Simulation of Photovoltaic/Diesel Hybrid Power Generation System with Energy Storage and Supervisory Control

Ani Vincent Anayochukwu*

*Department of Electronic Engineering, University of Nigeria, Nsukka

Enugu State, Nigeria. (Tel: +234 8054024629; vincent_ani@yahoo.com)

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Abstract- This paper describes the simulation of Photovoltaic (PV)-Diesel hybrid system with reliable control system. The control system supervise and control the operations of the hybrid system by coordinating when power should be generated by renewable energy (PV panels) and when it should be generated by diesel generator and is intended to maximize the use of renewable system while limiting the use of diesel generator. Diesel generator is allocated only when the demand cannot be met by the renewable energy source including battery bank. From the results of the simulation, it was shown that the PV-Diesel hybrid system provide a reduction of the operational costs and air pollutants emitted to the atmosphere when compared with diesel only system. The hybrid system also gives an opportunity for renewable energy to supply 63% of the annual energy demand of the digital library and results in 37% reduction on diesel use.

Keywords- Digital library, renewable energy, component sizing, hybrid system, system design, diesel generator, energy simulation

1. Introduction

Nigeria is the largest country in Africa, it has a population of 167 million [1] and it is still growing. One of the most basic things needed in Nigeria today is quality education. The education in Nigeria starts to improve though one third of the adults are illiterate [2]. Most people are willing to learn but unfortunately the tools needed to learn are limited. Digital library fills in this gap in the sense that it provides people the tools and materials needed to learn a new skill or improve their skill. The importance of information and communication technology (ICT) in Nigeria libraries is no longer an issue in contention. The issue in contention is the existence of erratic and epileptic power supply. Nigeria is a country characterized with constant power outage. This tends to have negative effects on all developmental projects, and clearly portrays a potential danger. Digital libraries cannot survive in this kind of unfortunate condition.

Most of the electricity in digital library is provided by generators, since the central electricity grid in Nigeria is very unstable with power failure being more rule than exception. The irony of this situation is that Nigeria is endowed with very abundant renewable energy resources that remained unexplored and unexploited for alternative energy solutions for power stations. Nigeria lies along the Equator, with abundant sunshine all the year round. Bala et al, [3] stated that Nigeria is endowed with an annual average daily sunshine of 6.25 hours, ranging between about 3.5 hours at the coastal areas and 9.0 hours at the far northern boundary. Similarly, it has an annual average daily solar radiation of about 5.25kWh/m^2/day, varying between about 3.5kWh/m^2/day at the coastal Area and 7.0kWh/m^2/day at the northern boundary. Nigeria receives about 4.851x 10^{12} kWh of energy per day from the sun. This is equivalent to about 1.082 million tones of oil equivalent (mtoe) per day, and is about 4 thousand times the current daily crude oil production, and about 13 thousand times that of natural gas daily production based on energy unit [2]. This huge energy resource from the sun is available for about 26% only of the day. Based on the land area of 924 x 10^3 km^2 for the country and an average of 5.535kWh/m^2/day, Nigeria has an average of 1.804 x 10^{15} kWh of incident solar energy annually [4]. There is therefore a great promise for alternative renewable energy for the power stations in Nigeria, if only the country could endeavour to explore and exploit these available resources. Hybrid PV system includes the PV generator, diesel generator and/or battery system. Battery storage increases the flexibility of system control and adds to overall system availability [5 - 7]. These energy systems have good prospects and many opportunities in Nigeria and are termed as one of the cost effective solutions [8] to meet energy requirements of ICT facilities. A review of hybrid PV/diesel system can be found in [8]. Hybrid PV/diesel system are best suited to reduce dependence on fossil fuel by using available solar radiation. This study is part and perhaps the beginning of this endeavour. Its major goal is to progressively increase the generation of renewable and clean energy so as to migrate digital libraries away from a dependence on fossil fuel energy. The aim of this paper is to design an optimized hybrid energy system that will produce the desired power needs of the digital library while minimizing the financial expenditure and emission; to investigate and analyze the benefits of the proposed hybrid energy system to diesel only system.

2. The Pattern of Using Electricity Power within the Digital Library

Table 1.1. Load estimation of the digital library

S/N	Digital Library Equipment Description	Rated Power Watt		Qty		Hrs/day		Watt hrs/day	Kilowatt hrs/day
1.	HP DL 380, G6 Servers	1000	x	3	x	24	=	72000	72
2.	Networked Computers	240	x	128	x	14	=	430080	430.08
3.	Printers	240	x	2	x	14	=	6720	0.48
4.	Cisco Routers	50	x	1	x	24	=	1200	1.2
5.	Cisco Switches	50	x	1	x	24	=	1200	1.2
6.	PABX	240	x	1	x	24	=	5760	5.76
7.	VSAT Modem	50	x	1	x	24	=	1200	1.2
8.	Lighting	13	x	16	x	14	=	2912	2.912
9	Climate Equipment	3516	x	1	x	14	=	49224	49.224
	Total							**570296**	**570.296**

Table 1.2. Daily load demands

Time	**Load**									
	HP DL 380, G6 Servers (W)	Networked Computers (W)	Printers (W)	Cisco Routers (W)	Cisco Switches (W)	PABX (W)	VSAT Modem (W)	Lighting (W)	Climate Equipment (W)	Total (W/Hr)
12	3000			50	50	240	50			3390
01	3000			50	50	240	50			3390
02	3000			50	50	240	50			3390
03	3000			50	50	240	50			3390
04	3000			50	50	240	50			3390
05	3000			50	50	240	50			3390
06	3000			50	50	240	50			3390
07	3000			50	50	240	50			3390
08	3000	30720	480	50	50	240	50	208	3516	38314
09	3000	30720	480	50	50	240	50	208	3516	38314
10	3000	30720	480	50	50	240	50	208	3516	38314
11	3000	30720	480	50	50	240	50	208	3516	38314
12	3000	30720	480	50	50	240	50	208	3516	38314
1	3000	30720	480	50	50	240	50	208	3516	38314
2	3000	30720	480	50	50	240	50	208	3516	38314
3	3000	30720	480	50	50	240	50	208	3516	38314
4	3000	30720	480	50	50	240	50	208	3516	38314
5	3000	30720	480	50	50	240	50	208	3516	38314
6	3000	30720	480	50	50	240	50	208	3516	38314
7	3000	30720	480	50	50	240	50	208	3516	38314
8	3000	30720	480	50	50	240	50	208	3516	38314
9	3000	30720	480	50	50	240	50	208	3516	38314
10	3000			50	50	240	50			3390
11	3000			50	50	240	50			3390
Total	72000	430080	6720	1200	1200	5760	1200	2912	49224	**570296**

