THE ANALYTICAL DESIGN OF A SOLAR POWERED SYSTEM FOR A TWO BEDROOM APARTMENT

BY

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IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING(B.ENG) DEGREE IN ELECTRICAL/ELECTRONICS ENGINEERING.

CERTIFICATION

This is to certify that this project work was carried out by **UVO OBARO PRECIOUS, UWATSE DANIEL AMUYIGBORITSE, ESENE MICHAEL EGHOGHON & ESENWA IFEANYI PAUL** of the Department of Electrical/Electronics Engineering, University of Benin, in partial fulfillment of the requirements for the award of the bachelor of engineering (B.Eng.) Degree.

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DEDICATION

This research work is dedicated to Almighty God, who is the repository of all knowledge and the Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State.

ACKNOWLEDGEMENT

First and foremost, we’d want to thank God almighty for his guidance all through this journey. We specially want to acknowledge our parents, as this won’t have been possible without their unending support, financially, spiritually and morally. We want to assure you that this is just the tip of an iceberg to what’s coming.

Appreciation goes to everyone that has supported one way or the other in achieving this height. This would be incomplete without the constant support of our supervisor, Engr. E.C. Ekoko for her kind approach to resolving and correcting our work.

ABSTRACT

In an era where sustainability and renewable energy are at the forefront of global discussions, the installation of solar panel systems presents an opportunity for individuals and communities to transition towards a cleaner, more sustainable energy future. This project focuses on the design, installation, and implementation of a solar panel system for a 2 bedroom apartment, situated within a residential setting. By harnessing the abundant energy of the sun, the project aims to meet the electricity needs of the apartment while reducing dependence on traditional grid electricity sources. Through a comprehensive approach encompassing site assessment, energy consumption analysis, component selection, system design, and performance evaluation, this project seeks to demonstrate the feasibility and effectiveness of solar energy as a viable alternative to conventional energy sources. By providing valuable insights and practical guidance on the design and implementation process of solar panel systems for residential applications, this project aims to empower homeowners and stakeholders to embrace renewable energy solutions and contribute to a more sustainable and environmentally conscious future.

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CHAPTER 1

INTRODUCTION

1.0 BACKGROUND OF STUDY

The increasing global demand for energy, coupled with growing concerns over climate change and environmental degradation, has prompted a shift towards sustainable energy solutions that reduce reliance on fossil fuels and mitigate greenhouse gas emissions. Solar energy, in particular, has emerged as a promising renewable energy source, offering abundant, clean, and inexhaustible power from the sun. In light of these developments, this project focuses on the installation of a solar panel system for a 2 bedroom apartment, located within a residential community. The project aims to leverage solar power to meet the electricity needs of the apartment, thereby reducing dependence on traditional grid electricity sources and minimizing carbon footprint. By harnessing the energy of the sun, the project seeks to demonstrate the feasibility and effectiveness of solar energy as a viable alternative to conventional energy sources for residential applications. Through a comprehensive analysis of site conditions, energy consumption patterns, system design considerations, and performance evaluation metrics, this project endeavors to provide valuable insights and practical guidance on the design and implementation process of solar panel systems. By exploring the benefits, challenges, and opportunities associated with solar energy adoption, this project aims to inspire and empower homeowners, policymakers, and stakeholders to embrace renewable energy solutions and contribute to a more sustainable and environmentally conscious future.

1.1 STATEMENT OF PROBLEM

The increasing demand for energy coupled with concerns over environmental sustainability and rising electricity costs has prompted homeowners to explore alternative energy sources such as solar power. However, despite the potential benefits of solar energy, the adoption of solar panel systems for residential applications faces several challenges, particularly in the context of installing solar panels for a 2 bedroom apartment.

Limited Awareness and Knowledge: Many homeowners lack awareness and understanding of solar energy technologies, system design considerations, installation procedures, and financial incentives available for solar panel installations. This lack of knowledge often leads to misconceptions, hesitation, or reluctance to invest in solar energy solutions.

Complexity of System Design: Designing an optimized solar panel system for a 2 bedroom apartment requires careful consideration of site-specific factors such as roof orientation, shading, available space, energy consumption patterns, and budget constraints. The complexity of system design and component selection can pose challenges for homeowners and installers, leading to suboptimal system performance or cost overruns.

Financial Barriers: The upfront costs associated with purchasing and installing a solar panel system, including equipment, labor, permits, and regulatory compliance, can be prohibitive for homeowners, especially those with limited financial resources or access to financing options. Despite the potential long-term cost savings, the initial investment required for solar energy may deter many homeowners from pursuing solar installations.

1.2 AIM

The aim of this project is to design, install, and implement a solar panel system for a 2 bedroom apartment, with the objective of harnessing renewable energy to meet the household's electricity needs sustainably. The project aims to demonstrate the feasibility, effectiveness, and benefits of solar energy as a clean and cost-effective alternative to traditional grid electricity for residential applications. By providing a comprehensive understanding of the design and implementation process of solar panel systems, the project seeks to empower homeowners and stakeholders to make informed decisions about adopting solar power and transitioning towards a more sustainable energy future.

1.3 SCOPE OF THE WORK

The project covers the installation of solar powered system in a two bedroom apartment. The project will provide solar panels, batteries and inverter that will power appliance such as fans, AC, water pump, TV's etc. During the day, the batteries are charged by the energy gotten from the sun through the solar panels and through the charge controller. The stored energy in DC is now supplied into the inverter which is now converted to AC that is now used to power household appliances.

1.4 METHODOLOGY

The design and installation will be carried out in a two bedroom apartment. The procedure goes thus;

a. The calculation and estimation of te electrical loads in the two bedroom apartment.

b. The calculation of the essential or critical load will be taken note of.

c. Sizing of the solar panels, battery and inverter will be done by required daily average energy demand for the critical loads needed.

d. The design of the charge controller will be carried out as well.

e. Installation of the solar panel, battery and inverter will as well be carried out.

f. Testing and maintenance procedures will be done after the installation.

1.5 RELEVANCE OF THE WORK

a. To tackle the problem of power supply unavailability.

b. To increase efficiency in energy consumption.

CHAPTER 2

LITERATURE REVIEW

The demand for electrical energy is ever increasing as technological advancement & population size around the world keeps increasing. In virtue of this, it is important to also improve the energy supply, ensure it's a reliable power supply and also causes zero to minimal environment hazard. The solar energy among other renewable sources of energy is a promising and freely available energy source for managing long-term issues in energy crisis. The demand for solar powered energy keeps increasing on one reason could be attributed to the fact that it's replenishable compared to other forms of energy sources like fossil fuels and nuclear energy. In consideration of all of these, the solar industry have more potential in the long run compared to the other sources of energy generation especially in terms of cost effectiveness, availability, capacity, and efficiency. In this chapter we'd see why solar energy is the future of electrical energy and improvements that have been made over the years.

2.0 OVERVIEW OF SOLAR ENERGY

World energy demand is increasing significantly because of population growth and industrial growth and it is important to ensure the availability of energy and not just any energy but renewable energy to avoid energy crises. It is vital to go for eco-friendly energy sources for the betterment of the future especially as it relates to global warming as harmful gases depletes our ozone layer. Renewable energy sources such as solar energy, wind energy, hydropower and geothermal (Herzog, 2001) are forms of renewable form energy that can be fully harnessed. In all of these options, solar energy could be our best option for reasons such as: First, it is the most abundant energy source of renewable energy with the sun emitting at a rate of 3.8×10^{23}KW out of which 1.8×10^{14} KW goes to our planet earth (Panwar N, 2011). Second, it's a promising source of energy because it cannot be exhausted giving solid and higher efficiency than other source of energies. Third, utilization and the tracking of solar energy do not have any dangerous or harmful effect or impact on the ecosystem as compared to the exploitation of fossil fuels that leads to the ecosystem damage which in turn damages natural balance (Schlamadinger B, 1997).

Considering these reasons it is wise to see the importance of solar energy as the future of energy supply as its sustainable with little to zero harmful emissions. Accprding to the International Energy Statistics (Agency, 2014), the world energy demand is significantly increasig and as at a total of 520 Quadrillion of energy have been consumed up until the year 2011 and one of the main reason foe this was beacsue of population growth.

2.1 HIGHLIGHTS OF PREVIOUS RESEARCH WORKS ON SOLAR ENERGY.

1. *Solar Power Generation*

A plant for power generation from photovoltaic technology has multiple components like solar cells arrays and modules and means of controlling or regulating systems for both electrical and mechanical connections. This system is designed in such a way that could provide higher conversion efficiencies. A grid connected system in many occasions is used to supply power into public electricity grid; hence, this system does provide a means of decentralized electricity generation. The below researches gives us insight into the improvements that have been done in solar power generation.

(Barton JP, 2006)

Barton and Infield described novel method of modeling an energy structure used to match the power output from a wind turbine and a solar PV array to a varying electrical load and validated the method against time-stepping. It showed good agreement over a wide range of store power ratings, store efficiencies, wind turbine capacities and solar PVcapacities.

(Katti PK, 2007)

Katti and Khedkar investigated hybrid power generation plant, integrated by wind turbine and PV panels, systematically to be used at the remote areas where electricity is highly demanded. They investigated further, wind-alone and solar-alone in isolation and it was compared with hybrid power generation panel.

(Deshmukh M, 2008)

Deshmukh and Deshmukh proposed methodologies to model hybrid renewable energy system components design and their evaluation. They also showed that hybrid PV/wind energy systems are becoming popular, because of their ability to provide undisturbed power generation. It is now being incorporated in various power networks for better improvement.

(Rehman S, 2007)

Rehman et al. investigated distribution of solar radiation and sunshine duration over Saudi Arabia, using monthly average daily global solar radiation and sunshine duration data. In addition, they further scientifically analyzed 5MW installed capacity photovoltaic based grid connected power plant for electricity generation in terms of renewable energy production and economic evaluation.

