RESEARCH

Simulation and Optimization of Photovoltaic/ Diesel Hybrid Power Generation Systems for Health Service Facilities in Rural Environments

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ABSTRACT Hybrid photovoltaic (PV)/diesel power systems can be used to upgrade power generation systems in medical clinics to improve the delivery of local health services. This study presents the design of hybrid (PV/diesel) power systems for medical facilities in the Agbani district (Nkanu-West) in Eastern Nigeria with a daily load of 19 kWh d^{-1}. Solar resources for the design of the system were obtained from the NASA Surface Meteorology and solar energy website at a location of 6° 00' N latitude and 7° 00' E longitude, with annual average solar radiation of 4.95 kWh m^{-2} d^{-1}. The design is based on theoretical model of the power stations using Hybrid Optimization Model for Electric Renewables (HOMER) software. The model was designed to provide an optimal system configuration based on hour-by-hour data for energy availability and demands. Energy source, energy storage and their applicability in terms of performance are discussed. From the simulation results, it is shown that the designed hybrid PV/diesel system reduces the operational cost and quantity of air pollutants from a diesel-only system. Details of the comparisons are presented.

KEYWORDS Hybrid system, power consumption, power supply, health clinic, HOMER.

Introduction

Electricity is an increasingly essential resource in remote health care facilities. Recent improvements in the distribution of vaccines and other cold chain dependant supplies, as well as the global push to deliver antiretroviral drugs and services to HIV-positive patients worldwide, introduce new demands for electricity in sites with little or no access to reliable electrical power. Refrigerators and electronic diagnostic tools are part of the standard of care in many rural clinics throughout the world. In rural health clinics, electric lighting provides public security, allows facilities to remain open in the evenings and supports limited surgical procedures (e.g. suturing). If a clinic is without lights, patients arriving at night must wait until morning to receive care. Beyond lighting, electricity is used to power an array of appliances (such as vaccine refrigerators and other medical supplies), and other specialized equipment (centrifuge, hematology mixer, microscope, incubator, and hand-

Table 1 Health facility's energy needs.

S/no	Power Consumption	Power (Watts)	Qty	Load (watt x qt)	Hours/day	On-Time (Time in Use)
1	Vaccine Refrigerator/Freezer	60	1	60	24	(0.00hr – 23.00hr)
2	Small Refrigerator (non-medical use)	300	1	300	5	(10.00hr – 15.00hr)
3	Centrifuge	575	1	575	2	(12.00hr – 14.00hr)
4	Hematology Mixer	28	1	28	2	(10.00hr – 12.00hr)
5	Microscope	15	1	15	5	(09.00hr – 14.00hr)
6	Security light	10	4	40	12	(18.00hr – 6.00hr)
7	Lighting	10	2	20	7	(09.00hr – 16.00hr)
8	Sterilizer Oven (Laboratory Autoclave)	1,564	1	1,564	1	(12.00hr – 13.00hr)
9	Incubator	400	1	400	24	(0.00hr – 23.00hr)
10	Water Bath	1,000	1	1,000	1	(14.00hr – 15.00hr)
	Communication via VHF Radio		1			
11	Stand-by	2		2	24	(0.00hr – 23.00hr)
12	Transmitting	30		30	4	(09.00hr – 13.00hr)
13	Desktop Computer	200	2	400	5	(09.00hr – 14.00hr)
14	Printer	65	1	65	3	(09.00hr – 10.00hr; 13.00 – 15.00hr)

powered aspirator). Access to electricity is vital to community service facilities in rural areas. Health service facilities without a connection to the national or local electricity grid must rely on alternative energy sources (e.g., independent diesel generators, solar photovoltaic (PV) systems, liquefied petroleum gas (LPG) or kerosene), or do without.

In many developing countries, rural electrification rates are low, and most community health facilities lack access to electricity. Nigeria is a typical example. In rural areas, where more than 80 percent of the country's 167 million [Population census, 2012] people live, most health facilities lack electricity. Selecting appropriate sources of reliable, sustainable energy can help mitigate the challenges of operating Elath facilities in Nigeria.

Overview of the study area – problem statement

The Health Service Facility under study is is a clinic located in a remote setting of the Agbani District in Nkanu-West, local government area of Enugu State, Nigeria. The clinic is not connected to the grid, and currently utilizes a diesel generator to partially meet its energy needs. Although the facility possesses a large generator, it is often in disuse because of the money required to use the generator. It is incresingly necessary that a reliable, alternative energy source is determined for this, and other rural clinics, which are crucial in the delivery of life-saving medicines.

Power consumption

Health clinics offers an array of services, including the treatment of illnesses, tending of injuries and provision of basic immunization services. Rural health

Table 2 The electrical load (daily load demands) data for a health facility.

