2025; 1-2 | pp.51-71

International Journal of Advances in Engineering and Computer Science

ISSN: 3121-6382

Volume 1, Issue 2, October-December, 2025
(An Academians Publishers of Research & Academic Resources)

Review Article

Received: 22-09-2025 Accepted: 14-10-2025 Published: 15-11-2025

Upgrade of Solar Energy System in Mechanical/Mechatronic Engineering Department

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Abstract: Energy is one of the major issues that the world is facing, the supply of energy has been one of the major problems for both urban and rural households. About 60% to 70% of the energy demand of any institution is met by fuelwood and agriculture residues. Solar energy is a renewable source of energy, which has a great potential and it is radiated or comes from the sun. Renewable energy is important to replace the using of electric energy generated by fossil fuel. Solar power has become a source of renewable energy and solar energy application should be enhanced.

Keywords: *Solar Energy System Upgrade, Renewable Energy Integration, Departmental Energy Upgrade, Institutional Energy Demand, Fossil Fuel Replacement, Sustainable Campus*

Introduction

Energy is a major component of the economic growth of any nation; factors such as urbanization, modernization and increase in population have led to an abrupt increase in the energy demand all over the world. As opined by a study, the energy consumption rate in developed countries is about 1%, while that of developing countries is within the neighbourhood of 5% per year. Future trends on energy reveal that the needed energy amount will be doubled by 2025 and beyond, as reported by the International Energy Agency (IEA). Energy is defined as the capacity of a system to do work and can be found in a number of different forms, such as mechanical energy, electrical energy, solar energy, thermal, etc. According to the law of energy conservation, energy cannot be created nor destroyed but can be converted from one form to another. For example, sunlight can be converted to heat, while chemical energy can be converted to electrical energy.

Electricity can be seen as one of the most popular forms of energy produced and consumed in powering Mechanical components. It became of utmost significance when it was revealed that electricity can be converted to other energy forms, such as heat, light, etc., to satisfy human needs. It was opined that electricity had been generated for the purpose of powering human technologies for a minimum of 120 years. It comes from various energy sources such as coal, gas, water, etc., and is converted to electrical energy. However, this process is not sustainable as it pollutes the environment with greenhouse gases, which cause global warming and are dangerous to the health of humans, animals and the ecosystem.

Statement Problem of the Study

The department building of Mechanical Engineering, Federal University Otueke,

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currently relies predominantly on conventional grid-based electricity sources, leading to escalating energy costs and a substantial carbon footprint. The absence of an efficient renewable energy solution not only impacts the department's financial resources, but also contradicts the global commitment towards sustainability and reduced greenhouse gas emissions. Additionally, the lack of a self-cleaning mechanism for solar panels results in reduced energy generation efficiency over time, necessitating costly manual cleaning efforts.

Aim and Objectives of the Study

Aim is to address the challenges posed in the project topic, "The upgrade and implementation of a 3.5kVA solar power system with automated self-cleaning in the department building of Mechanical engineering," we will design and construct a 3.5kVA solar power system with an integrated automated self-cleaning mechanism. This solution will enable the department to harness clean and cost-effective solar energy while maintaining the efficiency of the solar panels through automated cleaning, ultimately reducing electricity expenses and promoting sustainability.

Objectives

1. to design an effective upgrade for the department PV system
2. to simulate result for the system and implement the design
3. to implement a cost-effective PV system

Justification of the study

This study is justified because it directly addresses the pressing need for sustainable and cost-effective energy solutions in the department of Mechanical engineering. By designing and implementing a 3.5kVA solar power system with automated self-cleaning, which was proposed. Overall, this study directly addresses the challenges faced by the department and offers a tangible solution that aligns with both financial and environmental objectives.

1. Hands-On Learning: Provide students and faculty with practical experience in renewable energy and automation technologies.
2. Enhance Efficiency: Ensure optimal solar panel performance through automated cleaning, maximizing energy generation.
3. Reduce Costs: Lower electricity expenses for the department, allowing for more efficient resource allocation.
4. Promote Sustainability

Scope of the study

This study focuses on designing and implementing a 3.5kVA solar power system with automated self-cleaning specifically tailored for the department building of Mechanical engineering. The scope includes the selection and installation of solar panels, integration of a battery storage system, development of the automated cleaning mechanism, and monitoring and control systems. The study encompasses system efficiency analysis, cost-effectiveness assessment, and considerations for scalability within the department's building.

Definition of Terms

1. **Inverter unit:** This unit converts a DC voltage into AC voltage with the help of the inverter unit.
2. **Battery Unit:** This is a secondary cell unit, capable of storing enough DC voltage from either sun or AC main, of which is later converted to AC voltage.
3. **Solar Power System:** A setup that converts sunlight into electricity using solar panels. It typically includes solar panels, an inverter, a battery storage system (optional), and control systems.
4. **3.5kVA:** This refers to a 2-kilovolt-ampere rating, a measurement of

electrical power capacity. It indicates the system's maximum capacity to deliver power.

5. **Solar Panels:** Photovoltaic modules that capture sunlight and convert it into direct current (DC) electricity through the photovoltaic effect.

These definitions provide clarity on the key terms and concepts used within the study.

Literature Review

Preamble

Nigeria has abundant solar energy with an average solar radiation of 19.8MJm2 per day and sunlight of 6 hours per day. Nigeria has great solar energy potential that can be harnessed using solar photovoltaic (PV) panels together with a solar inverter,(Abu & Rahman, 2014; Xiao & Xie, 2010; Guo et al., 2014). The estimated solar power that can be generated in Nigeria through the use of solar power systems is about 42,700MW. Photovoltaic solar power system is reliable, with little maintenance and requires no cost of operation as the solar energy from the sun is freely available, (Ajiboye, 2016; Alok, 2015; Hasimah et al., 2009).

The use of the sun's energy is nothing new and dates back to the beginning of time. In recent years however, the focus on energy consumption worldwide rapidly spurred growth in the research and development of green" alternative fuel source including the sun, wind, " hydro, wave, geothermal, hydrogen and other forms of energy, (Babarinde et al., 2014; Vlachokostas & Madamopoulos, 2016; Kumar et al., 2011). And today, because of that focus, the use of solar energy is expanding by leaps and bounds especially since sunlight is free, unlimited, readily available, clean and reliable, (Badrul, 2022;Godwin, 2004; M. & Sanusi, 2009).

