# DESIGN AND INSTALLATION OF SOLAR SYSTEM FOR A 4 – BEDROOM BUNGALOW

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# CERTIFICATION

This certifies that this undertaking was completed by AIMUFUA ELVIS with matriculation number ENG1805029, OGBEVOEN JUSTICE EDOSA with matriculation number ENG1805099, UGWU VICTOR CHUKWUEMEKA with matriculation number ENG1905397, AGUELE ELIJAH OSEMUDIAMHEN with matriculation number ENG1805028, TIMOTHY EMMANUEL EDET with matriculation number ENG1910172, OGBOI CHUKWUMA DANIEL with matriculation number ENG1805100, ODEMILIN EMMANUEL OGBEIDE with matriculation number ENG1805098 of Electrical/Electronic Engineering Department, Faculty of Engineering, University of Benin, Benin City.

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Project Supervisor

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# ACKNOWLEDGEMENT

Firstly, we will like to acknowledge our project Supervisor, Prof. F. O. ODIASE who guided, directed and enlightened us throughout the project duration to ensure this project was successful despite his busy schedules. May God almighty bless you richly in Jesus name, Amen.

Also, special gratitude goes to Engr. P. Aikhoje who assisted and provided us the help necessary to make this project successful despite his busy schedules.

Finally, we willl also like to acknowledge our parents for their love and support towards our pursuit of academic excellence.

## DEDICATION

With deep reverence and gratitude, We dedicate this Project research to God almighty for His wisdom, enabling strength and inspiration bestowed on us for the completion of this work. Also, this project is dedicated to our parents whose financial support, love, guidance and sacrifices has helped in shaping us into the persons we are today.

To God be the glory forever. Amen

# ABSTRACT

This project looks into the designing and installation of solar PV system to power some appliances in a five bedroom bungalow building. This is necessary because of unreliable power supply. Solar energy is a clean and endless source of power from the sun, unlike electricity from utility companies which can be limited and affect daily activities.

In this project, we designed a solar PV system which consists of PV cells, charge controller, inverter, batteries.The size of the solar panels, battery capacity, and other components needed to run the appliances efficiently was calculated. Then testing of each part of the system was carried out to make sure it worked properly before putting it all together.

The photovoltaic cells were used to capture sunlight and convert it into electricity. This electricity is then sent to the charge controller and then to the inverter which then charges the batteries. The stored charges in the batteries can be used to power our appliances even when the sun isn't shining. The system is designed specifically for powering home equipment like fans, light bulbs, fans etc. The final system was tested in the University of Benin, Benin City, (6.3998° N, 5.6099° E). It was successfully used to power some home appliances like light bulb, fan.

From the test, graphs of current (amps) against time (hrs) and power (watts) against time (hrs) were plotted it was then observed that at the earlier hours of the day, the current and likewise the power from the panel increases and it is maximum at 1:30pm. It begins to reduce from 2pm. This is due to the reduction of the irradiance of the sun. The weather becomes a bit cloudy and towards evening there is minimal sunlight resulting in lesser current. The more the sunlight, the higher the current and vice versa.This shows that solar power can be a reliable way to run home equipment, even in places with frequent power outages. Overall, the project demonstrates that solar energy has the potential to reduce reliance on traditional electricity from utility companies.

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# CHAPTER ONE

## INTRODUCTION

### 1.1 BACKGROUND OF STUDY

A photovoltaic (PV) system, sometimes referred to as a solar power system, is a system that uses sunlight to create electricity. It collects solar radiation and converts it into a useful kind of electrical power (Swanson, 2009). Solar power systems are a clean and renewable energy source, making them an increasingly popular choice for generating electricity in homes, businesses, and large-scale utility projects (Akinbami, 2001).

Solar photovoltaic (PV) energy, which involves harnessing sunlight through PV panels to produce electricity, is considered one of the most promising sectors in the renewable energy portfolio due to its capacity to lower $CO_2$ emissions and mitigate global warming (Gbadebo & Okonkwo, 2009). In an era characterized by growing environmental awareness and the need for sustainable energy solutions, solar power systems have emerged as a promising source of clean and renewable energy (Joshua, 2002). The design and installation of solar power systems play a pivotal role in harnessing the abundant energy of the sun to meet our electricity needs, reduce greenhouse gas emissions, and promote energy independence.

Solar power systems, or photovoltaic (PV) systems, operate by transforming sunlight into electricity using solar panels. These panels contain solar cells that capture sunlight and produce direct current (DC) electricity. Inverters are employed in the conversion of DC electricity into alternating current (AC), which is compatible with the electrical grid and can be used in homes, businesses, and other settings (Museckaite et al., 2008).

The design and installation of a solar power system is a complex and multifaceted process, requiring careful planning, engineering, and compliance with local regulations. The main components of a solar power system include the solar panels, mounting structures, wiring, inverters, and energy storage if desired (Akinboro et al, 2012). System design involves considerations such as the orientation and tilt of the panels, system capacity, shading analysis, and electrical requirements. Each system must be tailored to the unique characteristics of the location, whether it's a residential rooftop, a commercial facility, or a utility-scale solar farm (Aminu, 2011).

Solar power systems have many advantages. They improve energy independence, lower electricity bills, and provide long-term cost benefits. Solar energy is also plentiful, clean, and renewable, which helps to lower carbon emissions and create a more sustainable future (Nasir, 2001). Furthermore, financial incentives and tax credits are provided by governments and incentive programs in numerous regions to promote the use of solar energy (Okoro et al, 2006).

But it's important to remember that achieving these advantages depends on effective design and execution. Erroneous architecture, inadequate placement, or poor assembly might compromise the system's efficacy and efficiency(Ohunakin et al, 2014). In order to guarantee the long-term performance of the system and the safety of individuals participating in the installation process, proper installation also necessitates adherence to construction and safety requirements.

## 1.2 STATEMENT OF PROBLEM

The problem we wish to solve with this project is the unreliability of power supply in a residential building. The inadequate supply of power has become a daily experience in the lives of every Nigerians. This power crisis has been identified as a major obstacle to all sectors of the country and slowing the economic development of the country.

The country's epileptic power supply has become a hindrance in large and small scale businesses across the country and even in academic activities in the country. Lack of access to reliable power supply has cost Nigeria enormous estimated amount of $29 billion a year (Samuel Ayokunle, 2019).

The project aims at electricity supply using pv systems, as a result of the followings:

i. The use of solar energy reduces reliance on fossil fuels, hence mitigating greenhouse gas emissions and contributing to the fight against climate change. It promotes a cleaner and more sustainable environment.

ii. Solar power provides homeowners with a degree of energy independence, reducing their dependence on centralized utility grids and the volatility of energy prices.

iii. Installing a solar system can lead to long-term cost savings on energy bills. This project can help individuals and homeowners make informed financial decisions to achieve such savings.

iv. Solar technology is rapidly evolving. This project serves as a platform to explore and understand the latest advancements in solar systems, helping individuals stay updated on cutting-edge technology.

v. The project imparts knowledge about renewable energy sources and practical skills for system design and installation, making it valuable for students, professionals, and homeowners interested in sustainable energy.

vi. By presenting a case study of a successful solar system installation in a five-bedroom bungalow, the project demonstrates that solar energy is a feasible and practical solution for residential use.

vii. The project aligns with the global trend towards sustainable living and eco-conscious choices, offering a way for individuals to reduce their carbon footprint and contribute to a greener future.

## 1.3 AIMS AND OBJECTIVES

### 1.3.1 AIM

To Design and Install a Solar system for a 5 bedroom Bungalow

### 1.3.2 OBJECTIVES

1. Evaluate the current energy challenges faced by homeowners.
2. Load survey of an existing 5-Bedroom bungalow to collect data on the load in the building.
3. Collation and analysis of the load data.
4. Design and selection of the followings:
    a. Pv panels.
    b. Battery bank.
    c. Charge controller.
    d. Inverter.
5. Purchase of solar system equipment and components (pv panels, batteries, charge controller, inverter etc)
6. Installation of solar equipment and components.
7. Testing of the pv system.

## 1.4 RESEARCH METHODOLOGY

i. Conduct a comprehensive literature review to learn about the latest solar system design and installation technologies. This includes reviewing journal articles, conference papers, industry reports, and government publications.
ii. Load survey using the name plate value or using the multi-meter to measure.
iii. Tabulate the load data from each room and then calculate to get the total load, energy, KWh etc.
iv. Use the relevant formula to calculate the followings:
    a. pv panel.
    b. Battery.
    c. Inverter.
    d. Charge controller etc
v. Procure the necessary equipment for the solar system from reputable suppliers.
vi. Install the solar system i.e pv panels, inverter, battery and charge controller using the following tools:
    - Spanner
    - Screw driver
    - Cutter etc
vii. Testing and Collecting data on the performance of the solar system. The data includes the followings:
    - The amount of electricity generated by the solar panels.
    - The amount of electricity consumed by the bungalow.
    - The state of charge of the batteries (if applicable).
viii. Analyze the data by plotting of graph.

## 1.5 SCOPE OF WORK

The scope of work of this project involves

1. Conducting a site assessment to evaluate solar potential, shading, and available space.
2. Identifying energy needs and consumption patterns.
3. Determining the optimal system size and configuration.
4. Estimating project costs, including solar panels, inverters, mounting structures, wiring, and labor.
5. System design
6. Equipment procurement
7. Installation

By systematically addressing these tasks and activities, a solar project can be efficiently planned, executed, and maintained, ensuring its long-term success and contribution to sustainable energy generation.

# CHAPTER TWO

## LITERATURE REVIEW

### 2.1 REVIEW OF SOLAR EQUIPMENTS USED IN THE WORK

Sunlight is a limitless supply. It is not the same as oil, which we take from the planet and use up. It is possible to continuously harvest energy from the sun without running out of it. Solar energy, sometimes referred to as solar power, is the energy we generate from sunshine. Through a process known as the photovoltaic effect, we are able to convert solar energy into electricity for our TVs, refrigerators, lights, and other appliances. Typical solar power supply components include solar panels, also referred to as photovoltaic or PV panels, an electrical distribution system, a charge controller, and a power inverter with a meter or monitoring system that can track voltages and system conditions.

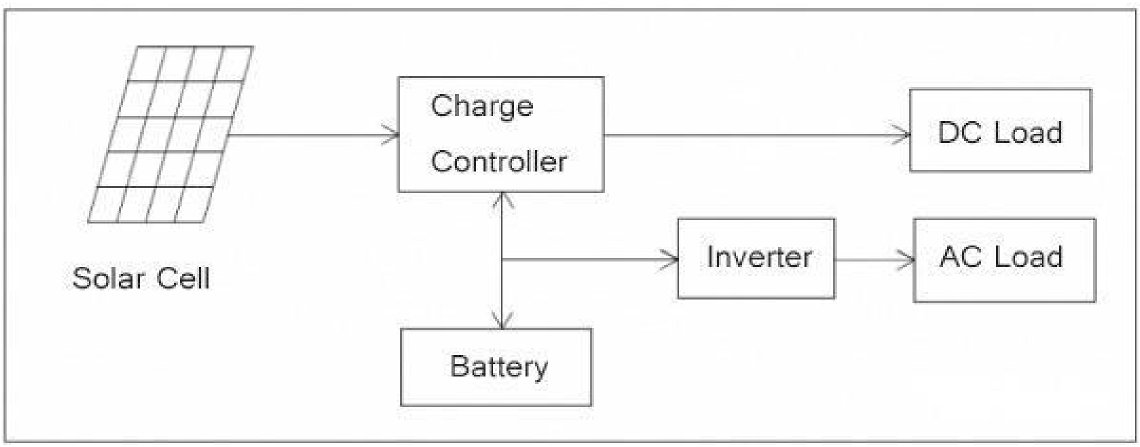


**Fig 2.1 Block Diagram of System Components**

The block diagram as shown in figure 2.1 above is a diagram of the solar system components. The solar system components include:

1. Solar Panels
2. Batteries
3. Inverters
4. Charge controllers
5. Change overs
6. AC breakers
7. DC breaker

8. Solar cables
9. Breaker assembly box
10. Ac/dc surges

## 2.2 SOLAR PANELS

**Fig 2.2: Solar Panel Mounted On A Rooftop**

A solar panel, also known as a photovoltaic (PV) module, is a collection of photovoltaic cells arranged in a framework for installation. These panels utilize sunlight, including UV-rays, as an energy source to produce direct current electricity. A group of PV modules is referred to as a PV panel, and a system of PV panels is known as an array.

The diagram illustrates a solar panel mounted on a rooftop. These panels convert sunlight into electricity using the photovoltaic effect. They typically contain crystalline silicon cells or thin film cells. When light hits a solar cell, electrons in the absorber layer move from a lower energy state to a higher state, creating an electric current. Junction forming layers add free electrons to the excited ones, creating an electric field that drives the electrons through electric contact layers into an external circuit, such as a battery, to do work.

### 2.2.1 TYPES OF SOLAR PANEL

Although there are tons of different solar panels, most will fit into one of these three types:

1. Monocrystalline solar panels
2. Polycrystalline solar panels
3. Thin-film solar panel

Each type has a distinct set of features that makes them better suited for certain solar projects. Let's take a closer look at each;

1. **MONOCRYSTALLINE SOLAR PANELS**

Monocrystalline solar panels are the preferred choice for rooftop solar installations currently. One of the key reasons for this preference is their aesthetic appeal. The solar cells in monocrystalline panels are single, flat, and black in color, which is a popular choice among homeowners.

**Fig 2.3: A Typical Monocrystalline Solar Panel**

The primary benefit of monocrystalline solar panels is their high efficiency and attractive appearance. Monocrystalline panels can be recognized by the square shape of their silicon wafers, which have corners cut off, as shown in Figure 2.3.

The moniker "monocrystalline" comes from the way these solar panels are made. A silicon wafer, formed from a single silicon crystal, is present in every solar cell. A "seed crystal" is melted pure silicon and heated to a high temperature in order to form this crystal. After then, the molten silicon hardens around the seed, creating a single crystal. This big crystal, sometimes referred to as a "ingot," is eventually cut into thin wafers that are utilized to make solar cells. Depending on its size, a monocrystalline panel usually has 60 or 72 solar cells. Monocrystalline silicon panels with 60 cells are frequently used in residential installations.

Due to their single-crystal structure, monocrystalline solar cells allow electrons to flow more smoothly, resulting in higher efficiency compared to other solar cell types. Their efficiency typically falls within the range of 17% to 22%.

Due to their high efficiency and power ratings, they end up costing more than any kind of solar panels. The mode of manufacture which is highly technical also bumps up the price. Most premium solar panels like the sun power, X-series and the LG Neon panels are monocrystalline.

### 2. POLYCRYSTALLINE SOLAR PANELS

Polycrystalline panels, also known as multi-crystalline panels, are favored by budget-conscious homeowners seeking to install solar panels. Unlike monocrystalline panels, polycrystalline silicon solar cells typically do not have their corners cut off, resulting in a more uniform appearance without large white spaces on the front. However, the manufacturing process gives them a blue color, which some find unattractive. Additionally, this manufacturing method renders them less efficient than monocrystalline panels.