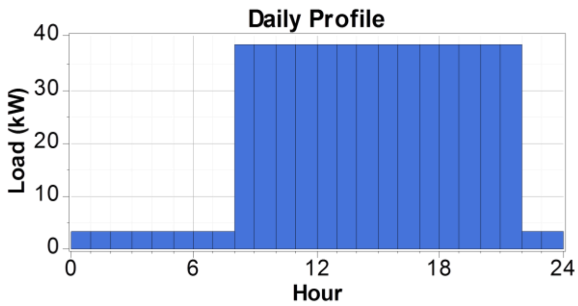


Fig. 1.1. Daily profile of electricity consumption in a digital library

The digital library opens by 7:30hr (7.30am) from Monday to Friday and closes by 22:00hr (10.00pm). Normally, training and browsing starts by 8:00hr (8.00am) and closes by 22:00hr (10.00pm). All PCs (128 networked computers) are expected to be ON for an average period of 14hrs (8:00hr-22:00hr). During the 14hrs (8:00hr-22:00hr) of using the facility for research, training and browsing, the climate equipment (air-conditioner) will be on as well as the printer. The VSAT equipment and internet connectivity will be ON all round the clock (0:00hr-23:00hr) for someone that wants to browse any-time, any-day provided his/her computer system (Laptop, notebook, handheld) has enough battery. The electrical load estimation, daily load demand data and daily profile of the digital library are given in Table 1.1, 1.2 and Figure 1.1, respectively.

2.1. Load variation

The abrupt changes as well as the flat lines for extended periods of time in Figure 1.1 are realistic of daily electricity consumption in the digital library in study. Normally in the morning and late hour of night load demands are very small. Here Table 1.2 explores the daily load profile of the digital library. As from 22:00hr to 08:00hr (10pm to 8am), load demand at the least (3390W), due to training and browsing are not yet started (not going on) in the digital library by that time. The load increased at 08:00hr (8am) to 38314W and remains there till 22:00hr (10pm), due to training and browsing are going on. It comes down at 22:00hr (10pm) to 3390W when the digital library is closed for the day, and remains there till 08:00hr (8am) when it increase again to 38314W.

3. Energy Simulation

Computer modeling permits optimization of the various engineering and economic parameters that have to be considered in order to plan, design and construct energy system. In particular, computer simulations can be used to perform a feasibility study on any new system. They can be used to diagnose problems that might occur in the system's operation. Morgan et al, [9] described the development of a simulation program that enables the designer to find the reliable level of a renewable energy system. When both load and meteorological data are known, the program calculates the system autonomy level and predicts the battery voltage.

Optimization analyses were carried out to arrive at the best possible sizing configurations. Solar energy system is among the most developed renewable energy systems (RES), with diesel generator and has been widely used in both autonomous and grid connected applications. The sizing tool performs dimensioning of the system: given an energy requirement, it determines the optimal size of each of the different components of the system. In an energy system, 40% of the total energy loss is due to the nonoptimal sizing of the system [10]. Simulation tools can be used for sizing [11] and this requires that the user correctly identify the key variables and then repeatedly run the simulation, adjusting the variables manually to converge on an acceptable sizing. Some packages automate this process. Much research has been carried out to optimize their size and evaluate their performance. Elhadidy et al and Nema et al, [12 - 13] carried out system sizing using (Hybrid Optimization Model for Electrical Renewables) HOMER-optimization and simulation software tool. De Vries et al, [14] used electrical resistance to simulate a PV system. Whilst mathematically correct, the drawback in these earlier works was the complexity of solar outputs at a site near where the system was to be installed because the power output may be intermittent, seasonal, and nondispatchable, and the availability of renewable resources may be uncertain. Ani and Emetu [8] have developed a control system to overcome these challenges. In this work, a different approach involving simulation and optimization has been adopted to solve these difficulties; the development of a control system that controls and supervises the operations of PV-Diesel hybrid power generation system.

3.1. System Design

In order to design a power system, we have to provide some information from a particular remote location such as the load profile that should be met by the system, solar radiation for PV generation, initial cost for each component (renewable energy generators, diesel generator, battery, converter), annual interest rate, project lifetime, etc [15 - 16]. After that, the simulation was performed to obtain the best power system configuration, by utilizing HOMER software from NREL [17 - 18]. Designing a hybrid system would require correct components selection and sizing with appropriate operation strategy [19 - 20]. The design and operational control is not a linear problem due to non-linear component characteristics with a large number of variables [21 - 22]. Simulation programs are the most common tools for the optimal design of problems like this. 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.

3.2. Choice of the Software

Among the two available software considered, we have chosen the Hybrid Optimization Model for Electrical

Renewables (HOMER). It is a users' friendly software that can be easily configured and, as for the managed information, it is complete, too. This software is a computer modelling tool that can evaluate different situations to determine the system configuration that will provide acceptable reliability at the lowest lifecycle cost. 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. There exist many references of using HOMER as a simulation tool including [23 - 28], etc. Many previous papers e.g. Morgan et al and Adebiyi et al [9, 29] have discussed optimization of renewable energy systems involving PV, storage and standby engine components. The optimisation process was achieved by developing total Net Present Costs (NPC's) for the energy systems (PV and diesel generator).