A solar power system (Renewable energy) is one which is capable of converting the absorbed sun energy; store it in a lead acid cell to be used on the load, (Osama & Egon, 2007; Bello et al., 2015; Labed & Lorenzo, 2004).

Renewable energy is considered energy that comes from natural sources and is unlimited. Renewable energy is seen as a clean form of energy that supports environmental sustainability as they are eco-friendly, (Perera et al., 2013; Chin et al., 2003; Westbrook & Collins, 2013). Solar energy is considered one of the most important types among all renewable energy types based on its advantages: it is clean, carbon-free and readily available. Solar energy system makes use of photovoltaic technology to convert solar energy into electrical energy, (Tran, 2020; Chattopadhyay et al., 2014; Kandasamy et al., 2013; Ramadhan & Naseeb, 2011).

In our part of the world, where power supply is not effective and efficient, the use of solar power supply is of immerse value and advantage considering the fact that we are blessed or rich in sun light i.e. high degrees of temperatures which is the main thing that feeds a solar power supply unit for uses. (Shalwala & Bleijs, 2009; Hasimah et al., 2009; Guo et al., 2014)

Basics of Solar Power System (PV System)

A typical solar power supply device is comprised of solar panel (a.k.a. photovoltaic or PV panels), a charge controller, and a power inverter having a meter or monitoring system which is capable of monitoring voltages and system condition and the electrical distribution system, (Muñoz et al., 2014; Labed & Lorenzo, 2004; Goura, 2015).

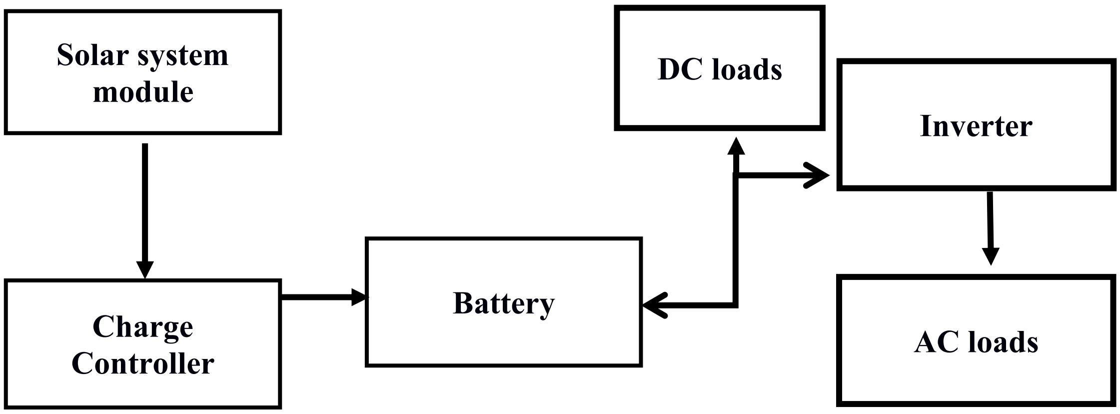

Figure 2.1 Block Diagram of PV System and Components, (Hasimah et al., 2009;Qoaider & Steinbrecht, 2010;M. & Sanusi, 2009).

Principle Of Solar Panel for PV System

A solar panel is a device that is able to absorb sun rays and convert it into electrical energy precisely DC. The photovoltaic panel comprised of silicon crystals, which reacts with sun ray and under this process, converts the sun rays into electricity, (Srikanth, 2014; Shalwala & Bleijs, 2009). They supply the electricity for charging the batteries and for use by the appliances either directly or through an inverter.

Solar Panels

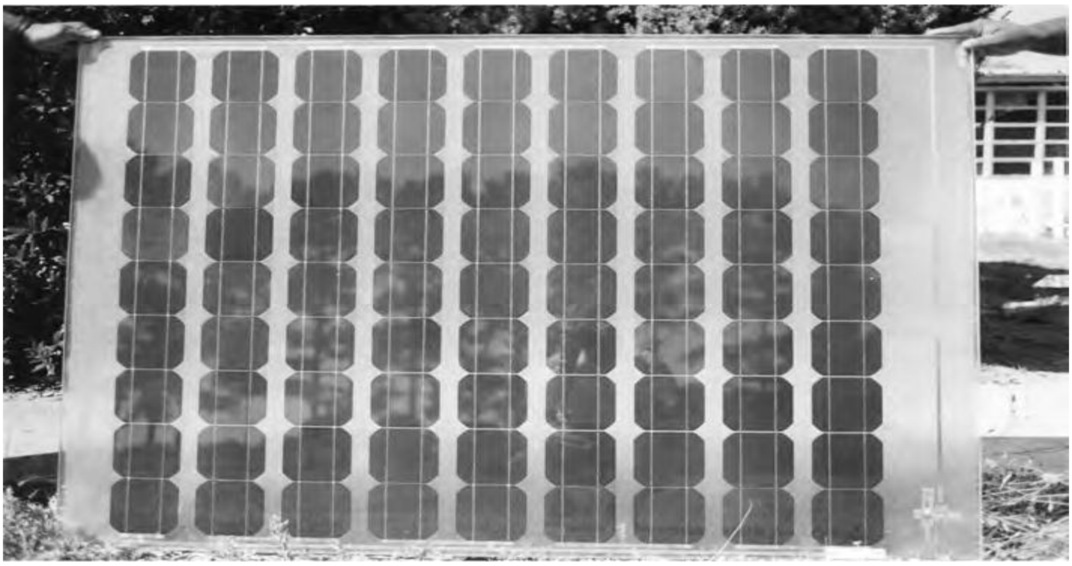

Figure 2.2: A photovoltaic solar pane l

Multiple modules were used to produce more electricity and then any excess energy that was produced was stored in the batteries for use during the cloudy/ rainy weather.

The panels are available in different sizes, voltages and amperage. They can be wired in series or in parallel depending on how the system is upgraded.

Estimating the Solar Panel Output

This PV system produced power in proportion to the intensity of sunlight striking the solar array surface and this varied throughout the day, so the actual power of the solar power system varied substantially. There were other factors that affected the output of the solar panel. These factors needed to be understood so that there will be realistic expectation of overall system output and its economic benefits under variable weather conditions over time.

