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Optimal Sizing of Hybrid Renewable Energy System for Off-Grid Electrification: A Case Study of University of Ibadan Abdusalam Abubakar Post Graduate Hall of Residence

Ifedayo Mofolorunso Opedare*, Taiwo Matthew Adekoya**‡, Adedayo Emmanuel Longe***

*Centre for Petroleum, Energy Economics and Law (CPEEL), University of Ibadan, Nigeria.
**Centre for Petroleum, Energy Economics and Law (CPEEL), University of Ibadan, Nigeria.
***Centre for Petroleum, Energy Economics and Law (CPEEL), University of Ibadan, Nigeria.
(ifedayoopedare@yahoo.com, adekoyatm@gmail.com, longeemmanuel28@gmail.com)

‡ Corresponding Author; Taiwo Matthew Adekoya,

adekoyatm@gmail.com

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Abstract- The main objective of this study is to design a Hybrid Renewable Energy System (HRES) to meet the energy demand of a major Post Graduate Student residential hostel. The specific objectives are to estimate the energy demand, perform economic and technical analysis of various combination of renewable energy technologies that can meet the estimated energy demand and to select the appropriate and optimum hybrid system for the hall of residence. Quantitative analysis was used to determine the energy demand of the hall of residence while the solar resource information was obtained from the NASA Surface Meteorology. The Hybrid Optimization Model for Electric Renewables (HOMER) software was used for analysis. The components of the system considered were solar photovoltaic (PV), diesel generator, batteries and inverter. The optimised hybrid system obtained was also compared to a system in which a diesel generator serves as the sole source of electricity supply. Economic analysis using the total net present cost and levelized cost of enegy was employed to determine the optimized hybrid combination. Environmental considerations were also made based on the amount of Carbon dioxide emitted per year. Results indicates that electricity generation through a hybrid system made up of 1000kW PV, 110 kVA generator, 11791 kWh Surrette S6CS25P battery arranged in parallel strings and a 220 kW Inverter had the lowest total net present cost, lowest cost of energy with a low emission. Hence, Hybrid Renewable Energy Systems (HRES) should be employed in the production of electricity due to its ability to reduce environmental degradation while ensuring a low total net present cost and a low cost of energy.

Keywords: Hybrid renewable energy system, renewable energy, HOMER, off-grid electrification.

1. Introduction

The various sources of energy can be grouped into two, namely non-renewable energy sources and renewable energy sources [1]. A non-renewable energy source comes from a finite stock while a renewable energy source can be replaced/replenished naturally [2]. Four major sources of non-renewable energy are crude oil, natural gas, coal and uranium [3]. The major source of renewable energy is solar energy [4]. Biomass, wind and hydropower which are other sources of renewable energy are secondary sources of solar energy – biomass products can be linked to the process of photosynthesis, wind results from heating of the planet by the sun, and the sun drives the evapotranspiration cycle which allows generation of power by water [5]. Other non-solar renewable energy sources are geothermal energy and tidal energy.

The availability of renewable energy is intermittent in nature; hence it needs to be complemented [6]. As a result, a hybrid system consisting of two or more energy sources are usually designed [7]. This kind of system helps to complement the drawbacks of individual sources of energy [8] and it is stable, reliable and efficient [9], eco-friendly and profitable for remote locations [10]. The design goals of an hybrid system have been highlighted to be minimal cost of producing power; reduced emision; reduced total cycle life cost; increased reliability; and if connected to the grid, minimal purchase of power from the grid [6].

One of the world's most critical development challenge is addressing the lack of access, by billions of people, to reliable and affordable energy services. Improving access to affordable and sustainable energy services is prominent and absolutely central to the broader developmental efforts aimed to reduce poverty, improve education, health, gender equality and environmental sustainability [11].

In Nigeria, one of the problems facing the power sector is its inability to easily diversify electricity generation. Although the country is blessed with many energy sources such as solar, biomass, nuclear, gas, crude oil, hydro, biofuel among others, the problem has been which is the most efficient and least costly to adopt. Efforts to generate electricity have been linked to the use of associated gas through various Independent Power Plants (IPP) projects. Such projects include Kaduna power plant, Azura power station (IPP), Calabar Power Station (IPP), Egbema Power Station (NIPP), Ihovbor Power Station (NIPP), Omoku II Power Station (NIPP), Omotosho II Power Station (NIPP), Olorunsogo II Power Station (NIPP), Alaoji Power Station (NIPP), Sapele Power Station, Geregu II Power Station (NIPP), Aba Power Station (IPP), Rivers IPP, Trans-Amadi Power Station (IPP), Omoku Power Station (IPP), AES barge (IPP), Ibom Power Station (IPP), Afam VI Power Station (IPP), Kwale Okpai Power Station (IPP), Papalanto (Olorunsogo) Power Station, Omotosho I Power Station, Geregu I Power Station, Afam I-IV, & V power station, Transcorp-Ughelli Power Station, Egbin Thermal Power Station [12]. Despite the installed capacity of these stations, the Nigerian power sector is still deficient in terms of meeting the increasing demand for power. As a result, various firms, homes and industries have resorted to generate power independently through the use of generators. These generators use only fossil fuels which have negative effects on the environment and have high operational and maintenance costs. Hence, the need to study other systems of generating power independently. The use of hybrid renewable energy system for independent power generation is considered in this paper.

The main objective of this study is to design a Hybrid Renewable Energy System (HRES) to meet the energy demand of a major Post Graduate Student residential hostel in the University of Ibadan which is Nigeria's premier university. The energy demand of the Post-Graduate Hall of Residence will be estimated. Then an economic and technical analysis of meeting the energy demand from three scenarios (solar only, diesel only and a hybris of solar and diesel) are considered. From the techno-economic analysis carried out, the appropriate and optimum hybrid system would be selected.

This study is organized in five sections. This first section has introduced the study. The second section is the literature review. Section three discusses the methodology used while results are discussed in the fourth section. The last section gives a conclusion.

