*Quest Journals*
*Journal of Electronics and Communication Engineering Research*
*Volume 3 ~ Issue 9 (2017) pp: 01-14*
*ISSN(Online) : 2321-5941*
*www.questjournals.org*

**Research Paper**

# Analysis and Simulation of Electrical Load in aHospital Using Hybrid (Diesel/Solar) System as aBack Up

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Received 22 Aug, 2017; Accepted 28 Sep, 2017 

***ABSTRACT:*** *Photovoltaic/Diesel hybrid off-grid systems provide an effective solution to power supply demands for isolated and remote areas far from grid connections. With the rapid growth in renewable energy systems, the work here presents an optimization model of Photovoltaic/Diesel hybrid system to power a hospital in Abuja. A methodology is developed for calculating the correct size of a photovoltaic hybrid system and for optimizing its management. The simulation was done using HOMER and PVSyst find the optimum combination and sizing of the components.Based on electricity demand profiles and current costs, the analysis shows a payback time is still too long. However, with the declining costs of photovoltaic technology predicted for the next few years and the continuously increasing costs of diesel, the hybrid system tends to become economically viable.*

***Keywords****: Renewable Energy, Hybrid System, Off-grid Electrification, Optimization Methods, Energy System Design, HOMER*

## I. INTRODUCTION

In developing countries such as Nigeria, more than 60% of the population lacks electricity and this really holds back their social, economic, health and educational development [Yamegueu et al., 2010]. This situation is more catastrophic in rural areas with less than 12% of their population has access to electricity. The Abuja Hospital has been using a diesel generator (DG) as a back-up supply in the event of loss of powerfrom the grid. This has not been economical for the hospital and as such it is deemed necessary to provide the hospital with a hybrid system.The West African region is strongly dependent upon fossil fuels and studies have shown that fossil fuel is being exhausted and with the threat of global warming worldwide, renewable energy sources is the future with significant solar energy potential ranging from 4 to 6 kWh/m$^2$/day. They have different applications ranging from single energy production, stand-alone or grid-connected systems or a combination with other forms of energy generations to produce a hybrid system [Joyashree and Soma,1999]. Solar energy resources seem to be the most popular choices for renewable energy, however they have their drawback which is its unpredictable nature. This simply means the energy produced by the solar and the electricity demand time distributions do not match. This usually leads to extensive use of independent solar systems which results in over-sizing in terms of system reliability and overall over-cost [Post and Thomas, 1992].
To design the system, the load analysis of the hospital was done first to enable us to determine the size of the system. Thesoftware HOMER, PVSyst were used tosimulate the system enabling to get the optimal system configuration for the location while PVGIS to get the solar irradiation of the region as the solar irradiance is also an important parameter to consider. The study investigates the possibilities of integrating solar energy into a DG power plant using a maximum power point tracker (MPPT) to track the sun for optimal output of the system.

### Overview of Hybrid System

Hybrid energy systems generally integrate renewable energy sources with fossil fuel powered diesel/petrol generator to provide electric power where the electricity is either fed either directly into the grid or to other forms of energy storage such as batteries etc [Gupta et al., 2002]. Research on hybrid power systems combining renewable and fossil derived electricity started sometime in the mid-eighties [Jacobus, 2010]. Hybrid systems literature was not popular until the early 1990s when the need to increase grid stability and reliability became imperative as large quantities of wind power were being added to small autonomous grids [Contaxis et al., 1991]. Optimization technique became a tool which researchers used to model how hybrid systems could reduce electricity generation cost over conventional fossil fuel systems.

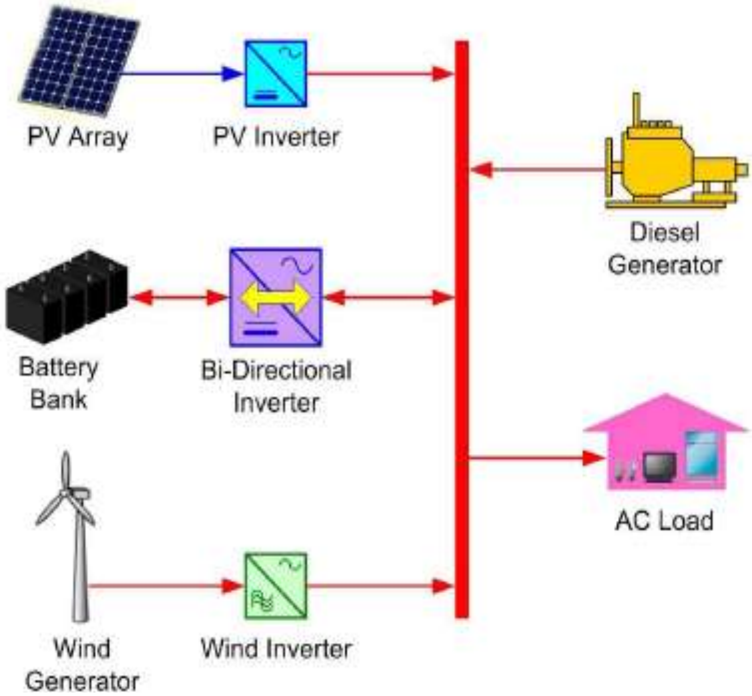



**Figure 1:** Simple schematic of a PV/Wind/Diesel Hybrid System [Nayar, 2007]

Solar energy is a non-polluting source of energy which is the conversion of energy from sunlight into electricity. This could be achieved directly using photovoltaic (PV) or indirectly using concentrated solar power (CSP) [Energy Resources, 2011].The photovoltaic module converts sunlight to electric current by photovoltaic effect while concentrated solar power systems focus large area of sunlight into a small beam by use of lenses or mirrors and tracking systems [Panapakidis, 2009]. Ioannis, 2009 evaluated two different hybrid systems in four regions in Greece with different solar and aeolic capacities. The first one involves a Photovoltaic system and a Diesel generator while the other one considers a wind turbine (WT) together with a Fuel cell (FC). The results show high initial capital cost of the FC units, the WT/FC hybrid system has higher total cost compared with the PV/DG hybrid [Vosen and Keller, 2001]. Another study on the design of a hybrid-photovoltaic power generator with optimization of energy management to supply small and medium power levels to remote area in Ajaccio, Corisca ($41^0$ 55'N, $8^0$ 39'E) was taken. The result indicate that gasoline powered engine generators are optimal when combined with 75% of solar with 25% fossil and A 3000-rpm diesel powered engine-generators is most economical with 80% solar and 20% fossil.While for a 1500-rpm diesel powered engine generator, the optimal combination is 65% solar with 35% fossil because of the diesel generator longer lifetime.