Time	DAILY LOAD DEMANDS														Total h^{-1}
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
00-10	60					40			400		2				502
01-02	60					40			400		2				502
02-03	60					40			400		2				502
03-04	60					40			400		2				502
04-05	60					40			400		2				502
05-06	60					40			400		2				502
06-07	60								400		2				462
07-08	60								400		2				462
08-09	60								400		2				462
09-10	60				15		20		400		2	30	400	65	992
10-11	60	300		28	15		20		400		2	30	400		1255
11-12	60	300		28	15		20		400		2	30	400		1255
12-13	60	300	575		15		20	1564	400		2	30	400		3366
13-14	60	300	575		15		20		400		2		400	65	1837
14-15	60	300					20		400	1000	2			65	1847
15-16	60						20		400		2				482
16-17	60								400		2				462
17-18	60								400		2				462
18-19	60					40			400		2				502
19-20	60					40			400		2				502
20-21	60					40			400		2				502
21-22	60					40			400		2				502
22-23	60					40			400		2				502
23-00	60					40			400		2				502
Total															

clinics possess sophisticated diagnostic equipment that requires a reliable power supply. The energy demand is based on the type and number of medical devices used in the facility, and the frequency with which they are used.

From the data acquired from the Agbani health clinic, a profile of the health service facility was created and it is shown in Tables 1 and 2.

The daily average load variation is shown in Fig. 1 and tabulated in Table 2; it is assumed that it is identical for every day of the year. The annual peak load of 3.4 kW was observed between 12:00 h and 13:00 h, with 19 kWh d^{-1} energy consumption.

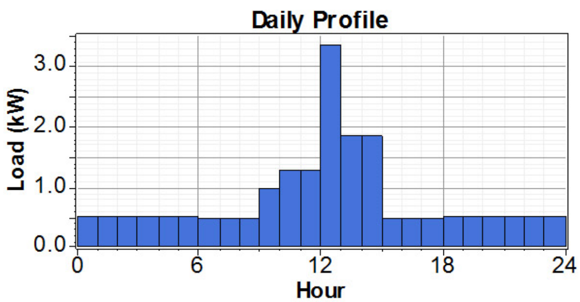

Figure 1 Daily average load variation for a health facility.

Hybrid power systems (HPS)

A hybrid powered system can be described as an electricity production system which consists of a combination of two or more types of electricity generating sources (e.g. solar photovoltaic panels, wind turbine generators, pico-hydro plants, and/or fuel generators) [Ani and Emetu, 2013]. The useful components of hybrid systems considered in this study are solar photovoltaic panels and wind turbine generators. A diesel generator can provide energy at any time, whereas energy from PV and wind is greatly dependent on the availability of solar radiation and wind speed, respectively [Wichert, 1997; Yu et al., 2005]. This makes the system (generator) more reliable, and can be used to operate when PV and/or wind fail to satisfy the load, or when the battery storage is depleted.

A hybrid system uses advanced system control logic (also known as a dispatch strategy) to coordinate when power should be generated by renewable energy and when it should be generated by sources like diesel generators [Ani and Emetu, 2013]. The real innovation of hybrid power generation is in closely matching the cheapest energy production with the load. Important in understanding this process is the realization that cost savings do not come from using the most powerful solar panels or the most efficient diesel engine, but from the refinement of this "matching" process. By coupling and coordinating sources together, the system provides more reliable and higher quality electricity at lower costs [Faruk et al., 2012]. For the hybrid power system, a diesel generator was used, hybridized with a PV system. The details of the power generating set and the weather conditions of Agbani are used as input data for the simulation software used for this study.

The aim of this study is to determine the suitability of hybrid PV/diesel systems in order to upgrade health clinic power generation systems, which would improve the delivery of local health care services.

Renewable energy sources

Photovoltaic energy

Nigeria is a tropical country situated in the West African region and lies between longitudes 3 degrees and 14 degrees and latitudes 4 degrees and 14 degrees [Nigerian Geography, 2013] with landmass of 9.24x105 km^2. Nigeria enjoys average daily sunshine of 6.25 h; ranging between about 3.5 h in coastal areas and 9.0 h at the far northern boundary [Bala et al., 2000]. Its climate varies from tropical to subtropical. There are two main seasons; the dry season lasting from October to March, and the rainy season lasting from April to October. In the north, it is hot and dry, and the rainy season extends from April to September. In the south, it is hot and wet, with the rainy season extending between March and December. From December to March there is a long dry season [Ojo, 2000]. Temperatures at the coast rarely rise above 32°C. The north is drier with temperature range between 32°C and 42°C. Humidity is about 95% [Falade, 1995]. The terrestrial radiation on Nigeria's land area is 2.079x1015 kWh year^{-1}. Solar energy is one of the in-exhaustible energy sources available for the implementation of renewable energy systems for health clinics in Nigeria. Therefore, integration of solar photovoltaic energy with a readily available standalone diesel generator (or generally known as the hybrid PV/diesel system) has a strong potential application in health care.