(Al-Hasan A, 2004)

Al-Hasanetal. did an experiment in Kuwait to optimize electrical load pattern using grid connected PV systems. They found that, during performance evaluation, peak load matches maximum incident solar radiation and hence use of photovoltaic station in Kuwait could be a best option to minimize the electrical load demand and peak load can be reduced significantly with grid connected PV systems.

(Alazraki R, 2007)

Alazraki and Haselip studied the impact of PV systems installed by an energy project in homes, schools and public buildings over last six years. They showed that this attempt has given an opportunity for rural communities to receive electricity by replacing traditional energy sources

(Zhou X, 2009).

Zhou et al. worked on solar chimney power plant to make economic analysis of its power generation by using cash flows during the whole service period of 100MW power plant.

(T. Muneer, 2003)

Muneer et al. studied long term prospects of large scale PV generation in arid and semi-arid locations around the world and its transmission using hydrogen as the energy vector.

(E.Cunow, 2001)

Cunow and Giesler investigated advance large MW PV plant technology at the new Munich Trade Fair Center, in terms of system technology, the components employed for operation, control and cost aspects. They compared renewable generators with non-renewable generators by determining their life cycle cost using net present value analysis. They showed that life cycle cost of PV energy is lower than the cost of energy from generators driven by either petrol or diesel and thus is economically feasible in such areas.

(D.B. Nelson, 2006)

Nelson et al. worked on sizing and economic evaluation of a hybrid wind/PV or fuel cell power generation system. They compared the cost of such system with wind/PV/battery system for a typical home in US Pacific Northwest. They also clearly pointed out that, after analyzing current cost figures as well as break even line distance comparison, traditional wind/PV/battery system is economically viable overwind/PV/fuel cell/electrolyzer system.

(Thanaa F. El-Shatter, 2006)

El-Shatter, et al, worked on an energy system to deliver energy at optimum efficiency using Fuzzy logic control to have maximum power tracking of PV and wind energies employed there. They developed such system in a way such that PV, wind and fuel cells combined together in a systematic way to deliver the maximum power to a fixed direct current (DC) voltage bus.

(S.M. Shaahid, 2008)

Shaahid and Elhadidy made an attempt to assess the techno- economic feasibility of hybrid PV-diesel-battery system by analyzing long term solar radiation data of Dhahran. It was to meet the load of a residential building and they found that, increase in PV capacity decreases operational hours of diesel generators and it is further reduced by inclusion of battery storage.

2. *Solar Heaters*

Solar energy is a freely available intermittent source of energy which is highly dependent on time. However, Conversion of solar energy into thermal energy is the easiest and widely accepted method. Therefore, the recent researches focused on the phase change materials based air heating systems, as it has high energy storage density compared to sensible heat storage. This part highlights researches conducted in this sector to increase its applicability. There is a need for the world to incorporate renewable energy source to meet existing demand.

(Eman-Bellah S. Mettawee, 2006)

Mettawee and Assassa fabricated and evaluated a compact phase change maternal solar collectors based on latent heat storage material with specific design configuration.

(D.L. Zhao, 2011)

Zhao et al. did an experiment in North China to study a solar heating system for building heating season and hot water supply all year with five different working modes for investigation.

(Sopian, 2009)

Sopian, K. B. et al. developed indoor prediction for output air temperature due to the discharge process in a solar air heater integrated with a phase change material units with eight different values of mass flow.

(C. Choudhury, 1991)

Choudhury and Garg introduced an air-based solar collectors developed using unique impingement concept to achieve high heat transfer efficiencies from absorber plate to the following air stream to improve overall efficiencies. Choudhury et al. fabricated a bare plate roof air heaters using corrugated aluminum sheet in a farm shed to provide hot air for agricultural use. They reported that its performance is influenced by various design parameters.

3. ***Design improvement and sizing***

Optimum sizing and improvement in design are two major considerations for industrialization of photovoltaic technology. One of the major challenges to such industry is that high cost of manufacturing that does not yield justifiable production efficiency. Hence, many researches do intensively work on techniques giving significant improvements in developing structured configuration for solar systems. This part hence summarizes remarkable works done to improve design configuration and sizing.

(B.J. Huang, 2006)

Huang et al. proposed a PV system design named near- maximum power point operation that can maintain the performance very close to PV system with maximum power point tracking

(So, 2006)

So et al. analyzed and evaluated the performance of a large scale grid connected PV system and monitoring system for better operation of such system.

(Marwan M Mahmoud, 2003)

Mahmoud and Ibrik demonstrated the reliability and flexibility of utilizing PV system by presenting test result of PV system for better operation.

(El-Tamaly, 2006)

El-Tamaly and Mohammed explained Fuzzy logic technique to calculate and assess the reliability of index for each photovoltaic/wind energy system and hybrid electric power configuration understudy.

(Tanrioven, 2005)

Tanrioven presented and explained about a simulation methodology for reliability and cost assessment of energy sources such as wind, solar energy and fuel cells.

2.2 WORKING OVERVIEW OF THE SOLAR POWER SYSTEM

The amount of sunlight (Solar energy) that hits the surface of the earth in a day, if stored in a vast powerful reserve is enough to supply energy for a much extended period of time. Solar technologies like PVs and CSPs convert sunlight into electrical energy. This energy can be used to generate electricity or be stored in batteries or thermal storage for future use. Solar radiation is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies. However, the amount of energy generated is largely dependent on the available solar radiation for a specific timeframe.

2.3 BASIC PRINCIPLES

Every location on Earth receives sunlight at least part of the year. The amount of solar radiation that reaches any one spot on the Earth's surface varies according to: Geographic location, Time of day, Season of the year, Local landscape & Local weather.

It is well known that the earth is spherical in shape and this causes the sun to strike the surface at different angles, ranging from 0° (just above the horizon) to 90° (directly overhead). At overhead or when the sun's rays are totally or completely vertical, the Earth's surface gets all the energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse. Because the Earth is round, the frigid polar regions never get a high sun, and because of the tilted axis of rotation, these areas receive no sun at all during part of the year.

The Earth revolves around the sun in an elliptical orbit and is closer to the sun during part of the year. When the sun is nearer the Earth, the Earth's surface receives solar energy more than usual. The rotation of the Earth is also responsible for hourly variations in sunlight. In the early morning and late afternoon, the sun is low in the sky. Its rays travel further through the atmosphere than at noon, when the sun is at its highest point. On a clear day, the greatest amount of solar energy reaches a solar collector around solar noon.

It is important to know that as sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by: Air molecules, Water vapor, Clouds, Dust, Pollutants, Forest fires, Volcanoes.

This is called **Diffuse Solar Radiation.** The solar radiation that reaches the Earth's surface without being diffused is called **Direct Beam Solar Radiation**. The sum of the diffuse and direct solar radiation is called global solar radiation. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days. Scientists measure the amount of sunlight falling on specific locations at different times of the year. They then estimate the amount of sunlight falling on regions at the same latitude with similar climates.

Measurements of solar energy are typically expressed as total radiation on a horizontal surface, or as total radiation on a surface tracking the sun.

Radiation data for solar electric (photovoltaic) systems are often represented as kilowatt-hours per square meter (kWh/m2). Direct estimates of solar energy may also be expressed as watts per square meter (W/m2).

2.4 TYPES OF SOLAR ENERGY TECHNOLOGY

There are two main types of solar energy technologies — Photovoltaic (PV) and Concentrating Solar-thermal Power (CSP).

2.4.1 PHOTOVOLTAIC (PV)

PVs are utilized in solar panels. When the sun shines onto a solar panel, energy from the sunlight is absorbed by the PV cells in the panel. This energy creates electrical charges that move in response to an internal electrical field in the cell, causing electricity to flow. PV materials and devices convert sunlight into electrical energy. A single PV device is known as a cell. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. These cells are made of different semiconductor materials and are often less than the thickness of four human hairs. In order to withstand the outdoors for many years, cells are sandwiched between protective materials in a combination of glass and/or plastics.

To boost the power output of PV cells, they are connected together in chains to form larger units known as modules or panels. Modules can be used individually, or several can be connected to form arrays. One or more arrays are then connected to the electrical grid as part of a complete PV system. Because of this design structure, PV systems can be built to meet almost any electric power need, small or large.

PV modules and arrays are just one part of a PV system. Systems also include mounting structures that point panels toward the sun, along with the components that take the direct-current (DC) electricity produced by modules and convert it to the alternating-current (AC) electricity used to power all of the appliances in your home, which are done by inverters. PV has made rapid progress in the past 20 years, yielding better efficiency, improved durability, and lower costs.

Figure 2.0: PV module

2.4.1.1 How a Solar Cell Works

Solar cells contain a material that conducts electricity only when energy is provided—by sunlight, in this case. This material is called a semiconductor; the “semi” means its electrical conductivity is less than that of a metal but more than an insulator’s. When the semiconductor is exposed to sunlight, it absorbs the light, transferring the energy to negatively charged particles called electrons. The electrons flow through the semiconductor as electrical current, because other layers of the PV cell are designed to extract the current from the semiconductor. Then the current flows through metal contacts—the grid-like lines on a solar cell—before it travels to an inverter. The inverter converts the direct current (DC) to an alternating current (AC), which flows into the electric grid and, eventually, connects to the circuit that is your home's electrical system. As long as sunlight continues to reach the module and the circuit is connected, electricity will continue to be generated.

A solar panel's ability to convert sunlight into electricity depends on the semiconductor. In the lab, this ability is called photovoltaic conversion efficiency. Outside, environmental conditions like heat, dirt, and shade can reduce conversion efficiency, along with other factors.

Capturing more light during the day increases energy yield, or the electricity output of a PV system over time. To boost energy yield, researchers and manufacturers are looking at bifacial solar cells, which are double-sided to capture light on both sides of a silicon solar module—they capture light reflected off the ground or roof where the panels are installed.