**Fig 2.4: A Typical Polycrystalline Solar Panel.**

Polycrystalline solar cells are produced similarly to monocrystalline panels, starting with a seed crystal in molten silicon. However, instead of extracting the silicon seed crystal, the entire vat of silicon is allowed to cool, resulting in the formation of multiple crystals. This cooling process gives the panels their characteristic "marbled" blue look. Like monocrystalline panels, polycrystalline panels can have up to 60-72 cells.

Polycrystalline panels have a lower efficiency compared to monocrystalline panels because they contain multiple silicon crystals in each solar cell, which hinders electron flow. The efficiency rating of polycrystalline panels ranges from 15% to 17%. They are more cost-effective to produce than monocrystalline panels, which has contributed to their significant market share in residential installations.

**3. THIN FILM SOLAR PANELS**

Thin film solar panels differ significantly from monocrystalline and polycrystalline solar panels. They have a solid black appearance without the typical outlines of silicon cells found on crystalline solar panels. Thin film solar panels are lightweight and flexible, making them simple to install. They are primarily used in large-scale operations, such as utility or industrial solar installations, due to their lower efficiency range.

**Fig 2.5: A Typical Thin Film Solar Panel**

Thin film solar panels are made by applying a thin layer of photovoltaic material onto a solid surface. These panels, also known as photovoltaic (PV) modules, contain photovoltaic cells mounted in a framework for installation. They use sunlight, including UV-rays, to produce direct current electricity. A group of PV modules is called a PV panel, and a system of PV panels is known as an array.

By utilizing the photovoltaic effect, the photovoltaic modules transform sunlight into power. Usually, they employ thin film or crystalline silicon wafer-based cells. When sunlight enters a solar cell, it causes electrons in the absorber layer to transition from their lower energy "ground state" to their higher energy "excited state," where they are free to flow through the solid. This is how this effect occurs. Subsequently, free excited electrons are mixed with junction-forming layers, creating an internal electric field that produces the photovoltaic effect. The electrons in this electric field are propelled collectively, and they can perform beneficial work by passing through electric contact layers and into an external circuit like an electrochemical battery.

## 2.3 SOLAR CHARGE CONTROLLERS

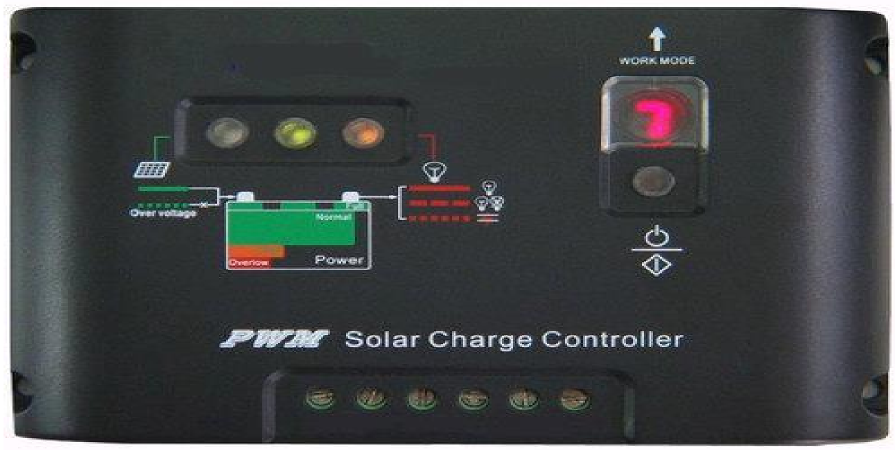


**Fig 2.6 A Solar Charge Controller**

An essential part of solar power systems, particularly those that include battery storage, is a solar charge controller. Its main job is to control the solar panels' voltage and current in order to effectively charge the batteries. The voltage levels produced by solar panels vary based on the intensity of the sun. This voltage is controlled by the charge controller to make sure it is appropriate for charging the batteries, A typical PWM solar charge controller is shown in the fig above.

By sustaining a safe charging voltage, the charge controller guards against overcharging batteries, which can cause damage. The current that travels from the solar panels to the batteries is likewise managed by the charge controller. It guards against excessive current, which could harm the linked electrical systems or the batteries.

Charge controllers protect batteries from overcharging, which can cause electrolyte loss and reduce battery life. They also prevent deep discharge, safeguarding batteries from damage and prolonging their lifespan. Some charge controllers have load control features, allowing them to manage the power supply to connected loads (such as lights or appliances). This ensures that the batteries are not excessively drained and that power is available when needed.

### 2.3.1 TYPES OF CHARGE CONTROLLERS

1. **PWM (Pulse Width Modulation):** PWM controllers rapidly switch the solar panel voltage on and off, effectively "modulating" the charging current to the batteries. While less efficient than

MPPT, PWM controllers are cost-effective and suitable for smaller solar systems. We will be making use of a PWM charge controller for the solar installation in a 5-Bedroom bungalow.

2. **MPPT (Maximum Power Point Tracking):** MPPT controllers optimize the power output from solar panels by adjusting the operating point to the maximum power available. This results in higher efficiency, especially in variable weather conditions.

### 2.4 INVERTERS


**Fig 2.7: A SOLAR INVERTER**

The inverter transforms the direct current (DC) voltage from the solar panels and the stored energy in the batteries into alternating current (AC) voltage. Additionally, if accessible, the inverter can utilize an alternative power source, such as the mains or a generator connected to it, to charge the batteries. To ensure the system's components function harmoniously, selecting the correct inverter depends on the system's load demand and power requirements.

As previously stated, the inverter is the component in a system that changes the direct current (DC) electricity generated by the solar panels into the alternating current (AC) electricity commonly used in households. There are three primary inverter technologies available: string inverters, string inverters with DC-to-DC optimizers, and micro-inverters. Although string inverters are presently the most prevalent choice, the adoption of micro-inverters and DC optimizers is rising as expenses decrease. A typical inverter system is illustrated in the figure above.

### 2.4.1 TYPES OF INVERTERS

#### 1. STRING INVERTERS

Solar panels are connected in series to form strings when string inverters are used. Several strings are connected in parallel to each inverter, referred to as an array.

Since only one device needs to be installed for multiple solar panels, string inverters are often the least expensive option. Additionally, they are usually more effective at converting DC to AC electricity. However, one issue with string inverters is that all the other modules in the string are also impacted when one solar panel gets shaded or has its output reduced due to dirt, bird droppings, etc.

#### 2. DC-to-DC OPTIMIZERS

DC-to-DC optimizers address the problem of shading on a single solar panel affecting all modules in a string. These compact devices connect to one or two panels and enhance the output of each panel individually. Despite their ability to enhance the total output of a solar system, particularly in shaded or soiled conditions, DC-to-DC optimizers still require connection to a string inverter to convert the output to AC electricity. However, their use increases the overall system cost compared to relying solely on string inverters.

#### 3. MICRO-INVERTERS

Micro-inverters, akin to DC-to-DC converters, optimize solar panel output at the individual panel level. Unlike DC-to-DC converters, however, micro-inverters also handle the DC to AC conversion, eliminating the need for a string inverter altogether. They can be externally mounted to the solar panel or integrated into the module itself, known as an AC module. While the use of micro-inverters can simplify the system and reduce installation costs, their higher price typically leads to a higher overall system cost. Additionally, within each type of inverter, there are various manufacturers to choose from, each offering their own advantages, features, and drawbacks.

### 2.4.2 INVERTER FUNCTIONS

In addition to converting solar DC electricity into AC electricity, the inverter serves several other vital roles, including:

- Enhancing the solar panels' power output.

• Managing battery charging if an inverter with this feature is installed, otherwise handled by an external charge controller.

• Monitoring the system.

• Implementing safety measures such as disconnecting from the grid during an outage.

### 2.4.3 INVERTER OVERSIZING

PV inverters are engineered to ensure that the generated module output power does not surpass the rated maximum inverter AC power. Oversizing refers to having an excess of DC power compared to AC power, which boosts power output during low light conditions. This allows for the installation of a smaller inverter for a given DC array size, or the installation of more PV modules for a given inverter. However, excessive oversizing of the inverter could adversely affect the total energy produced and the inverter's lifespan.

Excessive oversizing can have adverse effects on the inverter's power production. Inverters are engineered to generate AC output power up to a specified maximum, which cannot be surpassed. When the actual DC power produced exceeds the inverter's permitted maximum output, the inverter restricts or "clips" the power output, leading to energy loss. Oversizing the inverter can result in prolonged operation at high power levels, impacting its lifespan. Operating at high power levels increases internal heating in the inverter and may also heat its surroundings. In response to overheating, inverters reduce their peak power generation.

## 2.5 SOLAR BATTERIES


**Fig 2.8: A Solar Battery**

A solar battery is an accessory that stores surplus electricity produced by your solar panels, allowing you to power your home when your panels aren't generating enough electricity, such as at night or on cloudy days. Without a battery, surplus electricity is sent to the grid, meaning you're not fully utilizing the electricity you generate.

Lithium-ion batteries are currently the most popular type of solar batteries. They work by storing chemical energy through a reaction that converts it into electrical energy. Lithium ions release free electrons during this reaction, which move from the negatively charged anode to the positively charged cathode. This movement creates the current needed for electricity consumption.

During discharge, lithium ions travel back across the electrolyte to the positive electrode, while electrons move through the external circuit from the negative to the positive electrode, supplying power to the connected device. Solar batteries are rechargeable batteries that use solar power as their primary input to generate an electrical current. They consist of multiple ion battery cells and advanced electronics for operation and safety oversight.

### 2.5.1 COMPARING BATTERY STORAGE TECHNOLOGIES

There are four main types of battery technologies that pair with residential solar systems:

- Lead acid batteries
- Lithium-ion batteries
- Nickel based batteries
- Flow batteries

Each of these backup power technologies for batteries possesses distinct characteristics. Let's delve deeper into the features of each type of solar battery.

#### 1. LEAD ACID BATTERIES

Lead acid batteries, a well-established technology in the solar battery industry, have been utilized for energy storage since the 1800s. Their enduring popularity is owed to their reliability. These batteries come in two primary types: flooded lead acid batteries and sealed lead acid batteries.

Some popular lead acid batteries available to homeowners include:

- Trojan J185E-AC Deep Cycle Flooded Lead Acid Battery

- Crown Battery’s Crown1 absorbent glass mat (AGM) Sealed Lead Acid Battery
- Deka Solar’s 8g30H Gel sealed lead acid battery

Lead acid batteries are renowned for their cost-effectiveness, making them the most economical choice for energy storage. Their reliability is well-established, further enhancing their appeal. Moreover, their long-standing presence in the market ensures easy disposal and recycling processes.

However, flooded lead acid batteries require ventilation and regular maintenance for optimal performance, increasing the risk of leakage. Their installation is also limited, as they cannot be placed on their sides. Additionally, they have a low depth of discharge (DoD), necessitating more frequent charging. This low DoD contributes to a shorter lifespan, typically ranging from 5 to 10 years. Despite these drawbacks, the reliability of lead acid batteries makes them ideal for off-grid solar systems or as emergency backup storage during power outages.

## 2. LITHIUM-ION BATTERIES

Lithium-ion batteries are the latest entrants in the field of energy storage. Their potential as an energy storage solution was recognized by electric vehicle manufacturers as EV sales began to surge. They quickly became one of the most sought-after solar battery options. Some of the top lithium-ion solar batteries for residential use include:

- Tesla’s Powerwall battery
- LG’s Chem RESU lithium-ion battery Pros:

Lithium-ion batteries need minimal regular maintenance and boast a higher battery energy density, allowing them to store more energy in a smaller area compared to lead acid batteries. They also have a longer lifespan, often coming with a guaranteed warranty of at least ten years. Their higher depth of discharge allows for more use of the stored energy before recharging, contributing to their extended lifespan. However, the main drawback of lithium-ion batteries is their higher cost compared to other energy storage technologies.

Thermal runaway in lithium-ion storage systems, caused by their chemistry, raises the risk of fire. However, when installed correctly, the likelihood of battery fires is minimal. Lithium-ion batteries are ideal for residential solar installations due to their high energy density, enabling them to store more power in a confined space. Additionally, they allow for greater utilization of stored energy, making them well-suited for powering homes.

**3. NICKEL CADMIUM BATTERIES**

Lead acid or lithium-ion batteries are more commonly used than nickel cadmium (Ni-Cd) batteries. Although Ni-Cd batteries were first developed in the late 1800s, they underwent a significant upgrade in the 1980s that significantly increased their energy storage capacity. They are highly used in the aviation sector. Top producers of Ni-Cd batteries include Saft and Enersys.

The longevity of Ni-Cd batteries is their primary advantage. They can function in extremely hot or cold temperatures as well. They also basically require no maintenance and don't require complicated battery management systems.

The primary drawback of Ni-Cd batteries is the extreme toxicity of cadmium, which is banned in certain countries, making disposal challenging. Additionally, they are susceptible to the memory effect, reducing their ability to retain a charge. Despite these issues, Ni-Cd batteries are favored for large-scale applications such as utility solar energy storage due to their durability.

**4. FLOW BATTERIES**

Flow batteries are a developing technology in the energy storage field. They consist of a water-based electrolyte liquid that moves between two distinct chambers or tanks inside the battery. During charging, chemical reactions take place, enabling energy storage for later discharge. These batteries are now gaining traction in the market. They cost more than the other battery types because of their bigger size. It's challenging to modify them for residential use because of their high cost and large size. Redflow, on the other hand, produces a flow battery for homes that they call ZCell.

The 100% depth of discharge of flow batteries is one of their best features. This implies that you can fully utilize the battery's stored energy without endangering its condition.

Heat runaway is not a concern because the battery's liquid is likewise fire retardant. Among the listed options, flow batteries have the most extended lifespan, lasting up to 30 years. They also require minimal maintenance. However, flow batteries are significantly more costly than other types of solar batteries. Additionally, due to their lower storage capacity, they need to be larger to store a substantial amount of energy. They need to be big in order to be effective because of their extremely low charge and discharge rates.

The best flow batteries are those intended for large installations. They are more expensive because of their size requirement due to the way they operate, which makes them very large energy storage devices. Because of this, flow batteries haven't gained traction as a household choice.

### 2.5.3 AC COUPLED STORAGE VS. DC COUPLED STORAGE

The two types of coupling that are available for connecting your solar panels to your battery storage system are alternating current (AC) coupling and direct current (DC) coupling. The direction that the electricity produced by the solar panels travels determines the primary distinction between the two.

DC electricity produced by solar cells needs to be transformed into AC electricity in order for your home to use it. There are various ways to integrate a solar battery into your solar power system, but keep in mind that solar batteries can only hold DC electricity.

**DC COUPLED STORAGE**

DC coupling involves the direct flow of DC electricity from solar panels through a charge controller into the solar battery. The electricity remains in DC form until it is discharged to power your home or sent back to the grid, at which point it is converted to AC. While more efficient, as the electricity undergoes only one DC to AC conversion, DC-coupled storage systems often require a more intricate installation process, leading to higher initial costs and longer installation times.

**AC COUPLED STORAGE**

In an AC coupling, an inverter transforms the DC electricity produced by solar panels into AC electricity before it is used to power equipment in the home. After being converted to DC for storage in the solar battery by another converter, this AC power can be routed elsewhere. The stored energy exits the battery and passes via an inverter to be transformed back into AC for usage in homes when needed.

