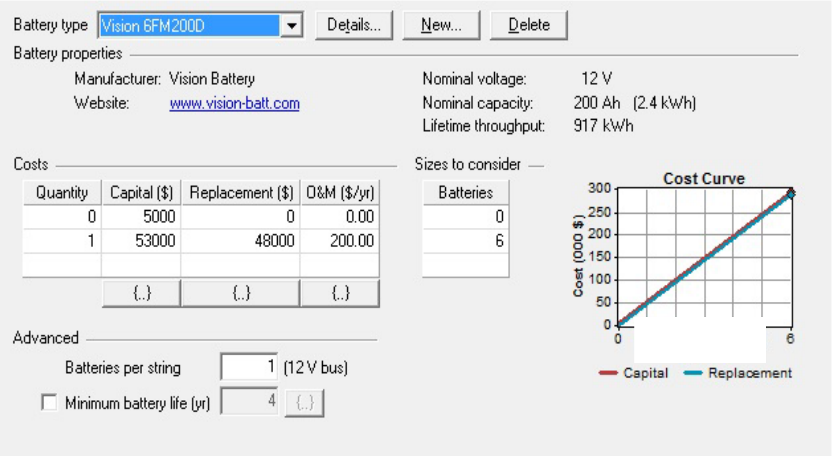
Where DOD is allowable depth of discharge of the battery, AD is number of autonomy days, η_B is battery efficiency, and η_V is the efficiency of the bidirectional inverter. The nominal voltage of one battery is 12 V with nominal capacity if 200 Ah and lifetime throughput 917 kWh. Cost of one battery is $35 with a replacement cost of $30 as recorded in equations 14 and 15.

$$Number\ of\ Batteries = \frac{6627.04}{200} = 33.135 \qquad \text{(eq. 14)}$$

Using 200Ah battery, total numbers of batteries needed are:

$$Number\ of\ Batteries = \frac{6627.04}{200} = 33.135 \qquad \text{(eq. 15)}$$

Therefore, a total of 34 batteries of 200Ah is suitable. In light of the large available solar energy supply, solar power is considered the most promising alternative energy source. Each second, the sun generates energy equal to 3.8 billion megawatts. Around 1.5 kW/m2 of energy is sent as electromagnetic radiation outwards from the atmosphere. Once it is in the atmosphere, a square meter of the earth's surface can be expected to get around 1 kW of solar power, giving it an average of 0.5 kW across all daylight hours as shown in Figure 6.



Battery type: Vision 6FM200D

Battery properties

Manufacturer: Vision Battery
Website: www.vision-batt.com
Nominal voltage: 12 V
Nominal capacity: 200 Ah (2.4 kWh)
Lifetime throughput: 917 kWh

Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
0	5000	0	0.00
1	53000	48000	200.00

Sizes to consider

Batteries
0
6

Advanced

Batteries per string: 1 (12 V bus)
☐ Minimum battery life (yr): 4

Figure 6: Simulation of battery details

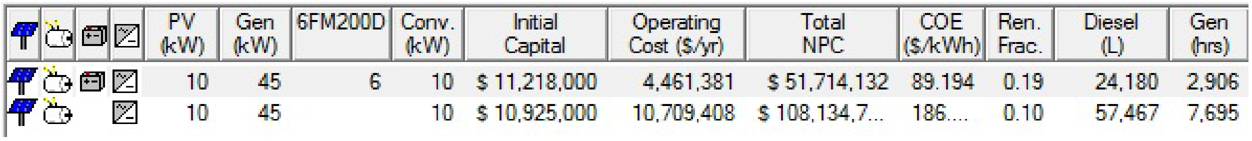
Diesel generator and converter

In general, diesel-engine generators are used to produce power when there is no connection to the electric grid. One big advantage of a combustion engine is its low installed capacity, high shaft efficiency, which is effective for operation that includes frequent start-stop events. These engines utilize the heat from combustion and turn it into work by using the rotating shaft. Electricity is created as the shaft is directly connected to the generator. They run at a frequency set by the supply grid's frequency. In this work, 45 kW diesel engines, together with a Photovoltaic system, are employed. The modeling of 45 kW diesel engines is used along with the Photovoltaic system.

