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Bir Ofis Kompleksi için Fotovoltaik Hibrit Sistem Şebeke Tasarım ve Simülasyonu

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Anahtar kelimeler
DC-AC Hibrit; Fotovoltaik sistem; Güneş ışınımı; Maksimum güç noktası takibi; Elektrik yükleri..

Öz

Bu araştırma çalışması, bir ofis kompleksi için Fotovoltaik (PV) hibrit sistem şebeke tasarımı ve simülasyonunu sunar. Rivers Eyaleti, Port Harcourt Üniversitesi'ndeki Lisansüstü çalışmalar okulunda bir vaka çalışması olarak kullanılmıştır. Tasarımın amacı, Lisansüstü Eğitim Bilimleri Fakültesi'nin günlük enerji talebini karşılamaktır.. Metodoloji, 5.242 kWh/m^2/gün'lük dik açı ışınlama ile lisansüstü çalışmalar okulunun binası içinde mevcut güneş ışınlama enerjisi veri kaynaklarının elde edilmesini içermektedir. Yük verileri üç hafta süreyle okul dağıtım hattından alınmıştır. Tüm binanın maksimum elektrik yükü talebi 37kVA olarak öngörülmüştür. Pik yük, 12 kVA'lık Normal yükler ve 25 kVA'lık Temel yük olarak bölünmüştür. Yaklaşık 141,7 m^2'lik bir alan sağlamak için 8 paralel dizide toplam 96 panel birleştirilmiştir. PV sistemi tasarımı ortalama 55.7kWh / gün enerji sağlayacak şekilde enerji talebi 50.7kWh/gün olarak öngörülmüştür.. Bu, PV sistemi tarafından üretilen enerjinin ofis kompleksindeki Normal yükleri karşılayabileceğini göstermektedir.

Design and Simulation of Grid – Photovoltaic Hybrid System for an Office complex

Keywords
DC-AC Hybrid; Photovoltaic system; Solar irradiance; Maximum power point tracking; Electrical loads.

Abstract

The research work presents the design and simulation of Grid – Photovoltaic (PV) hybrid system for an office complex. In this case, the School of Graduate Studies at the University of Port Harcourt, Rivers State is used as a case study. The purpose of the design is to augment the daily energy demand of School of Graduate Studies. The methodology involved obtaining the available solar irradiation energy data resources within the building of school of graduate studies vicinity with a peak irradiation of 5.242 kWh /m^2/day. The load readings were taken from the distribution board of the school for a period of three weeks. The peak electrical load demand of the entire building was estimated to be 37 kVA. The peak load was split into Regular loads of 12 kVA and Basic load of 25 kVA. A total of 96 panels were connected in 8 parallel strings to give an area of about 141.7 m^2. The PV system design yields an average energy of 55.7kWh/day and the energy demand was estimated as 50.7kWh/day. This shows that the energy generated by the PV system can cater for the Regular loads in the office complex.

1. Introduction

The Sun generates a huge amount of energy, which can be utilized by different living and non-living creatures on earth. The importance of huge potential of solar energy to humans could be appreciated within the context of greenhouse effect, cost and risk of fossil fuels and other environmental impacts (Eshita et. all. 2010). Solar photovoltaic system is a system which uses the solar cell module to produce electrical energy by solar power/light falling on it directly. Solar cell is a device which can achieve the transformation of photovoltaic by the electronic characteristic of semiconductor materials. Solar cell can also be utilized as a backup source of electric power for the electric power which is fed from the utility grid. Continuous power delivery helps to sustain and improve the economy. Developed countries have harnessed renewable sources for energy generation (Tianze, 2011). Renewable energy has become the fastest growing energy sector that is driven by four key factors: Energy demand increments as a result of growth in population and improvements in standard of livings, diversification of energy supplies due to scarcity in resources, prevention of climatic changes by reduction of emission of greenhouse gases into the environment and the necessity of reducing the balance of payments impact of importation of fossil fuels (Brian, 2015).

School of Graduate Studies is a facility in University of Port-Harcourt that manages the affairs of all the graduate programs ranging from Applications, Registration of all postgraduate students to the issuing of certificates at the end of the program. Availability of power supply is paramount for the smooth running and facilitation of the activities conducted in school such as Printing, Photocopying, Typing, Scanning of Documents, Data, Information and Forms. Inconsistence of power supply from the utility grid hinders the facilitation and smooth running of these activities in the school. Moreover, cost of maintenance and operation of diesel generators which are used as a backup power supply are relatively high. The noise and carbon-monoxide generated and emitted by these generators has a negative impact on the facility's environment.

The aim of the study is to assess, design and simulate a Grid – Photovoltaic Hybrid system that will augment the daily energy demand of the school of graduate studies.