Three distinct inversions are involved in AC-coupled storage: the first is from the solar panels to the home, the second is from the house to the battery storage, and the third is from the battery storage back to the house. AC-coupled storage is marginally less efficient than a DC-coupled system due to the efficiency loss that occurs with each inversion.

However, AC-coupled storage offers a significant advantage over DC-coupled systems by allowing the storage of energy from both solar panels and the grid. This flexibility enables the battery to be charged with grid electricity when solar generation is insufficient, providing backup power or allowing users to take advantage of electricity rate differences. Furthermore, upgrading an existing solar power setup with AC-coupled storage is simpler, as it can be seamlessly integrated without major modifications. These factors contribute to the popularity of AC-coupled battery storage for retrofit installations.

### 2.5.4 HOW SOLAR BATTERIES WORK WITH A SOLAR POWER SYSTEM

The solar panels on the roof generate power to initiate the process. In a DC-coupled system, the following steps occur:

- Sunlight is absorbed by the solar panels, converting energy into DC electricity.
- The DC electricity flows into the battery, where it is stored.
- From the battery, the DC electricity moves to an inverter, where it is converted into AC electricity for household use.

In an AC-coupled system, the process differs slightly:

- Solar panels convert sunlight into DC electricity.
- The DC electricity goes into an inverter to be converted into AC electricity for household use.
- Any surplus electricity passes through another inverter to be converted back into DC electricity for storage.
- When the stored energy is needed, it goes through the inverter again to become AC electricity for household use.

### 2.5.5 BENEFITS 0F SOLAR BATTERY STORAGE

Integrating battery backup with your solar panels maximizes the efficiency of your solar power setup. Here are the key advantages of having a home solar battery storage system:

1. **Stores Excess Electricity Generation:** On sunny days when your home is unoccupied, your solar panels often produce more electricity than you need. Without battery storage, this surplus energy is sent back to the grid. However, with batteries, you can store this excess energy for later use, reducing your reliance on the grid during times of lower solar generation.

2. **Provides Relief from Power Outages:** With the ability to store surplus solar energy, your batteries provide a reliable source of electricity for your home during power outages and grid failures.

3. **Reduces Your Carbon Footprint:** By utilizing as much of the clean energy generated by your solar panel system as possible, you can go green with solar panel battery storage. If that energy isn't stored, you won't be able to use your solar panels to power your home when they don't produce enough energy. However, the majority of grid electricity is generated by burning fossil fuels, so using the grid will probably expose you to dirty energy.

4. **Provides Electricity Even After the Sun Goes Down:** When sunlight fades and solar panels cease generating electricity, reliance on the grid becomes necessary without battery storage. However, with a solar battery, you can utilize more of your solar-generated electricity at night, enhancing energy self-sufficiency and reducing your electricity expenses.

5. **A Quiet Solution to Backup Power Needs:** A solar power battery offers silent backup power storage, providing maintenance-free clean energy without the noise associated with gas-powered generators.

## 2.6 REVIEW OF RELATED WORKS

### 1. STAND ALONE SOLAR PHOTOVOLTAIC SYSTEM

### ABSTRACT

The increasing demand for energy, coupled with the depletion of traditional energy sources, has led experts to explore sustainable alternatives. Solar energy, being a freely renewable and abundant resource, is a promising option. This study is focused on designing a stand-alone solar energy system for a medium house in Kano state, Nigeria. The research indicates that to power the house, a 300W solar PV array consisting of 30 modules, 22 (140Ah, 12V) batteries, and 4 (90A, 202-253V) voltage regulators are required. Despite the relatively high initial cost of the system compared to a fossil fuel generator, the estimated payback period is 2 years and 4 months, which is shorter than the 30-year lifespan of the selected PV modules.

**DESIGN METHOD OF THE SYSTEM**

Following an interview with the homeowner to estimate the load of household appliances, the system components, including solar photovoltaic, battery bank, inverter, voltage regulator (charge controller), and cable wires, were designed and sized appropriately.

**APPLIANCES LOADS ESTIMATION**

The house appliances load was presented in the Table 2.1 as:

**Table 2.1**. **ELECTRICAL ENERGY LOAD OF THE HOUSE APPLIANCES**

| S/N | Name | Quantity 'Q' | Power Rating 'P' (W) | Usage Hours 'T' (Hrs) | Total Power '$P_t$' (W) $P_t$=Q*P | Total Energy '$E_t$' (kWh/day) $E_t$=$P_t$*T |
|---|---|---|---|---|---|---|
| 1 | Fluorescents | 50 | 20 | 6 | 1000 | 6 |
| 2 | Television | 5 | 140 | 5 | 700 | 3.5 |
| 3 | DVD Player | 5 | 40 | 5 | 200 | 1 |
| 4 | Fans | 10 | 100 | 6 | 1000 | 6 |
| 5 | Laptop | 3 | 40 | 3 | 120 | 0.36 |
| 6 | Refrigerator | 4 | 140 | 5 | 560 | 2.8 |
| 7 | Pressing Iron | 3 | 1000 | 2 | 3000 | 6 |
| 8 | Accessories | 4 | 200 | 3 | 800 | 2.4 |
| | **Total** | | | | **7380** | **28.06** |

**DESIGN ASSUMPTIONS**

In the design of an off-grid solar PV system, several assumptions and considerations are made:

A. The peak solar intensity at the earth's surface is assumed to be 1 kW/m².

B. The inverter is assumed to convert DC into AC power with an efficiency of 90%.

C. The number of autonomy days is assumed to be 2 days.

D. The maximum depth of discharging is assumed to be 50%.

E. The design system voltage is assumed to be 48V.

F. The safety factor of the module is assumed to be 1.25.

G. The size of the wires and cables used in this design is determined based on the National Electrical Code (NEC).

## SELECTION AND SIZING OF SYSTEM

### Design and Sizing of Solar PV Module

The solar photovoltaic module is an electronic device that converts solar energy into usable energy. The selection of a module for the system involved determining the power output and the number of modules, ultimately leading to the choice of the Yingli 300Watt, 24V silicon-crystalline module.

## POWER OUTPUT OF SOLAR PV MODULE

The power output of the solar photovoltaic module (Ppv) can be obtained using the relation given by

$$P_{pv} = \frac{E_t \times PSI}{\eta_b \times K_{losses} \times H_{tilt}} ---------- (2.1)$$

Where:

Et is the total daily energy of the house load = 46.86kWh/day (From Table);

PSI is the Peak Solar Intensity at the earth surface = 1kW/m$^2$ ;

ηb is the Efficiency of the System;

Klosses are the decisive factor caused by system losses, such as dust accumulation and temperature fluctuations. Htilt represents the average solar irradiance received at the specific tilt angle, assumed to be 5.0 kWh/m$^2$.

.

The efficiency of the system can be found using the relation given as:

ηb = ηinverter × ηconnection losses------------------------ (2.2)

Where:

ηinverter is the efficiency of the inverter = 90% and

Hconnection losses is the efficiency of the system connection which is between the range 80-90% and 80% is taken in this design.

The determination factor can determine using equation given as:

Klosses = tmanuf. × Fdirt × Ftemp. ------------------------ (2.3)

Where:

tmanuf. is the manufacturer's tolerance = 97% ;

Fdirt is the de-rating due to dirt which is taken to be 90%  and;

Ftemp. is the temperature de-rating factor which can be found using equation given as:

Ftemp. = 1-[γ(Tcell,eff.-TSTC)]------------------------------- (2.4)

Where:

γ is the power temperature coefficient = 0.48%/°C;

TSTC is the standard temperature of the collector = 25°C and;

Tcell, effi. is the average daily temperature which is given as:

Tcell, effi.= 25 + Ta---------------------- (2.5)

Where:

Ta is the ambient temperature = 27°C

**Number of Modules**

The photovoltaic modules are arranged in series and parallel connections.

**A. Number of Modules in Series Connection**

The number of modules in series connection can be found using relation given  as:

$$N_{ms} = \frac{V_{system}}{V_{module}} --------------- (2.6)$$

Where:

Vmodule is the nominal voltage of the module = 24v and;

Vsystem is the designed system voltage = 48v.

**B. Number of strings in Parallel Connection**

The number of strings in parallel connection can be found using relation given  as:

$$N_{mp} = \frac{P_{pv}}{N_{ms} \times P_{module}} ---------- (2.7)$$

The number of modules of the system can be obtained by multiplying number of modules in series and that in parallel.

Nmt = Nms × Nmp ------------------------------- (2.8)

**DESIGN OF BATTERY BANK**

The battery bank plays a crucial role in smart grid design as it stores the solar energy absorbed by the photovoltaic modules. The capacity of the battery bank can be calculated using the following relationship:

The battery capacity is given as;

$$C_B = \frac{E_T \times N_c}{V_n \times DOD \times Eff_{inv}} ----------- (2.9)$$

Where; ET is the total watt-hour consumed

$N_c$ is number of days of autonomy ( which is taken as 2)

Vn is Norminal voltage of battery

DOD is depth of discharge and

$Eff_{inv}$ is the Inverter efficiency

In this design, a lead acid battery from Hoppecke Solar Power was chosen, with a nominal voltage of 12V and a capacity of 140Ah. The number of batteries required for this system can be calculated using the following equation:

$$N_{Breq} = \frac{C_B}{C_{selected}} --------- (2.10)$$

$N_{Breq}$ is the number of batteries required for the system

$C_{selected}$ is the capacity of the selected battery

Similar to solar PV modules, batteries can be connected in series and parallel arrangements. The number of batteries connected in series can be determined using the following relationship:

$$N_{B_{series}} = \frac{V_{system}}{V_{battery}} ---------- (2.11)$$

The number of batteries connected in parallel is obtained using;

$$N_{B_{parallel}} = \frac{C_{B_{req}}}{N_{B_{series}}} ---------- (2.12)$$

**Design of the Inverter**

An inverter is essential in systems requiring AC power output. Its input rating should always match or exceed the total power consumption of connected appliances. The inverter's nominal voltage must also match that of the battery. In stand-alone systems, the inverter should be sized to handle the maximum power demand anticipated. A recommended practice is to choose an inverter that is 25-30% larger than the total power consumption of all appliances.

**Voltage Regulator Sizing**

A voltage regulator controls the current flow and should withstand the maximum current from the array and load. To size the regulator, multiply the short circuit current of parallel-connected modules by a safety factor (fsafe) to determine the rated current.

$$I_{rated} = N_{mp} I_{sc} f_{safe} \text{---------} (2.13)$$

Where:

$N_{mp}$ is the number of PV modules connected in parallel

$I_{sc}$ is the short circuit current of the module and;

$f_{safe}$ is the safety factor which is usually taken to be (1.25)

**Sizing of System Cables and Wires**

Choosing the right size and type of wires and cables improves the performance and reliability of a photovoltaic system. The design selected cables and wires based on the National Electrical Code (NEC).

## RESULTS AND DISCUSSION

**Design Output of Solar PV Module of the System**

Table 2.2 presents the output parameters of the PV modules of the system as:

**Table 2.2** The output parameters of the PV modules of the system

| Input Parameters | Design Calculations | Output Parameters |
| --- | --- | --- |
| $E_t$=28.06kWh/day; $PSI$=1kW/m²; $H_{tilt}$=5.5m; $\eta_{inverter}$=90%; $\eta_{connection\ losses}$=85%; $t_{man}$=97%; $F_{dirt}$=90%; $\gamma$=0.48%/°C; $T_{STC}$=25°C and $T_a$=27°C. | From equation (2): $\eta_b = 0.90 \times 0.85 = 0.768$ From equation (5): $T_{cell,eff.} = 25 + 27 = 52°C$ From equation (4): $F_{temp.} = 1 - \left[\frac{0.48}{100}(52-27)\right] = 0.8704$ From equation (3): $K_{losses} = 0.97 \times 0.8704 \times 0.90 = 0.76$ From equation (1): $P_{pv} = \frac{28.06 \times 1}{0.768 \times 0.76 \times 5.5} = 8.74kWh/day$ | $\therefore P_{pv} = 8.74kWh/day$ |
| $V_{system}$=48V; $V_{module}$=24V and $P_{module}$=300W. | From equation (6): $N_{ms} = \frac{48}{24} = 2modules$ From equation (7): $N_{mp} = \frac{8.74 \times 10^3}{2 \times 300} = 14.57 \approx 15\ modules$ From equation (8): $N_{mt} = 2 \times 15 = 30\ modules$ | $\therefore N_{ms} = 2\ modules$ $\therefore N_{mp} = 15\ modules$ $\therefore N_{mt} = 30\ modules$ |

### Design Output of Solar Battery Bank of the System

Table 2.3 presents the output parameters of the solar battery bank of the system as:

**Table 2.3** The output parameters of the solar battery bank of the system

| Input Parameters | Design Calculations | Output Parameters |
|---|---|---|
| $E_t$ =28.06kWh/day; $V_n$=12V; $N_c$=2days; $DOD_{max}$=50%; $\eta_{inverter}$=90% and $C_{selected}$=140Ah | From equation (9): $$C_b = \frac{28.06 \times 10^3 \times 2}{0.50 \times 0.96 \times 12} = 9743Ah$$ From equation (10): $$N_{b_{requ}} = \frac{9743}{140} = 69.6 \approx 70\ batteries$$ | $\therefore C_b = 9743Ah$ and $N_{b_{requ}} = 70\ batteries$ |
| $V_{system}$=48V and $V_{battery}$=12V | From equation (11): $$N_{bseries} = \frac{48}{12} = 4\ batteries$$ From equation (12): $$N_{bparallel} = \frac{70}{4} = 17.5\ say\ 18\ batteries$$ | $\therefore N_{bs} = 4\ batteries$ $\therefore N_{bp} = 18\ batteries$ |

**Design Output of Voltage Regulator of the System**

Table 2.4. presents the output parameters of the voltage regulator of the system as:

**Table 2.4** The output parameters of the voltage regulator of the system

| Input Parameters | Design Calculations | Output Parameters |
|---|---|---|
| $N_{mp}$=25 modules; $f_{safe}$=1.25; $I_{SC}$=5.38A and $I_{selected}$=90A | From equation (13): $$I_{rated} = 25 \times 9.6 \times 1.25 = 300A$$ From equation (14): $$N_{v_{reg}} = \frac{300}{90} = 3.33 \approx 4$$ | $\therefore I_{rated} = 300A$ and $N_{v_{reg}} = 4\ Regulators$ |

**Cost Estimation and Analysis**

a) Estimated Cost of the System

Table 2.5 presents the estimate cost of system's components as

**Table 2.5** The estimate cost of system's components

| Components | Model | Quantity | Unit Price (₦) | Overall Cost (₦) |
|---|---|---|---|---|
| **Solar Modules** | Yingli 300W, 24V (Silicon-crystalline Technology) | 30 | 24,500 | 735,000 |
| **Battery** | Hoppecke Solar.power 140Ah, 12V (Lead Acid Type) | 22 | 4,000 | 88,000 |
| **Inverter** | Latronics LS-3000W, 24V (d.c), 220V (a.c). | 2 | 6,000 | 12,000 |
| **Voltage Regulator** | Sunny Island 202-253V, 90A | 4 | 3,500 | 14,000 |
| **Miscelleneous Cost** | | | | 30,000 |
| **Total** | | | | 879,000 |

The operating costs for solar PV installations are negligible, but the annual maintenance cost may amount to 0.5% to 1% of the capital cost of the system. Maintenance cost of the PV system is taken to be 0.8% of the capital cost of the system as:

= 0.8% × ₦879,000 = ₦7032

Therefore, the overall cost of the system can be found by adding the capital cost of the system with annual maintenance cost as given below:

= ₦879,000 + ₦7032 = ₦886,032

The house has a small generator used to charge the batteries of the system when there is no sun for a day.