Factors Affecting Output from PV Solar Panels

- **Temperature**
  Module output power reduces as module temperature increases. When operated on the roof, a solar module will be heated up substantially, reaching temperatures of 50-75^{o}c. For crystalline modules, the typical temperature reduction factor, recommended by the STC was 89% or 0.89. so the 3.5KVA module would be operated at about 85 watts (3.5KVA × 0.89 =3.115KVA) in the middle of a spring or fall day, under full sunlight conditions.
- **Standard test conditions**
  The Solar modules produced DC electricity. The DC output of the solar modules was rated by the manufacturers under standard test conditions (STC). These conditions were easily recreated in the factory, and allowed for constant comparisons of products, under common outdoor operating conditions. Solar cell temperature = 25^{o}c, solar irradiance (intensity) = 1000W/m^2 often referred to as peak sunlight intensity, comparable to clear summer noon time intensity.
- **Dirt and Dust**
  Dirt and dust would accumulate on the solar module surface, blocking some of the sunlight and reducing output. Although typical dirt and dust would clean off during every rainy season. The typical annual dust reduction factor was 93% or 0.93.
- **Mismatch and Wiring losses**
  The maximum power output of the total PV array was less than the sum of the maximum output of the individual modules. This difference was the result of slight inconsistency in the performance of one module to the next and was called module mismatch and amounts to at least 2% loss in system power. Power was also lost to resistance in system wiring. These losses were kept to Minimum but it was difficult to keep these losses below 3% for the system. A reasonable reduction factor for these losses was 95% or 0.95.

Solar Charge Controller

The charge controller is an electronic voltage regulator that was used to limit the rate at which electric current was being drawn in or out of the batteries. This charge controller turns off the charge when the battery reaches the optimum charging point and turns on when it goes below certain level. It fully charges the battery without permitting overcharge while preventing reverse current flow. Over voltage may reduce the battery performance or lifespan, and may pose a safety risk. This charge controller shows system operation parameters, battery status and protection from over discharge. The charge controller is the brain behind the system. It monitors the electricity produced by the solar panel and then regulates the electricity that was used to charge the batteries and prevent them from becoming over charged.

Figure 2.3: Solar Charge Controller

Proper charging was considered to prevent any damage to the batteries and thereby increasing the battery life and performance. Different technologies were available for selecting pulse width modulation and other charge controllers.

PV System Inverter

The inverter convert the DC voltage produced by the solar panels (and from the energy stored in the batteries) into A C voltage. The inverter could also charge the batteries by using an alternative source such as the mains or generator connected to the inverter when they are available.

Figure 2.4: A Solar System Inverter

Choosing the right inverter for the load demand and power requirements of the system was critical for the components to function properly.

System Inverter Sizing

An inverter uses the (DC) direct current power supply and creates an alternating current (AC) supply usually at the voltage similar to that of a normal mains power supply. In other words, it enabled the running household appliances from a low voltage DC supply such as a solar battery as the heart of the system.

Inverter sizing was considered before purchasing the inverter, while sizing the inverter, two figures were looked at

1. The continuous wattage output
2. The surge capacity.

The inverter was selected observing the largest load to be operated at one time.

DC to AC Conversion Losses

The DC power generated by the solar module was converted into common household AC power using an inverter. Some power was lost in the conversion process, and there were additional losses in the wires from the rooftop, from the panel down to the inverter and out to the house cut-out. The inverter used with the PV power systems have peak efficiencies of 9294% indicated by the manufacturer, but these again were measured under well-controlled conditions.

Actual field conditions that usually resulted in the overall dc-to ac conversion efficiencies was about 88-92% as a reasonable compromise.

Solar Battery

The battery that was used in this project is a solar battery. Without the battery, the system could only power when the sun is shining. The power would interrupt each time the cloud passes, the system would become very frustrating. The solar battery provided constant electricity and the load discharges 80% of its charge.

The batteries are the heart of the system and were available in different voltages and various amp-hour ratings depending on the requirement of the system.

Figure 2.5 Battery for Solar PV System

Temperature effect

The speed of the chemical reaction occurring in the lead-acid battery was determined by its temperature, the colder the temperature the slower the reaction and the warmer the temperature the faster the reaction and the more quickly the charge could be drawn from the battery. The optimum operating temperature of a lead acid battery is around 77^{o} Fahrenheit. An example of temperature effect on a battery could be seen when starting a car on a cold morning; the engine just does not turn over quickly.

Battery Power Conversion Efficiency

Energy can never be created or destroyed, but it merely changes form. The efficiency of conversion was never 100% and in the case of new batteries they ranged from 80% to 90%. That means that to discharge 100 watts power battery, it would be charged with 100 to 120 watts of power.

Battery Voltage

Voltage meters are used to indicate battery state of charge; they are relatively inexpensive and easy to use. In this PV system it was usually charging or discharging or doing the both at the same time.

As the battery was charged the indicator lit up and while it discharges, another lit to show the level of its discharge. A good, accurate digital meter with a tenth of a voltage calibration was used with success.

Battery Monitoring and Maintenance

Monitoring battery state of charge was the single largest responsibility of the system charge controller. The battery voltage was kept at above 50% state of charge for maximum battery life. Should the battery is contain wet cells then it would be good to keep the battery's electrolyte level to the indicated level and never let the plates be exposed above the electrolyte. Only distilled water could be used to refill the batteries, over watering dilutes the acid excessively and electrolytes would be expelled when charging.

Materials And Methodology

Materials for 3.5 KVA solar inverter system

The materials and electronic components used to implement the 3.5KVA solar system, including the construction of the 3.5 KVA solar inverter system, are stated, and the construction parameters and equipment and their ratings are specified and classified. The system is upgraded and implemented to power the Mechanical/Mechatronic Engineering Department of the Federal University Otueke.