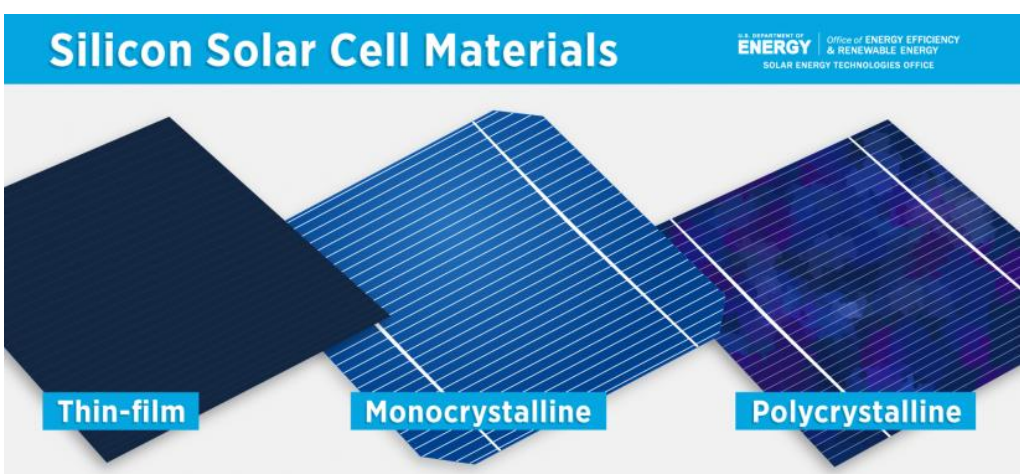


Figure 2.1: Silicon Solar Cells of different types

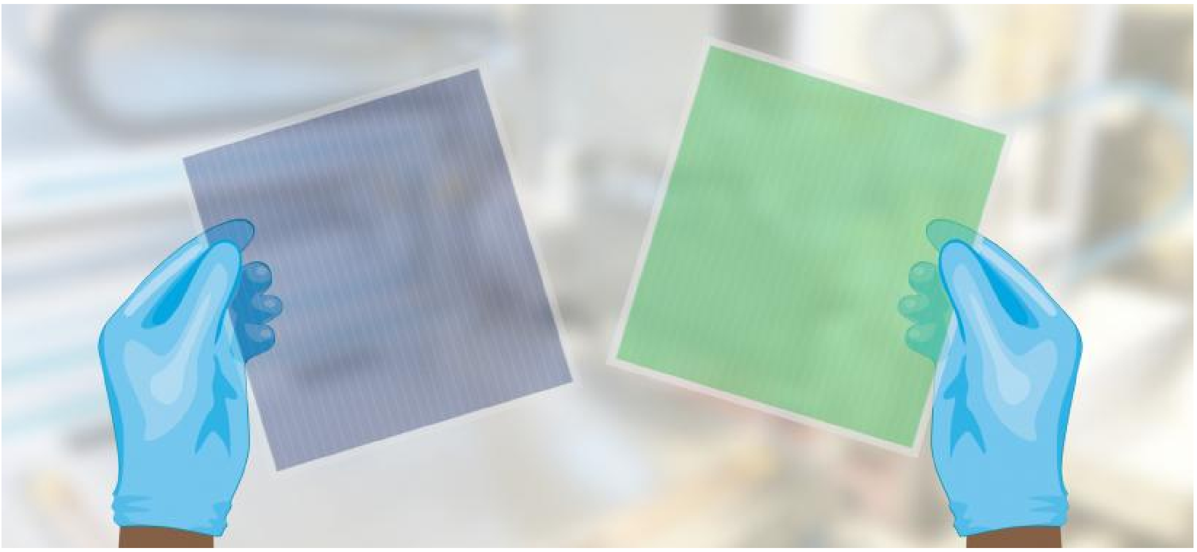


Figure 2.2: Oragnic Silicon Solar Cells of different types

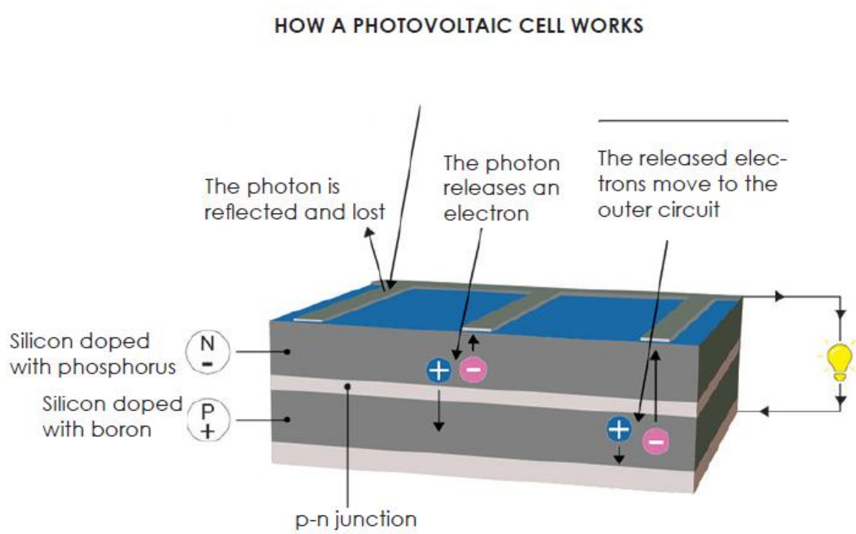


Figure 2.3: Working mechanism of a PV Cell

2.4.1.2 Silicon

The main semiconductor used in solar cells, not to mention most electronics, is silicon, an abundant element. In fact, it's found in sand, so it's inexpensive, but it needs to be refined in a chemical process before it can be turned into crystalline silicon and conduct electricity.

To make a silicon solar cell, blocks of crystalline silicon are cut into very thin wafers. The wafer is processed on both sides to separate the electrical charges and form a diode, a device that allows current to flow in only one direction. The diode is sandwiched between metal contacts to let the electrical current easily flow out of the cell.

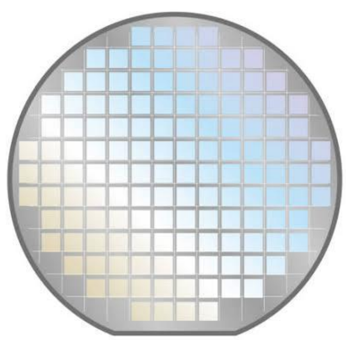


Figure 2.4: A Silicon wafer

About 95% of solar panels on the market today use either monocrystalline silicon or polycrystalline silicon as the semiconductor. Monocrystalline silicon wafers are made up of one crystal structure, and polycrystalline silicon is made up of lots of different crystals.

Monocrystalline panels are more efficient because the electrons move more freely to generate electricity, but polycrystalline cells are less expensive to manufacture.

The maximum theoretical efficiency level for a silicon solar cell is about 32% because of the portion of sunlight the silicon semiconductor is able to absorb above the band-gap —

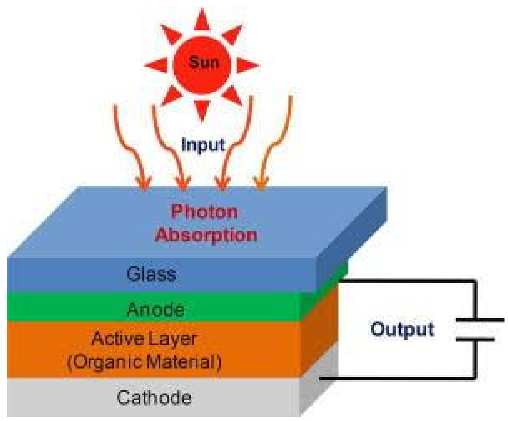


Figure 2.5: Structured Layer of the wafer

The best panels for commercial use have efficiencies around 18% to 22%, but researchers are studying how to improve efficiency and energy yield while keeping production costs low.

But silicon cells have a maximum theoretical efficiency of about 32%, so researchers are exploring new materials and cell designs that can improve conversion and performance. Here are the most promising ones:

2.4.1.3 Layering Up with Multijunction Solar Cells

Some researchers are working to improve cell efficiency by layering multiple different semiconductors to make multijunction solar cells. These cells are essentially semiconductor stacks, as opposed to single-junction cells, which have only one semiconductor. Each layer absorbs a different part of the solar spectrum, making greater use of sunlight than single-junction cells do.

The amount and type of light a semiconductor absorbs is determined by its band gap, a property that signifies the minimum amount of energy needed to free electrons so the material can conduct electricity. Without this energy, silicon acts like an insulator. Multijunction solar cells can reach record efficiency levels because the light that doesn't get absorbed by the first semiconductor layer is captured by a layer beneath it. Different layers absorb different parts of the solar spectrum. Once light is absorbed, the energy is converted to electrical current, and less energy is lost since the band gap is closer to the energy of the absorbed light.

While all solar cells with more than one band gap are multijunction solar cells, a solar cell with exactly two band gaps is called a tandem solar cell. Multijunction solar cells that combine semiconductors from columns III and V in the periodic table are called multijunction III-V solar cells. Multijunction solar cells have demonstrated efficiencies higher than 45%, but they're costly and difficult to manufacture, so they're reserved for space exploration. The military is using III-V solar cells in drones, and researchers are exploring other uses for them where power conversion efficiency is key.

Organic photovoltaics (OPV) are lightweight solar cells made with carbon compounds that can be dissolved and solution-processed, which can reduce cell fabrication costs. OPV use organic polymers and molecules that conduct and generate electricity like those in organic light-emitting diode display technologies. And because the organic molecules can be synthesized with tailored properties, OPV devices can be different colors or transparent. This is relevant to the building-integrated PV market, which seeks to replace building-construction materials with PV materials to make windows and facades. Researchers are working to improve device lifetime and efficiency and mitigate the visual effects of aging.