2. Review of Photovoltaic Hybrid systems

Comparative review of hybrid solar energy systems (Akikur et. all 2013) shows the benefit of having more than one source of energy to electrify a given system load. Hybrid photovoltaic system is achieved when the solar power gotten from a photovoltaic system is put into use in combination with another electrical power generated from a different energy source. The Grid – Photovoltaic hybrid system is attained when the solar photovoltaic system is put to use with the utility grid. As a result, it requires lesser numbers of panels and batteries to be utilized as compared to the off-grid solar photovoltaic system to achieve the same goal. Also, they are also built with a battery backup system which makes them highly reliable and cost effective. Hence this study is focused on the Grid – Photovoltaic hybrid system.

An extensive work on "Application of DC – AC Hybrid Grid and Solar Photovoltaic Generation with Battery Storage using Smart Grid" was conducted (Adewumi and Adelekan 2015). The entire load in consideration was split and powered separately from the Solar Photovoltaic System, since most home loads could be powered by DC while the rest of the load would be powered directly from the Grid. This arrangement was considered reliable and economical for both large and small consumers.

The design of a Hybrid Solar Power System project for Campus model, Federal College of Agriculture, Ibadan was designed (Adewumi and Adelekan 2015). The entire loads were powered by inverters which were powered by Battery bank. The battery banks were powered by the combination of the Solar Photovoltaic System and the National Grid.

An in-depth study on design and simulation of cost effective standalone solar PV system was conducted (Oladeji et. all. 2017). In the study, fluke 434 series II energy analyser was used to determine load profile of the office building. Measured load was grouped into two categories: category 1 comprising of the essential electrical loads, without high energy consuming loads such as air conditioner. Category 2 comprises total electrical loads with high energy consuming loads. Results showed that, comparatively, category 1 with essential electrical load demand without air conditioners is far cheaper than supplying loads with air conditioners.

A solar PV plant of 162kWp which supplied 60% of electrical load demand of the electrical department building of University of Tripoli with grid supplying the remaining 40% load demand was designed (Al-Refai, 2014). It was observed that heavy loads were assigned to the grid, whereas light loads which are essentials for day to day work were assigned to be powered by the PV system. 810 of 200 W rated solar panels connected in 9 series and parallel were mounted on roof so as to receive highest solar radiation falling on it. Also, 172 kW Inverter was used in the design. The essence of splitting loads between PV plant and the grid is to reduce system cost and ultimately cost of energy production.

Badwawi et all. 2010, stated that intermittent and unpredictable nature of solar and wind power could create high technical challenges to weak grid unless a proper storage system is integrated into the system. According to the author, integrating two different renewable resources could partially address the impact of the variable nature of renewable sources, and hence the overall system becomes more reliable and economical to run. This is possible because the weakness of one renewable energy source is complemented by the strength of the other. The integration of Hybrid Solar and Wind power system into the Grid can further help in improving the overall economy and reliability of renewable power generation to supply its load. Furthermore, optimal designs have been conducted for wind/photovoltaic/biodiesel/battery hybrid system to help minimize the life cycle cost of the system (Guangqian et. all, 2018).
This study implements the use of Matlab-Simulink software to design and simulate the hybrid Photovoltaic System. Similar works have also demonstrated the use of Matlab Simulink for the implementation of a Photovoltaic System (Ilyas et all, 2018), (Mahmood and Selman, 2016).

Materials and Method

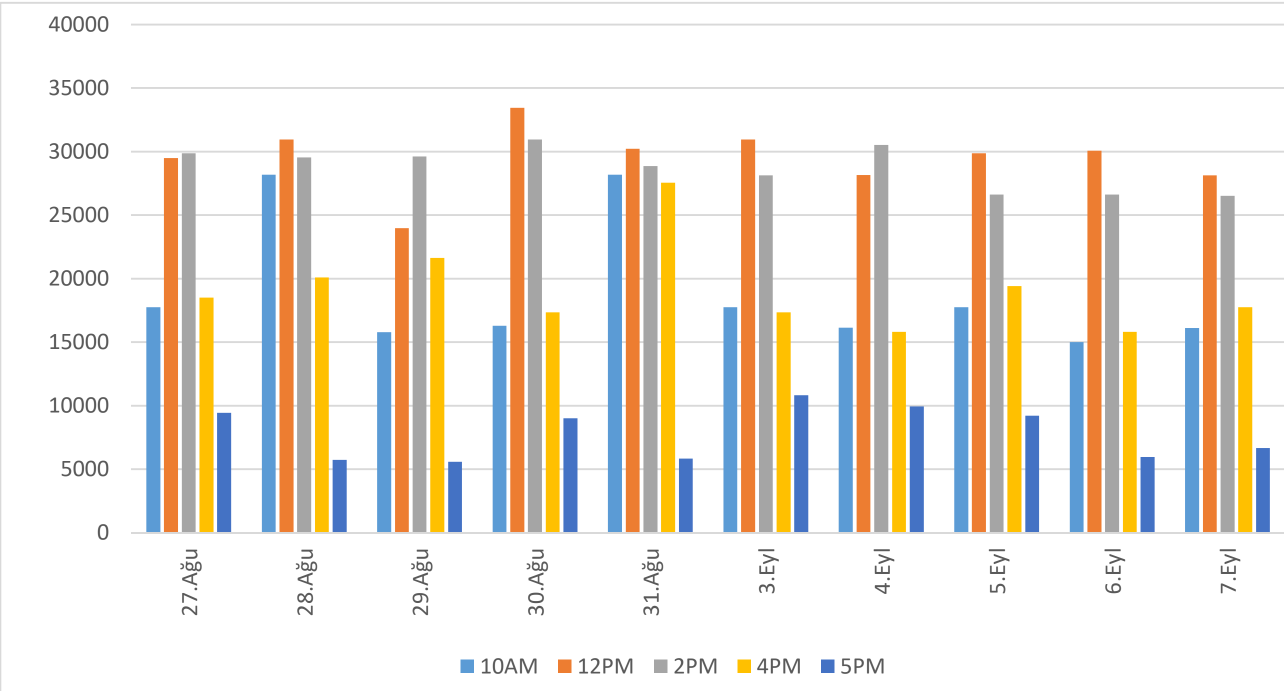
2.1. Site Parameters and Load Assessment