2. Literature Review

Various sources of hybrid renewable systems have been proposed. Wind-PV hybrid system with a battery [13], wind-PV hybrid system in a micro grid [14], wind-pumped hydro storage backed up by a generator [15], PV-hydro-wind hybrid system [16], battery supported PV-wind-hydro hybrid [17] and PV-wind-diesel hybrid system [18] have been proposed and investigated.

Analysis have also been done for different locations. Three scenarios (diesel only, diesel/PV and diesel/PV/battery) were considered for supplying electricity to a remote area in Cambodia [19]. PV/Wind/battery system [20] and PV/Wind/diesel [21] have been designed for different areas in Pakistan while PV/diesel/batttery system was designed for a village in Eastern Nigeria [22]. A hybrid power system was modelled and designed for a house in Benin City, Nigeria [23] while a wind/diesel/battery hybrid system was discovered to be the most economical combination for residential electric power supply in Iran [24]. A technical and financial analysis for sustainably generating electricty from solar, biomass and wind for 10 houses in Morocco has been performed [25] while a hybrid renewable power system has been designed for sustainable electricity in Benin, Nigeria [26].

Furthermore, some works have considered on-grid and off-grid power analysis. For example, the economic feasibility of a grid connected hybrid power system [27] and feasibility study of an off-grid hybrid system [28] have been done. A techno-economic analysis for a hybrid power system for off grid communities [29] and an off grid residence has been done [30]. Also, a grid connected hybrid system composed of wind, solar and hydrogen has been performed [31]. In addition, a grid integrated inverter to improve power quality of a HRES has also been designed and modelled [32].

In brief, different works have focused on different objectives. Some works focused only on designing a hybrid system to generate a certain amount of power, some were focused on comparison between different hybrid systems, some focused on designing different hybrid systems to deliver a specific amount of power while others focused on making optimal choice between different hybrid configurations.

Adding to the body of knowledge for off-grid power generation, this paper aims to design a hybrid off-grid power system for a post graduate hall of residence in the University of Ibadan, Ibadan, Oyo State, Nigeria.

3. Methodology

3.1. Study Area and Data Collection

The hall of residence surveyed in this study is Abdusalam Abubakar Post-Graduate Hall, University of Ibadan (UI) which is located at latitude of 7.444306° N (7°26'39.5"N) and longitude of 3.8995° E (3°53'58.2"E). The hall of residence's primary source of power supply is the Ibadan Electricity Distribution Company IBEDC.

Data was collected from the hall under study through on-site analysis and oral interviews of students residing in the hall, workers and the management staffs.

3.2. The Hybrid System

The proposed hybrid energy system would be made up of solar PV and a diesel generator. The primary source of electricity would be the solar PV with an inverter backed up by batteries. The diesel generator would be used as backup and in emergency situations. The main components for the system are PV panels, batteries, diesel generator and an inverter. The photovoltaic (PV) panels convert electromagnetic radiation from the sun into direct current (DC). The direct current produced by the PV panels is converted to alternating current (AC) by the inverter. The batteries would store excess electricity produced. The diesel generator is important in case of extra load or when there is a black-out and the battery bank is not sufficient to carry the load extra load [33]. The hybrid system was modelled in HOMER for an off-grid scenario using DC/AC Coupled hybrid configuration.

3.3. Solar Resource Assessment

For assessing the option of using solar power, we have considered the solar resources in our simulation. Data on the monthly averages of daily radiation and clearness index are given in Table 1. The solar resource information used for selected case study at 7°26'39.5" N latitude and 3°53'58.2" E longitude was taken from NASA Surface Meteorology. The clearness index is a measure of the fraction of the solar radiation that is transmitted through the atmosphere to the earth's surface. The annual average solar radiation is found to be 4.29 kWh/m^2/d and the average clearness index is found to be 0.429.

Table 1. Solar Radiation and Clearance Index

Month	Clearance Index	Daily Radiation (kWh/m^2/d)
January	0.563	5.183
February	0.481	4.719
March	0.488	5.043
April	0.476	4.979
May	0.466	4.779
June	0.428	4.300
July	0.394	3.980
August	0.351	3.616
September	0.434	4.477
October	0.515	5.105
November	0.536	4.992
December	0.563	5.057
Average	0.429	4.29

3.4. HOMER Simulation, Optimization and Sensitivity Analysis

HOMER simulates the operation of a specified system by performing energy balance calculation which is based on the system configuration specified by a designer. The simulation is based on cost of installation, cost of replacement, cost of operation and cost of maintenance.

Once simulation is carried out. HOMER displaces a list of configurations for the hybrid renewable energy system based on the project's levelized cost of energy (COE) and the project's net present value (NPV) of installation and operating costs throughout its lifetime. The resulting hybrid configuration with the least LCOE (Levelized Cost of Energy) or the least total NPC (Net Present Cost) is considered as the optimum hybrid system.

The total net present cost (NPC) of the system is the difference between the present values of all costs over the project lifetime and the present values of all revenue earned over project's lifetime. In order to find the LCOE, the total NPC of the project must be converted to series of equal annual cash flows which is known as total annualized cost calculated by equation (1)

$$Total\ annualized\ cost\ \left(\frac{\$}{year}\right) = Total\ NPC * CRF \qquad (1)$$

Where:
CRF = Capital Recovery Factor

Levelized Cost of Energy (LCOE) is the cost per kWh of electrical energy, such that the total NPC of the useful energy generated throughout the whole lifetime of the hybrid project is equal to the total NPC of the project. The calculation of LCOE of the electricity generated by an off-grid hybrid system is done as shown below in the equation (2).

$$LCOE = \frac{Total\ Annualized\ Cost(US\$/yr)}{Annual\ load\ served\ (\frac{kWh}{yr})} \qquad (2)$$

HOMER software will be used to carry out sensitivity analysis for each configuration considered. The sensitivity variables to be considered in the study are the greenhouse gases such as carbon dioxide, carbon monoxide, unburned hydrocarbon, particulate matter, sulfur dioxide and nitrogen oxides.