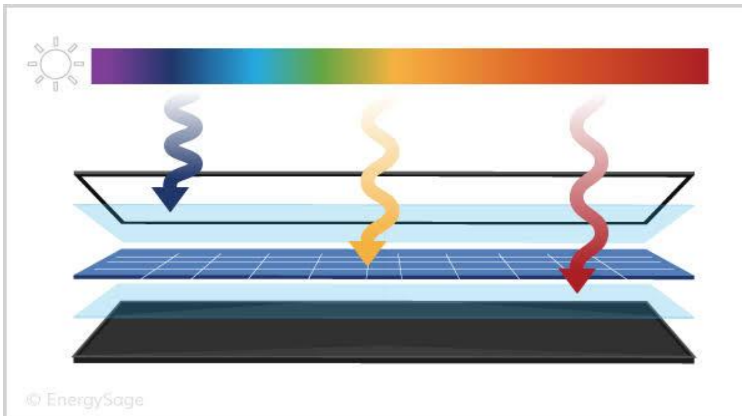


Figure 2.6: A multijunction layered PV module

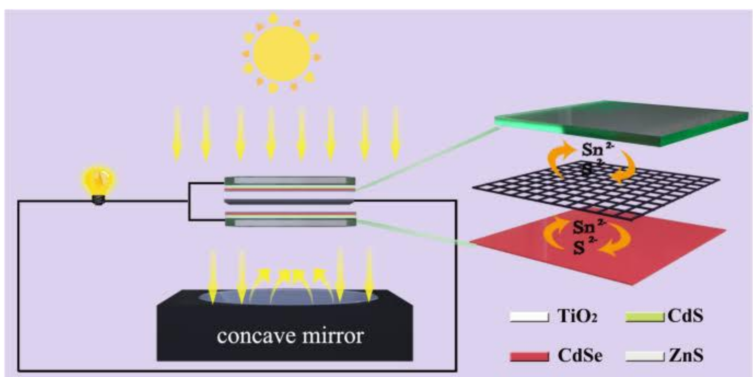


Figure 2.7: A multijunction layered PV module

Ultimately, researchers are exploring dozens of types of solar cells, aiming for higher efficiencies, longer lifetimes, and market success.

2.4.2 CONCENTRATING SOLAR-THERMAL POWER

Concentrating solar-thermal power (CSP) systems use mirrors to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat, which can then be used to produce electricity or stored for later use. It is used primarily in very large power plants. CSP technologies use mirrors to reflect and concentrate sunlight onto a receiver. The energy from the concentrated sunlight heats a high temperature fluid in the receiver.

This heat - also known as thermal energy - can be used to spin a turbine or power an engine to generate electricity. It can also be used in a variety of industrial applications, like water desalination, enhanced oil recovery, food processing, chemical production, and mineral processing.

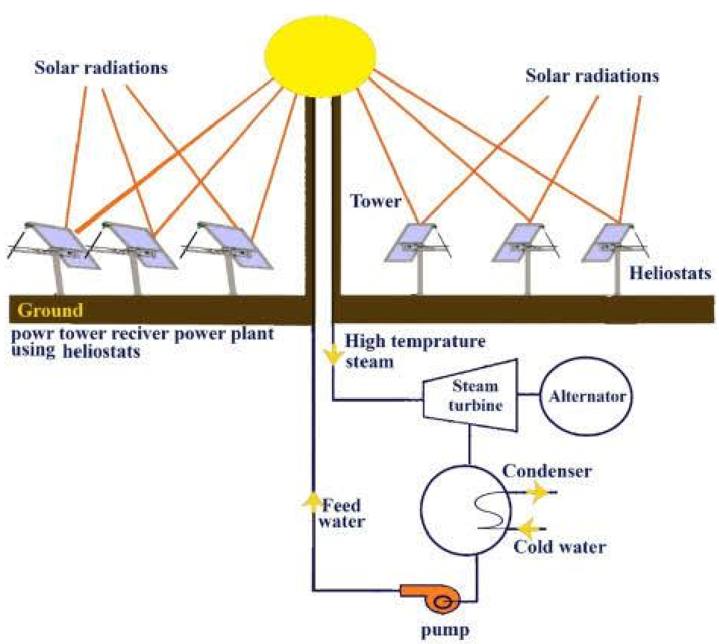


Figure 2.8: An Array of Concentrating Solar Thermal Power

Concentrating solar-thermal power systems are generally used for utility-scale projects. These utility-scale CSP plants can be configured in different ways. Power tower systems arrange mirrors around a central tower that acts as the receiver. Linear systems have rows of mirrors that concentrate the sunlight onto parallel tube receivers positioned above them. Smaller CSP systems can be located directly where power is needed. For example, single dish/engine systems can produce 5 to 25 kilowatts of power per dish and be used in distributed applications.

2.5 SYSTEM INTEGRATION OF THE ENERGY GENERATED BY SOLAR PANELS

Solar energy technology doesn't end with electricity generation by PV or CSP systems. These solar energy systems must be integrated into homes, businesses, and existing electrical grids with varying mixtures of traditional and other renewable energy sources. Solar systems integration involves developing technologies and tools that allow solar energy onto the electricity grid, while maintaining grid reliability, security, and efficiency.

2.5.1 The Electrical Grid

For most of the past 100 years, electrical grids involved large-scale, centralized energy generation located far from consumers. Modern electrical grids are much more complex. In addition to large utility-scale plants, modern grids also involve variable energy sources like solar and wind, energy storage systems, power electronic devices like inverters, and small-scale energy generation systems like rooftop installations and microgrids. These smaller-scale and dispersed energy sources are generally known as distributed energy resources (DER).

The electrical grid is separated into transmission and distribution systems. The transmission grid is the network of high-voltage power lines that carry electricity from centralized generation sources like large power plants. These high voltages allow power to be transported long distances without excessive loss. The distribution grid refers to low-voltage lines that eventually reach homes and businesses. Substations and transformers convert power between high and low voltage. Traditionally, electricity only needed to flow one way through these systems: from the central generation source to the consumer. However, systems like rooftop solar now require the grid to handle two-way electricity flow, as these systems can inject the excess power that they generate back into the grid.

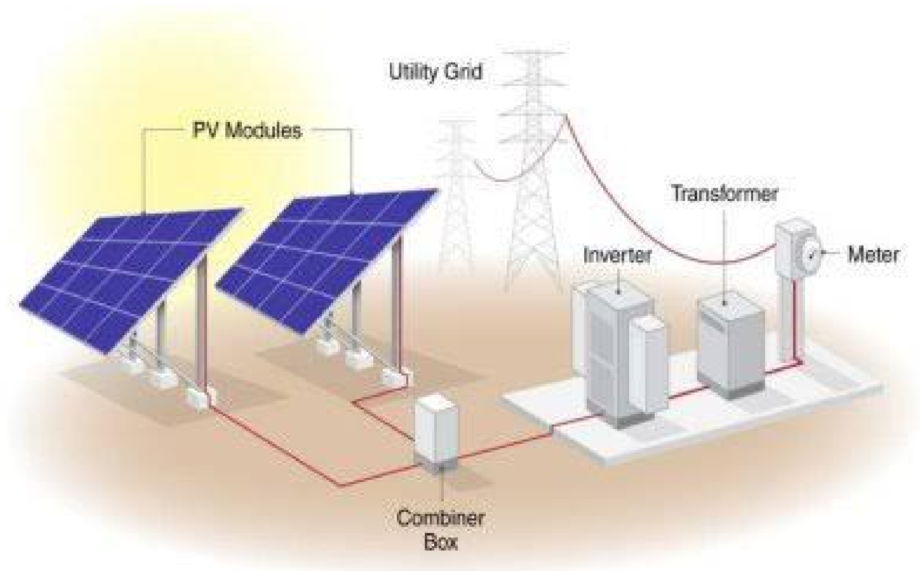
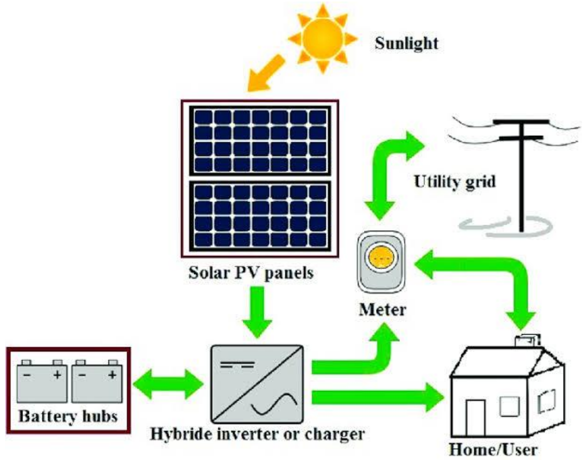


Figure 2.9: Solar Power generation integrated with a grid



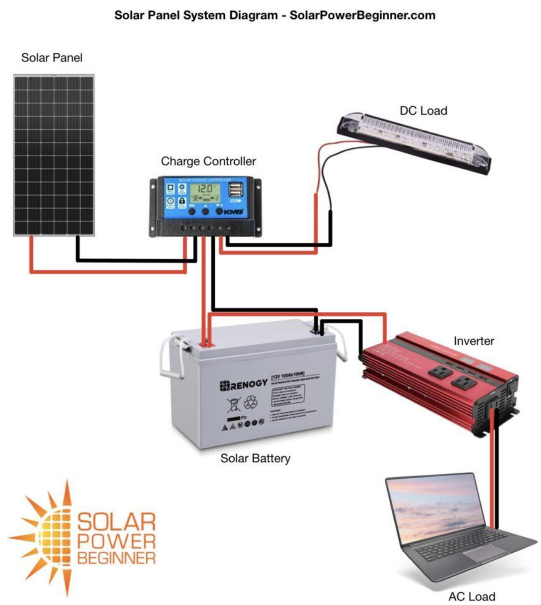


Figure 2.10: Block Diagram of Inverter-Grid Integration

2.5.2 Power Electronics

Increased solar and DER on the electrical grid means integrating more power electronic devices, which convert energy from one form to another. This could include converting between high and low voltage, regulating the amount of power flow, or converting between direct current (DC) and alternating current (AC) electricity, depending on where the electricity is going and how it will be used. One type of power electronic device that is particularly important for solar energy integration is the inverter. Inverters convert DC electricity, which is what a solar panel generates, to AC electricity, which the electrical grid uses.