This Converter subsystem converts Direct Current (DC) to Alternative Current (AC) and vice versa, acting as a bridge between the two. The converter also charges batteries even during the minute lose loss of power during inverter operation. A typical converter's conversion efficiency is estimated to be 90% (Woon, Rehbock and Setiawan, 2008). It is a transforming stage linkage between the source power and the output supply.

Discussion of Results

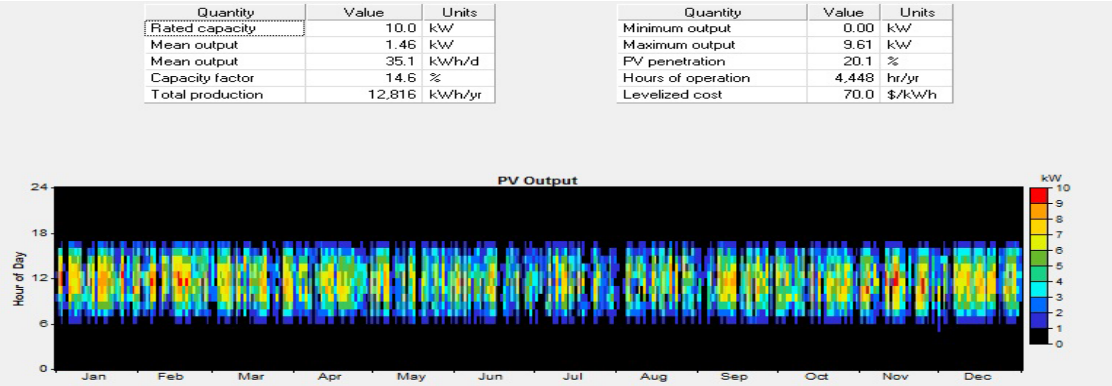
The result of this work is presented using the simulation outputs from HOMER software. The result includes details of the output system size, initial cost, net present cost, operational cost, and cost of energy's operational cost. Additionally, throughout the course of a year, data is collected regarding the usage of generator's fossil fuel, as well as the amount of daily operational time. The simulation graph shows the results of the average monthly electricity production for the energy sources included in the design configuration. As a result, the finance is further investigated and details on electricity output, fuel savings, and CO2 emission reduction are presented in the following sections. Financial results reflect the actual price of the component, the monetary cost incurred purchase of electricity, and the fuel cost incurred by customers linked to the grid and the generator. The results show the tabular and graphical plots of the optimal system combinations. Each of these combinations has details about the cash flow, equipment details and the emissions. For this system, two optimal systems have been chosen by HOMER according to the least total NPC. This is shown in Figure 7.



PV (kW)	Gen (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
10	45	6	10	$ 11,218,000	4,461,381	$ 51,714,132	89.194	0.19	24,180	2,906
10	45		10	$ 10,925,000	10,709,408	$ 108,134,7...	186....	0.10	57,467	7,695

Figure 7: Result showing the optimal system

The optimal system consists of a 10kW solar PV, 45kW Diesel generator, a 10kW converter and six 6FM200D batteries. The outputs of each of these components are further discussed based on the PV Output**.** The total production of the solar PV is given as 12,816kWh/yr. The hours of operation of the PV system is 4,448hours/year. Additional details are presented in figure 8.