3.5. Load Profile

The load profile for different types of electrical appliances and machines, such as bulbs, televisions, radios, standing and ceiling fans, air conditioning units, refrigerators, pumping machines etc., used in the hall is graphed in Fig. 1.

The daily and hourly noise inputs help to add randomness to the load data to make it more realistic. Fig. 2 shows how this noise will affect the average load profile. From fig. 2, the designed hybrid system will be for an average of load of 2512 kWh/d, peak load of 227 kW at 10% random variability.

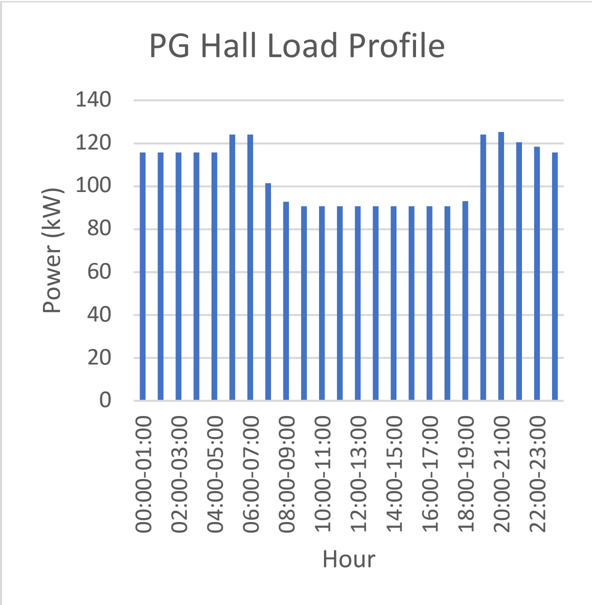


Fig. 1. Load Profile of Abdusalam Abubakar PG Hall

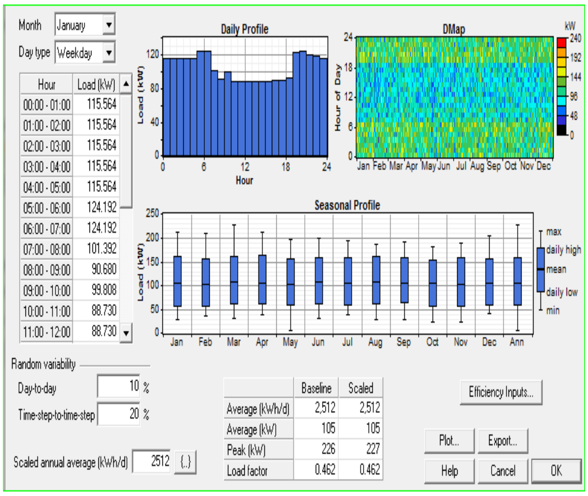


Fig. 2. Load Profile from HOMER Software

4. Results and Discussion

4.1. The Hybrid System Analysis

The proposed hybrid system to be designed is shown in Fig. 3. It consists of a primary load of 2512 kWh/d with a peak load of 227 kW at 10% random variability, PV system, diesel generator, battery and a converter for alternating current (AC) electrical loads. The HOMER software will determine the best combination for the hybrid system.

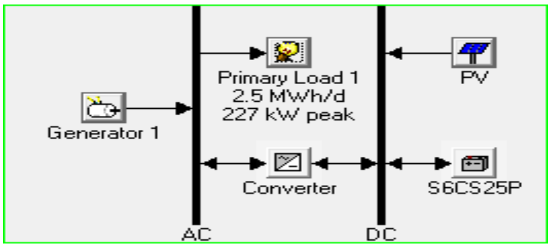


Fig. 3. PV-Diesel hybrid system

4.2. Optimal Sizing Analysis

Table 2 summarizes the configuration of the diesel generator, PV and hybrid renewable energy system. The summary of the economic result shows that the annual cost of energy of a 275 kVA (220 kW) diesel generator system is $265,479 with an operating cost of $263,979/year and net capital cost of $6,636,975. However, the optimal size of components for the solar PV system sizes are 1500 kW PV, 11791 kWh ESS (battery) and 240 kW converter (inverter) having an annual cost of energy of $194,911, operating cost of $84,447/year and net capital costs of $4,872,768. Furthermore, the hybrid renewable energy system had the optimal components size to be 1000 kW of PV, 5271 kWh ESS, 220 kW converter and 110 kVA (88 kW) diesel generator with annual cost of energy of $159,741, operating cost of $104,883/year and net capital costs of $3,993,533.

Table 2. Results of optimal configuration

Costs and Parameters	Unit	Diesel gen case	Solar PV case	HRES case
Economic results				
COE	$/kWh	0.290	0.215	0.175
Annual COE	$/yr.	265,479	194,911	159,741
Annual energy savings	$/yr.	-	70,568	105,738
Annual operating cost	$/yr.	263,979	84,447	104,883
Net capital cost	$	6,636,975	4,872,768	3,993,533
Sizing results				
PV	kW	-	1,500	1,000
ESS	kWh	-	11,791	5,271
Converter	kW	-	240	220
Diesel Generator	kVA	275	-	110

4.3. Optimized System Analysis

The optimal hybrid system is the one which can supply electricity needs at the lowest price or in other words, the system which is having the lowest total net present value while supplying the electricity at the required level of availability.