From the analysis, we could identify the percentages and kind of energy source combination we require to set up an optimal system. Abuja hospital already uses a 1500-rpm operational generator as a back-up which has a longer life span than the 3000-rpm due of its low rotational speed.A technical and economic analysis of a PV/Hybrid system applied to rural electrification for isolated communities in northern Brazilian region identifiesthe economic viability of hybrid system projects which is still strongly dependent on government subsidies [Denizer, Edson, and Ricardo, 2002]. Another project in rural Brazil converted diesel-only mini-grid into a hybrid system. The diesel consumption data shows that similar PV/diesel systems with no battery storage can reduce diesel consumption [Jacobus, 2010]. In Alaska, a system was examined using Simulink of a PV/diesel/battery, they compared the system with only a diesel generator and another diesel/battery system in supplying the same load. Contaminating emissions were also evaluated ($CO_2$, $NO_x$ and particles) for the different systems. Weis et al, 2005the result indicates that the system with only diesel generator is lower in installation cost, but has a higher operation and maintenance cost (O&M); additionally, lesser efficient and released more contaminating emissions than the PV/diesel/battery system. Chedid, 2000 a software and electrical engineer created personal software that he coulduse to predict the operational cost of a hypothetical autonomous PV/Wind/Diesel system and his result shows that the inclusion of renewable energy into a diesel power plant would reduce the operational cost of the plant substantially. An investigation of the control approach and design consideration of PV/Diesel hybrid distributed generation system used dual voltage source inverter for weak grid identifying the importance of the dual inverters (VCVSI and CCVSI) in describing the operating conditions and control algorithm [Dehbonie and Lee, 2004]. The experimental results affirm the validity of the system in the presence of different loads presenting it as the ideal solution in the applications such as hybrid power systems and in a weak grid althoughit failed to analyse the economic impacts of the project [El-Hefnawi, 2000].Than, Nabil, and Balakrishna, 2006 investigated the design considerations for upgrading diesel powered system to a hybrid energy system in rural Sarawak and from their analysis, they showed that in the existing generator set, the diesel consumption is almost 4838litres/year, and the COE is 3.46 RM/kWh but when the PV system is integrated with the generator, the COE is reduced to 2.915 RM/kWh and the diesel consumption was 863litres/year. This significant reduction in the consumption of diesel will maintain the COE as diesel prices rise in the future. These investigations helped in our decision and analysis in terms of economic while serving as a part of our reference telling us it supports our idea that we might be able to reduce the running cost of the system. Offiong, 2003 assessed the economic prospects of stand-by powered systems in Nigeria such as solar powered or diesel generators and he concluded that solar systems are economically viable compared to diesel generators, but that diesel-powered plants should be completely substituted for solar power systems.

This project tends to integrate the solar system with the diesel generator and not just integrating the systems but also aiming at being environmentally friendly and cost effective as well.

However, there is a limitation in PV/Diesel hybrid system which is, the total array's energy given to a hybrid system without energy storage cannot be above roughly 10% because of PV's propensity to destabilise a grid [Ruther, 2003].An experimental study onelectricity generation by PV/Diesel hybrid systems without battery storage as batteries generate additional investment costs and maintenance due to periodic replacement of the batteries due to short life time (3-5 years). The result showed that the cost of batteries could represent up to 16%-20% of the total life cycle of a hybrid PV/diesel/battery system [Yamegueu et al., 2011].

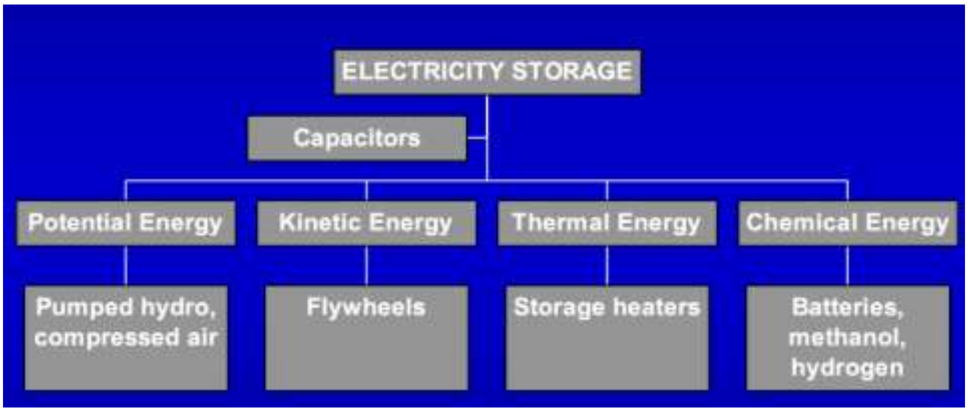



**Figure 2:** Forms of Energy Storage

Elhadidy and Shaahid, 2000 studied the effect of the size of batteries on the operation hours and on the power supplied by the diesel generator in wind/diesel/battery systems. The generator operates only when the wind cannot supply sufficient energy and the batteries are unable to supply the demand. Barley et al., 1999 proposed different kinds of strategies for the operation of hybrid PV/diesel/battery systems. They considered one-hour intervals, during which the system parameters remained constant. They also consider without considering losses or the kind of influence the cycles would have in the life span of the same system. Karakoulidis, 2010 examined an autonomous energy system that combines renewable energy sources and batteries or hydrogen as its storage medium and he could show and conclude that PV/diesel/battery system is the most suitable solution for stand-alone application because hydrogen energy systems COE is higher due to the high capital cost of the electrolyser and the fuel cell. Lopez and Agustin, 2005 examined the optimization of hybrid PV/diesel/battery systems using genetic algorithms and they determined the correct performance of genetic algorithm as a technique for the design of hybrid systems thus, it supports the idea that an optimum system could be achieved. Morinigo-Sotelo et al, 2011 applied neural networks to the control strategies of PV/diesel systems. Knowing the energy demand and the solar irradiation, dynamic programming was used to optimize the operation of diesel generator and minimise fuel costs substantially. They used an adaptive intelligence strategy, comparing the results obtained by applying two types of neural networks. 'Neural networks is an information processing paradigm that is inspired by the way biological nervous systems such as the brain and process information'

Muselli et al., 2002 did a simulation of a hybrid PV/diesel/battery system with a DC load alone in such a manner that the energy produced by the diesel generator goes through the batteries. The DG works at nominal power, provided that the state of charge (SOC) of the batteries is within a determined limit (SDM and SAR). SDM and SAR are the thresholds in battery charge at which the engine-generator is switched on or off, respectively, each expressed as a fraction of the battery capacity.