Wind resource

Wind speed is relatively weak in the study area, with an average of 2.1 m s^{-1} throughout the year. This shows that wind resource is extremely low at this site,

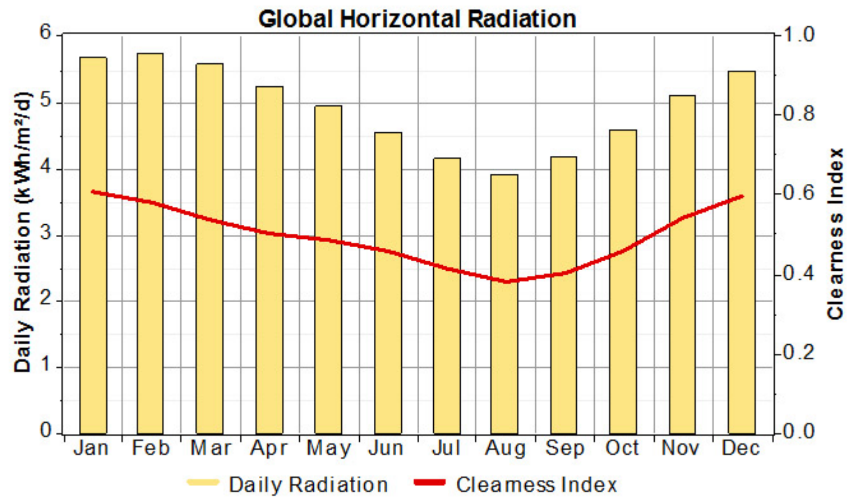

Figure 2 HOMER output graphic for solar radiation profile for Agbani in Nkanu-West (Enugu State).

and therefore this investigation will not include a wind turbine option.

Energy resources

For this study, only solar renewable energy resources were considered. The data for the solar (clearness index and radiation) resource was obtained from the NASA Surface Meteorology and Solar Energy web site [NASA, 2010] in Agbani of Nkanu-West (Enugu State) at a location of 6° 00' N latitude and 7° 00' E longitude with annual average solar (daily average radiation) of 4.925 kWh m^{-2} d^{-1}. Fig. 2 shows the solar resource profile for Agbani in Nkanu-West, and is tabulated in Table 3.

Table 3 Solar Resources for Agbani in Nkanu-West (Enugu State).

Month	Clearness Index	Average Radiation (kWh m^{-2} d^{-1})
Jan	0.605	5.680
Feb	0.578	5.740
Mar	0.537	5.570
Apr	0.503	5.250
May	0.487	4.940
Jun	0.458	4.540
Jul	0.415	4.140
Aug	0.382	3.910
Sep	0.406	4.190
Oct	0.457	4.570
Nov	0.539	5.110
Dec	0.595	5.460
Scaled annual average		4.925

Solar radiation variation

February is the sunniest month of the year, at which time solar energy resource is 5.7 kWh m^{-1} d^{-1}, while in August it drops to 3.9 kWh m^{-2} d^{-1} as shown in Fig. 2 and Table 3.

In the months of September, October, November, December, January, and February, the solar radiation increases with differences from month to month as (0.28), (0.38), (0.54), (0.35), (0.22), and (0.06) respectively. Whereas in the months of March, April, May, June, July, and August, the solar radiation decreases with differences from month to month as (0.17), (0.32), (0.31), (0.4), (0.4), and (0.23) respectively. In these months, the diesel generator can compensate.

Design and simulation

Numerous papers have been written about the optimum economic design of PV/diesel systems with energy storage in batteries. Wies et al. [2005] presented a simulation work, using Simulink, of a real hybrid PV–Diesel–Battery system located in Alaska, comparing it with a a diesel-only (generator) system,, and another diesel–battery system to supply energy for the same load. Contaminating emissions were evaluated (CO_2, NO_X and particles) for the various cases, comparing the results with those obtained by means of HOMER [HOMER, 2012] software. Additionally, the global efficiency of the system and its costs were determined. The results obtained indicate that the system with only a diesel generator had a lower installation cost, but higher operation and maintenance cost. Additionally, it was less efficient, and released more contaminating emissions than the PV–diesel–battery system.

[Shaahid and El-Amin, 2009] used HOMER to perform a techno-economic evaluation of PV/diesel/battery systems for rural electricity generation in Saudi Arabia. They examined the effect of the increase in PV/battery on the cost of energy (COE), operational hours of diesel generators and reduction in GHG emissions. Usually, the optimum design is carried out minimizing the Net Present Cost (NPC: investment costs plus the discounted present values of all future costs during the lifetime of the system) or by minimizing the Levelized Cost of Energy (LCE: total cost of the entire hybrid system divided by the energy supplied by the hybrid system).