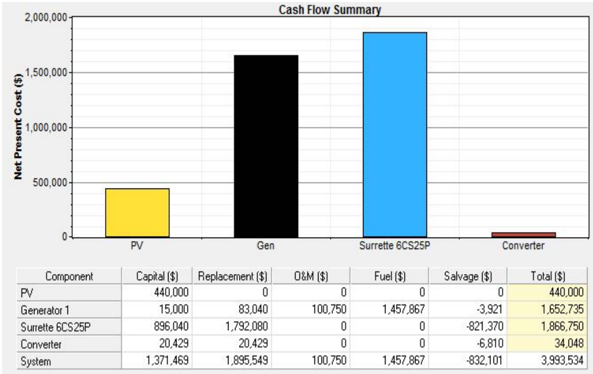
For the off-grid electrification of Abdusalam Abubakar PG Hall, various combinations of hybrid systems have been obtained from the HOMER optimization simulation. The HOMER software arranged the output from the most effective in terms of cost to the least. The optimal system configuration for this case study is 1000kW PV, 110kVA generator, 5271 kWh Surrette S6CS25P battery arranged in parallel strings and a 220 kW Inverter. The total net present cost (total NPC), and cost of energy (COE) for this optimal hybrid system are $3,993,533 and $0.175/kWh respectively. The cost breakdown and cash flow projected is shown in Fig. 4 and Fig. 5 respectively.

The energy obtained from the hybrid system is shown in Table 3. The total energy served by the PV array is 1,252,227 kWh/yr. which is 81% of the total energy served. The remaining 19% is served by the diesel generator which is 288,695 kW/yr.

The system produces an excess electricity capacity of 456,449 kWh/yr. which cannot be used to serve a load or charge the batteries as shown in Fig. 6.

Table 3. Energy analysis results

Value	Unit	Diesel gen case	Solar PV case	HRES case
Diesel Generator				
Production	kWh/yr.	923,004	-	288,695
Capacity factor	%	47.9	-	37.5
PV				
Production	kWh/yr.	-	1,878,341	1,252,227
Capacity factor	%	-	14.3	14.3
ESS				
Operation life	yr.		12	12
Annual throughput	kWh/yr.		675,514	486,005
Excess Electricity	kWh/yr.	6,127	721,604	456,449
	%	0.7	38.4	29.6



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	440,000	0	0	0	0	440,000
Generator 1	15,000	83,040	100,750	1,457,867	-3,921	1,652,735
Surrette 6CS25P	896,040	1,792,080	0	0	-821,370	1,866,750
Converter	20,429	20,429	0	0	-6,810	34,048
System	1,371,469	1,895,549	100,750	1,457,867	-832,101	3,993,534

Fig. 4. Cost breakdown of the optimized hybrid system

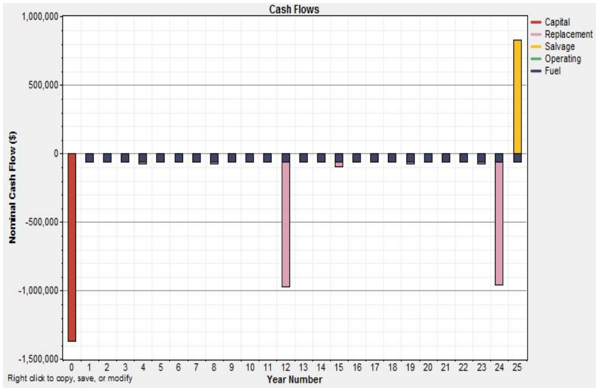
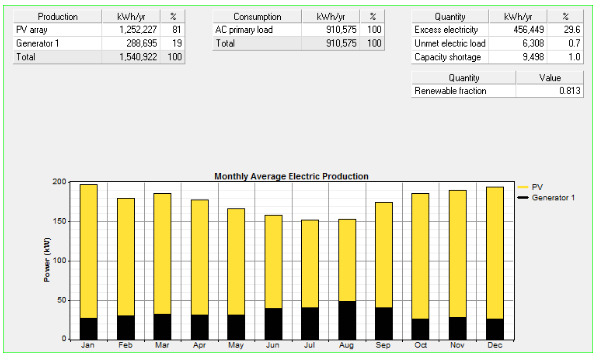


Fig. 5. Cash flow of optimized hybrid system



Production	kWh/yr	%
PV array	1,252,227	81
Generator 1	288,695	19
Total	1,540,922	100

Consumption	kWh/yr	%
AC primary load	910,575	100
Total	910,575	100

Quantity	kWh/yr	%
Excess electricity	456,449	29.6
Unmet electric load	6,308	0.7
Capacity shortage	9,498	1.0

Quantity	Value
Renewable fraction	0.813

Fig. 6. Energy Obtained from the Optimized Hybrid System

Another system which can be considered for the off-grid electricity supply is a situation in which the solar PV is used as the sole supply of electricity. This proposed designed is shown in Fig. 7.

The optimal system configuration for this case study is 1500kW PV, 11791 kWh Surrette S6CS25P battery arranged in parallel strings and a 240 kW Converter. The total net present cost (total NPC), and cost of energy (COE) for this optimal hybrid system are $4,872,768 and $0.215/kWh respectively as shown in Table 2. The costs breakdown and cash flow for the generator system are shown in Fig. 8 and Fig. 9.

The system produces an excess electricity capacity of 721,604 kWh/yr. which cannot be used to serve a load or charge the batteries as shown in Fig. 10.