**Solar Radiation in Nigeria**

Nigeria is a country that has lot of sunlight as it lays between about latitude 9º north and longitude 8º east of the equator [Offiong, 2003]. Lots of investigation has been done on the solar radiation in Nigeria. As a tropical country, the country receives on the average as high as 4.84kWh/m$^2$ per day of solar insolation as such has high potential for solar energy [Adeyemo, 1999]. Arinze, 2000 employed a parameter called peak sun hours to choose the required size of PV system to meet a typical household in Nigeria,the peak sun hours provide the number of hours needed at peak sunray condition to have an equal amount of solar energy for that day.

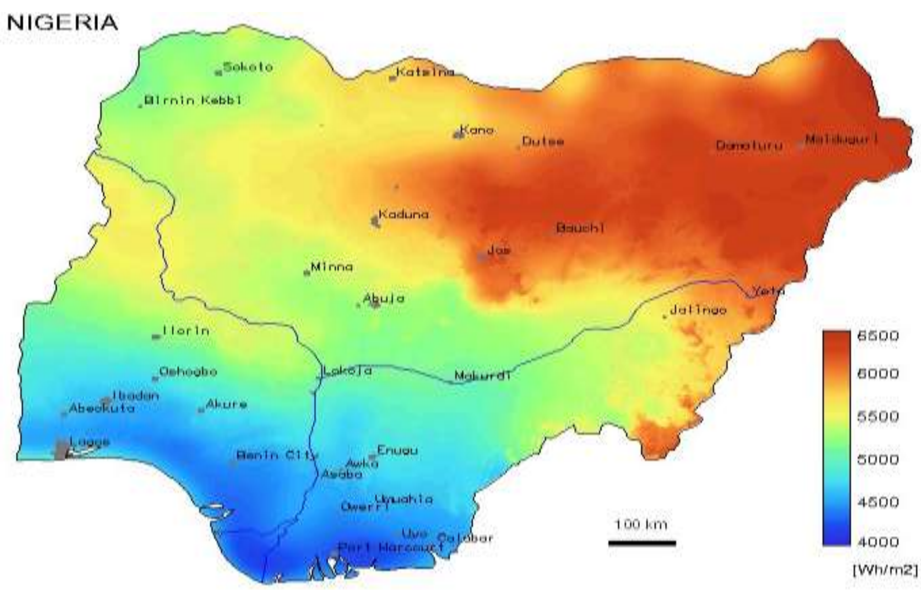



**Figure 3:** Yearly average of daily sums of global horizontal irradiation [Soda, 2014)

The radiation level is high during the summer months (April-August) as compared to other months. The solar radiation varies during different seasons (rainy and dry seasons) and different times of the day as well. Shaahid and elhadidy, 2006 said integration of battery storage or diesel system or with both can meet the required load distribution on a 24-hour basis where theloads require 24 hours power supply as PV system alone cannot meet the demand.

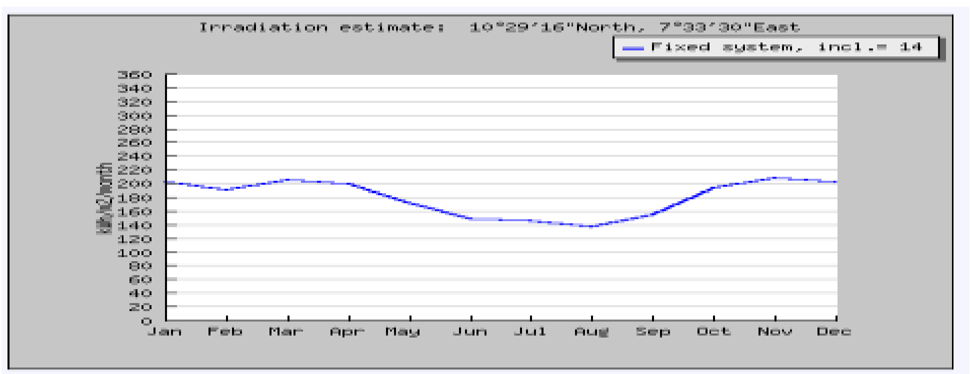



**Figure 4:** Monthly average daily global radiation at Abuja

**Methodology**

In achieving this project simulation, the lifetimes of the units are considerably the same (PV, DG and Inverter) except the batteries because they need to be replaced during their lifetime.

This cost of the system depends on the following:

1. The cost of purchasing PV panels, batteries and inverter.
2. The cost of replacing units throughout the lifetime of the system
3. The cost of operation and maintenance of the DG throughout the systems lifetime.
4. Cost of fuel consumption for DGs throughout the system lifetime.

**Power Design Criteria**

Below are the criteriafor our choice of design system to achieve the system configuration

1. The systemshould reduce the rate at which diesel is purchased, the operational time of the diesel generator thereby reducing operation andmaintenance cost providing long term cost savings[Ahmed and Ramesh,2011].
2. The system should be able to provide power stability to the hospital for 24hrs (previously the generators operated for 15hours per day) so most critical loads in the hospital would not go off again even when there is grid failure.
3. The system should be able to cope with significant daily and weekly power as well as energy fluctuations during the day or the entire week collectively.
4. The system should guarantee ideal battery recharge schedules (maximize battery life) as well improve the system efficiency.
5. Reliability of the system is another important area so the system operation should be reliable in such a way that loss of load probability would be low. It should be robust enough to provide power continually as robustness has precedence over efficiency. It should also be robust under field conditions by coping with the required temperature and humidity.
6. The system should also be able to incorporate load growth in the design as well as system expandability if practicable.

**Load Profile**

A hospital can have a simple or complex emergency power supply system (EPSS) but the technique and ability to ensure that the equipment continues contributing to safe and effective patient care with today's challenges is quite difficult.In a Hospital, different departments are equipped with devices such as refrigerators used for storage of blood and drugs, air-conditioners used to change room temperatures for patients, lightings for illumination, microwave is found in the kitchen.The operating lamp is used during surgery and from the hospital statistics for year 2016, they had general surgery cases amounted to 635 cases and from here we assumed for the operating lamp to operate for roughly 3hrs/day. The incubator is found in the neonatal intensive care unit and the number of incubators was assumed based on the birth rate statistics that says 1,716 deliveries took place in the year 2016 and few cases of premature birth were recorded. There is a central printer that would be used for some important printout and needs to stay on as the grid could fail for the whole day and we assumed an average 2hours/day for the printers and most assumptions on other devices were based on the hospital's previous 5 years statistics. The power consumption table is shown below.