Karakoulidis et al. [2011] developed a hybrid renewable energy technology (RET) model combining solar-photovoltaic (SPV), diesel generator (DG) and batteries to meet the load demand of an electric machinery laboratory in Kavala, Greece. Hybrid Optimization Model for Electric Renewable (HOMER) software was used for the optimization and simulation of different combinations and the best suited configuration was selected based on the Net Present Cost NPC. Giatrakos et al. [2009] created a sustainable renewable energy (RE) based system comprising wind energy, Solar-Photovoltaic (SPV) and a hydrogen system to replace the existing DG's in the Greek island Karpathos. HOMER was used for system design and planning analysis. With the help of historic data available for both supply and demand it was concluded that an RET system can penetrate up to 20% in the present electric energy mix.

Design of the hybrid system

Designing a hybrid system requires correct components selection and sizing with appropriate operational strategy [Borowy and Salameh, 1994; Dufo-López and Bernal-Agustín, 2005]. The design and operational control [Ashari and Nayar, 1999] is not a linear problem due to non-linear component characteristics with a large number of variables [Seeling-Hochmuth, 1998]. Simulation programs are the most common tools for optimal design of these systems. By using computer simulation, the optimum configuration can be found by comparing the performance and energy production cost of different system configurations. There are some programs that simulate hybrid systems, as HYBRID2 and HOMER. HYBRID2 simulates hybrid systems with very high precision calculations, but it does not optimize the system. HOMER simulates and optimizes the system. There are other simulation and optimization software tools, and some of them are free. A review of these software can be found in José et al. [2009].

Choice of the software

Among the two available software considered, HOMER was chosen. It is a user friendly software that can be easily configured, and the managed information is complete, as well. This software is a computer modelling tool based on a genetic algorithm that can evaluate different situations to determine the system configuration that will provide acceptable reliability at the lowest lifecycle cost [Ani and Emetu, 2013]. In addition to sizing the components of the hybrid system, HOMER also does a comparison between two simple dispatch strategies. HOMER's two dispatch strategies are Load Following and Cycle Charging.

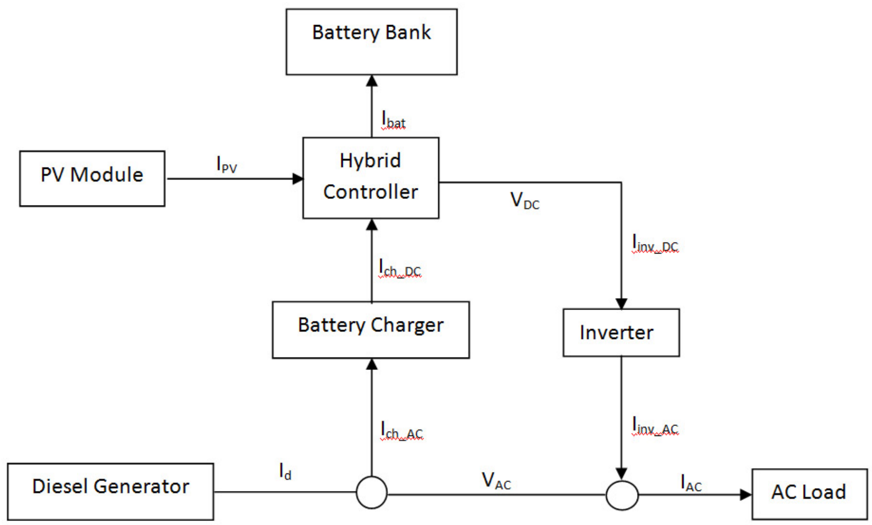

Figure 3 Proposed PV-Diesel Hybrid System.

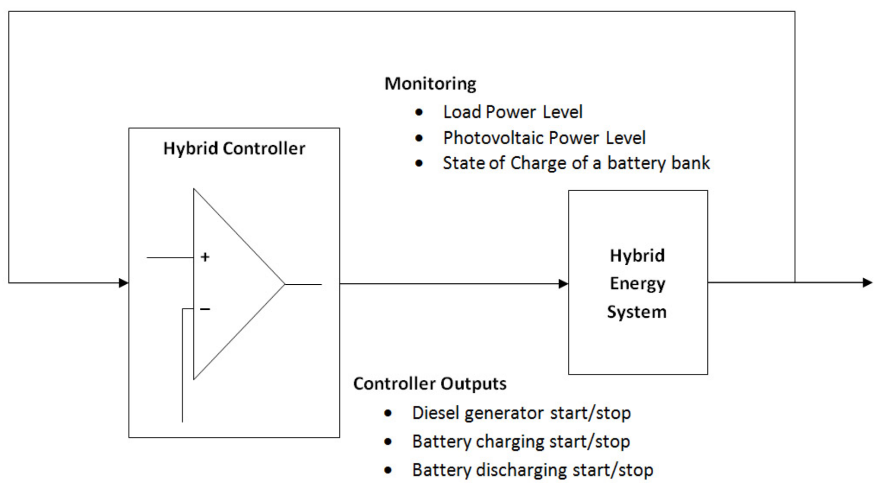

Figure 4 Hybrid system controller block diagram (Ani, 2013).