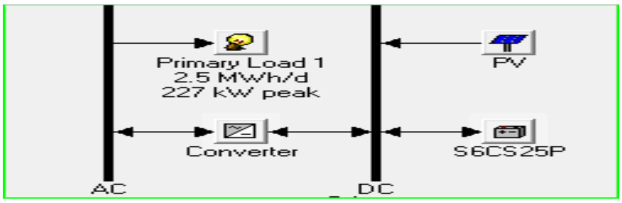


Fig. 7. PV System

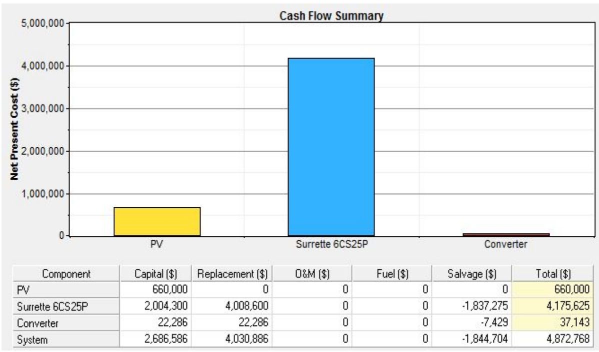


Fig. 8. Cost breakdown of the solar PV system

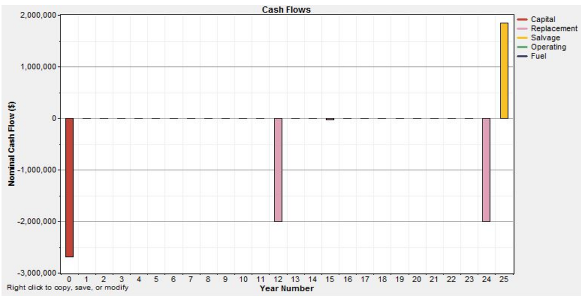


Fig. 9. Cash flow of the solar PV system

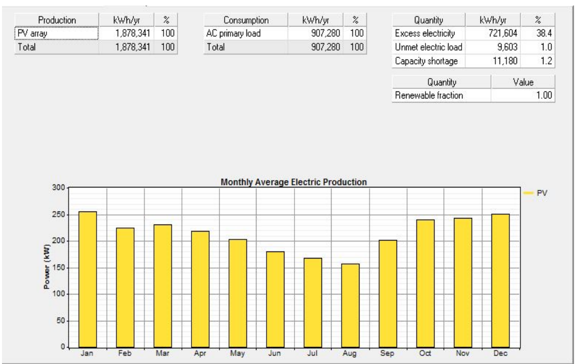


Fig. 10. Energy Obtained from the Optimized PV Stand-alone System

Another option which can be considered for the off-grid electricity supply is a situation in which the diesel generator is used as the sole supply of electricity. This proposed designed is shown in Fig. 11.

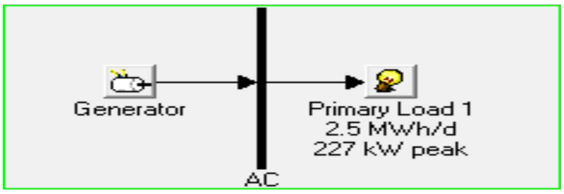


Fig. 11. Generator System

The optimised generator system is a diesel generator of 275 kVA (220 kW). The total net present cost obtained from the use of the genertor is $6,636,975 with a minimun cost of energy of 0.290$/kWh, depicted in table 2. These values are higher when compared to $3,993,533 and $0.175/kWh obtained for the hybrid system respectively. The costs breakdown and cash flow for the generator system are shown in Fig. 12 and Fig. 13. An excess electricity capacity of 6,127 kWh/yr. is produced (Fig. 14).

Comparing Fig. 4 and Fig. 12, it can be observed that the fuel cost is higher in the generator system when comparied to the optimised hybrid system. Similarly, in Table 2, operating cost is higher in the generator system than the hybrid system. In constrast, the capital cost and salvage value of the optimised hybrid system are higher when compared to the generator system.

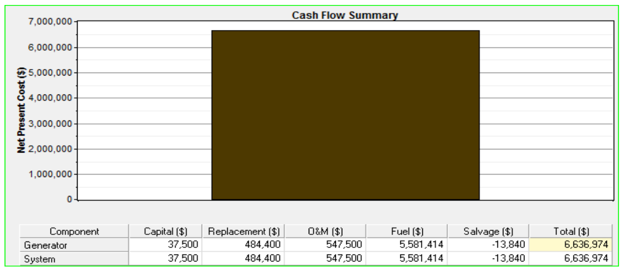


Fig. 12. Cost breakdown of the generator system

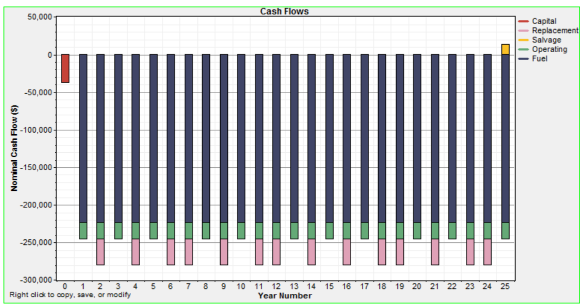


Fig. 13. Cash flow of the generator system

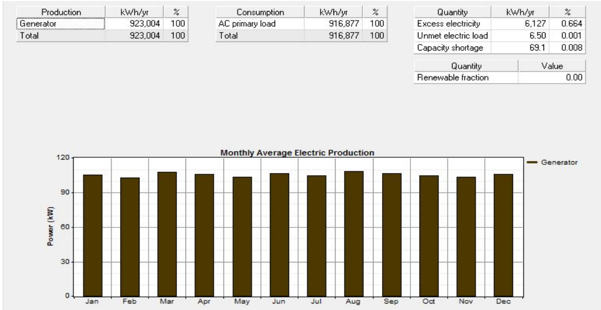


Fig. 14. Energy Obtained from the Optimized Generator System

4.4. Sensitivity Analysis Based on Green House Gases (GHG)

To compare the effect of each system on the environment, the derived levels of carbon dioxide (CO_2) emission are compared in Table 4. The total emission of the diesel generator case is 1,013,635 kg/yr. of CO_2, which reduces to 264,762 kg/yr. of CO_2 for the hybrid system case - a reduction of 74%. From all the pollutant figures reported, the generator system had higher values hence more negative impact on the environment.

Table 4. Emission levels of system

Pollutant	Unit	Diesel gen case	Solar PV case	HRES case
Carbon dioxide	kg/yr.	1,013,635	-	264,762
Carbon monoxide	kg/yr.	2,502	-	654
Unburned hydrocarbon	kg/yr.	277	-	72.4
Particulate matter	kg/yr.	189	-	49.3
Sulfur dioxide	kg/yr.	2,036	-	532
Nitrogen oxides	kg/yr.	22,326	-	5,831

5. Conclusion

This paper aimed to design an off-grid hybrid power system solution from the best combination of hybrid renewable energy technologies for a Hall of Residence. The Hybrid Optimization Model for Electric Renewables (HOMER) software was used for analysis. The components of the system considered were solar photovoltaic (PV), diesel generator, batteries and inverter. The optimised hybrid system obtained was also compared to a system in which a diesel generator serves as the sole source of electricity supply.