Study Area

The study is on the simulation of hybrid power generation system for digital library located inside Nnamdi Azikiwe Library, University of Nigeria, Nsukka. The University is located in a valley on a plateau at an average elevation of approximately 500 metres above sea level in the town of Nsukka, about eighty kilometers North of Enugu [30] at a specific geographical location of 6°51'52"N latitude and 7°24'26"E longitude [31] with annual average solar daily radiation of 4.92kWh/m²/d. The data for solar resource were obtained from the National Aeronautics and Space Administration (NASA) Surface Meteorology and Solar Energy web site [32]. The campus is located on 871 hectares of hilly savannah. For this study, PV technology was considered in terms of renewable energy. Figure 1.2 shows the solar resource profile of this location tabulated in Table 1.3.

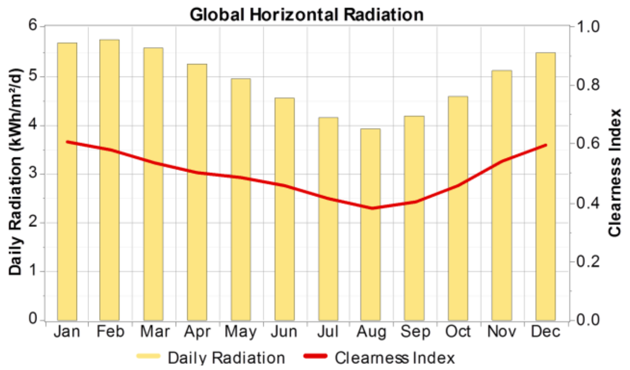


Fig. 1.2. Solar (clearness index and daily radiation) profile for University of Nigeria, Nsukka.

Table 1.3. Solar resource for University of Nigeria, Nsukka (Enugu State).

Month	Clearness Index	Average Daily Solar Radiation (kWh/m²/day)
Jan	0.607	5.680
Feb	0.579	5.740
Mar	0.537	5.570
Apr	0.503	5.250
May	0.486	4.940
Jun	0.457	4.540
Jul	0.414	4.140
Aug	0.381	3.910
Sep	0.406	4.190
Oct	0.457	4.570
Nov	0.541	5.110
Dec	0.598	5.460
Scaled annual average		**4.950**

Solar Radiation Variation

February was the sunniest month of the year. In this month (February), solar energy resource is 5.7kWh/m^2/day while in August it is only 3.9kWh/m^2/day as shown in Figure 1.2 and Table 1.3. 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, diesel generator can compensate.

In general, at night between 22:00hrs-08:00hrs, the stored energy in the battery compensates at these hours of time till day time when either PV or diesel generator takes up.

4. Methodology

4.1. Hybrid Energy System Configuration

The hybrid system model to be described is the core of the simulation. Apart from correct costing and optimization, the quality and accuracy of the model and its implementation in the algorithm, greatly determines the usefulness of the simulation results. Figure 1.3 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, a hybrid energy system is based on a generalized three-bus configuration. The three buses are a direct current (DC) bus, an alternate current (AC) bus, and a load bus. Technologies that generate DC current– PV and battery – are connected to the DC bus (V_{DC}). Technologies that generate 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}). 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 battery charger is used to convert AC (I_{ch_AC}) current from diesel generator to DC (I_{ch_DC}) current to charge the battery. A charge regulator is used to control the charge and discharge current from the battery. To serve the load, electrical energy can be produced either directly from PV (I_{PV}), diesel generator (I_d), or indirectly from the battery (I_{bat}). The energy generated from all generating technologies (PV and diesel generator) can be directed to serve the load and charge the battery.

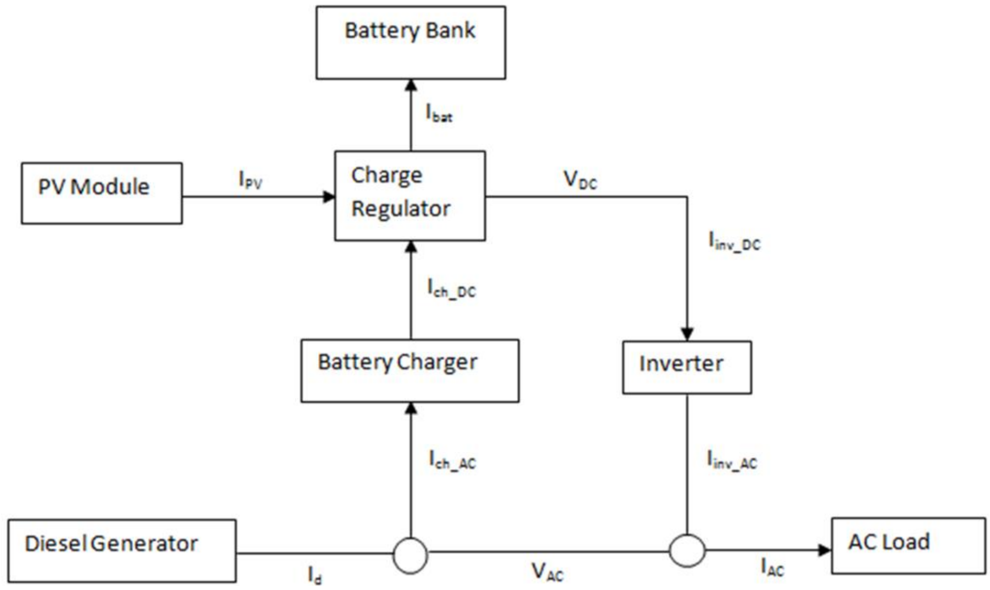


Fig. 1.3. Proposed pv-diesel hybrid system [8]

4.2. Development of Supervisory Control for PV-Diesel Hybrid System

As is well-known, a good operation of a hybrid system can be achieved only by a suitable control of the interaction in the operation of the different devices. An exhaustive knowledge of the management strategies to be chosen in the preliminary stage is therefore fundamental to optimize the use of the renewable sources, minimize the wear of batteries, consume the smaller possible quantity of fossil fuel [33 - 34]. The system algorithm considered a Loss of Load Probability equal to 0%; meaning that the load will always be satisfied. In other words, the system reliability is 100%, leading to autonomy for the system. In this study, the PV power ($P_P(t)$) generation is the primary source of energy, the battery ($P_{charger}(t)$) as the supplement and the diesel generator power (P_{DG}) as the back-up source of energy. Given the values of irradiation on tilted planes, and the consumption patterns previously described, the system behavior can be simulated using an hourly time step. Based on a system energy balance and on the storage continuity equation, the simulation method used here is similar to that used by others [35 - 36].