The hours estimated was 3hours per day,

The total estimated hours used per annum were:

$= 3 \times 365 = 1095h$

The estimated fuel (Petrol) used for the generator was two litres per hour;

The total estimated fuel consumed by the generator per annum was:

$= 1095 \times 2 = 2190$

The prevailing market price for a litre of petrol for running a generator in Nigeria was at the rate of ₦145 per litre [20].

The total cost fuel consumed by the generator per annum was:

= 2190 × 145 = ₦317,550

For the generator to work properly it needs maintenance regularly, therefore the estimated maintenance cost of the generator was ₦15,000.

The total running cost of the generator per annum was:

= ₦317,550 + ₦15,000 = ₦332,550

The cost of purchased of the generator was ₦46,800;

Finally, the cost of the petrol consumed and the cost of generator for the first year was:

= ₦332,550 + ₦46,800 = ₦379,350

## DISCUSSION OF THE RESULTS

The daily load was calculated at 28.06 kWh/day using the watt-hour ratings of the appliances, as detailed in Table 2.1. The stand-alone solar PV system was then designed according to this estimated load.

Table 2.5 shows that the house requires 30 Yingli mono-crystalline solar PV panels, arranged in series and parallel configurations of 2 modules and 15 modules, respectively. These panels, each with a 300W output and 24V, are expected to generate 8.74 kWh/day for the house. Additionally, to store energy for later use, a battery bank was designed using 22 batteries from Hoppecke Solar Power, with 18 connected in parallel and 4 in series, and a capacity of 140Ah.

For safe battery charging and to extend their lifespan, the house needs a 90A capacity voltage regulator. Since some appliances require AC current, inverters are needed to convert the system's DC current to AC. Only one inverter is required for the system.

In conclusion, the system's capital cost was ₦879,000, with an overall cost of ₦886,032. The analysis shows that the modules, batteries, and inverter are the most costly parts of an off-grid photovoltaic system (Table 2.5). The total system cost increases with the size of these components. Based on a cost estimate, the system is expected to pay for itself in 2 years and 4 months, a much shorter period than the 30-year lifespan of the solar PV modules.

## CONCLUSION AND RECOMMENDATION

This study estimated the daily electrical energy demand of a rural house in Kano state, Nigeria, at 8.74 kWh/day. Based on this estimate, the system design included a 300W solar PV array with 30 modules, 22 (140Ah, 12V) batteries, and 4 (90A, 202-253V) voltage regulators. The total system cost was ₦886,032, higher than the previous fossil fuel generator but with an estimated payback period of 2 years and 4 months, much shorter than the 30-year lifespan of the PV modules. It is recommended to make the system utility-interactive to allow users to sell surplus solar energy.

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## 2. DESIGN AND CONSTRUCTION OF 5KVA SOLAR INVERTER POWER SYSTEM

### SOLAR PANELS

For this study, Four (4) solar panels of 250 watts each were used to produce 5000W(5kva) of electricity and the energy that was produced was stored in the batteries for use during the cloudy/ rainy weather. The wattage of the Solar Panels was estimated as follows:

5000W/day ÷ 7 sun hours/day = 714.3W ÷ 0.8 (system losses) =893W

893/250 = 3.57(approximately 4 Solar panels of250watts each)

### BATTERY

For this study, the required power is 5000W. Therefore, the battery capacity was estimated as follows;

$$Battery\ Capacity\ (Ah) = \frac{total\ watt - hour\ required \times days\ of\ autonomy}{0.85 \times 0.6 \times nominal\ battery\ voltage} ----- (2.14)$$

$$= \frac{5000 \times 2}{0.85 \times 0.6 \times 24} = 816.9Ah$$

### CHARGE CONTROLLER

Solar charge controllers are defined in Amps, typically 10, 20, 30, 50, 75Amps.

Once you know the size of your solar array, if you are going to wire them in series, it is easy to specify your solar charge controller.

charge controller rating = $\frac{solar\ panel\ watts}{system\ voltage} \times 1.1 -------- (2.15)$

The 1.1, adds 10% to the calculation as a margin of safety.

For example:

= $\frac{500W\ solar\ array}{12V} \times 1.1 = 45.8Amps$

In this circumstance, a 50Amp solar charge controller would do the job just fine.

### INVERTER

The output voltage of the secondary winding is transferred to the socket outlet of the output of the inverter system (Theraja and Theraja, 2005).

**Output power of the Transformer:**

Output power = $V_S I_S Cos\theta$ (Watts)--------------- (2.16)

Where $V_s$ = Secondary voltage of the transformer,

$I_s$ = Secondary current of the transformer

and Cosθ= Power factor

But

$P_s = I_sV_s$-------------------------(2.17)

$P_s$ = 2000VA and $V_s$ = 220V using (2) $I_s$ = 9.1A.Using (1) Cosθ =0.9

Inputing given values

= 2002VA = 2.002 × $10^{-3}$MVA

the output power rating (VA) in terms of the power factor is

$$output\ power = \frac{Power\ (W)}{cos\theta} --------- (2.18)$$

$$output\ power = \frac{2.002 \times 10^{-3}}{0.9} = 2.224 \times 10^{-3} KVA$$

**RESULTS**

The results were obtained using a digital multimeter and the values obtained were compared with the expected values

Table 2.6: Measurement and testing of an inverter and solar cell

| **Measurements** | **Expected values** | **Achieved Values** |
|---|---|---|
| $V_{OUTPUT}$for Solar cell | 100V | 100V |
| $P_{OUTPUT}$ for solar Cell | 150W | 150W |
| $V_{OUTPUT}$ for inverter | 220V | 220V |
| $I_{OUTPUT}$ for inverter | 10A | 9.7A |
| $P_{OUTPUT}$ for inverter | 5kva | 4.83Kva |
| Frequency | 50Hz | 50Hz |

Table 2.7: Measurement of operational time of the inverter with different Load

| **S/No** | **Appliance description** | **Appliances Wattage** | **Runtime** |
|---|---|---|---|
| 1 | TV Set, DVD Player and home theatre | 1360W | 15hrs 25 mins |
| 2 | Electric Cooker | 2800W | 9hrs 7Mins |

| | | | |
|---|---|---|---|
| 3 | Electric iron | 2200W | 10hrs 2Mins |
| 4 | 5 lighting bulbs (200W each), Standing Fan and Computer system | 1750W | 13hrs 36mins |
| 4 | Washing Machine | 900W | 20hrs 5mins |

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## 3. DESIGN AND INSTALLATION OF SOLAR PHOTOVOLTAIC POWER SYSTEM

### LOAD ESTIMATION

**The total energy requirement of the system i.e Total connected load to PV panel system**

= No. of units × rating of equipments-------------------(**2.19**)

**Total watt-hours rating of the system** = Total connected load (watts) × Operating hours ----(**2.20**)

The daily energy consumption for a certain load is given as:

**Daily KWh=** $\frac{\boldsymbol{Wattage \times hours\ used\ per\ day}}{\mathbf{1000}} ------- (\mathbf{2.21})$

**PV MODULE RATING**

In the solar industry, the peak power rating (kWp) indicates a panel's maximum output under Standard Test Conditions (STC): solar radiation of 1,000W/m², a module temperature of 25°C, and a solar spectrum air mass of 1.5. These "full sun" conditions yield maximum irradiance, and any reduction in solar radiation proportionally decreases the current output.

Manufacturers typically rate a solar module's output at 100 Watts under STC, with a ±5% tolerance, meaning it can produce as low as 95 Watts and still be labeled "100-watt." To be cautious, consider the lower end of the power output spectrum.

Assume that the operating factor is 0.75

**Actual power output of a PV panel =** Peak power rating × operating factor **----------- (2.22)**

**The power used at the end use is less (due to lower combined efficiency of the system)**

**=** Actual power output of a panel × combined efficiency -------------(**2.23**)

**The power produced by the solar panel is given as:**

Energy = (Area of the panel) x (Intensity of light) x (Efficiency of the panel) x (Time)----(**2.24**).

This equation considers the dimensions of the solar panel, the strength of the sunlight it receives, and its efficiency. It provides an approximation of the panel's energy output over a specific timeframe.

**Power of Panel=** $\frac{\boldsymbol{daily\ energy\ load\ consumption}}{\boldsymbol{Hours\ of\ usable\ sunlight\ during\ day}} ------ (\mathbf{2.25})$

**NUMBER OF PANELS**

The number of solar panels needed= $\frac{hourly\ energy\ requirement \times peak\ sunlight\ hours}{Panels\ wattage} ---- (2.26)$

**BATTERIES**

**Capacity(Ah)** $= \frac{\boldsymbol{Daily\ energy\ consumption\ (Wh)}}{\boldsymbol{Maximum\ panel\ volt}}$ ------ $\mathbf{(2.27)}$

Given a battery efficiency of 85% and a discharge level to preserve its lifespan at 60% of its capacity, the required battery capacity for this system is calculated as follows:

Capacity (Ah)= $\frac{total\ watt-hours\ per\ day\ used\ by\ appliance}{0.85 \times 0.6 \times nominal\ battery\ voltage}$ --------- (2.28)

Capacity (Ah)= $\frac{total\ watt-hours\ per\ day\ used\ by\ appliance}{0.85 \times 0.6 \times nominal\ battery\ voltage}$ × days of autonomy----------(2.29)

**CHARGE CONTROLLER SIZING**

The power input from the panels to the charge controller is determined using the following equation, considering an assumed worst-case charge controller efficiency of 85%:

**Input Power (**from panels**)**= $\frac{\boldsymbol{output\ power}}{\boldsymbol{efficency}}$ ------ $\mathbf{(2.30)}$

**The charge controller rating**= $\frac{\boldsymbol{panels\ wattage\ rating}}{\boldsymbol{voltage\ rating}}$ ------- $\mathbf{(2.31)}$

**INVERTER SIZING**

The inverter converts the direct current (DC) generated by the panel into the alternating current (AC) required to power household AC loads. The inverter's efficiency typically falls between 90% and 95% due to power losses during conversion. The efficiency of the inverter can be calculated using the formula:

Efficiency= $\frac{output\ power\ (to\ loads)}{input\ power\ (coming\ from\ the\ charge\ controller)}$ ------ (2.32)

With an assumed worst-case inverter efficiency of 90%, the input power to the inverter from the charge controller is calculated using the following formula:

**Input power (from charge controller)**= $\frac{output\ power\ (to\ loads)}{efficiency}$ ----- (2.33)

The inverter must have enough power capacity to meet the total Wattage required by the system. It is recommended that the inverter size be 25-30% larger than the total load Wattage to account for safety and design margin.

$$\boldsymbol{Power\ rating\ of\ inverter\ in\ KVA} = \frac{\boldsymbol{total\ load\ in\ watts}}{\boldsymbol{nominal\ power\ factor}} \text{----} \mathbf{(2.34)}$$

**The inverter size should be based on the wattage and voltage level of the system.**

**INVERTER BACKUP TIME**

Inverter battery backup time is calculated as:

**Back up time = Battery Power in Watt hour (Wh)/Connected Load in Watts (W) --------(2.35)**

**Battery Power in Wh = Battery Capacity in AH x Battery Voltage (V) x Number of Batteries -------------------(2.36)**

Let us shorten the formula by using the following Symbols:

**Let BUT =** battery backup time in hours

**C =** battery capacity in AH

**V =** battery voltage in volts

**N =** Number of batteries in series or parallel as the case may be.

$P_L$ = connected load in watts (W)

$$BUT = \frac{C \times V \times N}{P_L} ---------- (2.37)$$


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## 4. DESIGN METHODOLOGY OF OFF GRID SOLAR POWERED SYSTEM

### SOLAR PV SYSTEM DESIGN

A solar PV system design can be done in four steps:

Load estimation

Estimation of number of PV panels

Estimation of battery bank

Cost estimation of the system.

Base condition:2 CFLs(18 watts each),2 fans (60 watts each) for 6hrs a day.

The total energy requirement of the system (total load) i.e. Total connected load to PV panel system

From equation 2.19,

Total connected load to PV panel sytem= No. of units × rating of equipment

$= 2 \times 18 + 2 \times 60 = 156$ watts

From equation 2.20,

Total watt-hours rating of the system

= Total connected load (watts) × Operating hours = $156 \times 6 = 936$ watt-hours

From equation 2.22,

Actual power output of a PV panel = Peak power rating × operating factor

$= 40 \times 0.75 = 30$ watt

From equation 2.23,

The power used at the end use is less (due to lower combined efficiency of the system

= Actual power output of a panel × combined efficiency

$= 30 \times 0.81 = 24.3$ watts (VA)

= 24.3 watts

Energy produced by one 40 Wp panel in a day

= Actual power output × 8 hours/day (peak equivalent)

$= 24.3 \times 8 = 194.4$ watts-hour

Number of solar panels required to satisfy given estimated daily load :

= (Total watt-hour rating (daily load)/(Daily energy produced by a panel)

=936/194.4 = 4.81 = 5 (round figure)

Inverter size is to be calculated as :

Total connected load to PV panel system = 156 watts

Inverter are available with rating of 100, 200, 500 VA, etc.

Therefore, the choice of the inverter should be 200 VA.

## COST ESTIMATION OF A PV SYSTEM

(a) Cost of arrays = No. of PV modules × $\frac{cost}{module}$ --------------- (2.38)

= 5 × 8000 (for a 40 Wp panel @ 200/Wp) = 40000

(b) Cost of batteries = No. of Batteries × $\frac{cost}{module}$ -------------------- (2.39)

=1 × 240000= 240000

(c) Cost of Inverter = No. of inverters × $\frac{cost}{module}$ ------------------------ (2.40)

= 1 × 100000 = 100000

Total cost of system = A + B + C = 40000 + 240000 + 100000 = 380,000

[Additional cost of wiring may be taken as 5% of total system cost]

## ASSUMPTIONS TAKEN FOR DESIGN:

1. Inverter converts DC into AC power with efficiency of about 90%.
2. Battery voltage used for operation = 12 volts
3. The combined efficiency of inverter and battery will be calculated as :

Combined efficiency = inverter efficiency × battery efficiency---------------- (2.41)

= 0.9 × 0.9 = 0.81 = 81%

4. Sunlight available in a day = 8 hours/day (equivalent of peak radiation).
5. Operation of lights and fan = 6 hours/day of PV panels.
6. PV panel power rating = 40 Wp (Wp, meaning, watt (peak), gives only peak power output of a PV panel)
7. A factor called „ operating factor" is used to estimate the actual output from a PV module.
8. [The operating factor between 0.60 and 0.90 (implying the output power is 60 to 80% lower than rated output power) in normal operating conditions, depending on temperature, dust on module, etc.]

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- James P. Dunlop,

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## 5. DESIGN METHODOLOGY OF OFF-GRID PV SOLAR POWERED SYSTEM (A CASE STUDY OF SOLAR POWERED BUS SHELTER)

### Battery Sizing

The PV battery system assesses various financial strategies, with the battery's useful life limited to either 5,000 cycles or its planned 20-year lifespan. Annual maintenance costs for the photovoltaic and rechargeable systems are estimated at 1.5% of the assumed cost. The cost system for the battery and PV is assumed to be proportional to their size. The provided formula enables the calculation of the necessary battery size.