Hybrid energy system configuration

The hybrid system model described in this essay is the core of the simulation. Fig. 3 shows the proposed hybrid system set-up. Embedded power generation is defined as the interconnection of several distributed generators (PV panels and diesel generator) and a set of batteries. In this study, the hybrid energy system is based on a generalized three-bus configuration. The three buses are a DC bus, an AC bus, and a load bus.

Technology that generates DC current– PV and battery – are connected to the DC bus (V_{DC}). Technology that generates AC current, i.e. diesel generators, are connected to the AC bus (V_{AC}). Only AC appliances are used and are connected to the load bus (I_{AC}). A battery charger is used to convert AC (I_{ch_AC}) current from diesel generator to DC (I_{ch_DC}) current to charge the battery and serve the load. An inverter, or a DC-to-AC converter, is used to convert DC current (I_{inv_DC}) to AC current (I_{inv_AC}) (from the DC bus to serve the AC load).

A Hybrid Controller shown in Fig. 4 is used to coordinate when power should be generated by renewable energy (PV panels) and when it should be generated by the diesel generator. It also controls the charge and discharge current from the battery.

Hybrid system controller

An operational control strategy consists of certain predetermined control settings that are configured when installing the system, as shown in Fig. 4.

Configuration of the stand-alone energy system

The design of a stand-alone hybrid system is site-specific and depends on both the resources available and the load demand [Ani and Nzeako, 2002]. A typical stand-alone hybrid diesel-solar PV system has an electricity generation device equipped with the wiring setup and supporting structures, as well as the necessary BOS components (i.e., the battery bank, the charging controller and the converter) [Kamaruzzaman et al., 2009]. The energy system proposed for the Health facility consists of solar PV and diesel power as depicted in Fig. 5.

The energy consumption of the health service facility is 19 kWh d^{-1} with a 3.4 kW peak demand load, and the proposed energy system (diesel/PV hybrid) consists of a 2.5 kW diesel generator, 5 kW solar PV array, 24 Surrette 6CS25P Battery Cycle Charging, and a 19 kW converter; whereas the existing system (diesel only) has a 2.5 kW diesel generator, 48 Surrette 6CS25P Battery Cycle Charging, and a 19 kW converter.

Economics and constraints

The project lifetime is estimated at 20 years. The annual interest rate is fixed at 6%. There is no capacity shortage for the system and the operating reserve as a percentage of hourly load was 10%. Meanwhile, the operating reserve as a percentage of solar power output was 25%. Operating reserve is the safety margin that helps ensure reliability of the supply despite variability in electric load, and solar power supply.

System economics

The capital costs for all system components including PV module, diesel generator, rectifier, battery and balance of system prices are based on quotes from PV system suppliers in Nigeria [Solarshopnigeria, 2012]. These costs are estimates based on a limited number of Internet enquiries and prices. They are likely to vary for the actual system quotes due to many market factors. The figures used in the analysis are therefore indicative.

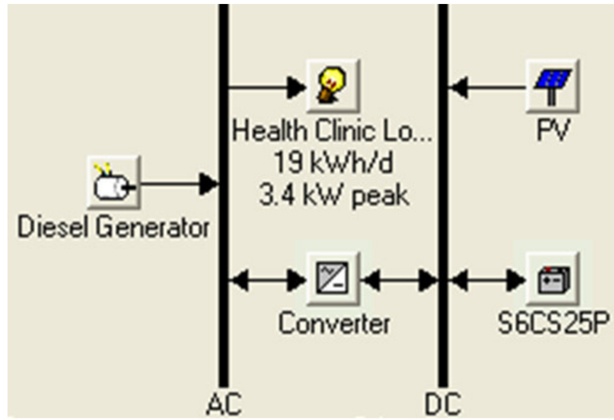

Figure 5 The network architecture for the HOMER simulator.

The replacement costs of equipment are estimated to be 20% – 30% lower than the initial costs, but because decommissioning and installation costs need to be added, it was assumed that they are the same as the initial costs. The PV array, diesel generator, rectifier and battery maintenance costs are estimates based on approximate time (20 yrs) required for the health facility. All initial costs including installation and commissioning, replacement costs and operating and maintenance costs at the health facility are summarized in Table 4. As HOMER calculates in US Dollar ($), all costs have been converted from Naira (N) into USD ($) as shown in Table 4 using the equivalent as N162 of Nigerian currency equal to 1US Dollar ($) [Exchange rate, 2012]. Initially, the cost of system components was gotten in Naira from the local vendors and therefore changed to dollars before calculations. All costs presented are in US Dollar ($).

Simulation results

The simulations provide information concerning the electricity production, economic costs and environmental characteristics of each system. The obtained

Table 4 Summary of initial system costs, replacement costs and operating and maintenance costs.