An operational control strategy consists of the setpoint of when to switch on the diesel or not, based on the system state, such as the battery state of charge and demand placed on the system as shown in the developed design system in Figure 1.4.

Considering the battery charger output power $P_{charger}(t)$, the PV output power $P_p(t)$ and the load power $P_L(t)$ on the simulation time-step Δt, the battery energy benefit during a charge time Δt_1 is given by ($\Delta t_1 < \Delta t$) [5, 37]:

$$C_1(t) = \rho_{ch} \int_{\Delta t_1} \left[P_p(t) + P_{charger}(t) - P_l(t) \right] dt \qquad (1)$$

The battery energy loss during a discharge time Δt_2 is given by ($\Delta t_2 < \Delta t$) [5]:

$$C_2(t) = \left(\frac{1}{\rho_{dch}} \right) \int_{\Delta t_2} \left[P_p(t) + P_{charger}(t) - P_l(t) \right] dt \qquad (2)$$

The state of charge of the battery is defined during the simulation time-step Δt by [5]:

$$C(t) = C(t - \Delta t) + C_1(t) + C_2(t) \qquad (3)$$

If C(t) reaches SAR (stopping threshold) by an energy benefit $C_1(t)$ during the charge period with the engine-generator working, the diesel generator has to be stopped and the charge time Δt_1 during Δt is calculated assuming a linear relation [5]:

$$\frac{\Delta t_1}{\Delta t} = \left| \frac{SAR - C(t - \Delta t)}{C_1(t)} \right| \qquad (4)$$

Moreover, if during the discharge period when the engine generator is stopped, C(t) reaches SDM (starting threshold), the diesel generator is started and the discharge time Δt_2 during Δt is calculated by a linear relation as [5]:

$$\frac{\Delta t_2}{\Delta t} = \left| \frac{C(t - \Delta t) - SDM}{C_2(t)} \right| \qquad (5)$$

As an input of a simulation time-step Δt (taken as 1h), several variables were determined: PV output power, load power, battery state of charge, and back-up generator state (ON or OFF). A battery energy balance indicates the operating strategy of the PV-Diesel hybrid system: charge (energy balance positive) or discharge (energy balance negative). If SOC(t) falls below SDM, the diesel generator is started; and if SOC(t) exceeds SAR, it is stopped.

4.3. Configuration of the Stand-Alone Energy System

The design of a stand-alone hybrid system is site specific

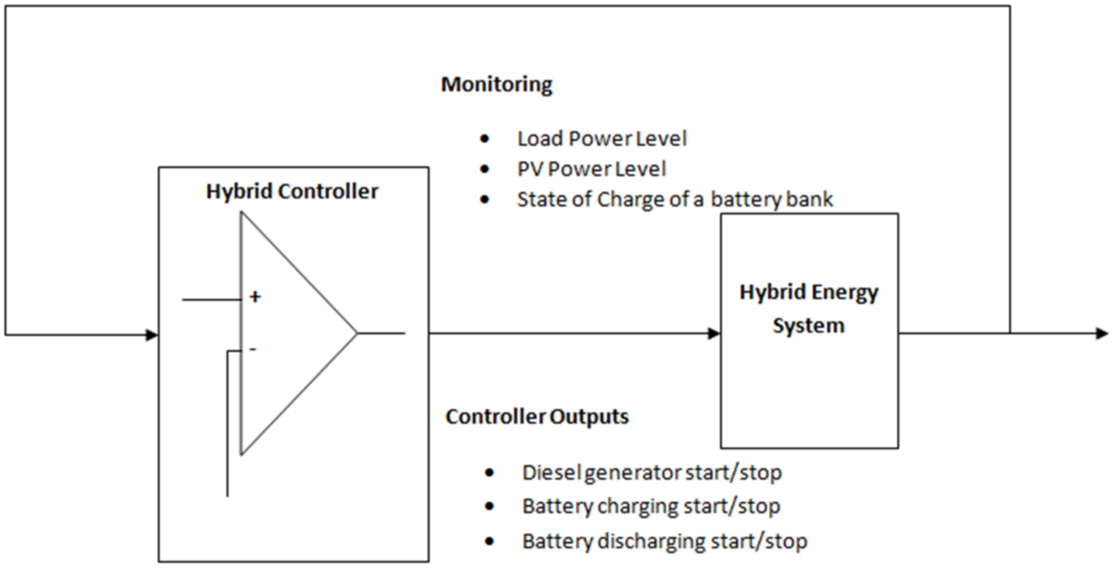


Fig. 1.4. Hybrid energy system controller [8].

and depends on both the resources available and the load demand [38]. A typical stand-alone hybrid PV-diesel 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 DC/AC inverter) [39]. The diagram of a proposed stand-alone hybrid PV-diesel system is shown in Figure 1.5 below.