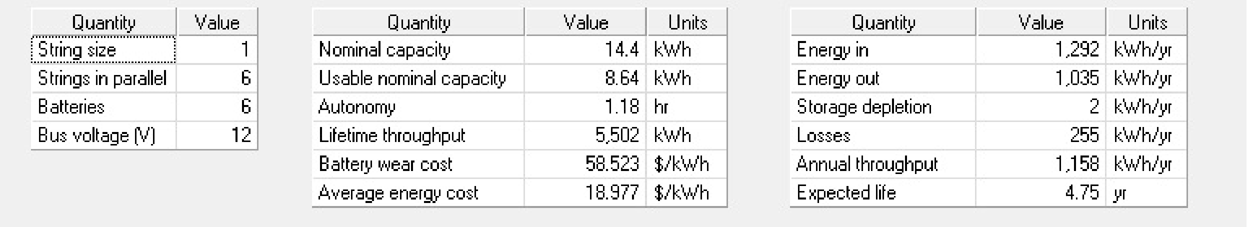
Quantity	Value	Units
Rated capacity	10.0	kW
Mean output	1.46	kW
Mean output	35.1	kWh/d
Capacity factor	14.6	%
Total production	12,816	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	9.61	kW
PV penetration	20.1	%
Hours of operation	4,448	hr/yr
Levelized cost	70.0	$/kWh

Figure 8: Solar PV output

Battery output

The output of the battery is 1,035kWh/yr with a 255kWh/yr loss. Figure 11 shows the details of the battery.



Quantity	Value
String size	1
Strings in parallel	6
Batteries	6
Bus voltage (V)	12

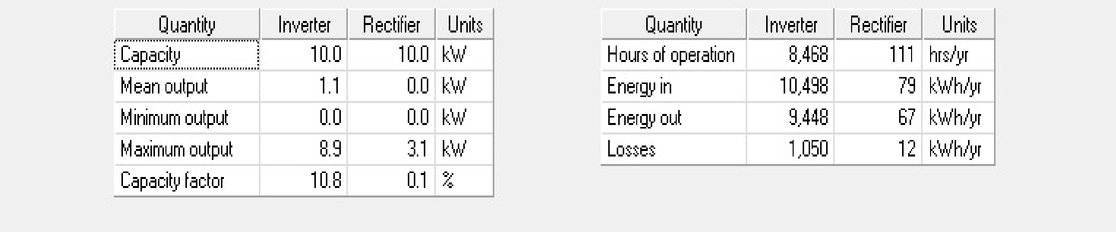
Quantity	Value	Units
Nominal capacity	14.4	kWh
Usable nominal capacity	8.64	kWh
Autonomy	1.18	hr
Lifetime throughput	5,502	kWh
Battery wear cost	58.523	$/kWh
Average energy cost	18.977	$/kWh

Quantity	Value	Units
Energy in	1,292	kWh/yr
Energy out	1,035	kWh/yr
Storage depletion	2	kWh/yr
Losses	255	kWh/yr
Annual throughput	1,158	kWh/yr
Expected life	4.75	yr

Figure 11: Battery output

Converter output

The converter (inverter and rectifier) has a lifetime of 15 years. The inverter and rectifier operated for 8,468 and 111 hours/year respectively. The output of the inverter is 9,448kWh/year, while that of the rectifier is 67kWh/yr as shown in figure 10.



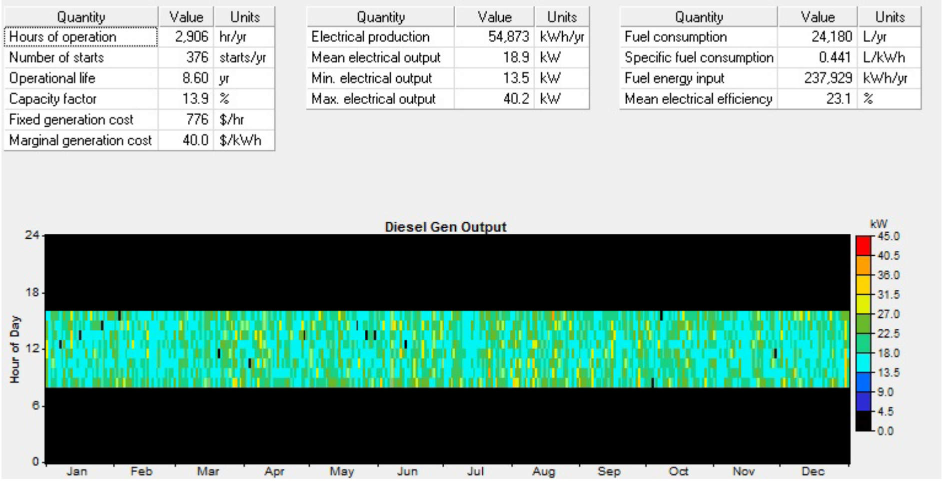
Quantity	Inverter	Rectifier	Units
Capacity	10.0	10.0	kW
Mean output	1.1	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	8.9	3.1	kW
Capacity factor	10.8	0.1	%