2.5.3 Solar Storage

Since solar energy can only be generated when the sun is shining, the ability to store solar energy for later use is important: It helps to keep the balance between electricity generation and demand. This means that developing batteries or thermal storage is key to adding more solar.

2.5.4 Grid Resilience & Reliability

The electrical grid must be able to reliably provide power, so it's important for utilities and other power system operators to have real-time information about how much electricity solar systems are producing. Increasing amounts of solar and DER on the grid lead to both opportunities and challenges for grid reliability. Complex modern grids with a mix of traditional generation and DER can make responding to abnormal situations like storms or blackouts more difficult. However, power electronics have the potential to collect real-time information on the grid and help to control grid operations. In fact, special "grid-forming" inverters could use solar energy to restart the grid in the event of a blackout.

2.6 SOLAR INTEGRATION: INVERTERS AND GRID SERVICES

2.6.1 Inverters

An inverter is one of the most important pieces of equipment in a solar energy system. It's a device that converts direct current (DC) electricity, which is what a solar panel generates, to alternating current (AC) electricity, which the electrical grid uses. In DC, electricity is maintained at constant voltage in one direction. In AC, electricity flows in both directions in the circuit as the voltage changes from positive to negative. Inverters are just one example of a class of devices called power electronics that regulate the flow of electrical power.

Fundamentally, an inverter accomplishes the DC-to-AC conversion by switching the direction of a DC input back and forth very rapidly. As a result, a DC input becomes an AC output. In addition, filters and other electronics can be used to produce a voltage that varies as a clean, repeating sine wave that can be injected into the power grid. The sine wave is a shape or pattern the voltage makes over time, and it's the pattern of power that the grid can use without damaging electrical equipment, which is built to operate at certain frequencies and voltages.

The first inverters were created in the 19th century and were mechanical. A spinning motor, for example, would be used to continually change whether the DC source was connected forward or backward. Today we make electrical switches out of transistors, solid-state devices with no moving parts. Transistors are made of semiconductor materials like silicon or gallium arsenide. They control the flow of electricity in response to outside electrical signals.

If you have a household solar system, your inverter probably performs several functions. In addition to converting your solar energy into AC power, it can monitor the system and provide a portal for communication with computer networks. Solar-plus–battery storage systems rely on advanced inverters to operate without any support from the grid in case of outages, if they are designed to do so.

2.6.2 Inverter-Based Grid

Historically, electrical power has been predominantly generated by burning a fuel and creating steam, which then spins a turbine generator, which creates electricity. The motion of these generators produces AC power as the device rotates, which also sets the frequency, or the number of times the sine wave repeats. Power frequency is an important indicator for monitoring the health of the electrical grid. For instance, if there is too much load—too many devices consuming energy—then energy is removed from the grid faster than it can be supplied. As a result, the turbines will slow down and the AC frequency will decrease. Because the turbines are massive spinning objects, they resist changes in the frequency just as all objects resist changes in their motion, a property known as inertia.

As more solar systems are added to the grid, more inverters are being connected to the grid than ever before. Inverter-based generation can produce energy at any frequency and does not have the same inertial properties as steam-based generation, because there is no turbine involved. As a result, transitioning to an electrical grid with more inverters requires building smarter inverters that can respond to changes in frequency and other disruptions that occur during grid operations and help stabilize the grid against those disruptions.

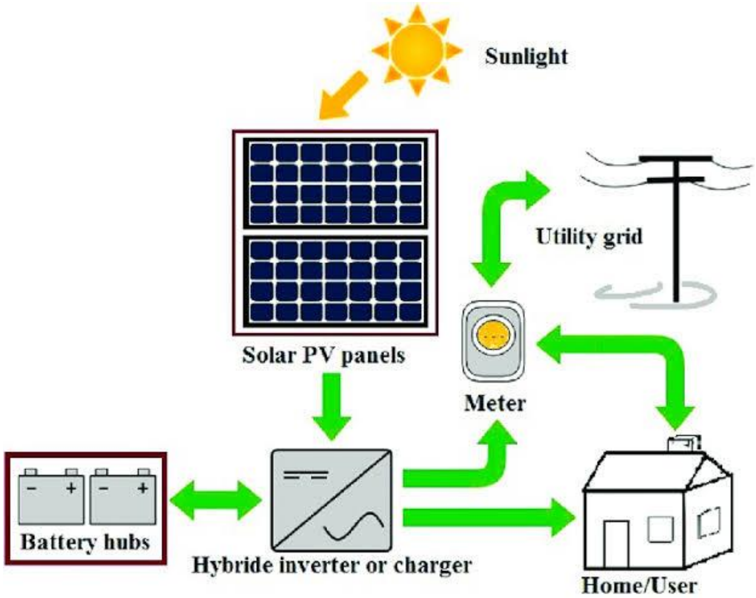


Figure 2.11: Inverter-Grid Integration

2.6.3 Grid Services and Inverters

Grid operators manage electricity supply and demand on the electric system by providing a range of grid services. Grid services are activities grid operators perform to maintain system-wide balance and manage electricity transmission better.

When the grid stops behaving as expected, like when there are deviations in voltage or frequency, smart inverters can respond in various ways. In general, the standard for small inverters, such as those attached to a household solar system, is to remain on during or “ride through” small disruptions in voltage or frequency, and if the disruption lasts for a long time or is larger than normal, they will disconnect themselves from the grid and shut down. Frequency response is especially important because a drop in frequency is associated with generation being knocked offline unexpectedly. In response to a change in frequency, inverters are configured to change their power output to restore the standard frequency.

Inverter-based resources might also respond to signals from an operator to change their power output as other supply and demand on the electrical system fluctuates, a grid service known as automatic generation control. In order to provide grid services, inverters need to have sources of power that they can control. This could be either generation, such as a solar panel that is currently producing electricity, or storage, like a battery system that can be used to provide power that was previously stored.

2.7 ENERGY STORAGE

Storage helps solar contribute to the electricity supply even when the sun isn't shining. It can also help smooth out variations in how solar energy flows on the grid. These variations are attributable to changes in the amount of sunlight that shines onto photovoltaic (PV) panels or concentrating solar-thermal power (CSP) systems. Solar energy production can be affected by season, time of day, clouds, dust, haze, or obstructions like shadows (Building & Trees), rain, snow, and dirt. Sometimes energy storage is co-located with, or placed next to, a solar energy system, and sometimes the storage system stands alone, but in either configuration, it can help more effectively integrate solar into the energy landscape.

"Storage" refers to technologies that can capture electricity, store it as another form of energy (chemical, thermal, mechanical), and then release it for use when it is needed. Lithium-ion batteries are one such technology. Although using energy storage is never 100% efficient—some energy is always lost in converting energy and retrieving it—storage allows the flexible use of energy at different times from when it was generated. So, storage can increase system efficiency and resilience, and it can improve power quality by matching supply and demand.

Storage facilities differ in both energy capacity, which is the total amount of energy that can be stored (usually in kilowatt-hours or megawatt-hours), and power capacity, which is the amount of energy that can be released at a given time (usually in kilowatts or megawatts). Different energy and power capacities of storage can be used to manage different tasks. Short-term storage that lasts just a few minutes will ensure a solar plant operates smoothly during output fluctuations due to passing clouds, while longer-term storage can help provide supply over days or weeks when solar energy production is low or during a major weather event, for example.

2.7.1 ADVANTAGES OF COMBINING STORAGE AND SOLAR

2.7.1.1 Balancing electricity loads – Without storage, electricity must be generated and consumed at the same time, which may mean that grid operators take some generation offline, or "curtail" it, to avoid over-generation and grid reliability issues. Conversely, there may be other times, after sunset or on cloudy days, when there is little solar production but plenty of demand for power. When some of the electricity produced by the sun is put into storage, that electricity can be used whenever grid operators need it, including after the sun has set. In this way, storage acts as an insurance policy for sunshine.

2.7.1.2 Firming solar generation – Short-term storage can ensure that quick changes in generation don't greatly affect the output of a solar power plant. For example, a small battery can be used to ride through a brief generation disruption from a passing cloud, helping the grid maintain a "firm" electrical supply that is reliable and consistent.

2.7.1.3 Providing resilience – Solar and storage can provide backup power during an electrical disruption. They can keep critical facilities operating to ensure continuous essential services, like communications. Solar and storage can also be used for microgrids and smaller-scale applications, like mobile or portable power units.

2.7.2 TYPES OF ENERGY STORAGE

The most common type of energy storage in the power grid is pumped hydropower. But the storage technologies most frequently coupled with solar power plants are electrochemical storage (batteries) with PV plants and thermal storage (fluids) with CSP plants. Other types of storage, such as compressed air storage and flywheels, may have different characteristics, such as very fast discharge or very large capacity, that make them attractive to grid operators.

2.7.2.1 Electrochemical Storage

Electrochemical batteries are very much quite familiar, like those found in laptops and mobile phones. When electricity is fed into a battery, it causes a chemical reaction, and energy is stored. When a battery is discharged, that chemical reaction is reversed, which creates voltage between two electrical contacts, causing current to flow out of the battery. The most common chemistry for battery cells is lithium-ion, but other common options include lead-acid, sodium, and nickel-based batteries.

2.7.2.2 Solar Fuels

Solar power can be used to create new fuels that can be combusted (burned) or consumed to provide energy, effectively storing the solar energy in the chemical bonds. Among the possible fuels researchers are examining are hydrogen, produced by separating it from the oxygen in water, and methane, produced by combining hydrogen and carbon dioxide. Methane is the main component of natural gas, which is commonly used to produce electricity or heat homes.