Recall, from equation 2.29,

$$\boldsymbol{B}attery\ capacity(Ah) = \frac{Total\ Watt-hours\ per\ day\ used\ by\ appliances \times Days\ of\ autonomy}{0.85 \times 0.6 \times nominal\ battery\ voltage}$$

**Calculating Energy Usage**

| Appliance | Appliance categories | Quantity | Watts (V*A) Multi* 1.5 for AC | Operation Hours/day "from table" | Watts Hours/day |
|---|---|---|---|---|---|
| LED Lights | Night use | 2 | 3 | 14 | 80 |
| High Flux LED | Night use | 6 | 18 | 14 | 1008 |
| Cell phone charger | 24 Hours use | 2 | 5 | 15 | 150 |
| WI-FI router | 24 Hours use | 1 | 20 | 24 | 480 |
| Solar charger controller | 24 Hours use | 1 | 1 | 24 | 24 |
| Sensor | 24 Hours use | 1 | 1 | 24 | 24 |
| Total Watt Hours per day | | | | | 1770.00 |

1770Wh/day ÷ 3 sun hours/day = 590W

590.W ÷ 0.8 (system losses) =737.5W

Wh = 737.5W x 30 days Wh = 22,125 Watt-hours (22.125 kWh/month)

The project will be dealing with lower voltage devices hence a 12V system is chosen.

**Calculate Wattage of the Solar Panels**

1770Wh/day ÷ 3 sun hours/day = 590W

590W ÷ 0.8 (system losses) =737.5W

737.5/250 = 2.95(3 Solar panels 250watts)

For the project we would be using 3 panels of 250 Watts each.

**Battery Sizing**

Recall, from equation 2.29,

Battery Capacity (Ah) = <u>Total Watt-hours per day used by appliances</u> x Days of autonomy

(0.85 x 0.6 x nominal battery voltage)

For this project, the daily average energy consumption per day is 1770 (W-h/day) for the month of December.

Battery Capacity (Ah) = 1770 x 2

(0.85 x 0.6 x 12)

= (1770/ (0.85x0.6x12)) x2

= 1770/0.85=2082.35

= 2082.35/0.6=3470.5

=3470.5/12=289.2

289.2x2=578.4

578.4 Ah Battery Capacity required for the system **Invertor Sizing**

As previously mentioned, the inverter size should match the wattage and voltage requirements of the system. This project utilizes a 12V and 2000W system, so an inverter with a similar rating should be employed.

**Charge Controller Sizing**

This project requires the use of a PWM charge controller. The following steps outline how to determine the necessary size for the charge controller.

Voltage level of the system: 12V

Maximum amperage: 10 A

There a PWM controller should be used with 12 V and 10 A with rated voltage and current specifications.

**Conclusion**

Electrifying rural houses can be costly, especially when the grid is far from the houses. In such cases, an off-grid PV system can be a viable alternative. Both grid-tied and off-grid PV systems have their own pros and cons. The choice between them depends on individual needs. Typically, grid-tied systems are more common in urban and suburban areas where electrification is already established. On the other hand, off-grid systems are preferable in areas without electrification or where consumers prefer not to supply excess energy back to the grid.

This paper outlines the methodology for designing an off-grid PV system, using a bus shelter at EIU as an example. The system is designed to accommodate various equipment such as a WIFI module, charging points, lights, and sensors for student use. While the design methodology is demonstrated using a bus shelter, it can be adapted for other purposes requiring an off-grid system. The paper does not delve into the economic aspects of the system, as there are numerous vendors in the market offering different equipment options. Once the system capacity is determined, individuals can explore various equipment options based on their budgetary considerations.

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## 6. DESIGN AND CONSTRUCTION OF A PV SYSTEM

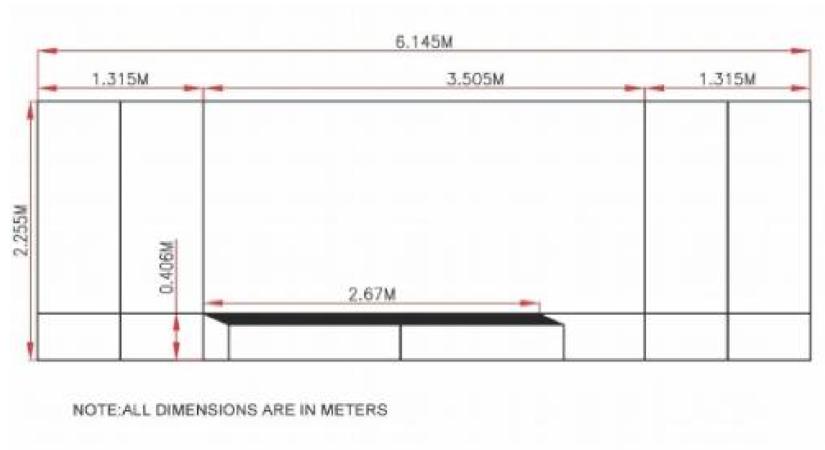


*Figure 6 CAD representation of the shelter*

**Calculating Energy Usage**

| Appliance | Appliance categories | Quantity | Watts (V*A) Multi* 1.5 for AC | Operation Hours/day "from table" | Watts Hours/day |
|---|---|---|---|---|---|
| LED Lights | Night use | 2 | 3 | 14 | 80 |
| High Flux LED | Night use | 6 | 18 | 14 | 1008 |
| Cell phone charger | 24 Hours use | 2 | 5 | 15 | 150 |
| WI-FI router | 24 Hours use | 1 | 20 | 24 | 480 |
| Solar charger controller | 24 Hours use | 1 | 1 | 24 | 24 |
| Sensor | 24 Hours use | 1 | 1 | 24 | 24 |
| Total Watt Hours per day | | | | | 1770.00 |

1770Wh/day ÷ 3 sun hours/day = 590W

590.W ÷ 0.8 (system losses) =737.5W

Wh = 737.5W x 30 days Wh = 22,125 Watt-hours (22.125 kWh/month)

The project will be dealing with lower voltage devices hence a 12V system is chosen

### Calculate Wattage of the Solar Panels

1770Wh/day ÷ 3 sun hours/day = 590W

590W ÷ 0.8 (system losses) =737.5W

737.5/250 = 2.95(3 Solar panels 250watts)

For the project we would be using 3 panels of 250 Watts each

**Battery Sizing**

Recall, from equation 2.29,

$$\text{Battery Capacity (Ah)} = \frac{\text{Total Watt-hours per day used by appliances}}{(0.85 \times 0.6 \times \text{nominal battery voltage})} \times \text{Days of autonomy}$$

For this project, the daily average energy consumption per day is 1770 (W-h/day) for the month of December.

Battery Capacity (Ah) = 1770/(0.85 x 0.6 x 12) x 2

= (1770/ (0.85x0.6x12)) x2

= 1770/0.85=2082.35

= 2082.35/0.6=3470.5

=3470.5/12=289.2

289.2x2=578.4

578.4 Ah Battery Capacity required for the system

**Inverter Sizing**

As mentioned earlier, the size of the inverter should match the wattage and voltage requirements of the system. This project utilizes a 12V and 2000W system, so the inverter selected should have a comparable rating.

**Charge Controller Sizing**

In this project, a PWM charge controller will be utilized. The following steps outline how to determine the appropriate size for the charge controller.

Voltage level of the system: 12V

Maximum amperage: 10 A

There a PWM controller should be used with 12 V and 10 A with rated voltage and current specifications.

**Conclusion**

Electrifying rural houses can be costly, particularly as the distance between the grid and the houses increases. In cases where electrification costs are prohibitively high, an off-grid PV system can be a suitable alternative. Both grid-tied and off-grid PV systems have their own sets of advantages and disadvantages. The choice between them depends entirely on individual needs. A noticeable trend is that grid-tied systems are predominantly found in urban and suburban areas where electrification is already established. In contrast, off-grid systems are better suited for areas where electrification has not yet been achieved or where consumers opt not to feed excess energy back into the grid.

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## CHAPTER THREE

### 3.1 DATA COLLECTION

Tables 3.1 and 3.2 shows the total load in the house (main house and boys quarters) which are in operation when there is BEDC or utility power supply.

**Table 3.1: MAIN HOUSE**

| S/N | LOCATION/ CATEGORY | LOAD | QTY | POWER RATING (KW) | TOTAL POWER (KW) |
|---|---|---|---|---|---|
| 1 | MASTER BEDROOM | LIGHTING POINT | 3 | 0.018 | 0.054 |
| 2 | | 13AMPS SOCKET POINT | 2 | 0.3 | 0.6 |
| 3 | | 15AMPS SOCKET POINT | 1 | 2 | 2 |
| 4 | | MASTER BATHROOM AND TOILET LIGHTING POINT | 1 | 0.018 | 0.018 |
| 5 | | TABLE FAN | 1 | 0.06 | 0.06 |
| 6 | | 1.5 HORSEPOWER AIR CONDITIONER | 1 | 1.12 | 1.12 |
| 7 | MADAM BEDROOM | LIGHTING POINTS | 3 | 0.018 | 0.054 |

| | | | | | |
|---|---|---|---|---|---|
| 8 | | 13AMPS SOCKETS | 2 | 0.3 | 0.6 |
| 9 | | 15AMPS SOCKET POINT | 1 | 2 | 2 |
| 10 | | TABLE FAN | 1 | 0.06 | 0.06 |
| 11 | | 1.5 HORSEPOWER AIR CONDITIONER | 1 | 1.12 | 1.12 |
| 12 | BOYS' ROOM | LIGHTING POINTS | 3 | 0.018 | 0.054 |
| 13 | | 13AMPS SOCKETS | 2 | 0.3 | 0.6 |
| 14 | | 15AMPS SOCKET POINT | 1 | 2 | 2 |
| 15 | | STANDING FAN | 1 | 0.04 | 0.04 |
| 16 | | 1.5 HORSEPOWER AIR CONDITIONER | 1 | 1.12 | 1.12 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| 17 | GIRLS' ROOM | LIGHTING POINTS | 3 | 0.018 | 0.054 |
| 18 | | 13AMPS SOCKETS | 2 | 0.3 | 0.6 |
| 19 | | 15AMPS SOCKET POINT | 1 | 2 | 2 |
| 20 | | STANDING FAN | 1 | 0.04 | 0.04 |
| 21 | | 1.5 HORSEPOWER AIR CONDITIONER | 1 | 1.12 | 1.12 |
| 22 | LIBRARY | LIGHTING POINTS | 3 | 0.018 | 0.054 |
| 23 | | 13AMPS SOCKETS | 2 | 0.3 | 0.6 |
| 24 | | 15AMPS SOCKET POINT | 1 | 2 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| 25 | | CEILING FAN | 1 | 0.075 | 0.075 |
| 26 | | 1.5 HORSEPOWER AIR CONDITIONER | 1 | 1.12 | 1.12 |
| 27 | SITTING ROOM/ DINING | LIGHTING POINTS | 4 | 0.018 | 0.072 |
| 28 | | 13AMPS SOCKETS | 4 | 0.3 | 1.2 |
| 29 | | 15AMPS SOCKET POINT | 1 | 2 | 2 |
| | | | | | |
| 30 | | CEILING FAN | 3 | 0.075 | 0.225 |
| 31 | | 2 HORSEPOWER AIR CONDITIONER | 1 | 1.492 | 1.492 |
| 32 | | TELEVISION SETS | 2 | 0.18 | 0.36 |
| 33 | KITCHEN | LIGHTING POINT | 1 | 0.018 | 0.018 |

| | | | | | |
|---|---|---|---|---|---|
| 34 | | 13 AMPS SOCKET | 1 | 0.3 | 0.3 |
| 35 | | 15 AMPS SOCKET | 1 | 2 | 2 |
| 36 | | ELECTRIC/GAS COOKER WITH CONTROL UNIT | 1 | 3 | 3 |
| 37 | | BURNER GAS | 2 | 3 | 6 |
| 38 | | BURNER ELECTRIC | 2 | 2 | 4 |
| 39 | GENERAL BATHROOM AND TOILET | LIGHTING POINT | 2 | 0.018 | 0.036 |
| 40 | VISITOR TOILET | LIGHTING POINT | 1 | 0.018 | 0.018 |
| 41 | LOBBY | LIGHTING POINT | 3 | 0.018 | 0.054 |
| 42 | OTHERS | WASHING MACHINE | 1 | 0.85 | 0.85 |
| 43 | | SMALL-SIZED FRIDGE | 1 | 0.1 | 0.1 |

| | | | | | |
|---|---|---|---|---|---|
| 44 | | MEDIUM-SIZED FRIDGE | 1 | 0.2 | 0.2 |
| 45 | | LARGE DEEP FREEZER | 1 | 0.8 | 0.8 |
| 46 | | WATER HEATERS | 2 | 1.125 | 2.25 |
| 47 | | EXTERNAL LIGHT | 6 | 0.018 | 0.018 |
| | | | | | **44.156** |

**TABLE 3.2: BOY'S QUARTER (TWO BEDROOM AND A KITCHEN)**

| S/N | LOCATION/ CATEGORY | LOAD | QTY | POWER RATING (KW) | TOTAL POWER RATING (KW) |
|---|---|---|---|---|---|
| 48 | | EXTERNAL LIGHTING | 4 | 0.018 | 0.072 |
| 49 | ROOM 1 | LIGHTING POINTS | 2 | 0.018 | 0.036 |
| 50 | | 13AMPS SOCKETS | 2 | 0.3 | 0.6 |
| 51 | ROOM 2 | LIGHTING POINTS | 2 | 0.018 | 0.036 |

| | | | | | |
|---|---|---|---|---|---|
| 52 | | 13AMPS SOCKETS | 2 | 0.3 | 0.6 |
| 53 | LOBBY | LIGHTING POINTS | 2 | 0.018 | 0.036 |
| 54 | | 13AMPS SOCKETS | 1 | 0.3 | 0.3 |
| 55 | KITCHEN, TOILET/ BATHROOM | LIGHTING POINTS | 3 | 0.018 | 0.054 |
| 56 | | 13AMPS SOCKETS | 2 | 0.3 | 0.6 |
| | | | | | **2.334** |

**SUMMARY OF TABLE 3.1 AND 3.2**

TOTAL LOAD OF THE MAIN HOUSE USING BEDC SUPPLY = 44.156KW

TOTAL LOAD OF THE BOY'S QUARTER USING BEDC SUPPLY = 2.343KW

TOTAL LOAD OF MAIN HOUSE AND BQ USING BEDC SUPPLY = 46.49KW

**TABLE 3.3: OPERATION HOURS OF EQUIPMENT AND THE KWH FOR THE MAIN HOUSE AND BOY'S QUARTERS**

| ITEMS | POWER RATING (KW) | QTY | OPERATION HOURS (Hrs) | TOTAL POWER (KW) | KWH |
|---|---|---|---|---|---|
| LIGHTING POINTS | 0.018 | 45 | 10 | 0.81 | 8.1 |

| | | | | | |
|---|---|---|---|---|---|
| 13 AMPS SOCKET POINT | 0.3 | 20 | 8 | 6 | 48 |
| 15 AMPS SOCKET POINT | 2 | 1 | 8 | 2 | 16 |
| FAN | 0.075 | 4 | 6 | 0.3 | 1.8 |
| AIR CONDITIONER | 1.12 | 4 | 6 | 4.48 | 26.88 |
| TELEVISION SET | 0.18 | 2 | 8 | 0.36 | 2.88 |
| FRIDGE | 0.15 | 2 | 24 | 0.3 | 7.2 |
| TOTAL | | | | **14.25** | **110.86** |

**SUMMARY OF TABLE 3.3**

Table 3.3 shows the load to be in operation when power supply is from pv system in both the main house and boys quarters and allocated hours of operation.