**Table 1:** Hospital Power Energy Consumption

| *APPLIANCES* | Quantity | Power (Watts) | Total Watts | Watt hours/day |
|---|---|---|---|---|
| *Vaccine Fridge* | 2 | 80 | 160 | 6.0-12.0 |
| *Air conditioners* | 2 | 745 | 1490 | 5.0 |
| *Incubator* | 2 | 400 | 800 | 2.0-12.0 |
| *Syringe Pumps* | 2 | 600 | 1200 | |
| *Bloodbank Fridges* | 2 | 50 | 100 | |
| *Lighting* | 40 | 100 | 400 | 12.0 |
| *Hematology Mixer* | 1 | 28 | 28 | 3.0 |
| *Microscope* | 2 | 15 | 30 | 6.0 |
| *Laboratory* | 1 | 165 | 165 | 4.0 |
| *Ventillator* | 1 | 100 | 100 | 2.0 |
| *Curing Light* | 1 | 90 | 90 | 3.0 |
| *Operating Lamp* | 1 | 125 | 125 | 3.0 |
| *Medical Centrifuge* | 1 | 575 | 575 | 3.0 |
| *Microwave* | 1 | 700 | 700 | 2.5 |
| *Washing Machine* | 1 | 450 | 450 | 2.5 |
| *PCand printer* | 1 | 120 | 120 | 2.0 |
| *TV* | 1 | 50 | 50 | 5.0 |
| *Drier* | 1 | 500 | 500 | 2.0 |
| *Ceiling Fan* | 4 | 100 | 400 | 4.0 |
| *Total* | | | 7433 | |

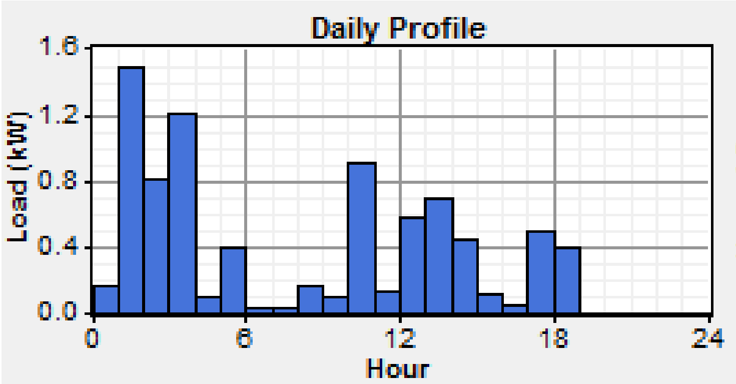



**Figure 6:** The load daily profile

**System Configuration**

The system consist of PV panels for the conversion of sunlight to electric energy, DG in the building, batteries for energy storage, inverters for the conversion of direct currentto alternating current to enable powering of the AC loads [Karasavvas, 2008]. The system also consist of a battery controller which is used to control battery charging by both the PV array and the generator. A maximum power point tracker (MPPT) is a system used to acquire the maximum output it could possibly get from the solar [Putrus, 2011].The DGs are usually connected at AC bus because it produces AC power whereas power from the photovoltaic energy source is DC power which requires inverter to convert DC to AC. Whenever there is less power from the photovoltaic energy source to meet the load demand, ideally the batteries power the load at that time instead of DG because of economical and environmental reasons as this would not consume fuel or cause emission of $CO_2$. Technically, the DG tends to charge the batteries whenever it is switched on to meet load demand, so it meets the load demand and charges the batteries at the same time.

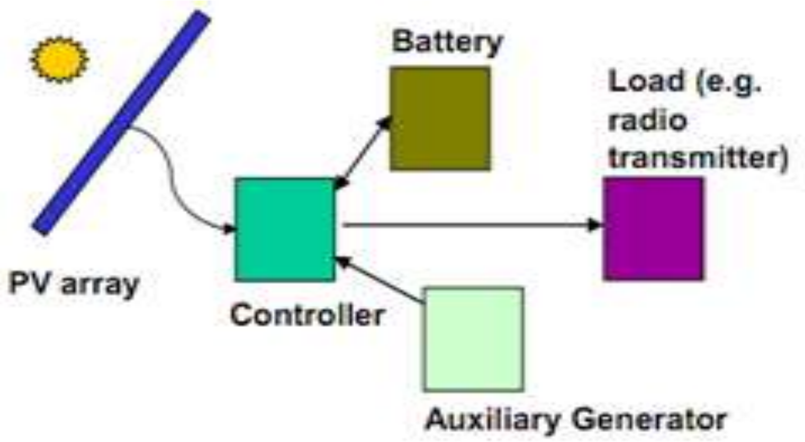



**Figure 7:** Schematic of PV/Diesel Configuration [Pearsall, 2011]

From the design point of view, hybrid systems can be classified into two topologies namely; series and parallel topology.

**Series Topology**

The series topology design allows the diesel generator and the PV source to charge the battery bank. The diesel generator is then connected in series with the inverter to supply the load which means the diesel generator cannot supply the load directly. The inverter (DC/AC) converts DC power from the battery bank to AC power at mains voltage and frequency and supplies the load. The battery bank and the battery capacity are always required to be enough to meet peak load demand, while the diesel generator capacity is also demanded to meet peak load and charge the battery bank at the same time. The power delivered to the battery can be controlled either by controlling the excitation of the alternator or by integrating a charger regulator in the photovoltaic energy source.

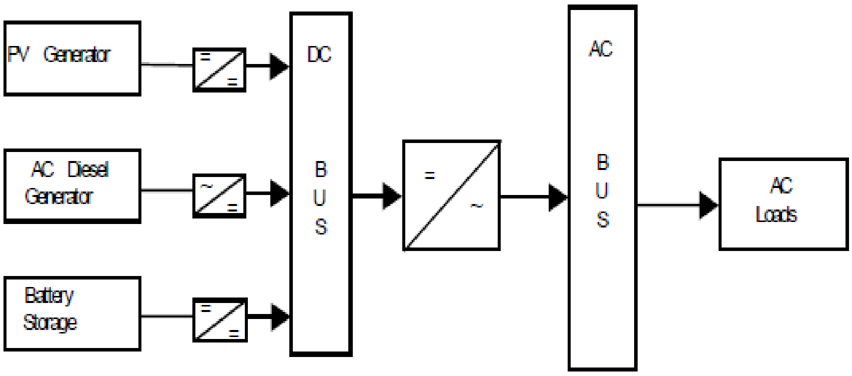



**Figure 8 :** Series Type (Delvecchio et al., 2004)

The merit of this design is that there is no power interruption when changing the diesel generator or the PV generator to charge the battery bank. The draw back is that there is low overall effieciency due to energy lost in switching, inverter failure results on power lost to the load and larger inverfter is required to meet peak load demand.