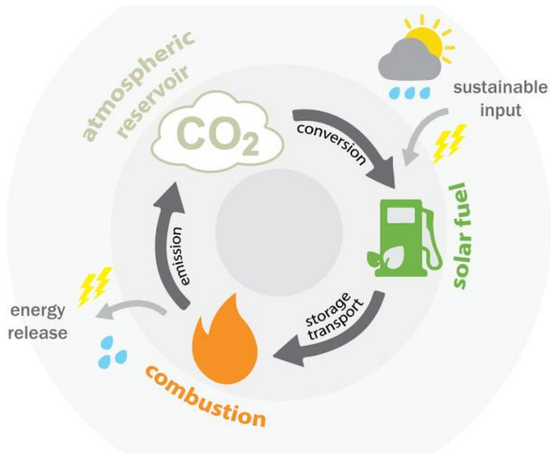


Figure 2.12: A solar fuel cycle

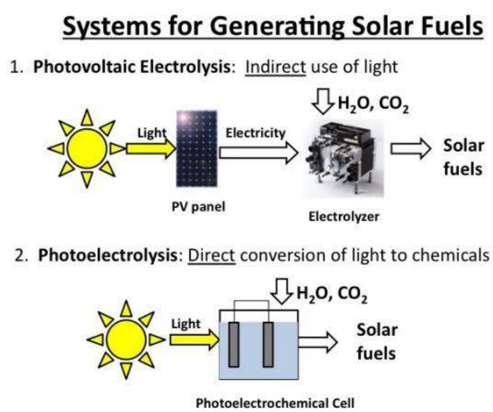


Figure 2.13: A Solar fuel generating system

2.7.2.3 Flywheel Storage

A flywheel is a heavy wheel attached to a rotating shaft. Expending energy can make the wheel turn faster. This energy can be extracted by attaching the wheel to an electrical generator, which uses electromagnetism to slow the wheel down and produce electricity. Although flywheels can quickly provide power, they can't store a lot of energy.

2.7.2.4 Thermal Energy Storage

Thermal energy storage is a family of technologies in which a fluid, such as water or molten salt, or other material is used to store heat. This thermal storage material is then stored in an insulated tank until the energy is needed. The energy may be used directly for heating and cooling, or it can be used to generate electricity. In thermal energy storage systems intended for electricity, the heat is used to boil water. The resulting steam drives a turbine and produces electrical power using the same equipment that is used in conventional electricity generating stations. Thermal energy storage is useful in CSP plants, which focus sunlight onto a receiver to heat a working fluid. Supercritical carbon dioxide is being explored as a working fluid that could take advantage of higher temperatures and reduce the size of generating plants.

2.7.2.5 Pumped-Storage Hydropower

Pumped-storage hydropower is an energy storage technology based on water. Electrical energy is used to pump water uphill into a reservoir when energy demand is low. Later, the water can be allowed to flow back downhill and turn a turbine to generate electricity when demand is high. Pumped hydro is a well-tested and mature storage technology that has been used in the United States since 1929. However, it requires suitable landscapes and reservoirs, which may be natural lakes or man-made by constructing dams, requiring lengthy regulatory permits, long implementation times, and large initial capital. Other than energy arbitrage, pumped hydro's value of services to integrate variable renewables are not fully realized, which can make the financial payback period long. These are some of the reasons pumped hydro has not been built recently, even though interest is evident from requests to the Federal Energy Regulatory Commission for preliminary permits and licenses.

2.8 COMPONENTS OF A COMPLETE SOLAR POWER SYSTEM

2.8.1 Solar Panels

Solar panels, which are also known as photovoltaic (PV) panels, are devices designed to convert sunlight directly into electricity through the photovoltaic effect. This effect involves the generation of an electric current when certain materials, typically semiconductors like silicon, are exposed to light.

At the heart of a solar panel is a semiconductor material, usually silicon, which is composed of atoms arranged in a crystalline structure. When photons from sunlight strike the surface of the semiconductor material, they transfer their energy to electrons in the material, causing them to become excited and break free from their atomic bonds. This process generates electron-hole pairs, where an electron is liberated from its position in the atomic lattice, leaving behind a positively charged "hole".

The semiconductor material within the solar panel is typically doped to create a p-n junction. This involves introducing impurities into the material to create regions with an excess of free electrons (n-type) and regions with an excess of positively charged "holes" (p-type). At the interface between these two regions, a built-in electric field is established due to the difference in charge carrier concentrations.

When sunlight strikes the solar panel, the photons with sufficient energy to overcome the band-gap of the semiconductor material generate electron-hole pairs in the vicinity of the p-n junction. The built-in electric field then causes the free electrons to move towards the n-type region and the "holes" to move towards the p-type region. This movement of charge carriers creates a voltage potential across the solar cell, resulting in an electric current if the cell is connected to an external circuit.

To harness this electric current efficiently, solar panels are typically constructed with multiple solar cells interconnected in series and/or parallel configurations. These cells are encapsulated within a protective layer, such as tempered glass, to shield them from environmental factors and to maximize light absorption.

The generated electricity from solar panels is typically in direct current (DC) form. However, since most household appliances and the electricity grid operate on alternating current (AC), solar panels are often connected to inverters to convert the DC electricity into AC electricity for practical use.

The fundamental principle behind the operation of solar panels lies in the conversion of sunlight into electricity through the photovoltaic effect within semiconductor materials. Understanding this principle is much vital for the design, development, and utilization of solar energy technologies, which play a significant role in the transition towards cleaner and more sustainable energy sources.

2.8.2 Monocrystalline Solar Panels

Monocrystalline solar panels are crafted from a single crystal of high-purity silicon. This silicon is grown from a single seed crystal in a controlled environment, resulting in a uniform and consistent crystal lattice structure. The high purity of monocrystalline silicon ensures minimal defects and impurities within the material, which contributes to its superior electrical properties. Due to the uniformity of the crystal structure, monocrystalline silicon exhibits higher electron mobility compared to other semiconductor materials, allowing for more efficient charge carrier transport within the solar cell.

Monocrystalline silicon has a well-defined bandgap, typically around 1.1 electron volts (eV), which determines its ability to absorb photons of specific energies. When photons from sunlight strike the surface of the monocrystalline solar cell, they must possess energy equal to or greater than the bandgap energy to initiate the photovoltaic effect. Photons with energy less than the bandgap are unable to generate electron-hole pairs and are either transmitted through the material or absorbed without producing useful electrical energy. The high purity and crystalline structure of monocrystalline silicon contribute to efficient light absorption and photon-to-electron conversion, maximizing the overall efficiency of the solar cell.

Figure 2.14: A monocrystalline PV module

Within the monocrystalline silicon solar cell, the absorption of photons generates electron-hole pairs near the p-n junction, where n-type and p-type regions meet. The built-in electric field at the p-n junction facilitates the separation of charge carriers, causing electrons to migrate towards the n-type region and holes towards the p-type region. As electrons and holes move within the silicon lattice, they contribute to the generation of an electric current, which can be harnessed for external use. Metal contacts strategically placed on the front and back surfaces of the solar cell collect the generated electrons and conduct them through an external circuit, creating a flow of electricity

The crystalline structure of monocrystalline silicon, along with its high purity and well-defined bandgap, contribute to the high efficiency of monocrystalline solar panels. These panels typically achieve efficiencies ranging from 15% to 22%, with some advanced designs surpassing 25% efficiency. Factors such as cell design, surface passivation techniques, and anti-reflective coatings further enhance the performance of monocrystalline solar cells, maximizing energy yield under varying environmental conditions.

2.8.3 Polycrystalline Solar Panels

Polycrystalline solar panels, also known as multicrystalline solar panels, are a type of photovoltaic module that utilizes silicon wafers made from multiple silicon crystals. Unlike monocrystalline panels, which are crafted from a single crystal structure, polycrystalline panels are produced by melting raw silicon and pouring it into molds to create ingots. These ingots are then sliced into wafers, resulting in a distinctive blue coloration due to the random orientation of the silicon crystals.

The production process of polycrystalline panels results in silicon crystals of varying sizes and orientations within each wafer. This random arrangement of crystals contributes to their characteristic grainy appearance. While polycrystalline panels typically exhibit lower efficiency compared to monocrystalline panels, advancements in manufacturing techniques have narrowed the efficiency gap between the two types. The manufacturing process of polycrystalline solar panels begins with the purification of raw silicon, usually sourced from quartz sand. The purified silicon is then melted in a furnace and cast into square-shaped molds to form ingots. Once solidified, these ingots are sliced into thin wafers using wire saws. The wafers are then treated with dopants to create the p-n junctions necessary for the photovoltaic effect to occur. Metal contacts are applied to the front and back of the wafers, and an anti-reflective coating is added to the front surface to minimize light reflection.

Figure 2.15: A polycrystalline PV module

Polycrystalline solar panels typically exhibit efficiencies ranging from 13% to 16%, although modern manufacturing techniques have pushed some models closer to 20% efficiency. While slightly lower than monocrystalline panels, polycrystalline panels offer a cost-effective alternative due to their simpler manufacturing process and lower material costs. They perform well in moderate to high light conditions but may experience slightly reduced efficiency in extreme temperatures or low-light environments.

2.8.4 Comparison Between Polycrystalline & Monocrystalline

The decision of choosing between Polycrystalline and Monocrystalline is largely dependent on factors such as:

2.8.4.1 Efficiency

Monocrystalline panels generally have higher efficiency compared to polycrystalline panels. Monocrystalline silicon is made from a single crystal structure, allowing for more efficient electron flow. This typically results in efficiencies ranging from 15% to 22% for monocrystalline panels.

Polycrystalline panels, on the other hand, have a lower efficiency range, typically from 13% to 16%. The presence of multiple silicon crystals of varying sizes and orientations within each wafer can lead to reduced electron mobility and lower efficiency.

2.8.4.2 Aesthetic Appeal

Monocrystalline panels typically have a uniform black color due to their single-crystal structure, which some homeowners find more aesthetically pleasing compared to the grainy blue appearance of polycrystalline panels.