**TABLE 3.3 LOAD CALCULATION**

TOTAL LOAD IN THE MAINHOUSE AND BOY'S QUARTERS USING SOLAR SUPPLY= 14.25KW

TOTAL KWH USING SOLAR SUPPLY = 110.86KWH

# CHAPTER FOUR
# DESIGN CALCULATION AND COMPONENT SELECTION

## 4.1 INVERTER SIZING

Most inverters have an efficiency of 80 to 90%. The inverter used for this research is assumed to have an efficiency of 85%.

From table 3.3…., the loads to be connected to the PV system are;

Lighting point - 810W

Fan – 300W

Air conditioner – 4480W

Inverter Fridge – 300W

Television – 360W

The total power consumed is 6250W.

To get the apparent power;

Apparent power = $\frac{real\ power}{power\ factor}$ ……………………….(4.1)

Apparent power = $\frac{6250}{0.85}$ = 7.35kVA

Available Inverter in the market is 8kVA, so an Inverter of 8kVA is selected.

## 4.2 BATTERY SIZING

The battery used for this research is rated 12v, 220Ah. A 220Ah means a battery can supply 220A for one hour.

From the table 3.3…;

To get the total energy consumed (KWH), the 13A sockets and 15A sockets are neglected because only the equipments being used are to be considered.

Total energy consumed = 46860Wh

Power = Current × Voltage …………………..(4.2)

$Curren\ t(I) = \frac{Power}{Voltage}$ ………………………(4.3)

$$Curren\ t(I) = \frac{46860}{12}$$

$$I = 3905Ah$$

The batteries available are 200Ah and 220Ah. For this research a battery of 220Ah is used.

Therefore;

Number of batteries $= \frac{3905}{220} = 17.75 \sim 18$

Therefore the total number of batteries required are 18.

## 4.3 PV MODULE CALCULATION

**Power Output of Solar PV Module ( rating: 24V, 300watts)**

**DESIGN ASSUMPTIONS:**

The power output of the solar photovoltaic module (Ppv) can be obtained using the relation given by

$$P_{pv} = \frac{E_t \times PSI}{\eta_b \times K_{losses} \times H_{tilt}} \quad ----------- \mathbf{(4.4)}$$

Where:

Et is the total daily energy of the house load = 46.86kWh/day (From Table);

PSI is the Peak Solar Intensity at the earth surface = 1kW/m² ;

ηb is the Efficiency of the System;

Klosses is the determination factor due losses on the system such as dust, change in temperature and

Htilt is the average solar irradiance falling on the specific tilt angle which is taken to be 5.0Kwh/m²

.

The efficiency of the system can be found using the relation given as:

ηb = ηinverter × ηconnection losses **-------------------------(4.5)**

Where:

ηinverter is the efficiency of the inverter = 90% and

Hconnection losses is the efficiency of the system connection which is between the range 80-90% and 80% is taken in this design.

The determination factor can determine using equation given as:

Klosses = tmanuf. × Fdirt × Ftemp. ---------------------------(**4.6**)

Where:

tmanuf. is the manufacturer's tolerance = 97% ;

Fdirt is the de-rating due to dirt which is taken to be 90% and;

Ftemp. is the temperature de-rating factor which can be found using equation given as:

Ftemp. = 1-[γ(Tcell,eff.-TSTC)]**-------------------------------(4.7)**

Where:

γ is the power temperature coefficient = 0.48%/°C;

TSTC is the standard temperature of the collector = 25°C and;

Tcell, effi. is the average daily temperature which is given as:

Tcell, effi.= 25 + Ta

Where:

Ta is the ambient temperature = 27°C

**Number of Modules**

The photovoltaic modules are arranged in series and parallel connections.

**A. Number of Modules in Series Connection**

The number of modules in series connection can be found using relation given as:

$N_{ms} = \frac{V_{system}}{V_{module}}$ **-----------------------------------(4.8)**

Where:

Vmodule is the nominal voltage of the module = 24v and;

Vsystem is the designed system voltage = 48v.

**B. Number of strings in Parallel Connection**

The number of strings in parallel connection can be found using relation given as:

$$N_{mp} = \frac{P_{pv}}{N_{ms} \times P_{module}} ------------ \mathbf{(4.9)}$$

The number of modules of the system can be obtained by multiplying number of modules in series and that in parallel.

Nmt = Nms × Nmp -------------------------------(**4.10**)

**CALCULATIONS**

PV module rating: 24V, 300 watts.

Tcell, effi.= 25 + 27 = 52 (from eqn 4.8 above)

Ftenp. = 1-[γ(Tcell,eff.-TSTC)] (from eqn 4.7 above)

Ftemp. = 1-[0.48%(52-25)] = 0.87

Klosses = tmanuf. × Fdirt × Ftemp (from eqn 4.6 above)

Klosses = 0.97×0.87×0.9= 0.76

ηb = ηinverter × ηconnectuin,losses (from eqn 4.5 above)

ηb = 0.9×0.8= 0.72

$$P_{pv} = \frac{E_t \times PSI}{\eta_b \times K_{losses} \times H_{tilt}} \quad \text{(from eqn 4.4 above)}$$

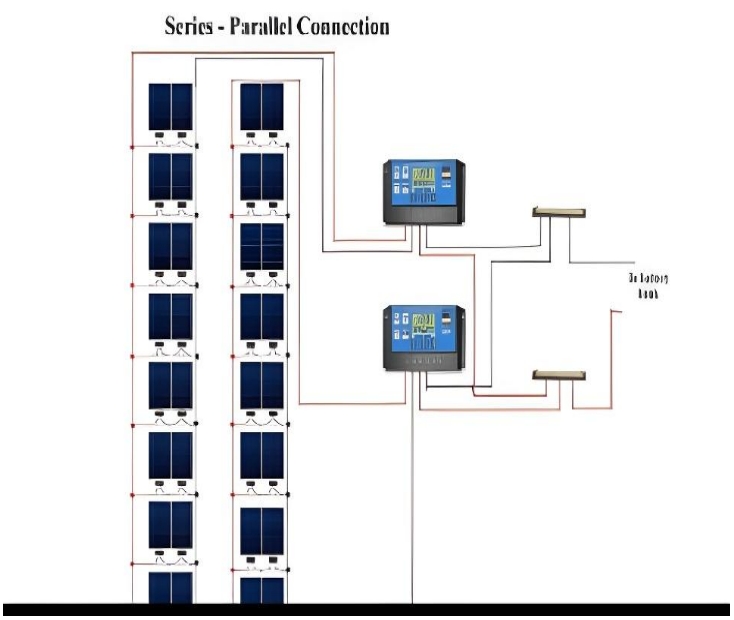
$$P_{pv} = \frac{46.86 \times 1}{0.72 \times 0.76 \times 5} = 17.13KW$$

$$N_{ms} = \frac{V_{system}}{V_{module}} = \frac{48}{24} = 2modules \quad \text{(from eqn 4.9 above)}$$

$$N_{mp} = \frac{P_{pv}}{N_{ms} \times P_{module}} \quad \text{(from eqn 4.10 above)}$$

$$N_{mp} = \frac{17.13 \times 1000}{2 \times 300} = 28.55 \approx 28strings$$

Nmt= Nms × Nmp = 2×28= 56modules




**24v, 300watts monocrystalline data sheet:**

| Rated Parameters | Values |
|---|---|
| Type | Mono-crystalline |
| Model | RD300M6 |
| Module Dimension (cm) | 164 x 99.2 x 3.5 |
| Total module area ($cm^2$) | 16268.8 |
| Maximum Power (W) | 300 |
| Maximum Voltage (V) | 32.38 |
| Maximum Current (A) | 9.26 |
| Open Circuit Voltage(V) | 38.55 |
| Short Circuit Current(A) | 9.47 |
| STC | 1000W/m2AM1.5, 25°C |

**4.4 CABLE SIZING**

**FOR THE CABLE SIZING**

FOR THE AC LOAD CABLE

Using the total load from table 3.3

Which is 14.25kw

Using diversity factor of 0.8

Then the total load is 11.400kw

To get the apparent power

KW = KVACosθ ------------------------ (4.11)

$$KVA = \frac{KW}{Cos\theta}$$

$$KVA = \frac{11400}{0.8}$$

= 14250

POWER = √3 X CURRENT X VOLTAGE ------------(4.12)

$$CURRENT = \frac{POWER}{\sqrt{3} \times VOLTAGE} \text{ -----------------------------(4.13)}$$

$$CURRENT = \frac{14250}{\sqrt{3} \times 230}$$

= 35.77 AMPS

ACCORDING TO THE IEE TABLE FOR CABLE SIZING FOR ONE THREE- CORE CABLE THREE PHASE

THE CABLE RATING OF 35.77 AMPS IS 6MM^2

### 4.4.1 THE LOAD BALANCING

From table table 3.3

Number of lighting point is = 45

Number of fans is 4

Number of 13 Amps socket is 24

Number of 15 A socket is 5

Following IEE regulations

18 WATT FOR EACH LIGHTNING POINT

Then the total number of lighting point is = 18 X 45 = 810WATT

FOR FAN

The rating is 75 watt

4 X 75 = 300 WATT

13 AMPS SOCKET

300 WATT EACH

24 X 300 WATT = 7200 WATT

15A SOCKETS

2000 EACH

5 X 2000 = 10000 WATT

| S/N | DESCRIPTION | R | Y | B | REMARK |
|---|---|---|---|---|---|
| 1 | LIGHTING POINT A1 | 810 W | | | LIGHTING CCT |
| 2 | LIGHTING POINT | | 300 W | | LIGHTING CCT |

| | | | | | |
|---|---|---|---|---|---|
| | FA2 | | | | |
| 3 | 13 AMPS SOCKET S1 | | | 2000 W | EARTHED RADIAN CCT |
| 4 | 13 AMPS SOCKET S2 | 2000 W | | | EARTHED RADIAN CCT |
| 5 | 13 AMPS SOCKET S3 | | 2000 W | | EARTHED RADIAN CCT |
| 6 | 13 AMPS SOCKET S4 | | | 2000 W | EARTHED RADIAN CCT |
| 7 | 15 AMPS SOCKTET S5 | 2000 W | | | EARTHED RADIAN CCT |
| 8 | 15 AMPS SOCKTET S6 | | 2000 W | | EARTHED RADIAN CCT |
| 9 | 15 AMPS SOCKTET S7 | | | 2000 W | EARTHED RADIAN CCT |
| 10 | 15 AMPS SOCKTET S8 | 2000 W | | | EARTHED RADIAN CCT |
| 11 | 15 AMPS SOCKTET S9 | | 2000 W | | EARTHED RADIAN CCT |
| 12 | SPARE | | | 1000 W | SPARE |
| TOTAL | | 6810 W | 6300 W | 7000 W | |

**4.4.2 THE DC LOAD CABLE SIZING**

From PV system sizing

The total power calculated was 17.13kw

DC supply has unity power factor

$\text{Cos}\theta = 1$

TO GET THE APPARENT POWER

Recall from equation 4.11,

$KW = KVA\text{Cos}\theta$

$$KVA = \frac{KW}{\cos\theta}$$

$$KVA = \frac{17130}{1}$$

= 17130

Recall from equation 4.12,

POWER = √3 X CURRENT X VOLTAGE

$$CURRENT = \frac{POWER}{\sqrt{3} \times VOLTAGE}$$

$$CURRENT = \frac{17130}{\sqrt{3} \times 230}$$

= 43.00 AMPS

ACCORDING TO THE IEE TABLE FOR CABLE SIZING FOR ONE THREE- CORE CABLE THREE PHASE

THE CABLE RATING OF 43.00 AMPS IS 10MM^2

**4.4.3 BATTERY CABLE RATING**

Inverter rating = 8KVA / 48V

$$\text{Current from battery} = \frac{\text{Inverter Battery wattage}}{\text{Voltage of battery}} \quad \text{---------------------- (4.14)}$$

$$\text{Current from battery} = \frac{8000}{48}$$

= 166.67 AMPS

From the IEE table a $50mm^2$ Cable can be used

**REFERENCE**

electrical services design by engr.prof. s. o onohaebi ,engr. prof. s.o. igbinovia. engr. m.o.yedoh

**4.5 CHARGE CONTROLLER SIZING**

The charge controller is essential for managing the current flow to and from the battery, preventing overcharging and protecting the battery from voltage fluctuations. It regulates the current flow, ensuring it does not exceed the array's maximum current output or the maximum load current.

$$P_{PV} = 17.13KW$$

Where

$P_{PV}$ is the power output of the pv panel

The panel produces dc current. Hence, Recall from equation 4.12,

POWER = √3 X CURRENT X VOLTAGE

$$\text{CURRENT} = \frac{\text{POWER}}{\sqrt{3} \text{ X VOLTAGE}}$$

$$\text{CURRENT} = \frac{17130}{\sqrt{3} \text{ X } 230}$$

= 43.00 AMPS

The current gotten is 43A. The available charge controller required for a current of 43A is 60A. Therefore, we choose a 60A MPPT solar charge controller. Also, a 60A charge controller will also ensure efficient and safe charging of the battery bank.

The rating of the MPPT charge controller is 60A.