Economic analysis using the total net present cost and levelized cost of enegy was employed to determine the optimized hybrid combination. This led to a choice of a hybrid system made up of 1000kW PV, 110 kVA generator, 11791 kWh Surrette S6CS25P battery arranged in parallel strings and a 220 kW Inverter due to the lowest total net present cost (total NPC) of $3,993,553 and the lowest cost of energy (COE) of $0.175/kWh. In contrast, the optimized generator system had a total net present cost of $6,636,975 and a minimun cost of energy of 0.290$/kWh. Analysis also showed that the generator system will have a higher negative impact on the environment. Hence, in terms of economic and environmental considerations, the PV-Diesel hybrid system is preferred to the generator system.

Succinctly put, Hybrid Renewable Energy Systems (HRES) should be employed in the production of energy in general and electricity in particular. This is due to its ability to reduce environmental degradation while ensuring a low total net present cost and a low cost of energy.

For a future work, the RETScreen Clean Energy Management software can be used for analysis [34].

References

[1] S. C. Bhattacharyya, Energy Economics: Concepts, Issues, Markets and Governance, London: Springer, 2011.

[2] M. Hassan, "Power Generation Methods, Tehniques and Economical Strategy," International Technical Sciences Journal, pp. 43-61, 2014.

[3] EIA, "Nonenewable Energy Explained," 8 August 2018. [Online]. Available: https://www.eia.gov/energyexplained/?page=nonrenewable_home. [Accessed August 2018].

[4] TREIA, "Definition of Renewable Energy," 2015. [Online]. Available: http://www.treia.org/renewable-energy-defined..

[5] D. Timmons, J. M. Harris and B. Roach, The Econoics of Renewable Energy, Medford, Massachusetts: Global Development And Environment Institute, 2014.

[6] B. Bhandari, S. R. Poudel, K. T. Lee and S. H. Ahn, "Mathematical Modeling of Hybrid Renewable Energy System: A Review on Small Hydro-Solar-Wind Power Generation," International Journal of Precision Engineering and Manufacturing- Green Technology, vol. 1, pp. 157-173, 2014.

[7] M. Dali, J. Belhadj and X. Roboam, "Hybrid solar–Wind System with Battery Storage Operating in Grid-Connected and Standalone Mode: Control and Energy Management – Experimental Investigation," Energy, vol. 35, pp. 2587-2595, 2010.

[8] M. Kane, "Small Hybrid Solar Power System," Energy, vol. 28, pp. 1427-1443, 2003.

[9] H. Nabipour-Afrouzi, S. H. Wen Yii, J. Ahmad and M. Tabassum, "Comprehensive Review on Appropriate Sizing and Optimization Technique of Hybrid PV-Wind System," in 2018 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Kota Kinabalu, 2018.

[10] P. Ganguly, A. Kalam and A. Zayegh, "Design a Control Mechanism for the Power Management of a Standalone Renewable Energy System," in International Conference on Power Electronics, Control and Automation (ICPECA), New Delhi, India, 2019.

[11] NAOC, "Access to Energy Initiatives," 2018. [Online]. Available: https://www.eni.com/en_NG/sustainability/community/social-investments/access-to-energy/access-to-energy.shtml. [Accessed 3 October 2018].

[12] InfoGuide Nigeria, "38 power stations in Nigeria, Locations and their Capacities," 2017. [Online]. Available: https://infoguidenigeria.com/power-stations-nigeria/. [Accessed 3 October 2018].

[13] S. Hashimoto, T. Yachi and T. Tani, "New Stand-Alone Hybrid Power System with Wind Turbine Generator and Photovoltaic Modules for a Small-Scale Radio Base Station," IEEJ Transactions on Power and Energy, vol. 11, pp. 1014-1046, 2005.

[14] A. M. Sharaf and M. A. H. El-Sayed, "A Novel Hybrid Integrated Wind-PV Micro Co-Generation Energy Scheme for Village Electricity," Proc. of IEEE International Electric Machines and Drives Conference (IEMDC '09),, 2009.

[15] G. C. Bakos, "Feasibility Study of a Hybrid Wind/Hydro Power System for Low-Cost Electricity Production," Applied Energy, vol. 72, pp. 599-608, 2002.

[16] G. Bekele and G. Tadesse, "Feasibility Study of Small Hydro/PV/Wind Hybrid System for Off-Grid Rural Electrification in Ethiopia," Applied Energy, vol. 97, pp. 5-15, 2012.

[17] J. Ram Prabhakar and K. Ragavan, "Power Management Based Current Control Technique for Photovoltaic-Battery Assisted Wind Hydro Hybrid System," International Journal of Emerging Electric Power Systems, vol. 14, pp. 351-362, 2013.

[18] D. Saheb-Koussa, M. Haddadi and M. Belhamel, "Economic and Technical Study of a Hybrid System (wind-photovoltaic-diesel) for Rural Electrification in Algeria," Applied Energy, vol. 86, pp. 1024-1030, 2009.

[19] C. Lao and S. Chungpaibulpatana, "Techno-Economic Analysis of Hybrid Systemfor Rural Electrification in Cambodia," Energy Procedia, pp. 524-529, 2017.

[20] E. A. Al-Ammar, H. U. R. Habib, K. M. Kotb, S. Wang, W. Ko, M. F. Elmorshedy and A. Wasqar, "Residential Community Load Management Based on Optimal Design of Standalone HRES With Model Predictive Control," IEEE Access, vol. 8, pp. 12542-12572, 2020.