Polycrystalline panels have a distinctive blue coloration resulting from the random arrangement of silicon crystals within each wafer. While this may be less appealing to some, others may find the blue hue acceptable or even preferable.

2.8.4.3 Cost

Monocrystalline panels tend to be more expensive to produce compared to polycrystalline panels due to the higher purity of the silicon required and the more complex manufacturing process. Polycrystalline panels are generally more cost-effective to produce than monocrystalline panels because they utilize raw silicon in a melted form, resulting in lower material and manufacturing costs.

2.8.4.4 Space Efficiency

Monocrystalline panels typically have higher efficiency per square foot compared to polycrystalline panels. This means that for installations with limited roof space or where maximizing power output is crucial, monocrystalline panels may be preferred.

Polycrystalline panels have a slightly lower efficiency per square foot compared to monocrystalline panels. While they may require slightly more space to achieve the same power output, they can still be a viable option for many installations.

2.8.4.5 Performance in Different Conditions

Monocrystalline panels tend to perform slightly better than polycrystalline panels in high-temperature and low-light conditions due to their higher efficiency and better electron mobility.

Polycrystalline panels perform well in moderate to high light conditions but may experience slightly reduced efficiency in extreme temperatures or low-light environments.

2.8.4.6 Longevity and Durability

Both monocrystalline and polycrystalline panels are known for their durability and longevity, typically coming with warranties ranging from 20 to 25 years. The choice between the two types is unlikely to significantly impact the overall lifespan or durability of the solar panel system.

2.9 HOW SOLAR PANELS ARE CONNECTED

Solar panels are either connected in series or in parallel. Let's look at them in detail.

2.9.1 SERIES CONNECTION

When connecting solar panels in series, the voltage increases while the current remains relatively constant. This principle is based on Kirchhoff's voltage law, which states that the total voltage around a closed loop in a circuit is equal to the sum of the voltage drops.

In series connection, each solar panel contributes its voltage output to the total voltage of the circuit. When panels are connected in series, the voltages of each panel add up. For example, if you connect two solar panels with a voltage output of 20 volts each in series, the total voltage output would be 40 volts (20 volts + 20 volts). The current remains relatively constant throughout a series circuit. In a series connection, the same current flows through each component of the circuit. Therefore, the current flowing through the solar panels in series will be the same as the current flowing through each individual panel.

It's quite necessary to know that while the voltage increases in a series connection, the overall power (wattage) of the system depends on both the voltage and the current. The power output of the series-connected panels will be the product of the total voltage and the total current, and it should be within the operating range of the charge controller or inverter in the system.

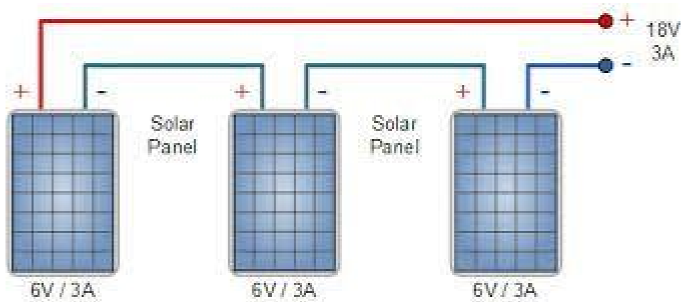


Figure 2.16: A series connection of solar panels

To connect solar panels in series, start by identifying the positive and negative terminals on each panel. These are usually labeled or marked. Connect the positive terminal of one panel to the negative terminal of the next panel using appropriate wiring and connectors. Repeat this process for all panels in the series. Ensure that all connections are secure and properly insulated to prevent short circuits or electrical hazards.

2.9.2 PARELLEL CONNECTION

In a parallel connection, the positive terminals of all the panels are connected together, and the negative terminals are also connected together. This creates multiple paths for the current to flow. Because the voltage is the potential difference between the positive and negative terminals of each individual panel, and these terminals are still connected in parallel, the voltage across each panel remains the same as the voltage of a single panel.

In a parallel connection, the total current output is the sum of the currents produced by each individual panel. Since each panel contributes its own current to the total, the overall current increases as more panels are added in parallel. This increase in current occurs because each panel is contributing its current independently, adding together to form the total output current of the system.

Since power (in watts) is the product of voltage and current, the power output of the system increases in a parallel configuration due to the increase in total current output. However, it's essential to ensure that the electrical components downstream, such as wires, inverters, and charge controllers, are capable of handling the increased current safely.

When connecting solar panels in parallel, the voltage across each panel remains constant, while the current output increases. This configuration allows for greater total power output and is commonly used to increase the current capacity of a solar PV system.

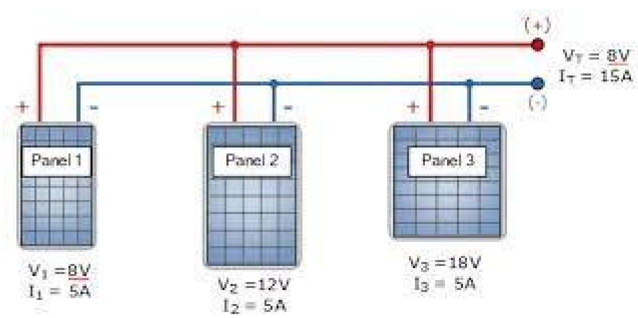


Figure 2.17: A parallel connection of solar panels

2.10 CHARGE CONTROLLERS

A charge controller, also known as a charge regulator, is an essential component in solar PV systems, particularly those with battery storage. Its primary function is to regulate the charging of batteries from the solar panels to prevent overcharging and ensure efficient energy management. Charge controllers operate based on the principles of pulse width modulation (PWM) or maximum power point tracking (MPPT).

2.10.1 PWM Charge Controllers:

PWM charge controllers regulate the charging of batteries by rapidly switching the connection between the solar panels and the batteries on and off. When the battery voltage reaches a preset level (typically a float or absorption voltage), the PWM controller interrupts the flow of current from the solar panels to the battery, effectively "pulsing" the charge. This on-off cycling maintains the battery voltage at the desired level, preventing overcharging while allowing the battery to reach its full capacity.

2.10.2 MPPT Charge Controllers:

MPPT charge controllers employ advanced electronics to continuously track and adjust the operating point of the solar panels to extract the maximum power available under varying environmental conditions. By dynamically optimizing the voltage and current output of the solar panels, MPPT controllers ensure that the maximum available power is delivered to the battery for charging. This maximizes the efficiency of the solar PV system, especially in situations where the solar panels are subjected to shading, temperature variations, or non-optimal orientation.

Charge controllers provide various protection mechanisms to safeguard the battery and other system components:

2.10.3 Overcharge Protection

Prevents the battery from being overcharged by disconnecting the solar panels when the battery reaches its maximum voltage threshold.

2.10.4 Over-discharge Protection

Disconnects the load from the battery to prevent excessive discharge, which can damage the battery and reduce its lifespan.

2.10.5 Temperature Compensation

Adjusts the charging voltage based on the temperature to ensure optimal charging efficiency and battery longevity.

2.10.6 Short Circuit Protection

Detects and responds to short circuits in the system, preventing damage to the charge controller and other components.

Charge controllers play a crucial role in managing the charging and discharging of batteries in off-grid and hybrid solar PV systems:

2.10.7 Bulk Charging

Initially, the charge controller allows the solar panels to deliver maximum current to the battery to rapidly replenish its charge.

2.10.8 Absorption Charging

Once the battery voltage reaches a predefined set point, the controller switches to absorption mode, maintaining a constant voltage to ensure complete charging.

2.10.9 Float Charging

After the battery is fully charged, the charge controller switches to float mode, maintaining a lower voltage to keep the battery topped off without overcharging.

Charge controllers are critical components in solar PV systems, ensuring efficient battery charging, protection against overcharging and discharging, and optimization of system performance. Understanding the principles and functions of charge controllers is essential for designing, installing, and maintaining reliable and efficient solar energy systems.

2.11 BATTERIES

Batteries play a crucial role in solar panel systems by storing excess energy generated during periods of sunlight for use during periods of low or no sunlight. This energy storage capability allows solar panel systems to provide electricity even when the sun isn't shining, enabling greater energy independence and reliability.

Batteries store energy in the form of chemical potential energy, which is converted to electrical energy when needed. This process involves the movement of charged particles, typically ions, between the battery's electrodes (anode and cathode) through an electrolyte solution. During charging, electrical energy from the solar panels is used to drive a chemical reaction that stores energy by transferring ions between the electrodes. This process is reversible, allowing the stored energy to be released as electrical current when needed, such as during periods of low solar generation or at night.

2.11.1 Types of Batteries

2.11.1.1 Lead-Acid Batteries

Lead-acid batteries are one of the oldest and most commonly used types of batteries in solar panel systems. They consist of lead plates immersed in sulfuric acid electrolyte. During charging, lead sulfate forms on the plates, and during discharging, the lead sulfate reverts to lead dioxide and lead. Lead-acid batteries are relatively inexpensive and have a long track record of reliable performance. However, they are heavy, require regular maintenance (such as topping up electrolyte levels and equalizing charges), and have a limited cycle life compared to newer battery technologies.

2.11.1.2 Lithium-Ion Batteries

Lithium-ion batteries have gained popularity in recent years due to their high energy density, lightweight design, and longer cycle life compared to lead-acid batteries. They utilize lithium compounds as the active material in the electrodes and a lithium salt dissolved in an organic solvent as the electrolyte. Lithium-ion batteries offer higher efficiency, faster charging rates, and deeper discharge capabilities compared to lead-acid batteries. They also require minimal maintenance and have a longer lifespan, making them well-suited for solar panel systems in residential, commercial, and off-grid applications.