System operation of the 3.5kVA solar power system

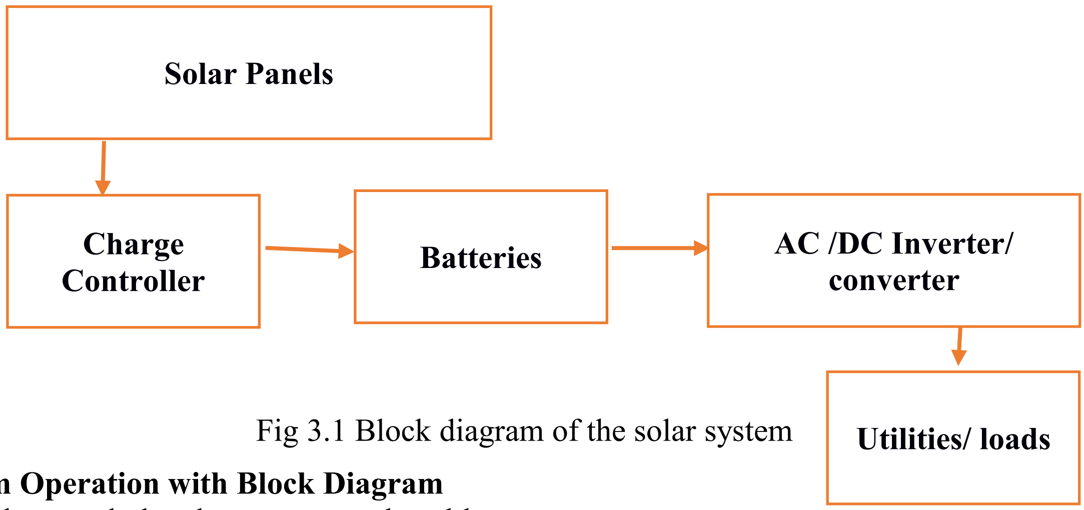

Fig 3.1 Block diagram of the solar system

System Operation with Block Diagram

The solar panel absorbs energy produced by the sun and converts it into electrical energy. It does this by absorbing the sun rays into the modules of the solar panel hence produced free electrical charge carriers in the conduction and valence bands. The electricity produced by the solar panel was then transferred to the charge controller as shown in fig 3.1 above. The charge controller regulates the rate at which electric current was drawn in and out of the battery. It turns off charge when the battery reaches the optimum charging point and turns it on when it goes below a certain level. It fully charges the battery without permitting overcharge.

The regulated voltage from the charge controller was then transferred to the solar battery. The batteries were the key component in this solar power system. It provided energy storage for the system.

The energy stored in the batteries was then used to power the load but it was first converted to AC voltage by the use of an inverter due to they were AC loads. The photovoltaic ally produced direct current was commuted periodically by controlled oscillatory system and feed to power electronic semiconductor switches such as transistors which were connected the power transformer. Here the voltage was stepped up to the desired ac voltage. The inverter could also charge the battery when there is public power supply.

The Solar Power System Upgrade

Load Evaluation and Power Consumption

Based on the table below

1. The electrical appliances to power were listed.
2. The operating watt of each load was recorded
3. The number of hours per day for each item was specified.
4. The operating wattage and the number of hours per day were multiplied out to determine the watt hour per day.
5. The total watt hour per week was determined by entering the number pf days per week the load should be operated.
6. Automatic cleaning system for PV panels

Calculating Power Consumption

There was need to determine the size of the load that were powered. The unit of measurement used was watt-Hour because it was applicable to both AC and DC circuits.

The table below shows the average daily watt hours, the highest AC load in watts, the total AC connected wattage at a time, the total watt-hour per day, load correction multiplying factor from page 15 and the corrected watt hour per day.

These had allowed for easy determination of how many modules that were needed to produce the power required and how many batteries that were also needed to store the power.

The table below was an analysis of energy usage for a representative of an office, the HOD's office. The loads were itemized for its individual run time per day and per week then summed the watt hour of all the units for a total daily watt hour figure.

The table below helps for clear understanding of where the power had gone to and it also gave an idea of how to reduce the loads in the most effective manner when required.

Appliance	AC	DC	Qty	×	Wattages (volt Amps)	×	Total Wattage
Bulb			42	×	30	×	1,260
Ceiling Fans			11	×	70	×	770
					Total load	×	2,030 W

Highest AC loads in watts = 70
Total AC connected in wattage at one time = 1,260
Total watt-hour per day =
Total watt – hour per day ÷ Load correction factor
Corrected Watt – Hour per day =

Solar Components Sizing

Accurately sizing the components of the solar electric system was important. This sizing helps ensure that the system produced the right amount of power that was required.

Typical PV Electrical System Types for the Upgrade

There are two general types of electrical upgrade for PV power systems for homes; systems that interact with the utility power grid and had no battery back- up capability and systems that interact and include battery back-up as well.

1. **Grid Interactive only (NO battery backup)**

   This type of system only operated when the utility was available. Since utility outages were rare, this system would normally provide the greatest amount of bill savings to the customers per charge cost of the investment.

   However, during the event of an outage, the system was required to shut down until utility power was restored.

2. **Stand-alone power system**

   For this project, a stand-alone power system was chosen for upgrade and installation. First there was need to consider the electricity needs which the PV system had to power, the unit measurement was in kilo watts for consideration.

Solar panels are classified according to their rated power output in watts. This rating was the amount of power the solar panel was be expected to produce in one peak sun hour. Different geographical locations received different quantities of average peak sun hour per day.

Solar panels could be wired in series or in parallel to increase voltage or current respectively. The rated terminal voltage of a 12 volts solar panel was usually around 17.0 volts, but through the use of a regulator, this voltage was reduced to around 13 to 15 volts as required for battery charging.

To size the solar panel, how much power each items consumed while operating was determined. Most appliances had a label on the back, which listed the wattage and specification sheets, local appliance dealers and the product manufacturers were the sources of the information.

Determination of Components Specifications for the PV System
Charge controller size

This is given as the Number of Panel × Maximum current × system loss

= 1 x (2 x 19.4) x 1.3 =50.44A

Recommended 60A/24V solar charge controller

3.1.1. Cable Size for the System

Available from solar array power =1600watts

The system voltage = 24V

P = VI

(1)

$$I = \frac{P}{V} = \frac{1600}{24} = 66.7A$$

According to the **IEEE** standard table for current capacity for air, cable size = 16mm².