The energy system proposed for the digital library consists of PV and diesel power as depicted in Fig. 1.5. This facility energy consumption is 570kWh/day with a 38kW peak demand load, and the energy system consists of 45kW diesel generator, 120kW PV array, 120 Surrette 6CS25P Battery Cycle Charging, and a 50kW AC/DC converter. The lifetime of the project is estimated at 25 years with a fixed annual interest rate of 6%. The data for the system configurations is shown in Table 1.4. The categorized list of HOMER solutions displays four different configurations from the best to worst as follows:

1. Hybrid PV/Diesel + Battery
2. Diesel only +Battery
3. PV/Diesel without Battery
4. Diesel only without Battery

5. Simulation Results

The simulations provide information concerning the electricity production, economic costs and environmental characteristics of each system, such as the CO_2 emissions. The obtained results are presented in Tables 1.5, 1.6, 1.7, and 1.8. The detailed analyses obtained at the end of the simulations are described below:

Diesel only system

The diesel only system (45kW Diesel generator) has the highest operating cost and total net present cost for the whole project as shown in Figure 1.6 and Table 1.5. Furthermore, this system emits CO_2, particulate matter (PM) and NO_x as a result of burning a lot of fossil fuel with a high capacity factor of 62.1% as shown in Tables 1.7 and 1.8.

Proposed Hybrid System

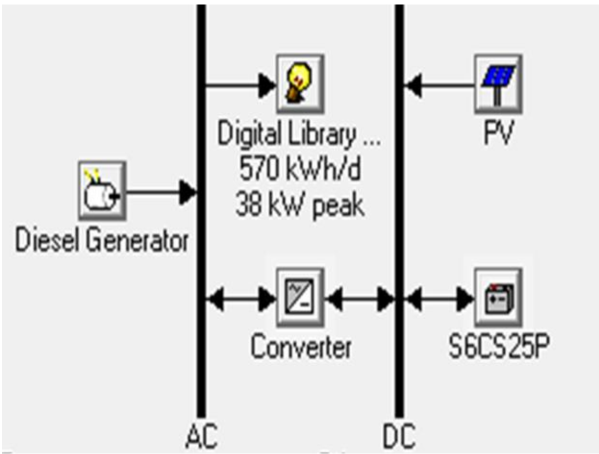


Fig. 1.5. Proposed stand-alone hybrid PV-diesel system

Table 1.4. Data for system configuration

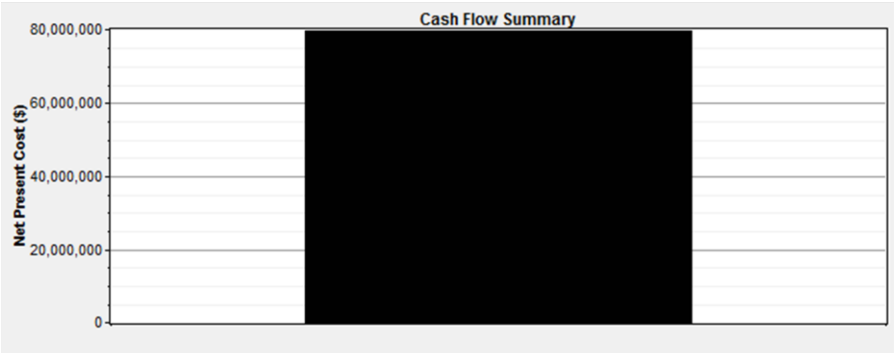
Component	Description	Data
PV	Size	120kW
	Lifetime	20yrs
Storage battery	Types of battery	Surrette 6CS25P
	Nominal voltage (1 batteries per string)	6V
	Nominal capacity	1156Ah
	Round Trip Efficiency	80%
	Min. State of Charge	40%
Inverter	Size	50kW
	Lifetime	20yrs
	Efficiency	85%
Diesel generators	Number of generators	1
	Size	45kW

PV-Diesel system gives an opportunity for renewable energy to supply 63% of the energy demand in the digital library as shown in Table 1.6. PV-Diesel System has less total net present cost as a result of less fuel consumption and low capacity factor of 27.1% from the diesel genset as shown in Figure 1.7 and Tables 1.5, 1.8. Reducing fuel consumption also means less emission from the energy system as shown by the PV-diesel system which has the lowest emission of CO_2, PM and NO_x as shown in Table 1.7.

Electricity Production

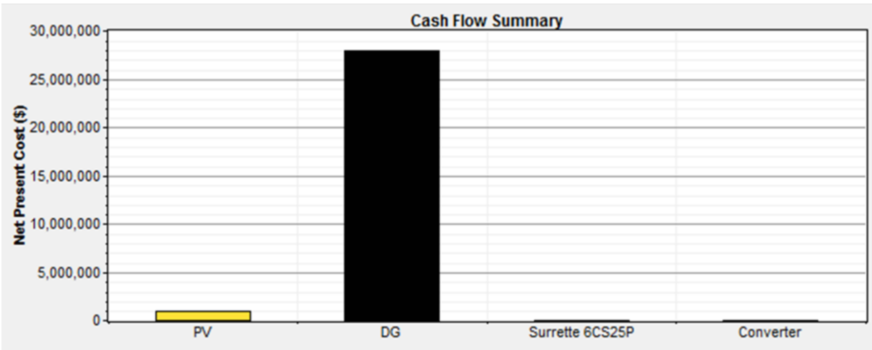
The Diesel only system produces 244,968kWh/yr (100%), whereas the proposed Hybrid system (PV-diesel) produces 179,183kWh/yr (63%) from PV array and 106,989kWh/yr (37%) from Diesel Generator making a total of 286,172kWh/yr (100%) as shown in Figures 1.8 and 1.9, respectively. The load demand is 208,065kWh/yr, while the excess electricity from the diesel only system is 36,903kWh/yr (15%) and the hybrid system has 78,107kWh/yr (21%) as shown in Table 1.6.