The proposed plant is to be sited at the Graduate School of the University of Port Harcourt, Rivers State, Nigeria. The site is located at latitude of 4.9^0 North and longitude of 6.92^0, and also at the elevation 20 m. The University location has a good topography that makes it an ideal location to deploy solar photovoltaic plant. The University of Port Harcourt is exposed an average of 6 hours of sunshine during the day. Thus the implementation of the solar plant at the graduate school is an economically viable project.

The purpose of the load survey is to estimate the appropriate capacity of the solar hybrid system that will serve the entire building. In this study, the load assessment was done by collecting the values of the input current into the whole building from the distribution box on a daily basis for four weeks at different time intervals. Thereafter, the input power rated at kVA was calculated by multiplying the values of the input current with an approximate voltage value of 232 V, which was also measured during the period of collection. The load consumption of the building is determined by work done at any given time of the day. The proposed PV power plant, which is expected to meet electricity demand of graduate school, will be rooftop. Figure 1 shows the aerial view of the facility being studied.

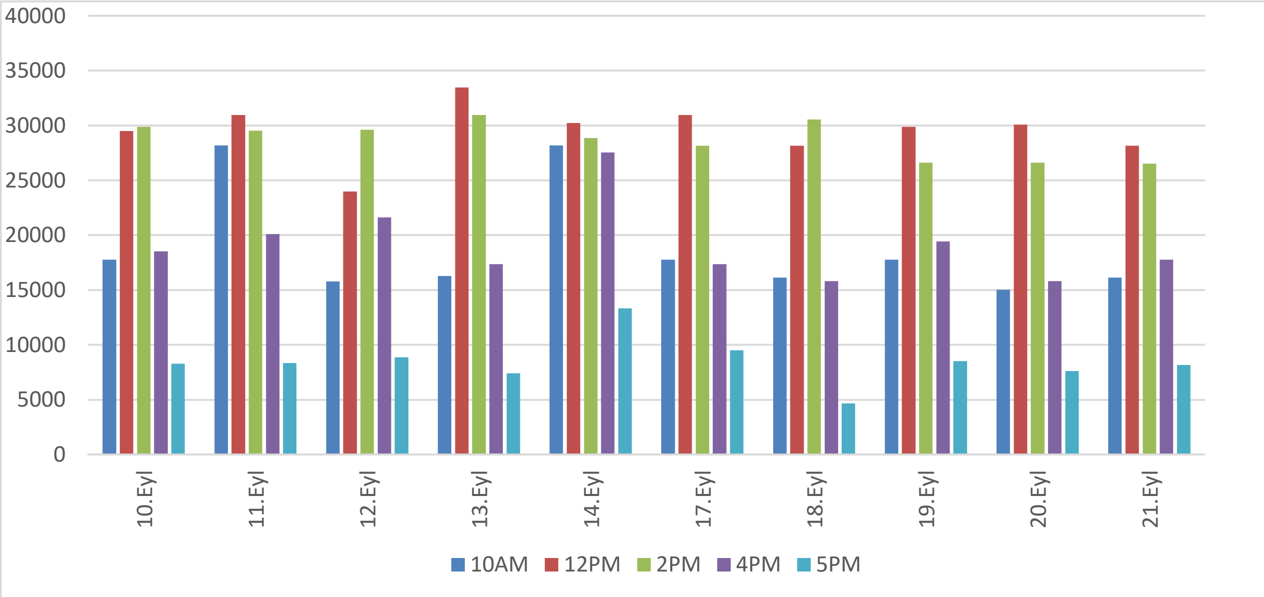
Fig 1: Aerial view of the facility (latitude of 4.9^0 and longitude of 6.92^0)

Figure 2 (a) and (b) presents the power consumption readings observed on a daily basis at five different time intervals approximately at 10am, 12pm, 2pm, 4pm and 5pm at the School of graduate Studies. The readings were taken from the distribution board of the school from the 27th August – 21th September, 2019.