Parameter	Existing system diesel only		Proposed hybrid diesel-solar PV system	
	Dollars($)	Naira(₦)	Dollars($)	Naira(₦)
Initial Cost	63,760	10,329,120	46,280	7,497,360
Operating Cost	30,254	4,901,148	7,012	1,135,944
Total NPC	410,769	66,544,578	126,712	20,527,344

results are presented in Tables 5, 6, 7 and 8. The detailed analyses obtained at the end of the simulations are described below:

Existing system:

The existing system (diesel generator) has higher initial capital cost, higher operating cost and higher total net present cost for the whole project due to it has more number of batteries in its configuration than the hybrid PV/diesel system as shown in Fig. 6 and Table 5. Furthermore, this system emits more CO_2 and NO_X as a result of burning a lot of fossil fuel as shown in Table 7.

Proposed hybrid system:

A hybrid solar PV-diesel system can supply renewable energy, corresponding to 78% of the energy demand in the health facility as shown in Table 6. The hybrid solar PV-diesel system has less total net present cost as a result of less fuel consumption as shown in Fig. 7 and Table 6. Reducing fuel consumption also means less emissions are caused by the solar PV-diesel system which has the lowest emission of CO_2 and NO_X as shown in Table 7.

Discussions

Economic Cost

The diesel-only system has a total NPC of $410,769 (N 66,544,578), operating cost of $30,254 (N 4,901,148), and initial cost of $63,760 (N 10,329,120) while the PV-diesel has total NPC of $126,712 (N 20,527,344), operating cost of $7,012 (N 1,135,944), and initial cost of $46,280 (N 7,497,360) as shown in Fig. 6 and 7, respectively and Table 5. This system (proposed) saves $284,057 N 46,017,234 to the health clinic when compared with the diesel-only system. Moreover, the operational life of the diesel only system is low (5.09 yrs), while in Hybrid system its diesel operational life is extended (23.4 yrs) as shown in Table 8.

Electricity Production

The existing system (diesel-only) produces 9,820 kWh yr^{-1} (100%) of the total electricity with a capacity factor of 44.8%; whereas the proposed hybrid system (diesel-solar PV) produces 7,488 kWh yr^{-1} (78%) from solar PV array and 2,124 kWh yr^{-1} (22%) from diesel generator with a capacity factor of 9.70% making a total of 9,612 kWh yr^{-1} (100%) as shown in Figs. 8 and 9, respectively. The load demand is 7,082 kWh yr^{-1}, while the excess electricity from the existing system is 2738 kWh yr^{-1} and the proposed project has excess electricity of 2530 kWh yr^{-1} (26%) as shown in Table 6. The hybrid PV-diesel system is a renewable energy (PV) source with the capacity to supply 78% of the total electricity, as shown in Table 6 and Fig. 9.

Environmental pollution

The diesel-only system operates for 3,928 h $annum^{-1}$ has a fuel consumption of 3,240 L $annum^{-1}$ as shown in Table 8. It generates 8.533 tonnes of CO_2, 0.0211 tonnes of CO, 0.00233 tonnes of UHC, 0.00159 tonnes of PM, 0.0171 tonnes of SO_2, and 0.188 tonnes of NO_X as shown in Table 7. In contrast, in the hybrid PV-diesel system, the diesel generator operates for 853 h $annum^{-1}$ and has a fuel consumption of 702

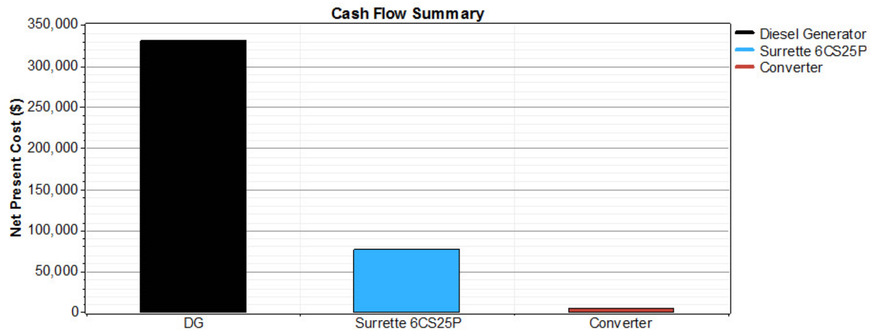

Figure 6 Net present cost of component of existing diesel only system.

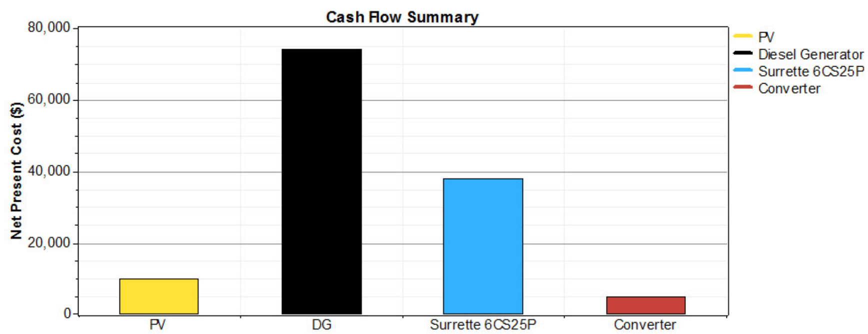

Figure 7 Net present cost of component of optimized hybrid diesel-solar PV energy system.