[21] S. Rehman, H. U. R. Habib, S. Wang, M. S. Buker, L. M. Alhems and H. Z. Al Garni, "Optimal Design and Model Predictive Control of Standalone HRES: A Real Case Study for Residential Demand Side Management," IEEE Access, vol. 8, pp. 29767-29814, 2020.

[22] C. Ndukwe, T. Iqbal, X. Liang and J. Khan, "Optimal Sizing and Analysis of a Small Hybrid Power System for Umuokpo Amumara in Eastern Nigeria," International Journal of Photoenergy, p. 8 pages, 2019.

[23] L. Aghenta and M. T. Iqbal, "Design and Dynamic Modelling of a Hybrid Power System for a House in Nigeria," International Journal of Photoenergy, p. 13 pages, 2019.

[24] F. Fazelpour, S. Farahi and N. Soltani, "Techno-Economic Analysis of a Hybrid Power System for a Residential Building in Zabol, Iran," IEEE, 2016.

[25] H. El-houari, A. Allouhi, S. Rehman, M. S. Buker, T. Kousksou, A. Jamil and B. El Amrani, "Feasibility evaluation of a hybrid renewable power generation system for sustainable electricity supply in a Moroccan remote site," Journal of Cleaner Production, vol. 227, pp. 1-12, 2020.

[26] T. Odou, R. Bhandari and R. Adamou, "Hybrid off-grid renewable power system for sustainable rural electrification in Benin," Renewable Energy, vol. 145, pp. 1266-1279, 2020.

[27] M. Nurunnabi and N. K. Roy, "Grid Connected Hybrid Power System Deign Using HOMER," IEEE, 2015.

[28] R. Debnath, N. Soren, S. Bhakta, R. K. Karsh and A. K. Roy, "Feasibility study of an off-grid hybrid renewable energy system," in TENCON 2017 - 2017 IEEE Region 10 Conference, Penang, 2017.

[29] O. M. Babatunde, M. U. Emezirinwune and H. Denwigwel , "Hybrid Power System for Off-grid Communities:Techno-Economic and Energy Mix Analysis," IEEE, 2017.

[30] B. P. P. Tchintchui and A. K. Raji, "Techno-economic analysis of a renewable energy solution for an off-grid residence," in International Conference on the Domestic Use of Energy (DUE), Wellington, South Africa, 2019.

[31] G. Lei, H. Song and D. Rodriguez, "Power generation cost minimization of the grid-connected hybrid renewable energy system through optimal sizing using the modified seagull optimization technique," Energy Reports, pp. 1-12, 2020.

[32] B. S. Goud, R. Rekha, M. R. L. Jyostna, S. Sarala, B. L. Rao and C. R. Reddy, "Energy Management and Power Quality Improvement in HRES Grid-Connected System," in 2020 FORTEI-International Conference on Electrical Engineering (FORTEI-ICEE), Bandung, Indonesia, 2020.

[33] L. Olatomiwa, S. Mekhilef, A. S. N. Huda and K. Sanusi, "Techno-economic analysis of hybrid PV–diesel–battery and PV–wind–diesel–battery power systems for mobile BTS: the way forward for rural development," Energy Science and Engineering, pp. 271-285, 2015.

[34] M. I. Abid, M. S. Khalid, M. Kamran, M. A. Rasheed, M. F. Masood and T. Murtaza, "Design and Optimization of the Micro-Hydro Power System for Remote Areas of Pakistan," International Journal of Smart Grid, vol. 4, no. 3, pp. 125-138, 2020.

APPENDIX I

Energy Audit

Electrical Appliance(s) and their Power Rating

S/N	Electrical Appliance	Number in Use	Power Rating (W)	Total Power (W)	Power (KW)
1	CLF Bulb	1058	13	13754	13.754
2	Fluorescent Tube	352	32	11264	11.264
3	Incandescent Bulb	80	100	8000	8
4	400W High Pressure Sodium Light	24	400	9600	9.6
5	Ceiling Fan	313	70	21910	21.91
6	Standing Fan	2	65	130	0.13
7	Laptop	842	60	50520	50.52
8	Mobile Phones	862	5	4310	4.31
9	Air Conditioning (A/C) Unit	5	1240	6200	6.2
10	Television (TV)	6	120	720	0.72
11	Decoder	6	25	150	0.15
12	Refrigerator	1	180	180	0.18
13	Deep Freezer	8	200	1600	1.6
14	Desktop PC	1	100	100	0.1
15	Printer	2	300	600	0.6
16	Photocopy Machine	4	500	2000	2
17	Pumping Machine	3	1100	3300	3.3
18	Clipper	1	10	10	0.01

Detailed Daily Consumption for Abdusalam Abubakar Post Graduate Hall

Hour	Bulbs	Fans	Computer	Mobile Phone	Air Conditioning	TV Set	Pumping Machine	Refrigerator	Printing Machine	Clipper	Total Load (KW)
12–1 AM	33.104	20.37	50.4	4.225	4.96	0.725		1.78			111.564
1 - 2 AM	33.104	20.37	50.4	4.225	4.96	0.725		1.78			115.564
2 - 3 AM	33.104	20.37	50.4	4.225	4.96	0.725		1.78			115.564
3 - 4 AM	33.104	20.37	50.4	4.225	4.96	0.725		1.78			115.564
4 - 5 AM	33.104	20.37	50.4	4.225	4.96	0.725		1.78			115.564
5 - 6 AM	38.432	20.37	50.4	4.225	4.96	0.725	3.3	1.78			124.192
6 - 7 AM	38.432	20.37	50.4	4.225	4.96	0.725	3.3	1.78			124.192
7 - 8 AM	15.632	20.37	50.4	4.225	4.96	0.725	3.3	1.78			101.392
8 - 9 AM	4.16	22.04	50.62	4.31	6.2	0.87		1.78	2.6	0.1	92.68
9–10 AM	2.288	22.04	50.62	4.31	6.2	0.87		1.78	2.6	0.1	90.808
10-11 AM	2.21	22.04	50.62	4.31	6.2	0.87		1.78	2.6	0.1	90.73
11-12 PM	2.21	22.04	50.62	4.31	6.2	0.87		1.78	2.6	0.1	90.73
12 - 1 PM	2.132	22.04	50.62	4.31	6.2	0.87		1.78	2.6	0.1	90.652
1 - 2 PM	2.132	22.04	50.62	4.31	6.2	0.87		1.78	2.6	0.1	90.652
2 - 3 PM	2.132	22.04	50.62	4.31	6.2	0.87		1.78	2.6	0.1	90.652

APPENDIX II Contd.