**Parallel Topology**

In this topology, the PV and the diesel generator supply a portion of the load demand directly, which makes the overall system efficiency high. This design enables the diesel generator and the inverter to operate in stand-alone or parallel mode. This design creates a room for combination of the source to meet the load. The diesel generator or inverter can operate the system in stand-alone mode when the load is low. However, both sources operate in parallel mode during peak load. Due to the parallel operation, the diesel generator and inverter capacity could be reduced. It is a kind of complicated design to implement due to the parallel operation but it has several advantages.

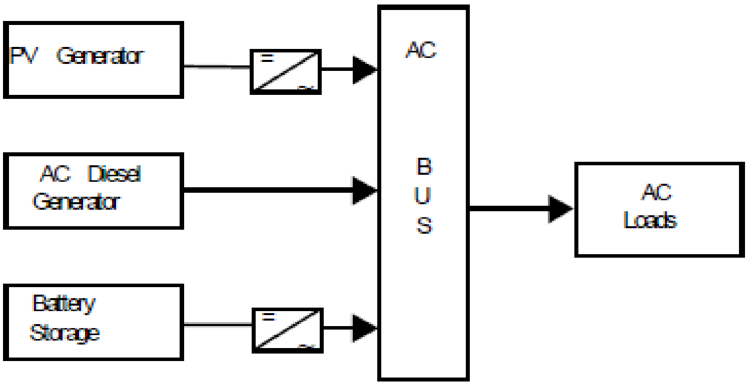



**Figure 9 :** Parallel Type (Delvecchio et al., 2004)

The advantage of this system is that the load can be met in an optimal waybecause both sources could be running same time during peak load and stand-alone during low load, diesl fuel efficiency can be maximised and maintenace cost reduced while the reducing the capacities of the PV, diesel and battery while meeting the load peaks. But this system is complex and requies sophisicated eqiupment.

**Photovoltaic Panels**

The performance of PV modules depends on the temperature and solar irradiance. A stepping motor (MPPT) is attached to the panel to enable it track the sun. The modules would be mounted on a system so that they can move the modules in the south direction and also tilt them at an angle from the ground so the modules can always point at the sun. The PV panel area has to be perpendicular to the sun to enhance maximum output. This modules are connected in an array in series or parallel connection to achieve the desired power output. The PV power output characteristics are peak power, voltage at peak power, current at peak power, short circuit current and open circuit voltage [PVGIS, 2011]. The PV model could be modelled based on the following equation

$$P_{PV}(t) = ŋ.\ A_p.\ N_{PV}.\ I_{ns}(t) \quad \ldots\ldots(1)$$

Where;

ŋ : Energy conversion efficiency (%)

$Ap$ : Area of single PV panels ($m^2$)

$N_{PV}$ : Number of PV panel

$I_{ns}(t)$ : Insolation data ($W/m^2$)

**Diesel Generator**

Bugaje, 1999 survey shows that DGs are mainly used in households, small scale businesses and hospitals in Nigeria to enable standby supply of power. A survey was also done on the existing DG. This120kWsystem(non-hybrid) is usually noisy, consumes lots of fuel and required regular maintenance cost. The DG has 1500rpm engine with a life expectancy to function actively is 15000hours [Musellliet al. 1999].

The fuel consumption could be calculated as;

$ŋ_c = P_G / PCI_V Q_V$............................................................ (2)

$Qv / Q^0_v = ɣ + ξ\, P_G / P^0_G = [1 - P^0_G / ŋ_c.PCI_v.Q^0_v] + [\, P^0_G / ŋ_c.PCI_v.Q^0_v]\, P_G/P^0_G$…….(3)

Where;

ŋ = Generator Efficiency (%)

$P_G$ and $Q_v$ = Generator power (kW)

$P^0_G$ and $Q^0_v$ = Rated power and consumption at the rated power

$PCI_v$ = Heating value of the diesel usually $10.08kWh.1^{-1}$

**Batteries for Energy Storage**

The batteries play a vital role in off-grid systems such as this project. Batteries operate under specific conditions which must be allowed for in the system design because they affect both the batteries life and the efficiency of the battery operation[Soe et al., 2006].Abd and Nafeh, 2010analysis below determines the charge/discharge percentage of the battery that usually does not exceed a given value for safe operation.

- Calculation of the seasonal energy deficit; This simply balances the energy for the year by setting the energy balance in a way that the energy produced during the excess period (summer) can be stored effectively to cover the cumulative energy deficit during the worst season (winter). Thus, it is easy to calculate the seasonal deficit $\Delta E_s$. It is noted that this energy deficit depends on the choice of the array size Ns × Np and on sunshine period of each month.
- Calculation of the daily energy deficit; Due to energy system maintenance, failure, or lack of sunshine which is due to unpredictable weather conditions, it is imperative to have a further stored energy to cover the daily energy deficit for night-time operation and when there is no sunshine at all. The value of the daily energy deficit $\Delta E_d$, which depends only the location of the system [Messenger and Ventre, 2002].

$$\Delta E_d = E_L \times D \quad \ldots\ldots (2)$$

Where $\Delta E_d$is daily energy deficit

$E_L$ is the daily load demand

$D$ is the number of storage days

- Determination of the battery life; Batteries are primarily used for storage of excess energy generated in such systems. Therefore, the battery size must be capable to supply the load with both the daily and seasonal energy deficits. When sizing batteries, we define the depth of discharge (DOD) which is the selected maximum permissible depth of discharge of the battery (80% is allowed here). Secondly is the battery autonomy (WHO recommended atleast 5 days) then, the required battery capacity could be determined by the equation below;

$C_n = \Delta E_s + \Delta E_d / VDC \times TDF \times ŋ_B \times DOD$……………..... (3)

Where; $C_n$ is battery nominal capacity

VDC is the DC voltage

TDF is the temperature derating factor

After this, the number of batteries in the system could be determined from;

$$N_B = C_n / C_B$$

Where $C_B$ is the nominal capacity of a single battery.