Inverter Size Determination

To get the inverter sizing we deduce that the Inductive Load (100w x 4) = 400Watts

Non-Inductive load (socket + Bulbs) = (130 × 5) + (20 × 4) = 650 +80 = 730Watts

Capacitive Load (printer) = 1000Watts

Total connected load = 400 + 730 + 1000 = 2130W

15% of total connected load =2130 x 0.15 = 319.5W

Total loads = Total connected load + % of Total connected load

= 2130+ 319.5=2449.5W

Inverter Efficiency = 90% (0.9)

Inverter size = 2449.5 ×0.9 = 2204.6AVA

(2)

Therefore, I recommend 2500VA (3.5KVA/24V) inverter for it

Battery Size for the System

Day of Autonomy = 1day

DOD = 90% = 0.9

$$\text{Battery Size} = \frac{\text{ELD (Ah) x DoA}}{\text{DoD}} = \frac{211.8\ Ah \times 1}{0.9} = \frac{211.8\ Ah}{0.9} = 235.3Ah \quad (3)$$

The group recommended a tubular battery of 240Ah/12V.

$$\text{Number of batteries} = \frac{235.3Ah}{240Ah} = 0.98 \quad (4)$$

Approximately number of batteries proposed for use = 1.

$$\text{Number of Battery in series} = \frac{\text{System Voltage}}{\text{Nominal Voltage of Selected Battery}} = 24V/12V = 2$$

batteries in series (8)

The Solar Charge Controller

Number of the solar panel = 4 each 400watt

Therefore, 400W x 4 = 1.600watts

(5)

1600 Watts with a maximum current of (9.7x 2) =19.4A

Maximum voltage = 41volts ×2=82volts

Installation Of The 3.5Kv Solar Power System

3.2. Procurement of components for the installation of 3.5kVA solar system

During the process of procuring all the materials used for this project, taking the right decision for the battery, inverter, solar panel and the charge controller was totally based on the result of individual evaluations.

The materials; solar panel, inverter, batteries and the charge controllers were purchased with the following price list:

Table 3.2 Materials for the installation of 3.5kVA solar system

S/N	Items	Quantity	Unit Price (N)	Total Price (N)
1	380 W solar panel	4	80,000	320,000
2	Felicity 12V MMPT charge control	1	35,000	35,000
3	Tubular Battery (220V)	2	180,000	360,000
4	2.5 KVA Inverter	1	320,000	320,000
5	Battery rack	1	10,000	10,000
6	6mm Wire	25 Y	800	20,000
7	Circuit breaker	1	10,000	10,000
8	Trunking	2	2,000	4,000
9	Fuse	1	3,500	3,500
10	Single Core AC	10 Y	800	8,000
11	Change over switch	1	10,000	10,000
12	DC wire (complete core)	30 Y	2,500	75,000
13	Workmanship			100,000
14	Miscellaneous			30,000

The above listed materials were all tested before delivery and were confirmed to be in good condition. With the addition of all cost of transportation it amounted to ₦293100.

This amount was got through the collective financing process. Next procurement was that for the upgrade of the automated cleaning system on the PV solar panel array. Procurement was gotten from the same source as the major components for the installation of the solar power system.

Determination of Installation Site

1. **Mounting options:** The PV was mounted on a roof. The PV system produced 5 to 10 watts per square foot area. This was based on a variety of different technologies and the varying efficiencies of different PV products.
2. **Roof mount:** Often the most convenient and appropriate place to put up the PV array is on the roof of the building. The PV array was mounted above and parallel to the

roof surface with a stand-off, several inches for cooling purposes.

The 3.5KVA PV system needed about 40 square feet of unobstructed area to site the system. Consideration had to be given for access to the system. This access to mounting had added space up to 2% of needed area to the mounting area used.

As the PV system was properly mounted, it was labour intensive. Particular attention was paid to the roof structure and the weather sealing of roof penetrations. It was typical to have two support brackets for the 3.5KVA of solar panel modules. During the installation, support brackets were mounted for holding the solar panel.

Installation process for the 3.5kVA solar systems.

Basic steps that were followed while installing the PV system includes;

1. It was ensured that the roof area for installation was capable of handling the system area or size.
2. It was ensured that there were no roof penetrations that needed roofing industry approved sealing methods.
3. The PV system was installed according to the manufacturer specifications, using installation requirements such as the right wire gauge, nuts and bolts from the manufacturers' specification.
4. The PV system was properly grounded with the system parts to reduce the threat of shock hazard induced surges.
5. It was ensured that the right wire with the right polarity was observed while connecting the solar panel to the charge controller.
6. It was ensured local utility interconnection requirement.
7. It was finally inspected for completion by the HOD of mechanical department.

Test, Simulation and Results

Test of the PV 3.5kVA solar system

The solar panel was set placed under the sun at angle 45^o south west, there the peak sun irradiation was on the panel surface and then at 40 volts was observed using a multi meter. While observing the voltage, the panel was slightly adjusted and the voltage varied at an angle away from the sun, the voltage depreciated.

The output from the solar panel was connected to the charge controller with respect to their polarities and when the output voltage was observed, it then read 26 volts which was right for charging 24 volts battery, since the two 12 volts batteries were connected in series. Also, there was an indicator on the charge controller that showed when the battery was full by showing green light and the other LED showed red when load was connected to the system.

Each battery read 12.8 volts each and then connected in series to give an output of 24 volts afterwards was connected to the inverter. The voltage was 25.7 volts DC because the solar and the charge controller were also connected but without load, then load was added to the inverter which gave an output of 220 volts and was left for about 30 minutes after then it was observed again and the voltage did not vary. The inverter had three indicators. The first displayed if the system was connected to the mains or not, the second displayed if the inverter system was switched ON or OFF and the third was to display if the system was experiencing any fault or not.

The inverter also had an additional socket for plugging the inverter to mains to serves as another means to charge the batteries other than the solar system. When tested with the volt meter as it was plugged on the mains out, it read 14.4 volts which was basically because of the state of the charge level of the batteries. The batteries would normally self-discharge over time even when not used. Since the inverter included a triple cycle charger, it could continue to maintain the battery with equalization charge voltage of about 12 volts just to make sure that the battery does not discharge even it was on standby mode.