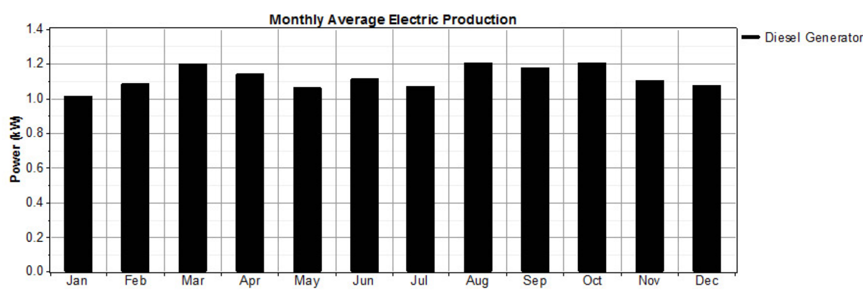

Figure 8 Electrical production of diesel only energy system.

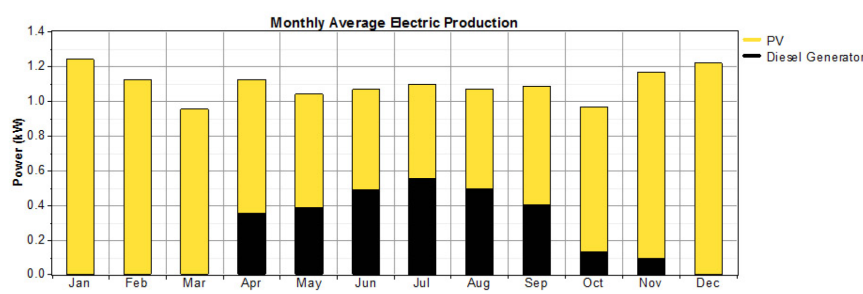

Figure 9 Electrical production of hybrid diesel-solar PV energy system.

L annum^{-1} as shown in Table 8. This system emits 1.848 tonnes of CO_2, 0.00456 tonnes of CO, 0.000505 tonnes of UHC, 0.000344 tonnes of PM, 0.00371 tonnes of SO_2, and 0.0407 tonnes of NO_X annually into the atmosphere of the location of the health clinic as shown in Table 7. An approximate 78% decrease in each pollutant is noticed for a 78% renewable penetration into the existing diesel only power system. The

Table 5 Comparison of Simulation results of Economic.

Parameter	Existing system diesel only		Proposed hybrid diesel-solar PV system	
	Dollars($)	Naira(₦)	Dollars($)	Naira(₦)
Initial Cost	63,760	10,329,120	46,280	7,497,360
Operating Cost	30,254	4,901,148	7,012	1,135,944
Total NPC	410,769	66,544,578	126,712	20,527,344

Table 6 Comparison of simulation results of electricity production (kWh yr^{-1}).

Quantity	Diesel only		Diesel in hybrid system (diesel-solar PV)	
	kWh yr^{-1}	%	kWh yr^{-1}	%
Load Consumption				
AC primary load	7,082	100	7,082	100
Production				
PV array	None	None	7,488	78
Diesel Generator	9,820	100	2,124	22
Total energy	9,820	100	9,612	100
Excess electricity	2738		2530	26

reduction in the quantity of different air pollutants for 78% renewable penetration compared to that diesel only are thus: 6.685 tonnes of CO_2, 0.01654 tonnes of CO, 0.001825 tonnes of UHC, 0.001246 tonnes of PM, 0.01339 tonnes of SO_2, and 0.1473 tonnes of NO_X. Moreover, from the fuel consumption, this hybrid system saves 2,538 Litres of fuel per year to the health clinic when compared with diesel only.

From an environmental impact perspective, an increase in the operational hours of a diesel generator brings about increase in the fuel consumption, as well an increase in GHG emission, whereas a reduction in the operational hours of diesel generator brings about reduction in the fuel consumption thereby a reduction in GHG emission.

Excess energy = Total energy Production – Total energy Consumption

Excess energy = (9,612 – 7,082) kWh/year = 2,530 kWh/year.

The excess electricity occurs in the months of January, February, November, December and few days in March but occur most in January (as can be clearly seen in Fig. 10) when the energy generated by the solar energy system are at the highest (Table 3). This excess electricity of about 26% power supply is guaranteed in the location simulated in order to give room for future Clinic expansion or can be sold to nearby villages, factories, schools or facilities. The sale of this excess electricity will offer a promising approach for health facilities to finance operations and maintenance costs of the hybrid system.