After the computation, the system designer carefully rounds up to integer to satisfy the requirements of the battery bank configuration. The batteries could be connected in series and parallel strings [Pearsall, 2011].

**Inverter**
The inverter connects the PV system and the DG, inverter converts the DC power generated by the PV array to AC power to enable it to feedthe AC loads [Yamegueuet al., 2010].

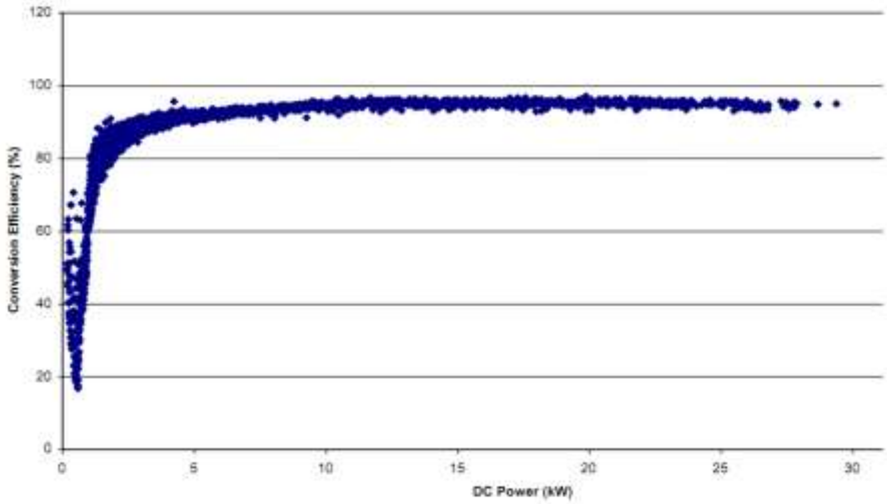



**Figure 11:** Typical Inverter efficiency as a function of PV DC power [Pearsall, 2011]

Figure 11 illustrate low DC input power loses more power than high DC power. Up to 70% of incoming energy to the inverter could be lost while the inverter efficiency for high DC power is around 95%, only 5% of the incoming energy is lost [Yamegueu et al., 2011].

**Software Analysis and Results**
Software such as the HOMER, PVSyst, PVGIS and Matlabwere used in the simulation to test the system limitations and to define its operating parameters.There are five designs which were simulated using the HOMER to evaluate and compare their COE (cost of energy), capital cost and state of battery charge. The results obtained are shown in detail below. The solar irradiation level was first calculated and the probable system load was tested. Several tests were undertaken on the hybrid system in the laboratory hardware.Software testing was used toanalyse how the system will perform with the available solar irradiation and the diesel/battery as well based on the design criteria of Abuja ($9^0$ 12' North latitude and $7^0$ 11' East).

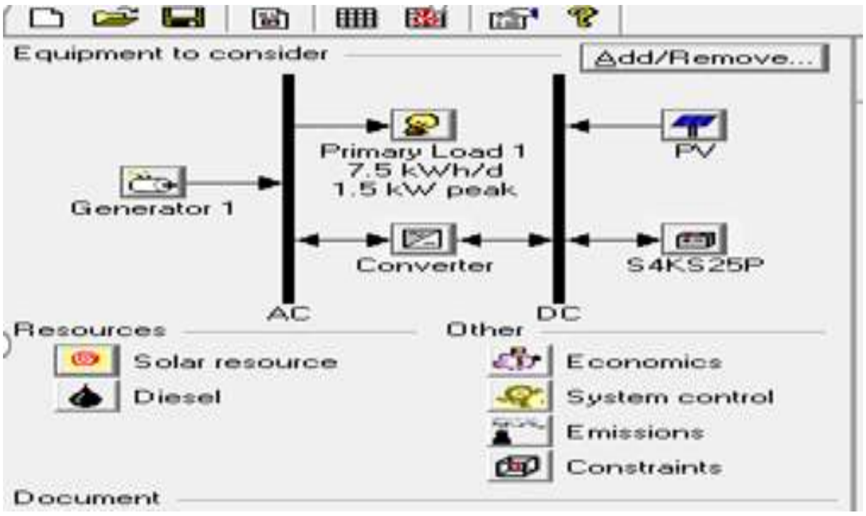
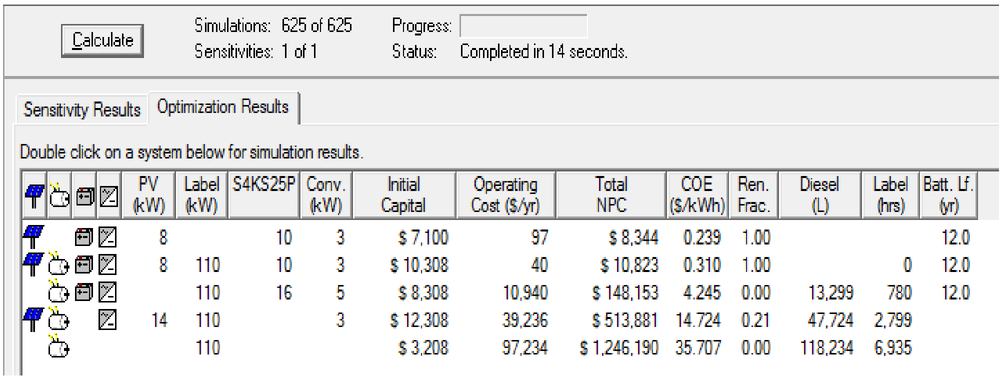



**Figure 12:** The system to be simulated



Calculate    Simulations: 625 of 625    Progress:
Sensitivities: 1 of 1    Status: Completed in 14 seconds.

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

| PV (kW) | Label (kW) | S4KS25P | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Label (hrs) | Batt. Lf. (yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | | 10 | 3 | $ 7,100 | 97 | $ 8,344 | 0.239 | 1.00 | | | 12.0 |
| 8 | 110 | 10 | 3 | $ 10,308 | 40 | $ 10,823 | 0.310 | 1.00 | | 0 | 12.0 |
| | 110 | 16 | 5 | $ 8,308 | 10,940 | $ 148,153 | 4.245 | 0.00 | 13,299 | 780 | 12.0 |
| 14 | 110 | | 3 | $ 12,308 | 39,236 | $ 513,881 | 14.724 | 0.21 | 47,724 | 2,799 | |
| | 110 | | | $ 3,208 | 97,234 | $ 1,246,190 | 35.707 | 0.00 | 118,234 | 6,935 | |

**Figure 13:** The optimization of 5 different systems simulated

**Photovoltaic Analysis**

For the PV subsystem, we assume a constant PV efficiency $\eta_{PV}$ of 10%. The PV power production is $P_p(t)$ is computed by multiplying the PV efficiency, hourly radiation and the PV module area (Iskander and Scerri, 1999). The module area is about 150m$^2$and the thin film technology (a-Si)was chosen because it is agood technology for large area deposition with amorphous silicon layers deposited by plasma enhanced chemical vapour deposition (PECVD).