The operational life of the diesel in hybrid system is high (6.57yrs) when compared with diesel only system (2.28yrs). This is because, out of 8,760hr/yr, only 3,043hr/yr was used by diesel in hybrid system to produce 106,989kWh/yr; whereas in diesel only system, its operating hours is 8,760hr/yr and produces 244,968kWh/yr thus reducing its operational lifetime to 2.28yrs as shown in Table



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Diesel Generator	675,000	2,093,792	75,588,016	1,185,962	-4,718	79,538,056
System	675,000	2,093,792	75,588,016	1,185,962	-4,718	79,538,056

Fig. 1.6. Net present cost of component of diesel only system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	840,000	224,500	0	0	-125,819	938,680
Diesel Generator	675,000	592,804	26,257,350	481,956	-18,519	27,988,592
Surrette 6CS25P	25,200	17,855	6,136	0	-5,126	44,065
Converter	10,100	3,118	0	0	-1,747	11,471
System	1,550,300	838,276	26,263,482	481,956	-151,212	28,982,802

Fig. 1.7. Net present cost of component of optimized hybrid diesel- pv energy system.

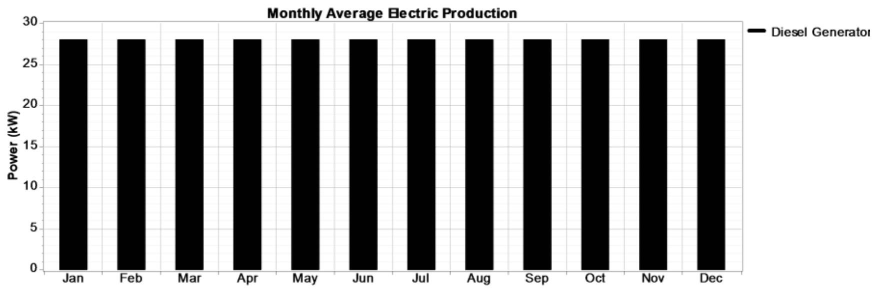


Fig. 1.8. Electrical production of diesel only energy system

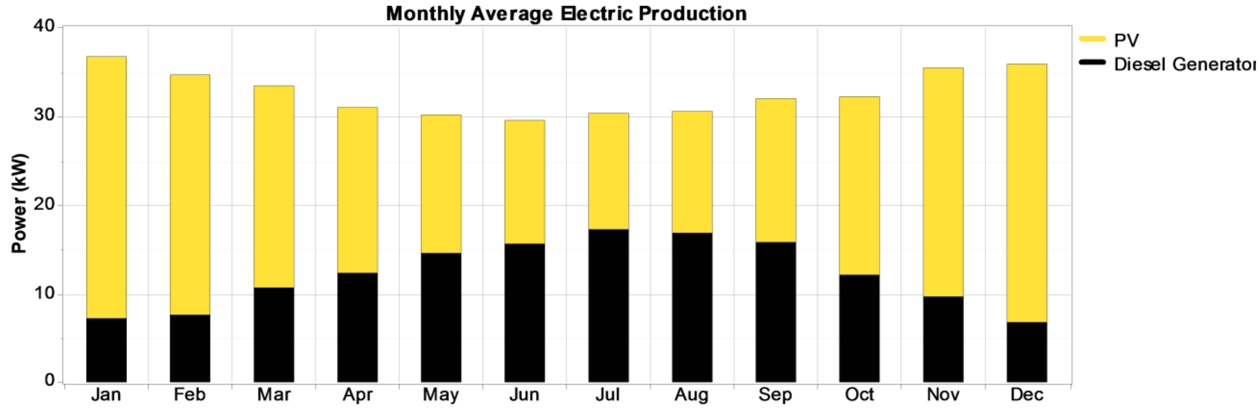


Fig. 1.9. Electrical production of hybrid PV-diesel energy system

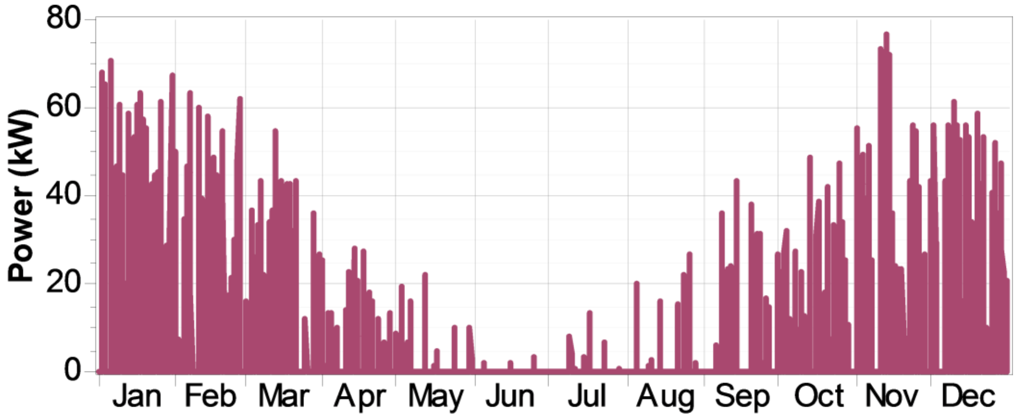


Fig. 1.10. Excess electricity generated by the hybrid PV/diesel energy system

1.8.

Pollutant Emissions

Diesel only system operates for 8,760hrs/yr and has a fuel consumption of 92,774L/yr as shown in Table 1.8. It emits 244,304kg of CO_2, 603kg of CO, 66.8kg of UHC, 45.5kg of PM, 491kg of SO_2, and 5,381kg of NO_x as shown in Table 1.7.

In hybrid PV/diesel system, the diesel system operates for 3,043hrs/yr and has a fuel consumption of 37,702L/yr as shown in Table 1.8. This system generates 99,281kg of CO_2, 245kg of CO, 27.1kg of UHC, 18.5kg of PM, 199kg of SO_2, and 2,187kg of NO_x annually as shown in Table 1.7. The difference in the quantity of different air pollutants from hybrid system compared to that of diesel only are thus: 145,023kg of CO_2, 358kg of CO, 39.7kg of UHC, 27kg of PM, 292kg of SO_2, and 3194kg of NO_x. These differences in the amount of emission would be prevented from entering into the atmosphere annually by the proposed hybrid system, when compared with the diesel only system.