Simulated Design Array with Specification and Conditions

Project summary

Geographical Site		**Situation**		**Project settings**	
Otuoke		Latitude	4.79 °N	Albedo	0.20
Nigeria		Longitude	6.32 °E		
		Altitude	2 m		
		Time zone	UTC+1		

Meteo data
Otuoke
NASA-SSE satellite data 1983-2005 - Synthetic

System summary

Standalone system — **Standalone system with batteries**

PV Field Orientation		**User's needs**	
Fixed plane		Daily household consumers	
Tilt/Azimuth	35 / 0 °	Monthly Specifications	
		Average	0.0 kWh/Day

System information

PV Array		**Battery pack**	
Nb. of modules	4 units	Technology	Lead-acid, sealed, Gel
Pnom total	1140 Wp	Nb. of units	2 units
		Voltage	24 V
		Capacity	90 Ah

Results summary

Available Energy	1372 kWh/year	Specific production	1204 kWh/kWp/year	Perf. Ratio PR	0.62 %
Used Energy	10 kWh/year			Solar Fraction SF	100.00 %

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Figure 4.1. Showing system summary and value specifications

Figure 4.1 above shows the system summary where user needs were measured considering the standardized system with batteries. The availability of energy this system can produce per year was measured to be 1372KWh/year and the used energy was 10KWh/year. Also, the specification production was measured to be 1204KWh/year with a performance ratio (PR) of 0.62% and a solar fraction of 100.0%.

4.1. Simulation Measuring PV Array Characteristics and Array Loses

General parameters

Standalone system — **Standalone system with batteries**

PV Field Orientation

Orientation		Sheds configuration	Models used	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	35 / 0 °		Diffuse	Perez, Meteonorm
			Circumsolar	separate

User's needs

Daily household consumers

Monthly Specifications

Average 0.0 kWh/Day

PV Array Characteristics

PV module		**Battery**	
Manufacturer	Generic	Manufacturer	Generic
Model	SR-P660285	Model	Solar PV 8G30H
(Original PVsyst database)		Technology	Lead-acid, sealed, Gel
Unit Nom. Power	285 Wp	Nb. of units	2 in series
Number of PV modules	4 units	Discharging min. SOC	7.2 %
Nominal (STC)	1140 Wp	Stored energy	2.0 kWh
Modules	2 Strings x 2 In series	**Battery Pack Characteristics**	
At operating cond. (50°C)		Voltage	24 V
Pmpp	1013 Wp	Nominal Capacity	90 Ah (C10)
U mpp	56 V	Temperature	Fixed 20 °C
I mpp	18 A		
Controller		**Battery Management control**	
Manufacturer	Generic	Threshold commands as	Battery voltage
Model	SmartSolar MPPT 150/35 24V	Charging	28.9 / 25.1 V
Technology	MPPT converter	Corresp. SOC	0.91 / 0.75
Temp coeff.	-2.7 mV/°C/Elem.	Discharging	21.8 / 24.4 V
Converter		Corresp. SOC	0.07 / 0.45
Maxi and EURO efficiencies	98.0 / 96.0 %		
Total PV power			
Nominal (STC)	1.14 kWp		
Total	4 modules		
Module area	6.5 m²		
Cell area	5.8 m²		

Array losses

Thermal Loss factor		**DC wiring losses**		**Serie Diode Loss**	
Module temperature according to irradiance		Global array res.	53 mΩ	Voltage drop	0.7 V
Uc (const)	20.0 W/m²K	Loss Fraction	1.5 % at STC	Loss Fraction	1.1 % at STC
Uv (wind)	0.0 W/m²K/m/s				
Module Quality Loss		**Module mismatch losses**		**Strings Mismatch loss**	
Loss Fraction	-0.8 %	Loss Fraction	0.6 % at MPP	Loss Fraction	0.1 %

IAM loss factor

Incidence effect (IAM): Fresnel smooth glass, n = 1.526

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.998	0.981	0.948	0.862	0.776	0.636	0.403	0.000

Figure 4.2. Array Characteristics and Array Loses

In Figure 4.2 above, the array characteristics and array losses were measured using the simulator, and their values were generated as shown in Figure 4.2 above.

Measuring Detailed User Needs by Months

The monthly consumption of the inverter system was simulated from January to December on a scale of one year. And the data obtained is shown bellow

Measuring Detailed Array

Detailed User's needs

Daily household consumers, Monthly Specifications, average = 0.0 kWh/day

January and February

Use 5 days a week	Nb.	Power	Use	Energy	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Lamps (LED or fluo)	15	24/lamp	0.5	180				
Fans	4	70/app	0.5	140				
Laptops	3	65/app	0.5	98				
Stand-by consumers			24.0	24				
Total daily energy				442				0

March and April

	Nb.	Power	Use	Energy	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Total daily energy				0				0

May and June

	Nb.	Power	Use	Energy	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Total daily energy				0				0

July and August

	Nb.	Power	Use	Energy	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Total daily energy				0				0

September and October

	Nb.	Power	Use	Energy	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Total daily energy				0				0

November and December

	Nb.	Power	Use	Energy	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Total daily energy				0				0

Figure 4.3. Monthly Rating of User Detailed User Needs

Measuring Detailed User Needs by Hourly Rating

The hourly rating of user needs was measured and the result was graphically represented on a scale of 100. It was observed from the graph that the hourly consumption per day went high at exactly 4 hours