Load (VA)

Figure 2a: Daily (hourly) energy consumption for School of Graduate studies



Load (VA)

Fig 2b: Daily (hourly) energy consumption for School of Graduate studies

2.2. Load Profile

In order to fully attain the peak load for the entire building the peak power ever attained was

required. Thus, the peak power ever attained on each line on a daily basis were measured and recorded as shown in Figure 3. From Figure 3, the peak loads recorded on each line are recorded on;

- L1 ---- 28th of August
- L2 ---- 28th of August
- L3 ---- 20th of September

From our record, the total peak power that was ever fed to the distribution board would be the summation of the peak loads ever achieved on the different lines which are;

$$L1 + L2 + L3 =$$
$$15961.6 + 11646.4 + 10115.2 = 37723.2VA$$

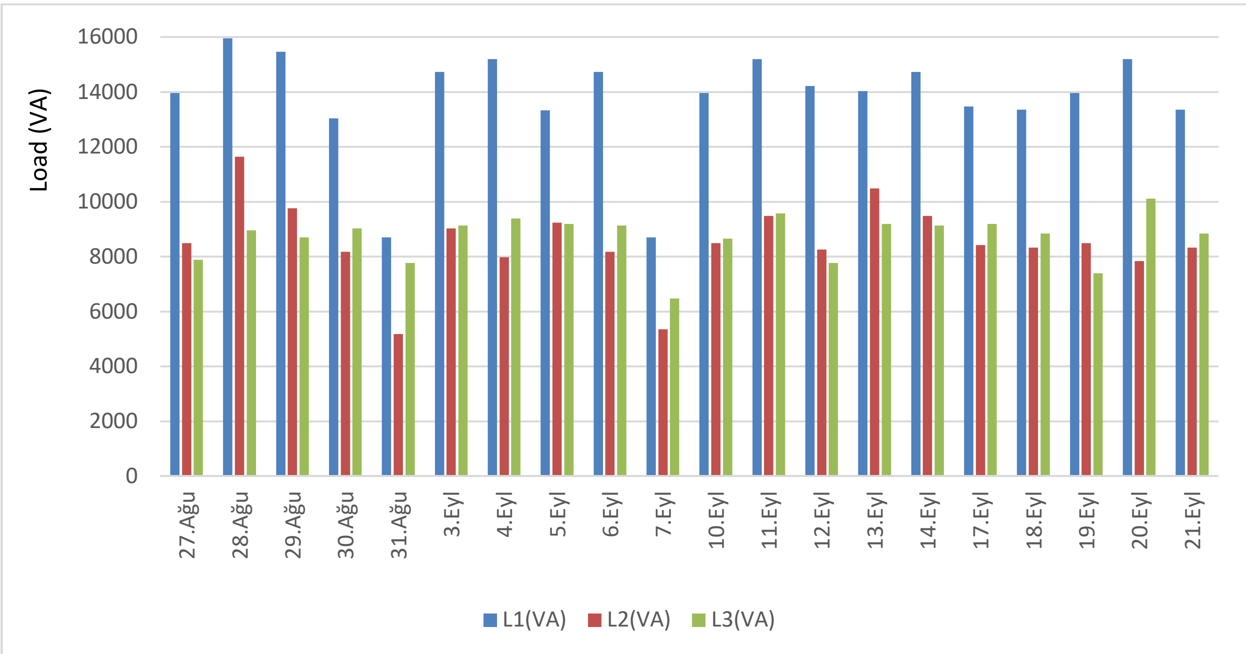


Fig 3: Daily Peak Load recorded on each line

Load differentiation

The total loads being fed from the distribution board of the School of basic studies can be split into two main types of loads namely; (1) Light loads and (2) Heavy loads

Light loads: These are the loads with a power capacity within the range of 1000 KVA and below. They are made up of equipment that are called up or required at regular interval for the entire office period of 8 hours such as the Photocopying machines, Printers, Desktop Computers, Laptops, Ceiling fan and some Lighting points and for those required for 12 hours such as some Security Lighting points. These are the loads that are required to be fed by the solar photovoltaic system.

Heavy loads: These loads are made up of equipment's that may not be called up or required regularly for official duties for the entire official period of 8 hours. Table 1 shows the major heavy loads such as the air conditions and the Refrigerators. These loads are to be fed directly from the utility grid.