Detailed Daily Consumption for Abdusalam Abubakar Post Graduate Hall

Hour	Bulbs	Fans	Computer	Mobile Phone	Air Conditioning	TV Set	Pumping Machine	Refrigerator	Printing Machine	Clipper	Total Load (KW)
3 - 4 PM	2.132	22.04	50.62	4.31	6.2	0.87		1.78	2.6	0.1	90.652
4 - 5 PM	2.028	21.765	50.52	4.285	4.96	0.725	3.3	1.78	1.3	0.1	90.763
5 - 6 PM	2.028	21.765	50.52	4.285	4.96	0.725	3.3	1.78	1.3	0.1	90.763
6 - 7 PM	4.42	21.765	50.52	4.285	4.96	0.725	3.3	1.78	1.3	0.1	93.155
7 - 8 PM	38.718	21.765	50.52	4.285	4.96	0.725		1.78	1.3	0.1	124.153
8 - 9 PM	39.784	21.765	50.52	4.285	4.96	0.725		1.78	1.3	0.1	125.219
9-10 PM	37.424	20.93	50.4	4.285	4.96	0.725		1.78			120.444
10-11 PM	36.002	20.37	50.4	4.285	4.96	0.725		1.78			118.462
11-12 PM	33.182	20.37	50.4	4.285	4.96	0.725		1.78			115.642

APPENDIX III

Cash flow for Hybrid System

Year	0	1	2	3	4	5	6	7	8
Capital	-1,371,469	0	0	0	0	0	0	0	0
Replacement	0	0	0	0	-13,840	0	0	0	-13,840
Salvage	0	0	0	0	0	0	0	0	0
Operating	0	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030
Fuel	0	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315
Total	-1,371,469	-62,345	-62,345	-62,345	-76,185	-62,345	-62,345	-62,345	-76,185

Year	9	10	11	12	13	14	15	16	17
Capital	0	0	0	0	0	0	0	0	0
Replacement	0	0	0	-909,880	0	0	-34,269	0	0
Salvage	0	0	0	0	0	0	0	0	0
Operating	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030
Fuel	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315
Total	-62,345	-62,345	-62,345	-972,225	-62,345	-62,345	-96,613	-62,345	-62,345

Year	18	19	20	21	22	23	24	25	Total
Capital	0	0	0	0	0	0	0	0	-1,371,469
Replacement	0	-13,840	0	0	0	-13,840	-896,040	0	-1,895,549
Salvage	0	0	0	0	0	0	0	832,101	832,101
Operating	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030	-4,030	-100,750
Fuel	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315	-58,315	-1,457,867
Total	-62,345	-76,185	-62,345	-62,345	-62,345	-76,185	-958,385	769,756	**-3,993,534**

APPENDIX IV

Cash Flow for Stand-alone PV

Year	0	1	2	3	4	5	6	7	8
Capital	-2,686,586	0	0	0	0	0	0	0	0
Replacement	0	0	0	0	0	0	0	0	0
Salvage	0	0	0	0	0	0	0	0	0
Operating	0	0	0	0	0	0	0	0	0
Fuel	0	0	0	0	0	0	0	0	0
Total	-2,686,586	0	0	0	0	0	0	0	0

Year	9	10	11	12	13	14	15	16	17
Capital	0	0	0	0	0	0	0	0	0
Replacement	0	0	0	-2,004,300	0	0	-22,286	0	0
Salvage	0	0	0	0	0	0	0	0	0
Operating	0	0	0	0	0	0	0	0	0
Fuel	0	0	0	0	0	0	0	0	0
Total	0	0	0	-2,004,300	0	0	-22,286	0	0

Year	18	19	20	21	22	23	24	25	Total
Capital	0	0	0	0	0	0	0	0	-2,686,586
Replacement	0	0	0	0	0	0	-2,004,300	0	-4,030,886
Salvage	0	0	0	0	0	0	0	1,844,704	1,844,704
Operating	0	0	0	0	0	0	0	0	0
Fuel	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	-2,004,300	1,844,704	**-4,872,768**

APPENDIX V

Cash flow for Generator

Year	0	1	2	3	4	5	6	7	8
Capital	-37,500	0	0	0	0	0	0	0	0
Replacement	0	0	-34,600	0	-34,600	0	-34,600	-34,600	0
Salvage	0	0	0	0	0	0	0	0	0
Operating	0	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900
Fuel	0	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257
Total	-37,500	-245,157	-279,757	-245,157	-279,757	-245,157	-279,757	-279,757	-245,157

Year	9	10	11	12	13	14	15	16	17
Capital	0	0	0	0	0	0	0	0	0
Replacement	-34,600	0	-34,600	-34,600	0	-34,600	0	-34,600	0
Salvage	0	0	0	0	0	0	0	0	0
Operating	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900
Fuel	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257
Total	-279,757	-245,157	-279,757	-279,757	-245,157	-279,757	-245,157	-279,757	-245,157

Year	18	19	20	21	22	23	24	25	Total
Capital	0	0	0	0	0	0	0	0	-37,500
Replacement	-34,600	-34,600	0	-34,600	0	-34,600	-34,600	0	-484,400
Salvage	0	0	0	0	0	0	0	13,840	13,840
Operating	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900	-21,900	-547,500
Fuel	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257	-223,257	-5,581,414
Total	-279,757	-279,757	-245,157	-279,757	-245,157	-279,757	-279,757	-231,317	**-6,636,974**