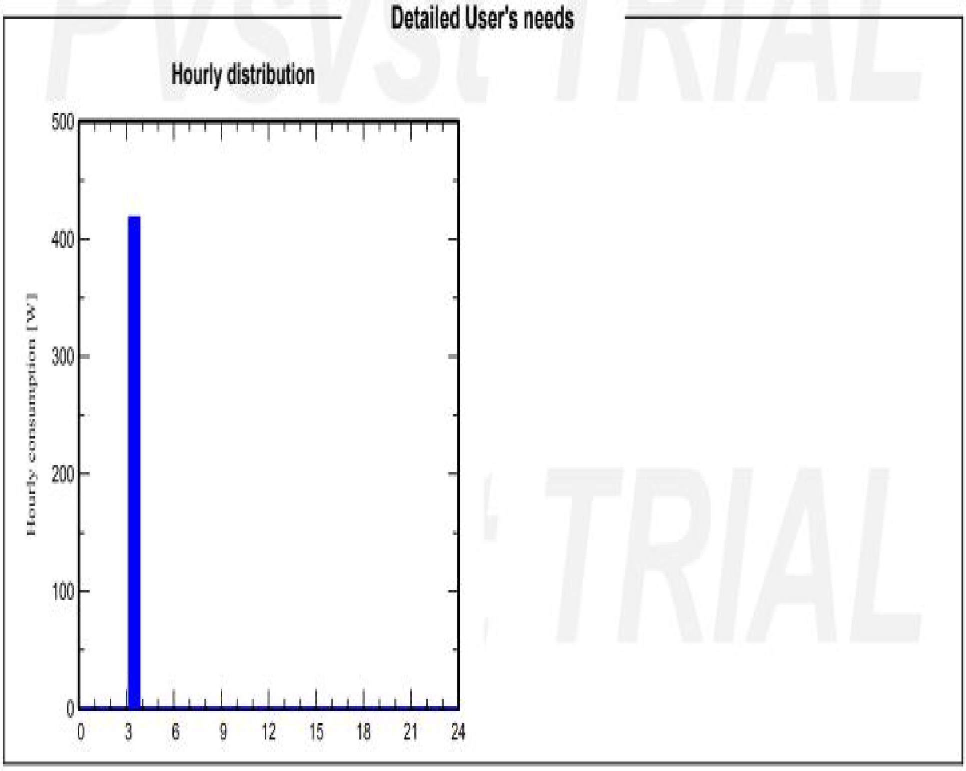

Figure 4.4. Hourly Rating of Detailed User Needs

Balance and Main Result

The power supply balance was simulated and the data is represented in the table below

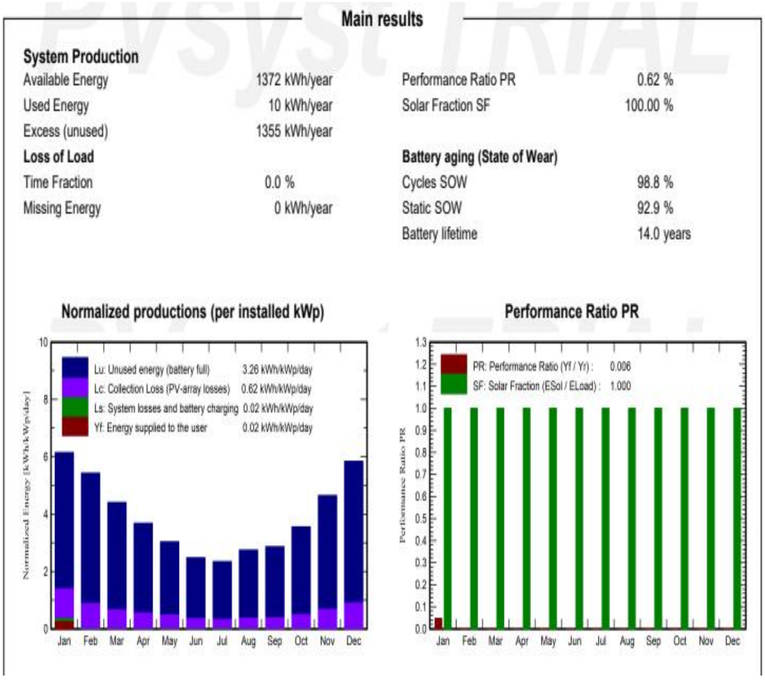

Figure 4.5. Showing Normalized production Performance Ratio (PR)

Daily input/output Ratio

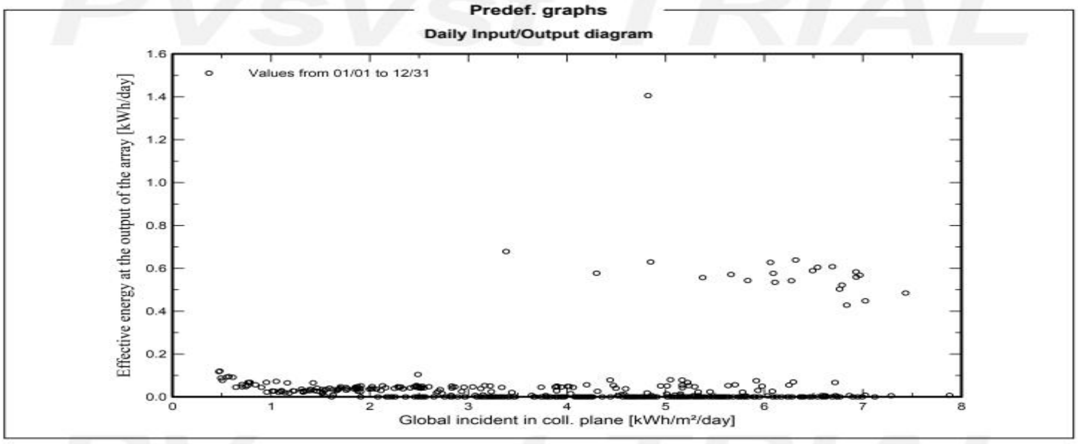

Figure 4.6. Showing Daily Input/Out Ratio

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	162.4	187.2	179.8	166.3	0.000	10.15	10.15	1.000
February	143.6	149.2	144.3	143.9	0.000	0.00	0.00	1.000
March	146.6	132.8	131.0	130.7	0.000	0.00	0.00	1.000
April	135.0	105.6	105.6	105.4	0.000	0.00	0.00	1.000
May	126.8	88.8	89.2	88.8	0.000	0.00	0.00	1.000
June	103.5	70.0	71.4	71.0	0.000	0.00	0.00	1.000
July	96.4	68.7	70.3	69.7	0.000	0.00	0.00	1.000
August	106.0	81.3	82.8	82.4	0.000	0.00	0.00	1.000
September	96.6	82.7	83.4	83.1	0.000	0.00	0.00	1.000
October	111.6	106.9	106.8	106.5	0.000	0.00	0.00	1.000
November	125.4	136.5	134.5	134.4	0.000	0.00	0.00	1.000
December	151.3	178.2	173.2	173.0	0.000	0.00	0.00	1.000
Year	1505.2	1388.0	1372.4	1355.2	0.000	10.15	10.15	1.000

Legends

GlobHor Global horizontal irradiation
GlobEff Effective Global, corr. for IAM and shadings
E_Avail Available Solar Energy
EUnused Unused energy (battery full)
E_Miss Missing energy
E_User Energy supplied to the user
E_Load Energy need of the user (Load)
SolFrac Solar fraction (EUsed / ELoad)

Figure 4.7. Showing balances and main result for one year

Input and Output Analysis

The daily input and output of the solar inverter were simulated as effective energy at the output of the array against the global incident in the coil plane with a 0.1 scalability as represented in the graph below.

PV Array Maintenance

1. Cleaning using detergents from time to time to remove dust and other greasy particles.
2. Check PV modules for cracked cells and corrosion.
3. Check the wiring connection and electrical leakage to the ground.