From the optimization results the best optimal combination of energy system components (2.5 kW

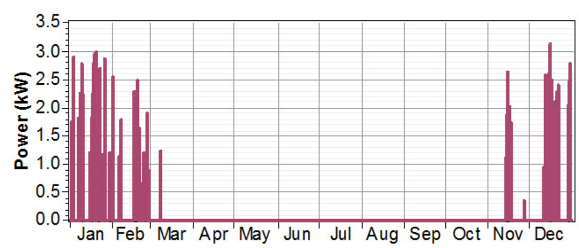

Figure 10 Excess electricity generated by the hybrid diesel/PV energy system.

Table 7 Comparison of simulation results of emissions from existing and proposed system.

Pollutant	Emissions (kg yr^{-1}) Existing diesel only		Proposed PV/diesel hybrid system		Difference
	(kg yr^{-1})	(ton yr^{-1})	(kg yr^{-1})	(ton yr^{-1})	(ton yr^{-1})
Carbon dioxide	8,533	8.533	1,848	1.848	6.685
Carbon monoxide	21.1	0.0211	4.56	0.00456	0.01654
Unburned hydrocarbons	2.33	0.00233	0.505	0.000505	0.001825
Particulate matter	1.59	0.00159	0.344	0.000344	0.001246
Sulfur dioxide	17.1	0.0171	3.71	0.00371	0.01339
Nitrogen oxides	188	0.188	40.7	0.0407	0.1473

Table 8 Comparison of simulation of existing system (diesel only) and proposed hybrid system (diesel-solar PV).

Quantity	Diesel only		Diesel in hybrid system (diesel-solar PV)	
	Value	Units	Value	Units
Operational life	5.09	yr	23.4	yr
Capacity factor	44.8	%	9.70	%
Hours of operation	3,928	h yr^{-1}	853	h yr^{-1}
Fuel consumption	3,240	L yr^{-1}	702	L yr^{-1}

diesel generator, 5 kW solar PV array, 24 Surrette 6CS25P Battery Cycle Charging, and a 19 kW converter) was determined for health facility located in rural area of Nkanu-West (Enugu State) as shown in Fig. 11.

Conclusion

It is determined that using a hybrid system to power health service facilities is far better than using the diesel-only power generation system, especially in areas where there is no utility power. The economic analysis of hybrid PV/diesel stand-alone systems carried out in this investigation verifies the predictions for the brilliant future of hybrid energy technology for health clinics in Nigeria. From the environmental analysis on pollutant emission, the hybrid PV/diesel system is preferred over diesel generators. The designed hybrid system minimizes the diesel operational hours, thus reducing fuel consumption, which significantly reduces pollution. If the diesel-only generator system is continued to be used by the health clinics in Nigeria, the CO_2 generated in each clinic based on the simulation results will possibly cause an epidemic in the near future i.e global warming.

From the simulation results (costs and emissions), it has been demonstrated that the use of hybrid PV/diesel system with battery could achieve significantly lower NPC and reduction of CO_2 as compared to a standalone diesel system. Therefore, the suitability of a hybrid PV/diesel system with battery in health clinics was determined from the perspective of technical and economical analysis. It is concluded that, the hybrid PV/diesel system has a high potential for use in power generation at health clinics in Nigeria.

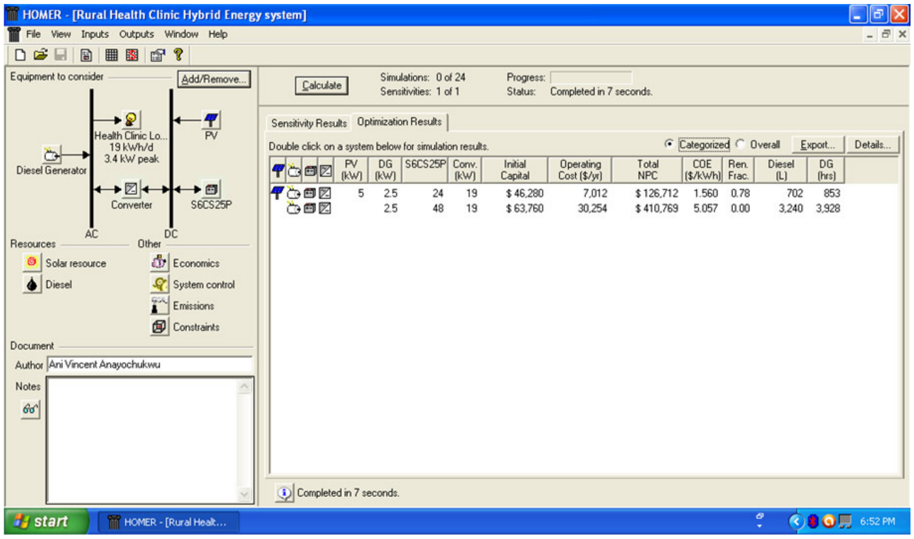

Figure 11 Overall optimization results of HOMER solutions.

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