Table 1. Major Heavy loads for School of Graduate Studies

Heavy Loads	Average Power capacity (KVA)
Air Conditions	22574
Fridges and Refrigerators	2200
Total	24774

The proposed solar PV system is expected to supply only the light loads in school of graduate studies, while heavy loads are connected to the grid.

$$Light\ capacity = Entire\ Load\ capacity - Heavy\ Loads\ capacity$$

$$= 37{,}723.2VA - 24{,}774VA \quad = 12949.2VA$$

$$= 10359.4watts\ @\ 0.8p.f \qquad (1)$$

An addition of about 20% was included to cater for any unplanned and unwanted loads that may be fed into the hybrid system. Thus, the new Full Regular load capacity would be 13000watts.

Since the School of Graduate building would always be in full operation and capacity for at least 8hours, our daily load would be; Daily Full Regular Load = 13000 x 8 = 104,000 WattHrs. The peak irradiance ever attained from The Solar and Weather data report collected from Nigeria Meteorological Agency (NIMET) Port Harcourt on the latitude of $4^0$49'27'' north and longitude of $7^0$2'1'' east was found to be 5.242 kWh/m^2/day.

4. Results and Discussion

There are four major components which can be interconnected to generate electricity from solar radiation. These components include: solar PV array, charge controller, batteries and inverters. These components together with the distribution board and the Grid are utilized in this study.

4.1. Dimensioning of Inverter sizing

The main function of the Inverter is to convert the dc output of the solar array into its ac equivalent. The inverter so chosen in this design is based on the Full Regular load of 13 kW.

A PV 15 kVA rated inverter is connected to fully supply the power from the PV or Battery.

Inverter voltage range = 200 – 880 V

$$Efficiency = \frac{P_{out}}{P_{in}} = 80\% \qquad (2)$$

Where $P_{out} = 13\ kW$

$$P_{in} = \frac{P_{out}}{Efficiency} = \frac{13\ kW}{0.8} = 16.250\ kW \qquad (3)$$

Therefore, the full power supplied would be less than the Inverters rated power thereby making it fit and suitable for the task. The Daily power input required by our inverter to sustain our daily Full Regular load would be;

$$P_{in} = \frac{P_{out}}{Efficiency} = \frac{104kWh/day}{0.8} = 130kWh/day \quad (4)$$

4.2. Dimensioning of PV module

As a result of the daily Full Regular load demand of the School of Graduate studies, it is necessary to calculate the Photovoltaic power so as to meet the required daily load energy. The Irradiance was used to determine accurately the total number of solar panels. Other system parameters were considered so as to ensure optimal system operation. Number of solar PV module is estimated thus: 1Panel Capacity = 300 watts, Panel efficiency = 90% ; Therefore,

$$Panel\ capacity\ = 300\ x\ 0.9 = 270\ Watts \quad (5)$$

Peak Irradiance = 5.242 kWh/day. Therefore, the kWh/day of a Solar panel would be;
(Irradiance/day) x 1 Panel capacity

$$= \left[\frac{5.242\ \text{h}}{\text{day}} \text{x} \left(\frac{1\ \text{kW}}{1000\ \text{W}}\right)\right] \text{x}\ 270\ \text{W} = 1.415\ \text{kWh/day} \quad (6)$$

Due to our Charge controller's efficiency, its daily required input would be;
Charge controllers efficiency $= \frac{Pout}{Pin}$; $Pout$ = Daily inverter power Input
Therefore, our Daily charge controllers Input (Pin) =

$$\frac{Pout}{Efficiency}$$

$$\frac{130000\ Wh/day}{0.98} = 132{,}653\ Wh/day \quad (7)$$

Finally, the total number of panel required would be;

Numbers of panels required =

$$\frac{Daily\ charge\ controllers\ Input}{kWh\ of\ a\ Solar\ panel}$$

$$= \frac{132.653\ \text{kWh/day}}{1.415\ \text{kWh/day}} = 93.75 \quad (8)$$

Hence, **96** JINPO-300-M mono-crystalline silicon solar panels would be used in the design. These modules would be arranged in 8 parallel strings with 12 panels in each. The tilt angle of each panel will be 15^0 and mounted on rooftop to maximize yearly energy production.

4.3. Dimensioning of charge controller

The Charge controller put to use in our System would be a Tristar MPPT 600 V charge controller. Its capacity is:
Charge current = 60 A;
PV Voltage = Voltage range of 100 – 660 Volts DC;
Efficiency = 98%;
Therefore, the number of charge controller required for our system would be:
Total current from the Charge controllers = $\frac{Pout}{Charger\ voltage}$;
Output power (Pout) = Inverter input power;
Charger voltage = Inverter input voltage.
Therefore; total current from the Charge controllers $= \frac{16{,}250\ W}{324\ V} = 50.2A$ (9)
Maximum Charger current for 1 (one) = 60A, therefore, total number of Chargers required would be;

$$\frac{Total\ current\ from\ the\ Charge\ controllers}{Maximum\ Charger\ current\ for\ 1} = \frac{50.2A}{60A} = 0.84 \quad (10)$$

Therefore, approximately **1 charger** would be required.