Excess energy = [Total energy Production – (battery losses + Total energy Consumption)]. Excess energy = [286,172 – (19,193+208,065)] = 58,914**kWh/year**.

The excess electricity occurs in almost all the months with most in November (as can be clearly seen in Fig. 1.10). This excess electricity of about 21% power supply is guaranteed in the location simulated in order to give room for future digital expansion or can be sold to nearby schools or facilities. The sale of this excess electricity will offer a promising approach for digital library to finance operations and maintenance costs of the hybrid system.

Table 1.5. Comparison of simulation results of economic cost

Parameter	**Diesel only system**	**Hybrid PV-diesel System**
Initial Cost	$675,000	$1,550,300
Operating Cost	$6,169,195	$2,145,954
Levelized Cost($/kWh)	$29.904	$10.897
Total NPC	$79,538,016	$28,982,802

Table 1.6. *Comparison of simulation results of electricity production (kWh/yr)*

Quantity	**Diesel only system**		**Diesel in Hybrid System (PV-diesel)**	
	kWh/yr	%	kWh/yr	%
Load				
AC primary load	208,065	100	208,065	100
Battery losses	-	-	19,193	-
Production				
PV array	None	None	179,183	63
Diesel Generator	244,968	100	106,989	37
Total energy	244,968	100	286,172	100
Excess electricity	36903	15	58,914	21

Table 1.7. Comparison of simulation results of emissions from diesel only and diesel in hybrid system

Pollutant	Emissions (kg/yr)		
	Diesel only System	PV-diesel system	Differences in System Emission
Carbon dioxide (kg/yr)	244,304	99,281	145,023
Carbon monoxide (kg/yr)	603	245	358
Unburned Hydrocarbons (kg/yr)	66.8	27.1	39.7
Particulate matter (kg/yr)	45.5	18.5	27.0
Sulfur dioxide (kg/yr)	491	199	292
Nitrogen oxide (kg/yr)	5,381	2,187	3194

Table 1.8. Comparison of simulation results of characteristics from diesel only and diesel in hybrid system

Quantity	**Diesel only system**		**Diesel in Hybrid System (PV-diesel)**	
	Value	Units	Value	Units
Operational life	2.28	yr	6.57	yr
Capacity factor	62.1	%	27.1	%
Hours of operation	8,760	hr/yr	3,043	hr/yr
Fuel consumption	92,774	L/yr	37,702	L/yr

6. Conclusion

This paper proves that using hybrid system to power digital libraries is far better than the conventional diesel system in economic and environmental point of view. From the simulation results, the hybrid PV-Diesel system saves and reduces both the economic cost ($50,555,214) and the amount of CO_2 (145,023kg) emitted when compared with the diesel only. In summary, the results demonstrate that the hybrid PV-Diesel system provides greater flexibility, higher efficiency, lower costs and minimum environmental impact than diesel only system for the same energy quantity produced.

References

[1] Population Nigeria's over 167 million population: Implications and Challenges. http://www.population.gov.ng/ Last Updated on Monday, 05 March 2012 14:46

[2] Ani, Vincent Anayochukwu (2013) Energy Optimization of Power Station for a Small Research Institute. International Journal of Energy Optimization and Engineering (IJEOE). Volume 2, Issue 2, 15-31DOI: 10.4018/ijeoe.2013040102 Publisher IGI Global

[3] Bala, E.J., Ojosu, J.O. and Umar, I. H. (2000). Government Policies and Programmes on the Development of PV Sub-sector in Nigeria. Nigerian Journal of Renewable Energy, Vol. 8, No. 1&2, pp. 1-6.

[4] Chendo, M. A. C. (2002). Factors Militating Against the Growth of the Solars-PV Industry in Nigeria and their Removal. *Nigerian Journal of Renewable Energy* 10 (1&2), 151-158.

[5] Ani, Vincent Anayochukwu (in press) Optimal Operational Strategy for Hybrid Power Generation at GSM Base Station Site. International Journal of Energy Optimization and Engineering (IJEOE). Publisher IGI Global

[6] Shaahid S. M. and El-Hadidy M.A., (2003) Opportunities for Utilization of Stand-Alone Hybrid (Photovoltaic+Diesel+Battery) Power Systems in Hot Climates', Renewable Energy, Vol.28, No.11, pp.1741-1753

[7] Shaahid S. M. and El-Hadidy M.A., (2004) Prospects of Autonomous/Stand-Alone hybrid (Photovoltaic+Diesel+Battery) Power Systems in Commercial Applications in Hot Regions', Renewable Energy, Vol.29, No.2, pp.165-177

[8] Ani, Vincent Anayochukwu and Emetu, Alice Nnene (2013) Simulation and Optimization of Photovoltaic/diesel hybrid system for health service facilities in rural environments. Vol. 1, No. 1, DOI: 10.7770/ejee-V1N1-art521. Electronic Journal of Energy and Environment (EJEE)

[9] Morgan T., Marshall R. and Brinkworth B., (1997) "ARES"- A Refined Simulation Program for the Sizing and optimization Of Autonomous Hybrid Energy Systems', Solar energy, Vol.59, Nos.4-6

[10] Peterson A J, Perez R, Bailey B and Elsholz K. (1999) Operational experience of a residential photovoltaic hybrid system. Solar Energy 65, 227–235

[11] Ani, V. A. (2012). Energy Optimization at Telecommunication Base Station Sites. Unpublished doctoral dissertation, University of Nigeria, Nsukka. Nigeria

[12] Elhadidy MA, Shaahid SM. (2004). Role of hybrid (wind + diesel) power systems in meeting commercial loads. *Renewable Energy,* 29 (12), 109–18