The loose diagram

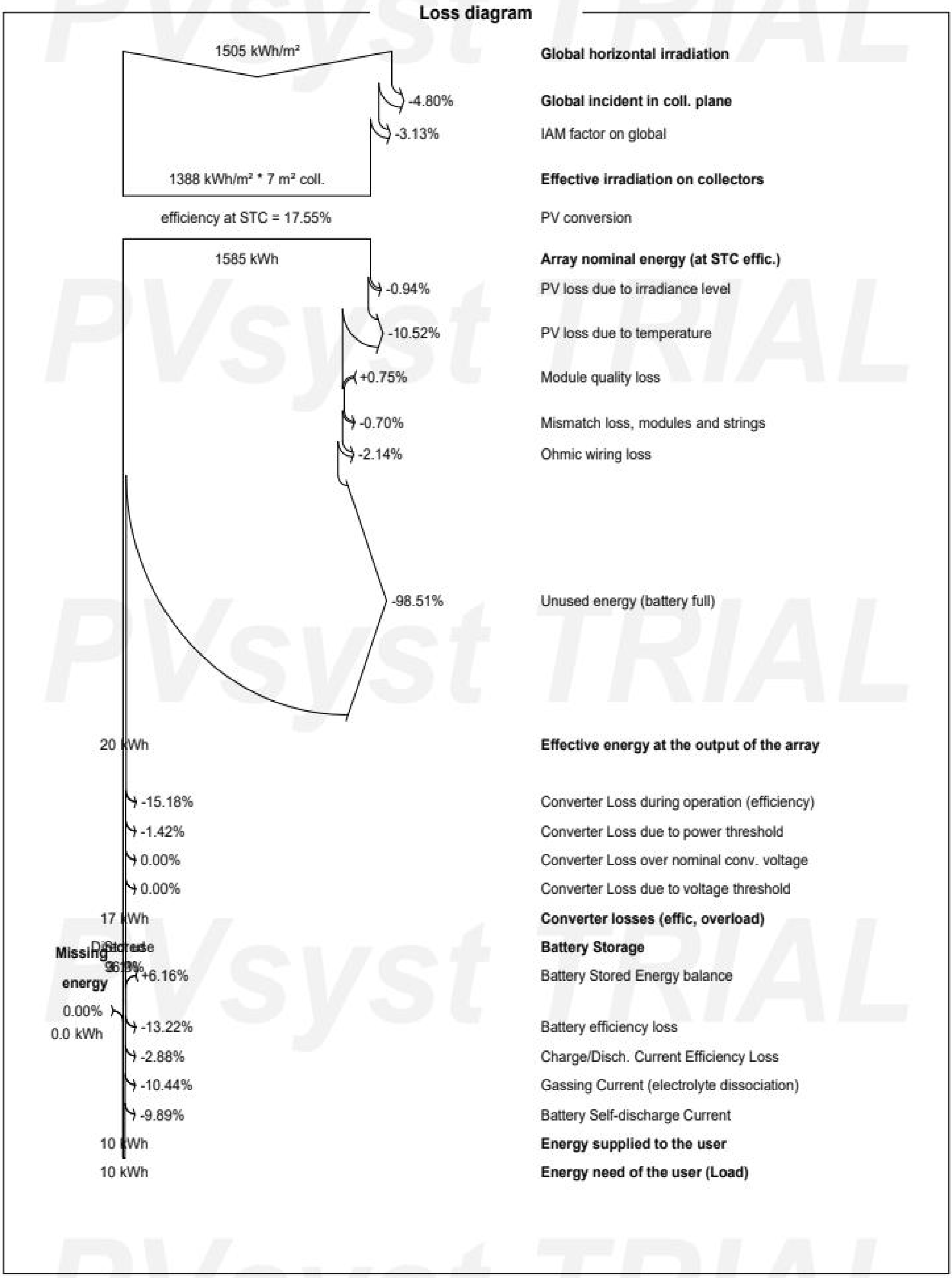

Figure 4.8. Showing the Lose Diagram of the System

Battery Maintenance

Routine test procedures to look for differences in color, sediment in cell boxes, and corrosion on cells and connectors. All these parameters tell us the state of the battery.

Check electrolyte levels and refill using distilled water when necessary.

Measure and record cell voltage with a DC voltmeter for discrepancies and correct them by checking the charging system and the battery terminal.

Power Conditioning System (Regulator, Inverters, and Controllers) Maintenance.

These systems have solid and complicated designs and come with protection against power surges and system overload and so cannot fail easily. When necessary, maintenance should be done by trained personnel.

Conclusion and Recommendation

Conclusion

The project was intended to supply 3.5kVA of energy to the departmental building and the HOD of office mechanical department. To serve as another source of alternative energy besides the mikano diesel engine this serves the electrical utilities of the faculty.

The installation was a successful one and worked efficiently as intended. However, during the upgrade of the system requirement, it was considered to adjust the wattage of the inverter from 3.5kVA to 3.2KVA inverter system due to an expected future expansion of the load capacity. Another change that had occurred during the upgrade was the change from 12 volts solar panel to 24 volts solar panel and from 12 volts battery to an additional one more battery, which then became a 24 volts system to fit the solar panel that was already purchased.

The solar system worked effectively and cost no further operational cost. When compared to a mikano diesel generator, it was costly but for the initial expenses. However, it was later seen to be cheap since the system needed no petrol to operate but sunlight which was nature's free gift. Therefore, there was no need to time or limit the hour of power supply of the up and down experiences from the mains supply.

Recommendations

Solar panel with inverter would be recommended since it was a noiseless, it does not use fuel and it is environmentally friendly. The solar power system was a convenient way of producing an alternative means of power supply to supplement the mains failure. It was advantageous to user who could afford its initial cost of installation. This project was recommended for expansion if the need arose. There would be need to add up more batteries to meet up with the running time and the system load capacity since the system had an adjusted wattage, more load could be added only with addition of more batteries to meet up with the capacity.

Limitations of the study

1. Low energy efficiency: For now, the commercially available have efficiency of 45%.
2. Space: The photovoltaic cells take up a lot space with this we can predict that with proper design can be taken care of.
3. High cost: Currently, the cost of solar system in short term is high for average Nigerian citizen.

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