4.4. Battery unit

The main function of the Battery Unit is to store Power for the system which can later be put to use during the night or period of low irradiance thereby preventing power blackout and fluctuations. A battery of capacity 200 AH, 12 V was put to use. In a day, kWh/day that would be fed into the inverter input through the charge controller would be 130 kWh/day. Therefore, AH in a day is:

$$\left[\frac{\left(\frac{kWh}{day}\right)}{Battery\ voltage}\right] = \frac{132{,}653\ Wh/day}{12\ V} = 11{,}054.4\ AH \qquad (11)$$

Therefore, number of batteries required

$$\left(\frac{AH\ in\ a\ days}{AH\ per\ battery}\right) = (11054.4\ AH)/(200\ AH) = 54.2 \qquad (12)$$

In this system 54 batteries would be used. These modules would be arranged in 2 parallel strings with 27 batteries each as shown in Figure 4.1

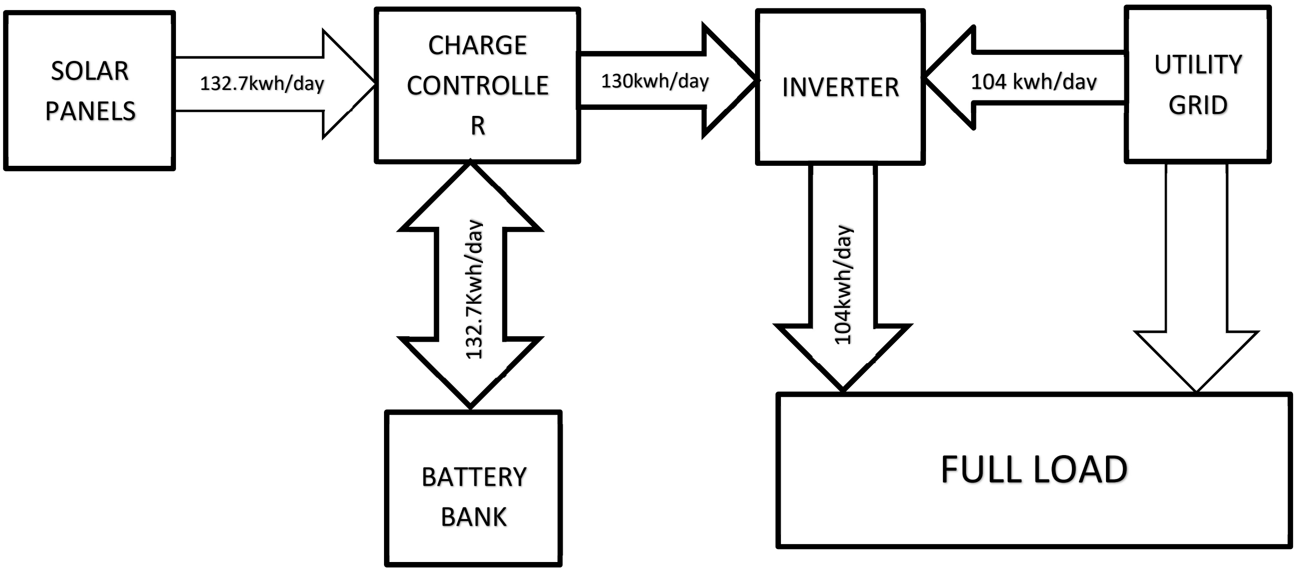


Fig 4.1. Overview of a grid - Photovoltaic hybrid system with the daily load transfer

The area of rooftop required to install the PV module = 1.476 m^2 × 96 = 141.696m^2

Thus, the minimum roof area needed for module installation is 150m^2. Matlab/Simulink software was used for the simulation of the hybrid system. (Refer to Figure 4.2).