Quantity	Inverter	Rectifier	Units
Hours of operation	8,468	111	hrs/yr
Energy in	10,498	79	kWh/yr
Energy out	9,448	67	kWh/yr
Losses	1,050	12	kWh/yr

Figure 10: Converter output

Diesel generator output

The diesel generator which has a lifetime of 25000 hours operates for 2,906hours/year. It produces 54,873kWh/year with a fuel consumption of 24,180l/year as shown in figure 9.



Quantity	Value	Units
Hours of operation	2,906	hr/yr
Number of starts	376	starts/yr
Operational life	8.60	yr
Capacity factor	13.9	%
Fixed generation cost	776	$/hr
Marginal generation cost	40.0	$/kWh

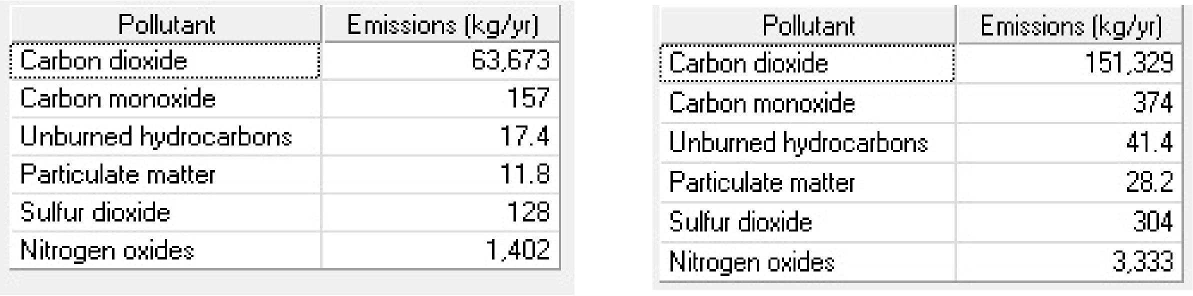
Quantity	Value	Units
Electrical production	54,873	kWh/yr
Mean electrical output	18.9	kW
Min. electrical output	13.5	kW
Max. electrical output	40.2	kW

Quantity	Value	Units
Fuel consumption	24,180	L/yr
Specific fuel consumption	0.441	L/kWh
Fuel energy input	237,929	kWh/yr
Mean electrical efficiency	23.1	%

Figure 9: Diesel generator output

Emissions

The optimal system has 87,656kg/yr less carbon IV oxide than the second system. figures 11a and 11b revealed that the first optimal system produced fewer emissions than the other, which makes it a better option.



Pollutant	Emissions (kg/yr)
Carbon dioxide	63,673
Carbon monoxide	157
Unburned hydrocarbons	17.4
Particulate matter	11.8
Sulfur dioxide	128
Nitrogen oxides	1,402

(a)

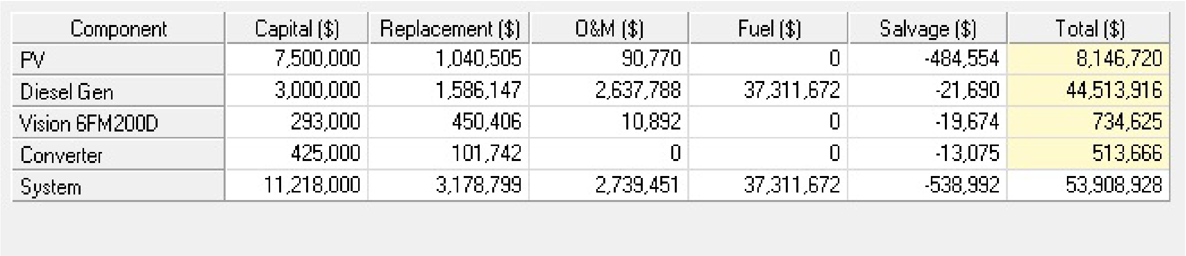
Pollutant	Emissions (kg/yr)
Carbon dioxide	151,329
Carbon monoxide	374
Unburned hydrocarbons	41.4
Particulate matter	28.2
Sulfur dioxide	304
Nitrogen oxides	3,333