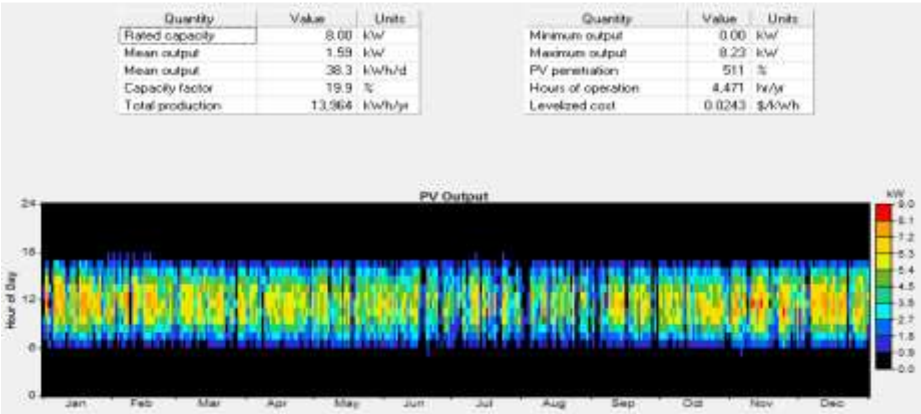



**Figure 14:** The PV Output

| Month | Clearness Index | Daily Radiation (kWh/m2/d) |
|---|---|---|
| January | 0.612 | 5.429 |
| February | 0.623 | 5.952 |
| March | 0.599 | 6.127 |
| April | 0.614 | 6.462 |
| May | 0.603 | 6.292 |
| June | 0.581 | 5.974 |
| July | 0.500 | 5.152 |
| August | 0.486 | 5.061 |
| September | 0.547 | 5.616 |
| October | 0.636 | 6.178 |
| November | 0.662 | 5.956 |
| December | 0.639 | 5.504 |
| Average: | 0.589 | 5.805 |

**Table 2:** Months and daily radiation

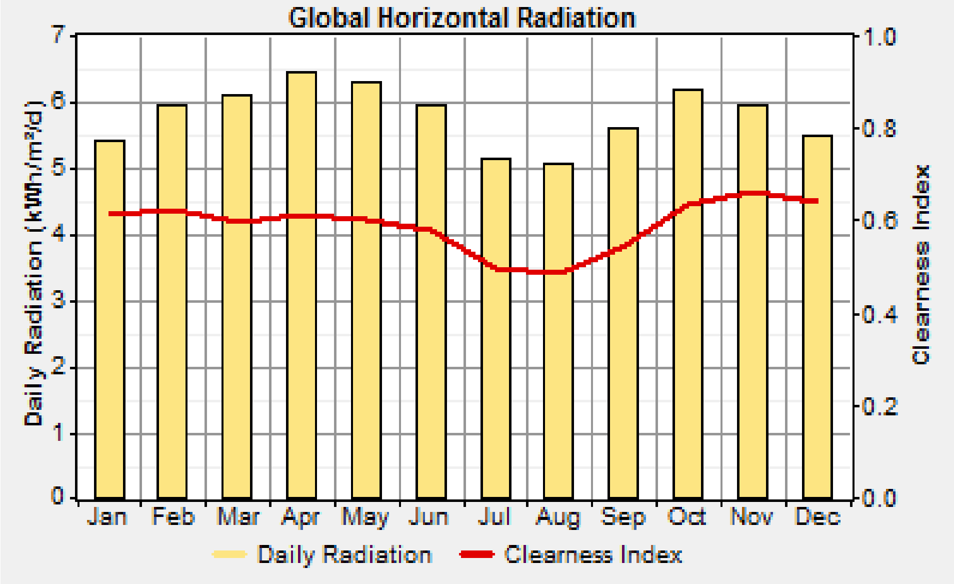



**Figure 15:** Solar Radiation Data of the Region

The tracker was used to track the sun even during the winter periods of July and August which had the least radiation of 5.152kWh/m$^2$/d and 5.061kWh/m$^2$/d respectively.

| | |
|---|---|
| Rated Capacity | 10 kW |
| Mean Output | 1.9kW |
| Mean Output | 38.3kwh/d |
| Capacity Factor | 19.9% |
| Minimum Output | 0.00kW |
| Maximum Output | 8. 23kW |
| PV penetration | 511% |
| Hours of operation | 4,471hr/yr |
| Levelised cost | 0.0243£/kWh |

**Table 2**: PV Specifications

**Diesel Generator Parameters**

DGs system design involves selecting a locally available unit that is closest to the peak load requirements of the application [Abd and Nafeh, 2010]. The DG operates most efficiently when running between 80-90% of its rated capacity and become less efficient as the load decreases [El-Hefnawi, 1999].

| Type | Marapco |
|---|---|
| Nominal Power kW | 120 |
| Velocity (rpm) | 1500 |
| Voltage (V) | 400/230 |
| Maximum Current (A) | 17 |
| Dimensions : L × l × h (mm×mm×mm) | 1405 ×715 × 1053 |
| Weight (kg) | 438 |

**Table 3:** Diesel Generator Specifications

**Battery Bank**

The type of batteries used in the battery bank is the lead-acid batteries. The batteries were used because of their deep cycle feature and the location temperature is ideal for their optimum operation.

| String size | 1 |
|---|---|
| Strings in parallel | 10 |
| Number of Batteries | 10 |
| Bus Voltage (V) | 4 |
| Nominal capacity | 76.0Kwh |
| Usable nominal capacity | 45.0Kwh |
| Autonomy | 120hours (5Days) |
| Lifetime throughput | 105,686Kwh |