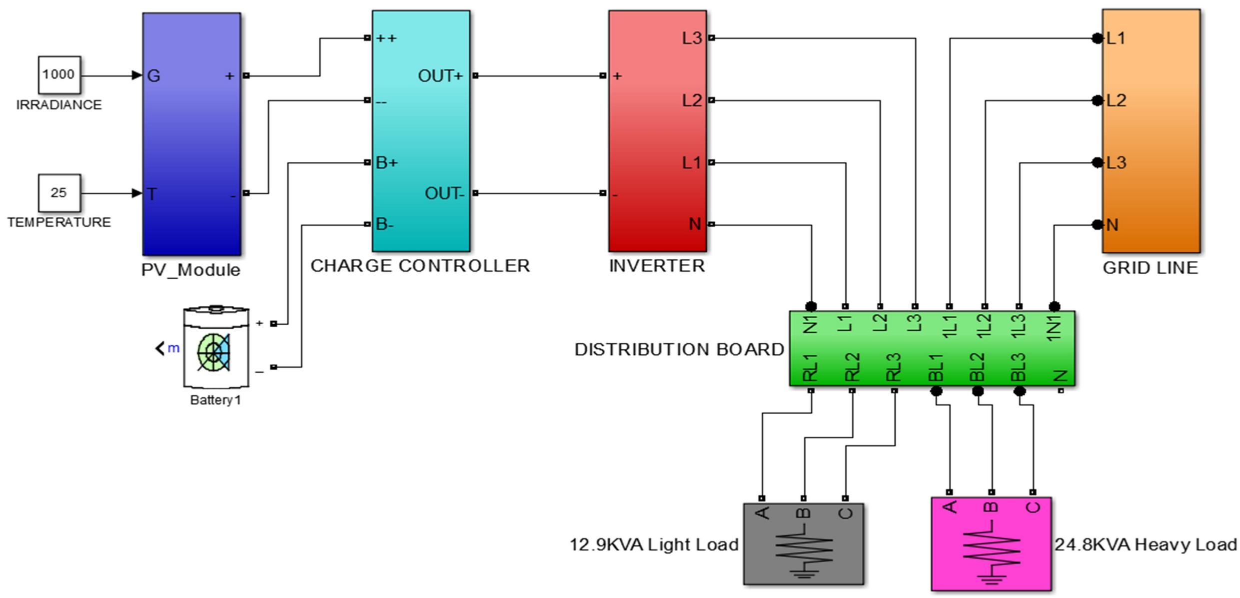


Fig 4.2: Simulink Model of a Photovoltaic Grid hybrid System

Figure 4.2. displays the proposed model of a Photovoltaic grid hybrid System as designed with Matlab/Simulink software. The model comprises of seven components, which are the Pv_Module, Charge Controller, Battery1, Inverter, Grid Line, Distribution Board and the 12.9kVA Light Load/ 24.8kVA Heavy Load. As seen above, the PV_Module generates DC power from the solar energy and then feeds the generated DC power directly to the Charge Controller. The Battery1 also feeds stored DC power and receives charging DC power directly from/ to the Charge Controller. The Charge Controller which receives DC power from the different sources regulates and controls this DC power before finally feeding to the Inverter and also to Battery1 during charging. The Inverter now receives the DC power from the Charge Controller and finally converts it to AC power which is required by the 12.9kVA Light Load but feeds it through the Distribution Board. The Grid line provides the other AC power required by the 24.8kVA Heavy Load and also feeds them through the Distribution Board.

4.5. Simulation using PVSyst V6.7^{TM} simulation software

The system is further simulated using PVSyst V6.7^{TM} simulation software using the same input parameters for the PV sizing. It is observed that the months of June - August gives a much lower solar energy yield as compared to the other months. This is majorly attributed to the drop in the solar irradiation for those months of about 3.042 kWh/day as compared to the Peak Irradiance of 5.242 kWh/day.

Notwithstanding, the available average solar energy was obtained as 55.7 kWh/day, and the User's energy need was estimated as 50.7 kWh/day. The system has autonomy of 4 days and a loss of load time fraction of 5%. This makes the design to be economically viable. Figure 4.3 presents the comparison between the available solar energy yield and the Users' energy needs from the months of January to December.