(b)

Figure 11: Optimal system 1 and 2

Cost summary

The cost summary comprises a graphical and tabular breakdown of the capital, replacement and Operation and Maintenance (OandM) costs. It also includes the fuel cost (if applicable) and the salvage cost. These are shown in figures 12 and 13 respectively.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	7,500,000	1,040,505	90,770	0	-484,554	8,146,720
Diesel Gen	3,000,000	1,586,147	2,637,788	37,311,672	-21,690	44,513,916
Vision 6FM200D	293,000	450,406	10,892	0	-19,674	734,625
Converter	425,000	101,742	0	0	-13,075	513,666
System	11,218,000	3,178,799	2,739,451	37,311,672	-538,992	53,908,928

Figure 12: Cost summary

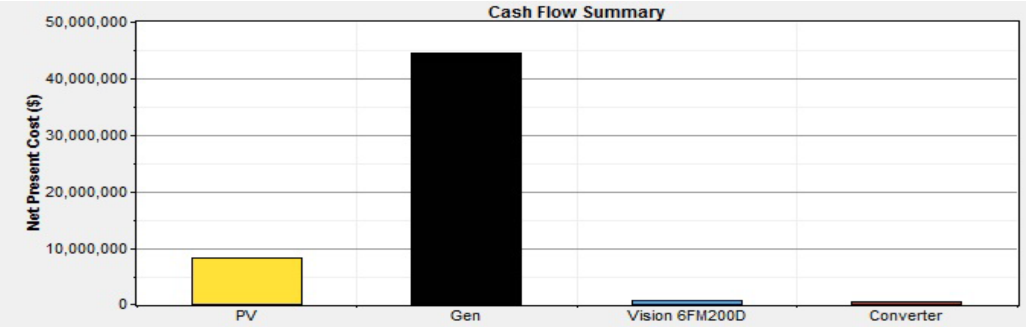


Figure 13: Graphical cost summary

From the simulations and results presented, it is important to note that adequate calculations of data and getting real-time information was fed into the software for analysis. Consequently, the results obtained establishes of importance of the proposed design. From the application of the methodology, the PV/diesel system with battery was able to foot the load of a residential building and immensely lowered the net present cost (NPC) and cost of energy (COE) by 35% as compared to the other system without battery. It was further observed that the optimal system which comprises of PV, diesel and battery reduces diesel operational hours by 4,789 hours. Consequently, this minimizes fuel consumption which brings about significant reduction in pollution as compared to the second system without incorporation of a storage facility. To overcome a low power output during the low insolation days, incorporation of battery which stores the excess charges from the solar panel was used. Therefore, with the incorporation of MPPT technique which tracks peak power from the solar array is used to maximize the produced energy.

Conclusions

This work provides a hybrid PV/Diesel system which was designed using HOMER to determine the optimal system combination to serve the load of a residential building. The results obtained show that the system with a battery unit is optimal and cost effective. This is because excess electricity produced by this system is being stored by the backup battery unit, for future use. Moreover, with the incorporation of the MPPT technology the controller is able to track the maximum output power which meets the required load output. The system is thus, reinforced in efficiency and reliability with fewer emissions. With the use of HOMER, the output of the research is able to select the optimal system size as a function of the net present cost. In the future, we intend to extend this study to capture a larger data collection over a year from a larger household and geographical area for accurate profile load estimation. The result of this work can contribute to the enhancement of similar projects that are looking forward to decrease the diesel generator operation hours and size. Also, the inclusion of other renewable energy sources (biomass, hydro, hydrogen and wind) can be studied and their suitability for electricity production can be compared.

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