**60A MPPT CHARGE CONTROLLER SPECIFICATION**

| **Models** | **POW-M60-PRO** |
|---|---|
| Charging mode | MPPT Maximum power point tracking automatically |
| Charging | 3-stage:constant current(MPPT), constant voltage(Absorption Voltage), floating charge |
| System type | DC12V/24V/36V/48V Recognition automatically |
| System voltage automatic recognition | 1 2V system (DC9V-DC15V) |
| | 24V system (DC18V-DC29V) |
| | 36V system (DC30V-DC39V) |
| | 48V system (DC40V～DC60V) |
| Soft start time | <1S |

| | |
|---|---|
| Dynamic response and recovery time | >98.1 % (Voc is 1.5 or 2 times than battery, then it's the best efficiency) |
| PV utilization | >99% |
| Input specification | |
| VOC from PV( Make sure the Voc of PV meeting the requirement as right. Voc is 1.5 or 2 times than battery, then it's the best efficiency.) | 12V system (DC20V～DC80V) |
| | 24V system (DC37V-DC105V) |
| | 36V system (DC50V～DC160V) |
| | 48V system (DC72V～DC160V) |
| The maximum PV input voltage (Voc) | DC190V(The controller can't work at this voltage of long duration that will break controller. Please refer to the Input voltage from PV.) |
| The maximum PV input power (The total power rated of PV can't be over this watt that will break the controller.) | 12V system (720W) |
| | 24V system (1440W) |
| | 36V system (2100W) |
| | 48V system (2800W) |

| Output specification | |
|---|---|
| Selectable battery type(default is Sealed) | Vented/ Sealed / Gel / NiCd / Lithium battery(defined voltage for other battery by user) |
| Absorption Charging Voltage | Refer to Batteries charging reference |
| Floating Charging Voltage | Refer to Batteries charging reference |
| Overcharging protection voltage | 12V system (15V) |
| | 24V system (30V) |
| | 36V system (45V) |
| | 48V system (60V) |
| Rated output current | 60A |
| Temperature Coefficient | ±0.02%/ °C |
| Automatic temperature compensation | 14.2V-(Max temperature-25 °C)*0.3 |
| Output voltage ripple-peak | 100mv |
| Output voltage accuracy | <±1% |
| Input Anti-intrusion | Yes |

| | |
|---|---|
| protection | |
| Temperature Protection | 75°C |
| Temperature increased protection | Output power will reduce when it’s more than 70 °C |
| | Output power will be normal when it’s less than 55 °C |
| Fan-on temperature | >40 °C |
| Fan-off temperature | <35 °C |
| Acoustic noise | <40dB |
| Cooling way | Forced air cooling |
| Components | Imported materials, Accord to EU standards, Industrial grade range. |
| Environmental requirements | Meet 2002/95/EC; No cadmium, hydrides, and fluorides |
| Security Level | Accord to CE, PSE, FCC, EMC, EN60950 |
| Electromagnetic Compatibility | Accord to EN6W00, EN55022, EN55024 |
| Enclosure | IP21 |
| Net weight(Kg) | 1.3 |
| Gross weight(Kg) | 1.5 |

# CHAPTER 5

# CONSTRUCTION/INSTALLATION

## 5.1 CONNECTION AND TEST

This chapter presents the test results obtained from the connection and installation of the solar system.

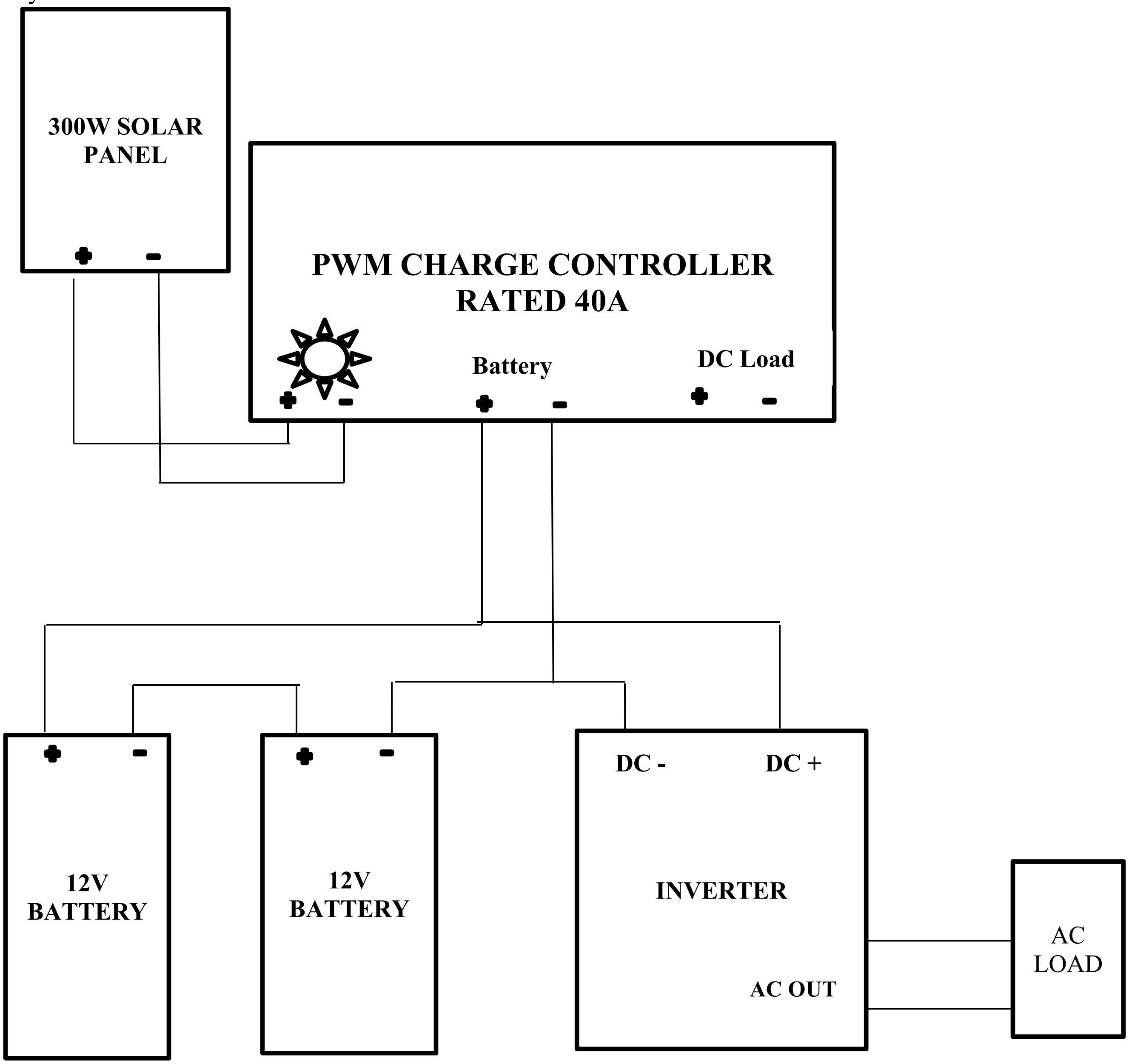



**Fig 5.1: shematic diagram of the system design**

The figure 5.1 above shows the schematic diagram of the connection of the solar system main components which include the solar panel, charge controller, battery and the inverter. The first operation that was carried out during the installation involves the solar panel. The solar panel is usually mounted on the roof of a building. At the initial stage of the installation, we tested for the open circuit voltage and short circuit current of the pv array.

**Fig 5.2: Short circuit current and open circuit voltage test using a multimeter**

The short circuit current ($I_{SC}$) of the panel during installation was gotten as 5.05A and the open circuit voltage ($V_{OC}$) was 37V. The name plate value of the short circuit current is 9.81A and the open circuit voltage is 38.2V. The experimental value for the short circuit current and open circuit voltage may vary due to intensity of the sunlight.

The next operation was to connect the batteries. We made use of **De Bull 220AH 12V Tabular Deepcycle Battery Wet Cell**. The batteries were connected in series (i.e the positive terminal of one battery is connected to the negative terminal of the other battery) in order to obtain a 48V system.The other two terminals of the batteries (positive and negative terminals) are connected to the charge controllers. Connecting batteries in series will only increase the voltage level (current is the same in series while voltage is additive)

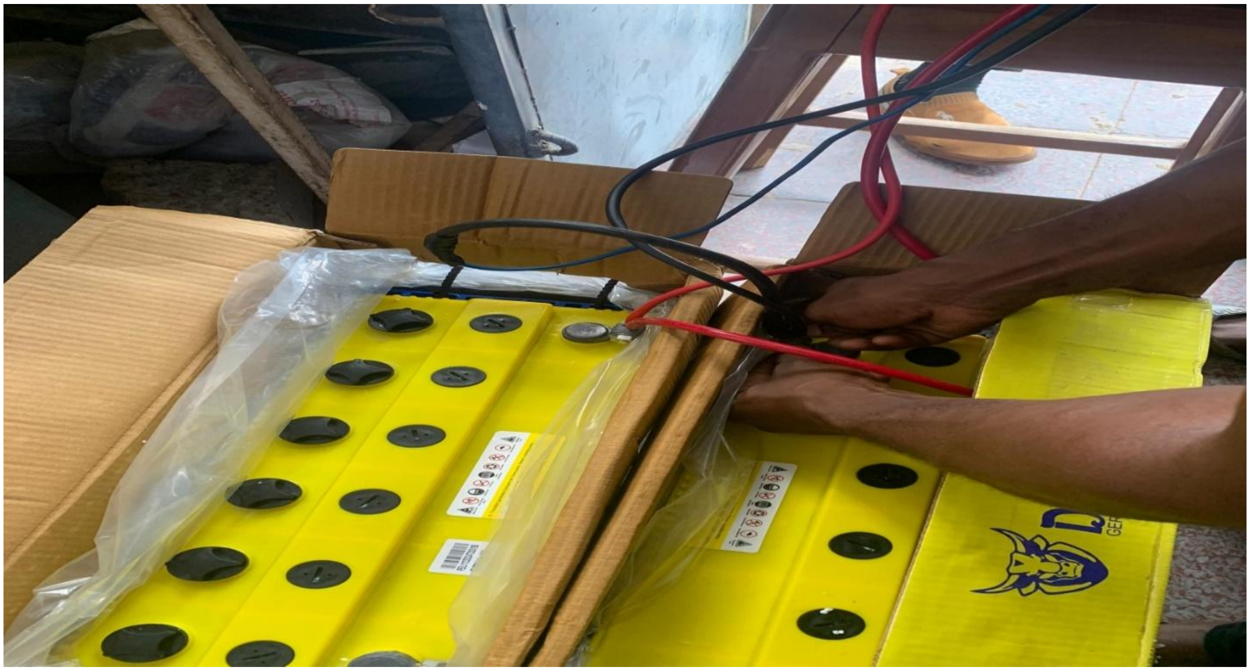


**Fig 5.3: Two 12V batteries being connected in series**

The next operation is to connect the positive terminal of the battery and the positive terminal of the inverter to the positive terminal of the battery port on the charge controller. Also connect the negative terminal of the battery and the negative terminal of the inverter to the negative terminal of the battery port on the charge controller. The solar panels are then connected to the charge controller using a solar wire.

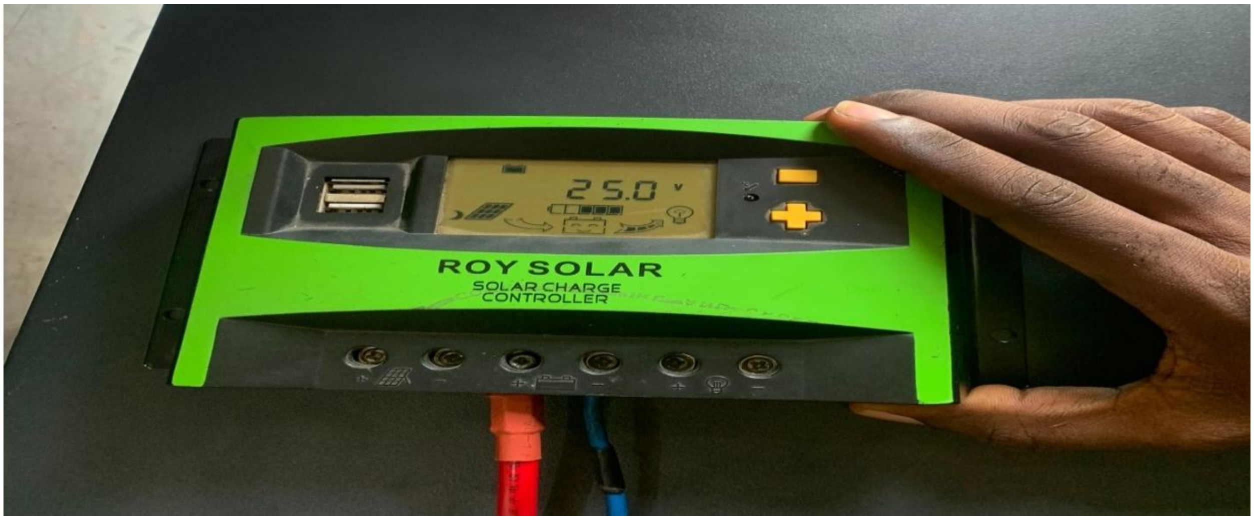



**Fig 5.4: The Battery connected to a charge controller**

From the fig 5.4 above, it should be noted that the wires from the battery should be connected to the battery port on the charge controller. Proper connection is very necessary in solar system as any wrong connection could lead to damage of the solar equipments.


**Fig 5.5: connection of the battery, the charge controller and the inverter**

The charge controller controls and regulates the charging and discharging condition of the battery. The solar wire from the pv array comes into the charge controller. The charge controller has a screen that displays the current from the panel and also the battery voltage as shown is figure 5.6 below.

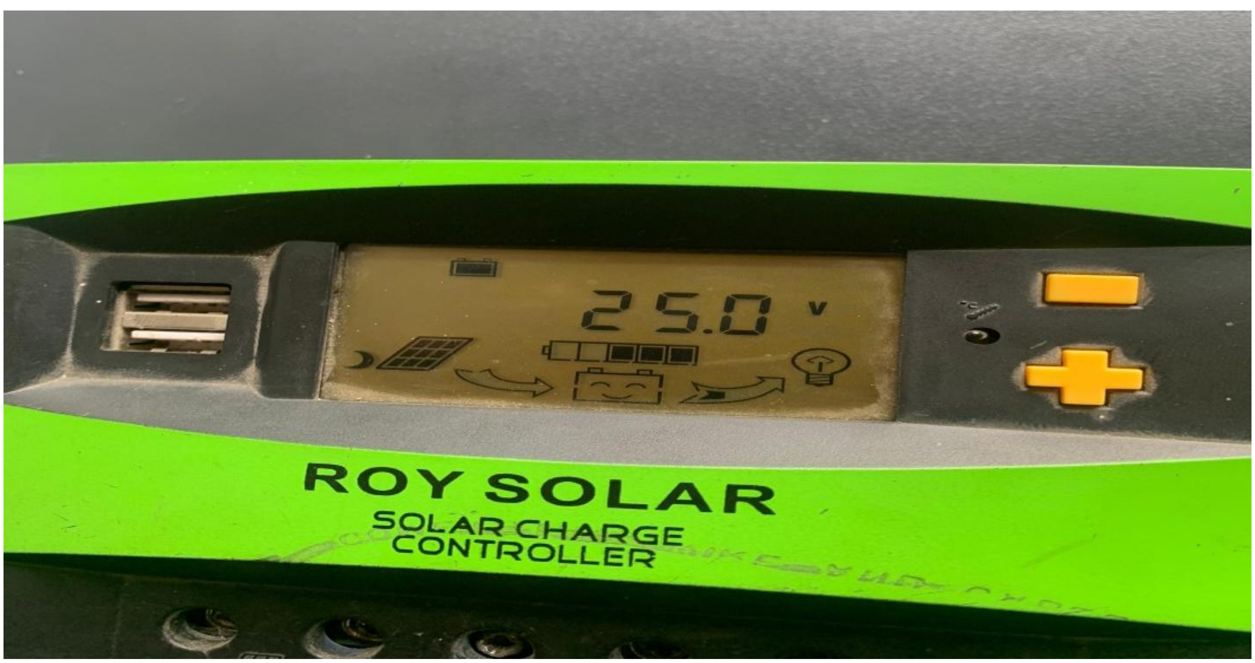



**Fig 5.6: A charge controller showing the battery voltage**

The next operation was to connect the solar panel to the charge controller by using a solar wire. The negative terminal of the pv array is connected to the negative terminals of the charge controller and the positive terminal of the pv array is connected to the positive terminal of the charge controller.