**Table 4:** Batteries specifications

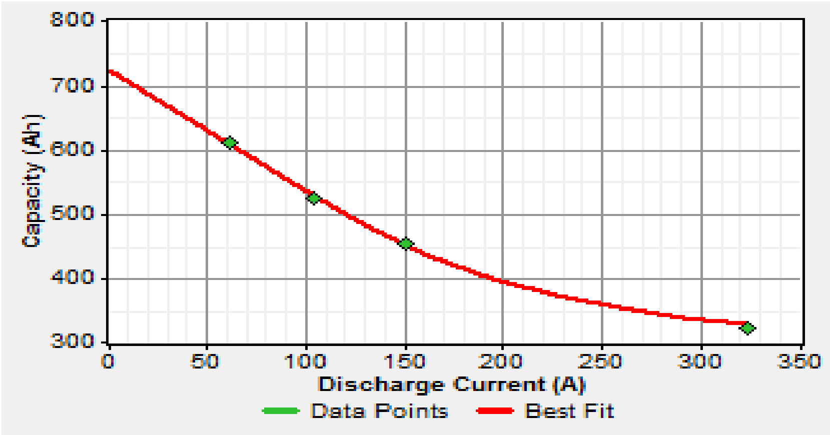



**Figure 16:** Batteries discharge current vs capacity graph

The sizing technique ensured the optimum and safe operation for both the selected sizes of the DG and the battery bank. The battery life is enhanced provided the SOC remains near 100% or returns to that state as quickly as possible after a partial or deep discharge condition [Ashok, 2007].

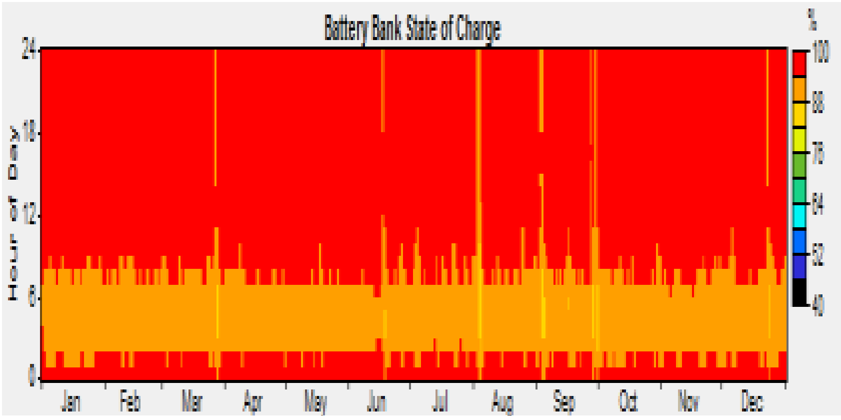



**Figure 17:** Battery bank state of charge

| **Capacity** | **3kW** |
|---|---|
| **Mean Output** | 0.31kW |
| **Minimum Output** | 0.00kW |
| **Maximum Output** | 1.49kW |
| **Capacity factor** | 10.4% |
| **Hours of operation** | 6,935hrs/y |
| **Energy in** | 3,034kWh/yr |
| **Energy out** | 2,730kWh/yr |
| **Losses** | 303 kWh/yr |

**Table 5:** Inverter specification

**Operational Mode**

The parallel system of configuration was chosen as the optimal pattern for the system because it is more reliable, it could allow both energy sources to operate at the same time. During its operation, the power generated from PV panels charges the batteries if the load demand is low, if the excess power is higher than the inverter capacity, the batteries are charged as amount as inverter capacity while the excess power is dumped. When the load demand is higher than PV source and the batteries SOC is high enough, the insufficiency power will be supplied by batteries. Otherwise, if the SOC of battery is at the minimum, the DG is started to supply the loads and charge batteries as well. However, if insufficiency power is higher than inverter capacity, the batteries are discharged as amount as inverter capacity, then the DG is stared to meet load demand [Ashariet al., 2009].

The control strategy was the predictive control strategy which means the charging of the batteries depends on the prediction of the demand and the energy expected to be generated by means of renewable sources, so there will be a certain degree of uncertainty. This strategy tends to decrease the losses in renewable energies.

| | PV/Diesel | Diesel Alone |
|---|---|---|
| Mean output | 1.9Kw | - |
| Capacity of batteries | 76.0 ×10Kwh | - |
| Diesel Generator Capacities | 120kw | 120kw |
| Project life time | 20yrs | 20yrs |
| SOC minimum of batteries | 20% | - |
| Annual fuel cost | £200 | £500 |
| $C0_2$ emission (ton/year) | 114,250 | 200,430 |

**Table 6:**Comparison of Hybrid with Diesel alone

## II. CONCLUSION

The main goal of this paper was to check the possibilities of integrating PV solar energy and diesel power plant to supply critical loads in an Abuja Hospital. The system relied on the renewable energy source (PV) more than the DG. Apparently, the DG was used for extended periods of low renewable energy input or high load demand. Consequently, making this system economically viability although it is dependent on government subsidies. From this paper, we could say that stand-alone electric generation systems are more suitable than systems that have only one energy source for the supply of electricity to areas that the grid power is not reliable.The DG is optimally sized to meet the peak load with 85% of its rated power. Whereas, the PV array was adjusted to face the south direction with an angle from horizontal that maximises the incident solar radiation and at the same time has an MPPT to help track the sun during the worst months for maximum output. The sizing of the PV modules is based on the module characteristic, system voltage, and the daily energy balance between the PV array and the load. The system batteries were sized in such a way it could can supply the load with both the daily and seasonal energy deficits. Load towards the major power supplier which is the renewable energy source (PV) was limited to help cut cost of energy (COE). We can also agree that, from the investigation, hybrid system have low maintenance cost. The study shows us that for a given hybrid configuration, the number of operational hours of DG decreases with increase in PV capacity. The percentage fuel savings by using hybrid PV/Diesel system is 30% as compared to diesel only system. From the investigation, the contribution of a given load affects the performance of the DG. When the hybrid system operates under loads less than 62% of the DG rated power, the PV contributes substantial power and reduces the performance of the DG. The hybrid is more economic than DG alone system because of the minimization of array size and battery capacity also more environmentally friendly because $C0_2$ emission is reduced to more than 80%.

The results clearly illustrate the potent of renewable energy option of solar energy in Nigeria as fossil fuels poses greatnegative environmentalimpact on the society as such the need to promote investment by the Government to mitigate energy crisis in foreseeable future.

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*Rilwan Usman. "Analysis And Simulation of Electrical Load in A Hospital Using Hybrid (Diesel/Solar) System As A Back Up." Quest Journals Journal of Electronics and Communication Engineering Research, vol. 03, no. 09, 2017, pp. 01–14.