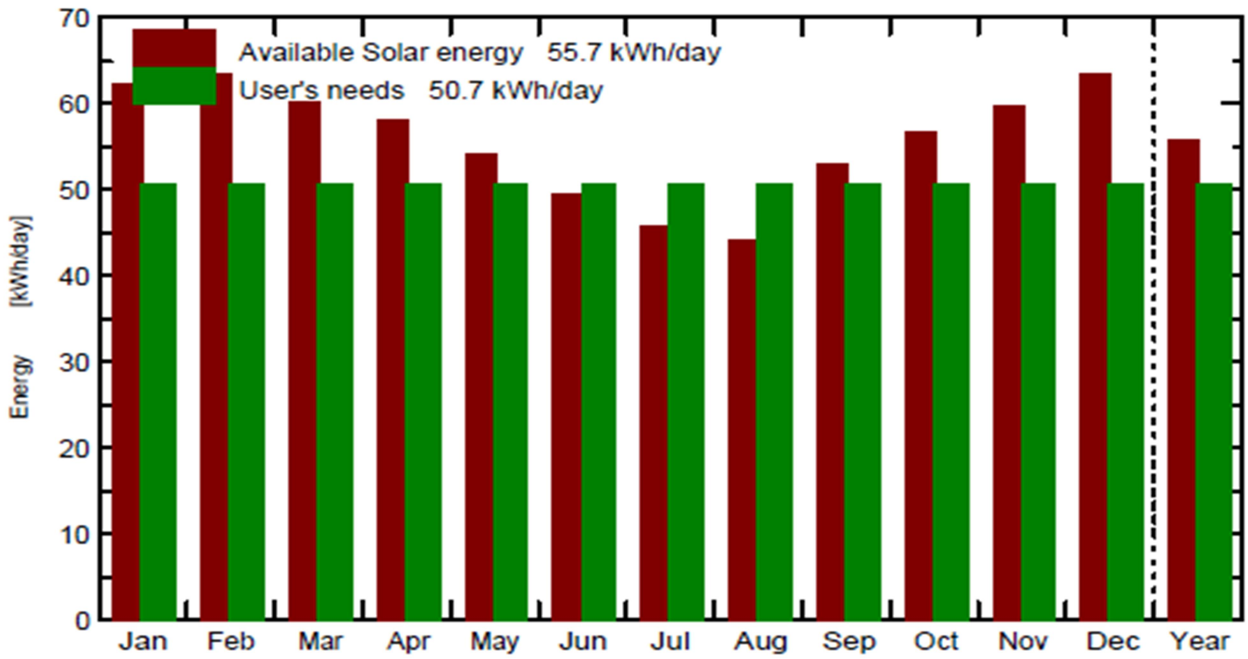


Figure 4.3: Comparison between the solar energy yield and the Users' energy need

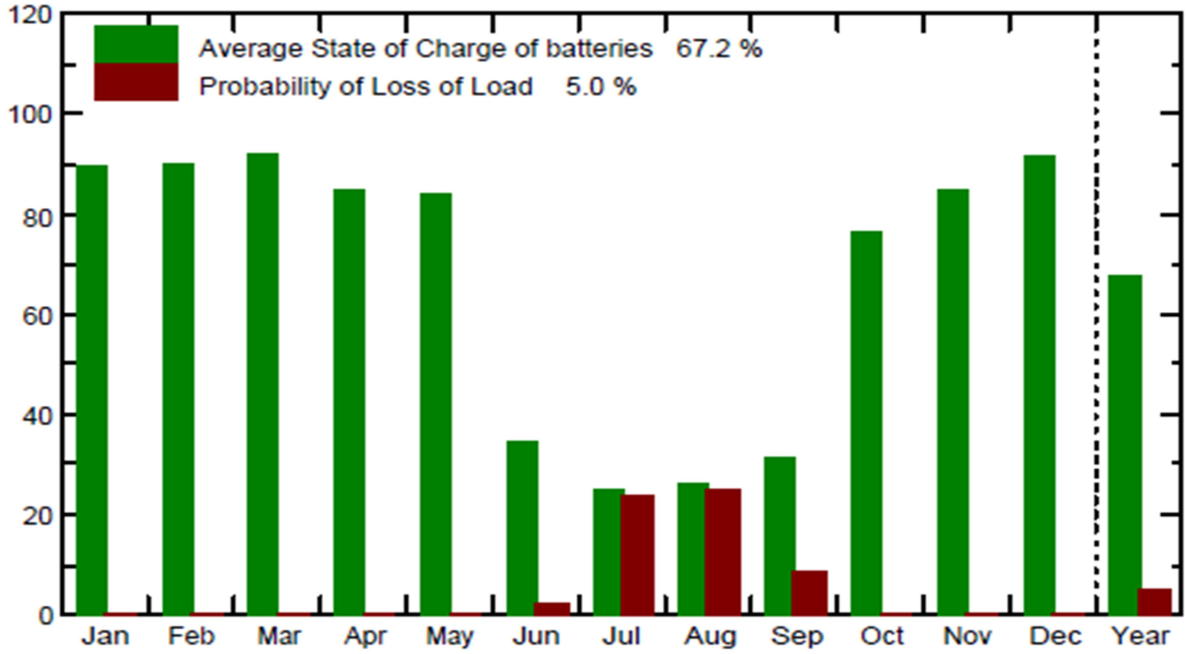


Figure 4.4: Battery State of Charge and loss of Load probability

Figure 4.4 presents the average state of charge (SOC) of batteries to be 67.2 %. Hence, the probability of loss of load is estimated to be 5%

5. Conclusion

component; (1) Solar PV Modules: the basic function of PV module is to convert solar energy directly into electricity. (2) Electrical power source: This is the second source of electrical power, in this case the utility grid. (3) Charge Controllers: these charge controllers control the charging process of the batteries and ensure that batteries are neither overcharged nor undercharged (4) Battery or Battery Bank: excess energy is stored in the battery bank so that it can perform backup function. (5) Inverter: it converts the DC current generated by the solar PV modules and batteries to AC current for AC consumer loads.

The regular business and official activities conducted in the entire building of School of Graduate Studies,

Hybrid photovoltaic system is achieved when the solar power gotten from a photovoltaic system is put into use in combination with another electrical power generated from a different energy source. In this study, the Photovoltaic - Grid hybrid photovoltaic system was used. This system comprises of the following main

requires constant electrical power. Due to unreliable power supply from the grid, local generators are used to augment the National Grid and ensure constant power supply in the School of Graduate studies. This practice faces a lot of enormous logistical challenges making it less cost effective with a very high operating cost. It also has various negative impacts such as noise and air pollution to the environment. This study presents the performance of a proposed photovoltaic – Grid hybrid system in a view to provide a cost effective, clean and reliable solution for power supply deficiency in the School of Graduate studies.

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