**Fig 5.7: A Connection of the solar panel to the charge controller using a solar wire**


**Fig 5.8: Solar wire connected to the charge controller**

The figure above shows the complete connection of the pv array, charge controller, inverter and battery bank. After a successful connection, values for the panel current and battery voltage were obtained.

## 5.2 SOLAR SYSTEM ON LOAD AND NO LOAD

**Fig 5.9: AC load in its OFF state connected to the solar system**

**Fig 5.10: AC load in its ON state connected to the solar system**

The AC load was connected so as to discharge the battery when the battery is fully charged.

### 5.3 OPEN CIRCUIT CHARGING TEST

An hourly solar charging test shows the performance of the Photovoltaic charging system. This test is aimed at analyzing how the efficiency of the system varies throughout the day under different solar condition. The time interval considered in the test are periods of the day when the sun is out (9AM to 5PM). An hourly interval is also chosen to get a consistent variation in terms of the charging current and voltage.

The current of the panel was obtained from the charge controller during a time interval of 30minutes and the voltage of the battery was also determined during a time interval of an hour. This test was carried out on no load condition.

**Table 5.1. CURRENT OF THE PV ARRAY DURING A 30 MINUTES INTERVAL**

| Time (secs) | Current(A) |
|---|---|
| 9:00am | 1.2 |
| 9:30am | 3.9 |
| 10:00am | 4.6 |
| 10:30am | 5.1 |
| 11:00am | 4.7 |
| 11:30am | 5.7 |
| 12:00pm | 6.5 |
| 12:30pm | 6.9 |
| 1:00pm | 6.7 |
| 1:30pm | 6.8 |
| 2:00pm | 5.5 |
| 2:30pm | 5.7 |
| 3:00pm | 4.3 |
| 3:30pm | 3.6 |
| 4:00pm | 2.0 |
| 4:30pm | 2.2 |
| 5:00pm | 2.2 |

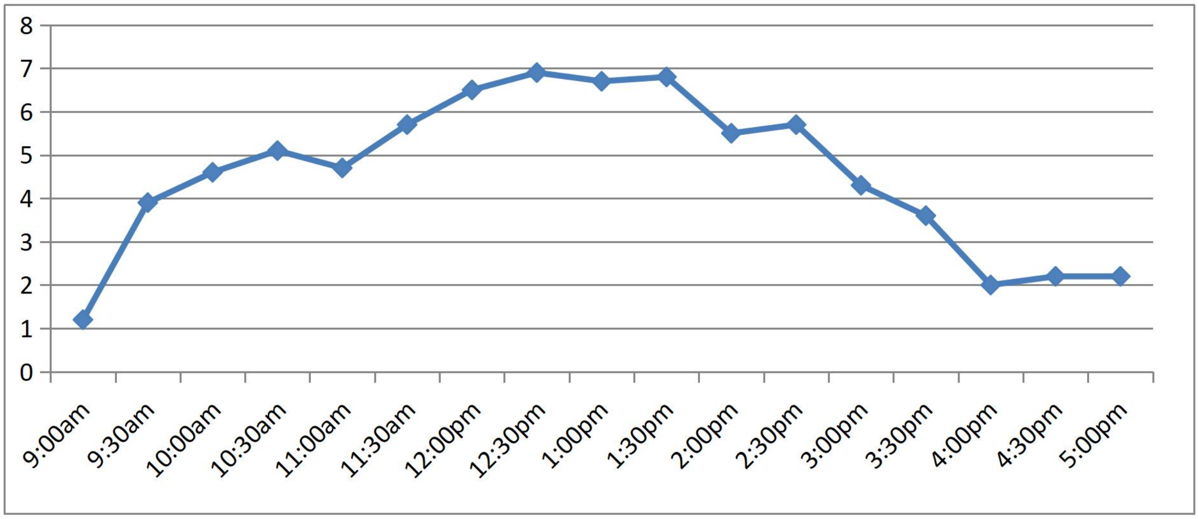



**Fig 5.11: Graph of current (A) against time (sec)**

From table 5.1 and also from the graph of current against time, it is observed that at the earlier hours of the day, the current from the panel increases and it is maximum at 12:30pm. It begins to reduce from 2pm. This is due to the reduction of the irradiance of the sun. The weather becomes a bit cloudy and towards evening there is minimal sunlight resulting in lesser current. The more the sunlight, the higher the current and vice versa.

**Table 5.2: VOLTAGE OF THE BATTERY DURING AN HOUR PERIOD**

| Time (secs) | Voltage (V) |
|---|---|
| 9:00AM | 24.7 |
| 10:00AM | 25.4 |
| 11:00AM | 25.8 |
| 12:00AM | 25.9 |
| 1:00PM | 25.6 |
| 2:00PM | 25.8 |
| 3:00PM | 25.9 |
| 4:00PM | 25.4 |
| 5:00PM | 25.5 |

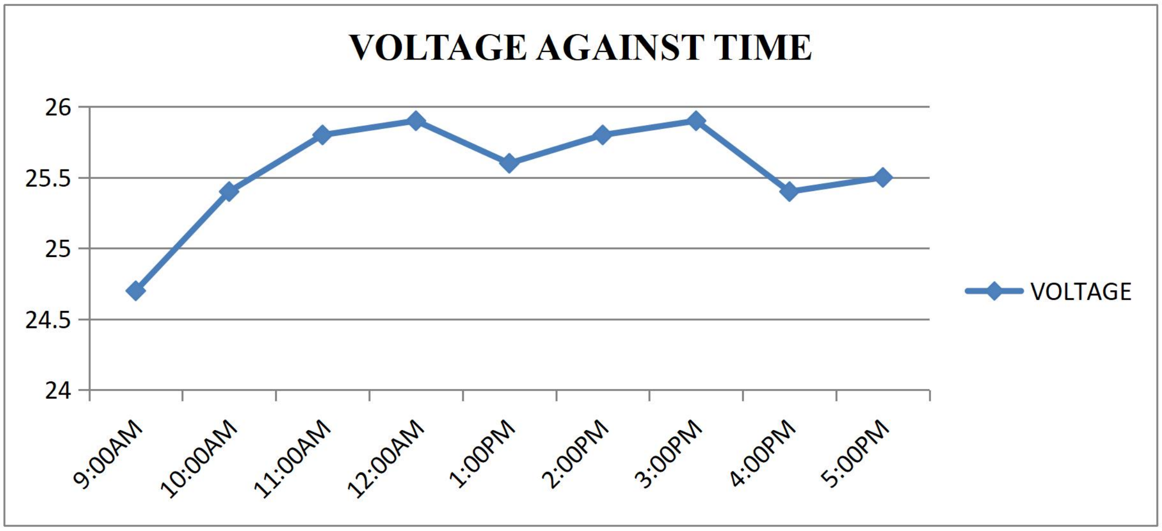



**Fig 5.12: Plot of voltage(V) against time (s)**

From fig 5.12 above, i.e the graph of voltage (V) against time(s), it is observed that voltage increases from 9:00am to 12:00am. This is because as the irradiance of the sun increases, the current generated by the panel increases, thus, increasing the voltage stored by the battery.

**Table 5.3: POWER(W) DURING DURING AN HOUR PERIOD**

| Time (secs) | Voltage (V) | Current (A) | Power(P=IV)(W) |
|---|---|---|---|
| 9:00AM | 24.7 | 1.2 | 29.64 |
| 10:00AM | 25.4 | 4.6 | 116.84 |
| 11:00AM | 25.8 | 4.7 | 121.26 |
| 12:00AM | 25.9 | 6.5 | 168.35 |
| 1:00PM | 25.6 | 6.7 | 171.52 |
| 2:00PM | 25.8 | 5.5 | 141.90 |
| 3:00PM | 25.9 | 4.3 | 111.37 |
| 4:00PM | 25.4 | 2.0 | 50.80 |
| 5:00PM | 25.5 | 2.2 | 56.10 |

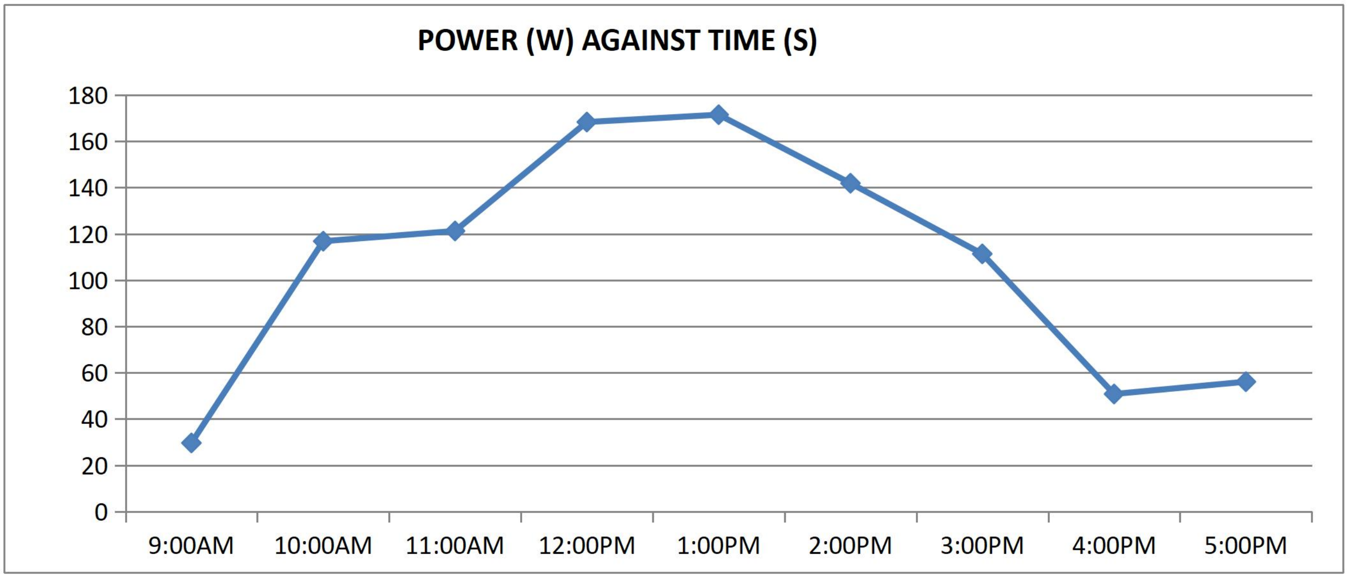



**Fig 5.13: Graph of Power (W) against Time (s)**

In testing the PV system, the graph of Power (W) is plotted against time (s). It was observed that at the earlier hours of the day, Power increases. It begins to reduce from 2pm. Power is the product of the current of the panel and the voltage of the battery bank. The weather becomes a bit cloudy and towards evening there is minimal sunlight resulting in lesser current and therefore power also decreases.

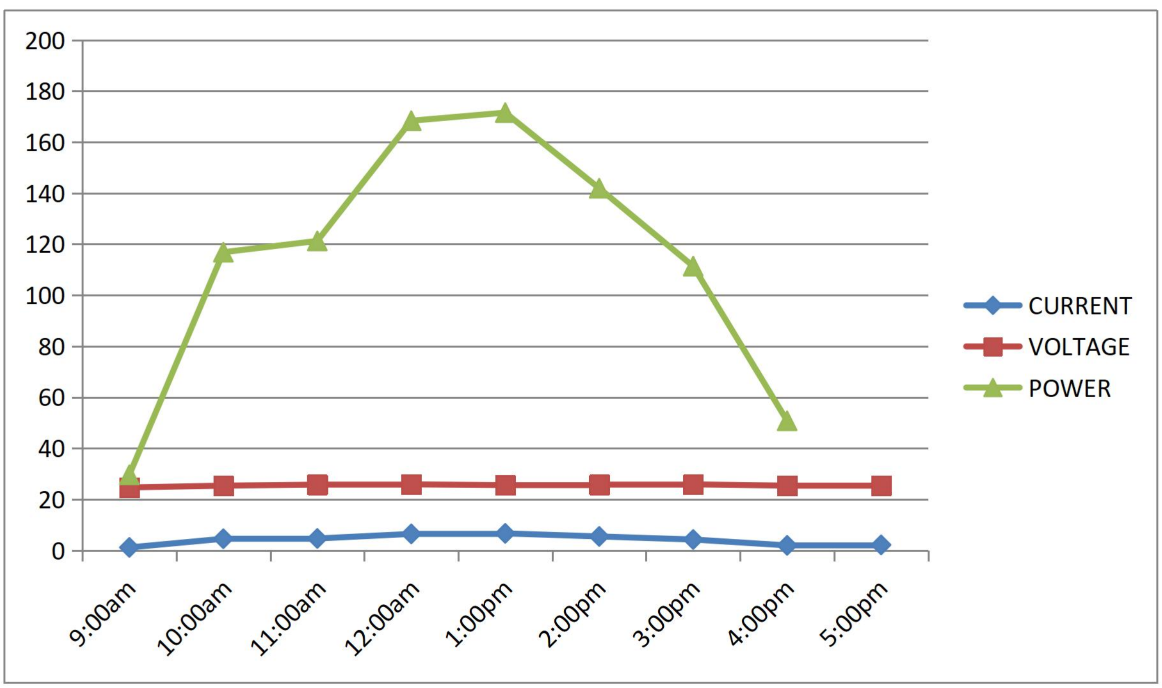



**Fig 5.13: Graph of Current, Voltage and Power against time**

From the graph of Current (A), Voltage (V) and Power (W) as shown in fig 5.12, it is observed that at 12:00am to 1:00pm, current, voltage and power are maximum. This is occurs as a result of greater intensity of sunlight. As the day goes by, the intensity of the sun reduces and the curve reduces.

### 5.4 BILL OF ENGINEERING MATERIALS & EVALUATION (BEME)

**Table 5.4 PROTOTYPE OF MATERIAL USED**

| S/N | ITEMS | QTY | UNIT RATE (#) | TOTAL AMOUNT (#) |
|---|---|---|---|---|
| 1 | 12V/220AH RED BULL LUMINOUS BATTERY | 2 | 265000 | 530000 |
| 2 | 2KVA INVERTER | 1 | 120000 | 12000 |
| 3 | 40 AMPS PWM CHARGE CONTROLLER 12V24V | 1 | 30000 | 30000 |
| 4 | 300W MONOCRYSTALLINE SOLAR PANELS | 1 | 85000 | 85000 |
| 5 | DIGITAL MULTIMETER | 1 | 9000 | 9000 |
| 6 | CABLE LOCK | 4 | 150 | 600 |
| 7 | 10 MM^2 WIRE | 8 METER | 2000 | 16000 |
| 8 | 6 MM^2 WIRE | 4 METER | 1000 | 6000 |
| 9 | CONNECTING WIRE | 4 METER | 1000 | 4000 |
| 10 | CELLOTAPE | 1 | 150 | 150 |
| 11 | MISCELLANEOUS | | | 10000 |
| | **TOTAL** | | | **810750** |

### 5.5 CONCLUSION

At the end of the project, the following factors, in accordance with the objectives of the study, were actualized

i. The load surveys of the 5 bedroom bungalow including the boy's quarters were obtained

ii. Suitable battery bank, inverter, charge controller and PV array were determined.

iii. Accurate number of batteries and solar panels for the needed installation were duly determined via corresponding calculations.

iv. The cost (budget) analysis of the project was obtained and presented herein.

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