[13] Nema, P., Nema, R.K., Rangnekar, S. (2007, March). *'Sizing and methodology of PV/wind hybrid energy systems'* Paper presented at the national conference of power electronics & intelligent control held at Malaviya National Institute of technology, Jaipur (rajasthan), India

[14] De Vries, H.F. and Francken, J.C. (1980). Simulation of a solar energy system by means of electrical resistance. *Solar Energy*, 25: 279–281

[15] Elliot D., Schwartz M., Scott G., Haymes S., Heimiller D., and George R., (2003) "Wind Energy Resource

Atlas of Sri Lanka and the Maldives," National Renewable Energy Laboratory

[16] Rehman, S., El-Amin, I.M., Ahmad, F., Shaahid, S.M., Al-Shehri, A.M., Bakhashwain, J.M., Renne D., George R., Marion B., Heimiller D., and Gueymard C., (2003) "Solar Resource Assessment for Sri Lanka and Maldives," National Renewable Energy Laboratory, Colorado

[17] Lambert T., Gilman P., and Lilienthal P., (2006) "Micropower System Modeling with HOMER," in *Integration of Alternative Sources of Energy*, F. A. Farret and M. G. Simoes, Eds.: John Wiley & Sons.

[18] Lilienthal P., Gilman P., and Lambert T., (2005) "HOMER the micropower optimization model," National Renewable Energy Laboratory.

[19] Borowy, B.S. & Salameh, Z.M., (1994) Optimum Photovoltaic Array Size for a Hybrid Wind/PV System, *IEEE Transaction on Energy Conversion*, Vol. 9, No. 3, 1994, pp.482-488.

[20] Dufo-Lopez, R., & Bernal-Augustin, J.L., (2005) Design and Control Strategies of PV-Diesel Systems Using Genetic Algorithm, *Solar Energy*, Vol. 79, 2005, pp. 33-46.

[21] Ashari M, Nayar CV. (1999), An optimum dispatch strategy using set points for a Photovoltaic (PV)–Diesel–Battery hybrid power system. Solar Energy 1999; Vol.66 (1):1–9.19

[22] Seeling-Hochmuth, G.C (1998) “Optimization of hybrid energy systems sizing and operation control, A Dissertation presented to the University of Kassel in Candidacy for the Degree of Dr.-Ing.

[23] Nfah, E.M., Ngundam, J.M., Vandenbergh, M., Schmid, J., (2008). Simulation of off-grid generation options for remote villages in Cameroon. *Renewable Energy*. 33 (2008) 1064–1072

[24] Shash, A., (2007) Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant. *Renewable and Sustainable Energy Reviews*, Volume 11, Issue 4, 635-653

[25] Georgilakis, P.S., (2005) State-of-the-art of decision support systems for the choice of renewable energy sources for energy supply in isolated regions, *International Journal of Distributed Energy Resources*, 2 (2), 129-150

[26] Khan, M.J., Iqbal, M.T., (2005) Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland, *Renewable Energy*, 30 (6), 835-854

[27] Shaahid, S.M., El-Amin, I., Rehman, S., Al-Shehri, A., Bakashwain, J., Ahmad, F., (2004). Potential of autonomous/off-grid hybrid wind-diesel power system for electrification of a remote settlement in Saudi Arabia, *Wind Engineering*, 28 (5), 621-628

[28] Lilienthal, P., Lambert, T., Gilman, P., (2004) Computer modeling of renewable power systems. In (Ed.) Cleveland, C.J., *Encyclopedia of Energy*, Elsevier Inc., Volume 1, pp. 633-647

[29] Adebiyi, G.A., Nsofor, E.C., Steele, W.G., and Jalalzadeh- Azar, A.A. (1997). Optimisation of a class of latent thermal energy storage systems with multiple phase-change material. *ASME Journal of Solar Energy Engineering*, 120(1): 14–19.

[30] Postgraduate Studies Prospectus (2012) University of Nigeria, Nsukka

[31] UNN geographical Location (2012) http://wikimapia.org/1455825/University-of-Nigeria-Nsukka-Enugu-State.

[32] NASA (2012). Atmospheric Science Data Center http://eosweb.larc.nasa.gov/sse/2012.

[33] Seeling-Hochmuth, G. (1997) “A Combined Optimization Concept for the Design and Operation Strategy of Hybrid PV Energy Systems”, Solar Energy, Vol. 61, No. 2, pp.77-87, Elsevier Science Ltd.

[34] Seeling, G. C. (1995) “Optimization of PV-Hybrid Energy System Design and System Operation Control Using Genetic Algorithms”, in Proc. of the 13th EC PV Conference, Nice, France, pp. 4.

[35] Sidrach de Cardona M. and Mora Lopez L.I. (1992) Optimizing of hybrid photovoltaic generator systems for installations of rural electrification. In *Proceedings of the* 11*th* *European Photovoltaic Solar Energy Conference*, pp. 1287– 1290, Montreux.

[36] Kaye J. (1994) Optimizing the value of photovoltaic energy in electricity supply systems with storage. In *Proceedings of the* 12*th European Photovoltaic Solar Energy Conference*, pp. 431–434, Amsterdam.

[37] Muselli. M., Notton. G. & Louche. A., (1999). Design of Hybrid-Photovoltaic Power Generator, with Optimization of Energy Management *Solar Energy* Vol. 65, No. 3, pp. 143–157, 1999

[38] Ani, V. A. & Nzeako, A. N (2012). Energy optimization at GSM Base Station located at rural areas. International Journal of Energy Optimization and Engineering (IJEOE) Volume 1. Issue 3. DOI:10.4018/ijeoe.2012070101.

[39] Kamaruzzaman, S, Ahmad. F, Mohd. H. R, Mohd. Y, S, Mohammad. A. A, Muhammad. Y, Nowshad. A, Lim. C. H, Azami. Z, (2009), Optimization of a stand-Alone Wind/PV Hybrid System to provide Electricity for a house in Malaysia. Proceedings of the 4th IASME/WSEAS International Conference on Energy & Environment