2.11.1.3 Nickel-Cadmium (Ni-Cd) Batteries

Nickel-cadmium batteries were once widely used in solar panel systems but have become less common due to environmental concerns related to cadmium toxicity and the emergence of newer battery technologies. They consist of nickel hydroxide and cadmium electrodes with a potassium hydroxide electrolyte. Nickel-cadmium batteries offer good cycle life, wide temperature tolerance, and resistance to overcharging and deep discharging. However, they are less energy-dense than lithium-ion batteries and have higher self-discharge rates.

2.11.1.4 Flow Batteries

Flow batteries are a type of rechargeable battery in which energy is stored in chemical solutions contained in external tanks. They utilize redox reactions between electrolyte solutions flowing through electrodes to store and release energy. Flow batteries offer scalability, long cycle life, and the ability to decouple energy storage capacity from power output. They are suitable for grid-scale energy storage applications but are less common in residential solar panel systems due to their complexity and higher cost.

Selecting the right type of battery for a solar panel system depends on factors such as cost, energy requirements, space constraints, maintenance considerations, and environmental preferences. While lead-acid batteries have been a traditional choice, lithium-ion batteries are increasingly favored for their superior performance and reliability in modern solar PV installations.

2.12 INVERTERS

Inverters play a crucial role in solar photovoltaic (PV) systems by converting the direct current (DC) electricity generated by solar panels into alternating current (AC) electricity suitable for use in homes, businesses, and the electrical grid.

Solar panels produce DC electricity through the photovoltaic effect. However, most household appliances and the electrical grid operate on AC electricity. Inverters facilitate the conversion of DC electricity from solar panels into AC electricity by utilizing semiconductor devices such as transistors and diodes to manipulate the flow of electrical current.

Inverters also regulate the voltage of the AC electricity output to match the voltage requirements of the electrical grid or the load. This ensures compatibility with existing electrical systems and appliances.

Grid-tied solar PV systems require inverters that can synchronize the output frequency and phase of the AC electricity with the electrical grid. This enables seamless integration of solar-generated electricity with the grid.

Many modern inverters incorporate MPPT technology, which optimizes the power output of solar panels by continuously adjusting the operating voltage and current to track the maximum power point of the solar array under varying sunlight conditions.

2.12.1 Types of Inverters

2.12.1.1 String Inverters:

String inverters are the most common type used in residential and commercial solar PV systems. They are designed to connect multiple solar panels in series, forming a "string" of panels.

String inverters have a single MPPT tracker for the entire string of panels, which means that shading or soiling on one panel can affect the performance of the entire string. These inverters are cost-effective and relatively simple to install, making them popular for smaller-scale installations.

2.12.1.2 Microinverters:

Microinverters are installed on each individual solar panel, converting the DC electricity directly at the source. This means that each panel operates independently, maximizing energy production and minimizing the impact of shading or panel mismatch. Microinverters offer higher efficiency and flexibility compared to string inverters but tend to be more expensive upfront. However, they may provide better long-term performance and reliability, especially in installations with challenging conditions.

2.12.1.3 Power Optimizers:

Power optimizers are devices installed at the back of each solar panel that perform DC to DC conversion and maximize energy harvest. They work in conjunction with a central string inverter to optimize the performance of the solar array. Like microinverters, power optimizers mitigate the effects of shading, panel mismatch, and soiling, resulting in increased energy production compared to traditional string inverters.

2.12.1.4 Hybrid Inverters:

Hybrid inverters combine the functionality of a solar PV inverter with that of a battery inverter, allowing for energy storage and grid interaction in a single unit. These inverters are commonly used in solar-plus-storage systems, where excess solar energy is stored in batteries for later use or exported to the grid.

2.12.1.5 Three-Phase Inverters:

Three-phase inverters are designed for larger commercial or industrial-scale solar PV systems that require three-phase AC electricity. These inverters typically have higher power ratings and may feature advanced grid management capabilities to ensure stability and compliance with grid regulations.

CHAPTER 3

METHODOLOGY OF THE DESIGN

In this chapter, we will delve into the intricacies of the design process and decisions involved in creating a sustainable and efficient solar solution tailored to the specific requirements of a 2 bedroom apartment.

We would perform analysis from the initial assessment of the site to the selection of components and the integration of the system with existing infrastructure, each step of the design process plays a crucial role in ensuring the success and effectiveness of the solar panel installation. By carefully analyzing the energy needs, available resources, and environmental factors, we aim to create a comprehensive and optimized design that maximizes energy production, minimizes costs, and enhances the overall sustainability of our living space.

3.1 STEPS TO BE CONSIDERED BEFORE BEGINNING THE DEISGN

1. Defining the size of the project

2. Surveying the site of the project

3. Determining the amount of energy to be consumed

4. Costing the project

5. Design and Layout of the project

3.1.1 DEFINING THE SIZE OF THE PROJECT

It's of importance to determine how big the project would be. This is determined by the building or project in consideration. The size of the project is determined by what the project is meant to do. Project sizing can range from simple;

i. Lights: Solar panels can power interior and exterior lighting systems, including LED bulbs, fixtures, and outdoor security lights.

ii. Appliances: Solar energy can be used to power various household appliances such as refrigerators, freezers, washing machines, dryers, dishwashers, and microwaves.

iii. Home Office Equipment: Solar power can support home office equipment such as computers, printers, scanners, monitors, routers, and other office electronics, enabling remote work without relying on the grid.

iv. Outdoor Equipment: Solar energy can power outdoor equipment and amenities such as garden lights, landscape irrigation systems, electric gates, garage door openers, and outdoor entertainment systems.

To complex systems such as:

i. HVAC Systems: Solar energy can supplement or power heating, ventilation, and air conditioning (HVAC) systems, including electric heaters, air conditioners, and fans, reducing reliance on the grid for climate control.

ii. Water Heating: Solar panels can heat water for domestic use, including showers, baths, sinks, and laundry, using solar thermal systems or solar water heaters.

iii. Pool Pumps: Solar energy can power pool pumps and filtration systems, maintaining water circulation and cleanliness in swimming pools and spas.

iv. Electric Vehicle Charging: Solar panels can charge electric vehicles (EVs) or plug-in hybrid vehicles (PHEVs) using dedicated EV charging stations, enabling sustainable transportation powered by renewable energy.

But as a case study, we are considering a 2 Bedroom apartment for this research.

3.1.2. SURVEYING THE SITE OF THE PROJECT

Assessing Sunlight Exposure: The first aspect of the site assessment involves evaluating the sunlight exposure of the apartment's location. Factors such as roof orientation, tilt angle, and shading from nearby buildings or trees significantly impact the amount of sunlight available for solar energy generation. By analyzing the sun's path throughout the day and across different seasons, we can identify optimal locations for solar panel placement to maximize sunlight exposure and energy production.

Roof Condition and Structure: Another critical consideration is the condition and structure of the apartment's roof, which will serve as the primary location for mounting the solar panels. We must assess the roof's age, material, slope, and load-bearing capacity to ensure it can support the weight of the solar panels and withstand environmental factors such as wind, snow, and rain. Any necessary repairs or reinforcements should be addressed before proceeding with the installation.

3.1.3. DETERMINING THE AMOUNT OF ENERGY TO BE CONSUMED

In doing this effectively, we need to ensure the following;

i. Calculate Total Energy Demand: Run a summation of the energy consumption estimates for all appliances and activities to determine the total energy demand of the apartment. This will provide an overall picture of the energy needs that the solar panel system must meet. Depending on the budget and requirement of the house owner, in most cases once the total energy has been calculated, it is important to know the load percentage use of the house owner since 100% of the load won't be in usage especially because the life span of the inverter will be shortened and the run-time of the inverter will be less, in simpler terms consuming more battery.

ii. Estimate Future Energy Needs: It is very possible that the house owner may increase his/her appliance usage or consumption and as such it's important to factor in or anticipate any changes or additions to the household that may affect energy consumption in the future, such as purchasing new appliances, adding more occupants, or implementing energy-saving measures.

3.1.4. COSTING THE PROJECT

Costing the project means calculating the total cost of the project. This means costing the solar panels, the conducting wires, charge controller (Control the amount of charges coming from the solar panel), battery & battery racks, Inverter and panel holders.

3.2. LOAD AUDIT FOR THE 2 BEDROOM APARTMENT.

In order to know the amount of panel, battery and possible inverter rating, we need to know the available or estimated load requirement of the building.

3.2.1 LIGHTINGS

LOCATION	QTY	WATT PER UNIT	TOTAL POWER RATING(WATT)	HOUR USAGE PER DAY	ENERGY CONSUMED IN KWH
Outside Lighting	4	100	400	10	4000
General Bathroom	1	60	60	1	60
Sitting Room(Wall Brackets & Chandelier)	4 & 1	20 & 360	440		1320
Lobby	1	60	60	2	120
Kitchen	2	60	120	2	240
Bedroom 1(wall Brackets & Ceiling light)	2 & 2	20 & 60	160	2	320
Bedroom 2(wall Brackets & Ceiling	2 & 2	20 & 60	60	2	320

light)					
Master Bathroom 1	1		60	1	60
Master Bathroom 2	1		60	1	60
TOTAL ENERGY CONSUMED					6.5KWH

Table 1.0 Total power consumption for lighting

3.2.2 AIR CONDITIONER

LOCATION	QUANTITY	HORSE POWER(HP) PER UNIT	TOTAL POWER RATING(WATT)	HOUR USAGE PER DAY	ENERGY CONSUMED IN KWH
Sitting Room	1	1.5	1118.55	2	2237.1
Bedroom 1	1	1.5	1118.55	2	2237.1
Bedroom 2	1	1.5	1118.55	2	2237.1
TOTAL ENERGY CONSUMED					6.7113KWH

Table 2.0 Total power consumption for Air conditioner

3.2.3. WATER HEATER

LOCATION	QTY	WATT PER UNIT	TOTAL POWER RATING(WATT)	HOUR USAGE PER DAY	ENERGY CONSUMED IN KWH
General Bedroom	1	2000	2000	1	2000
Master Bathroom 1	1	2000	2000	1	2000
Master Bathroom 2	1	2000	2000	1	2000
TOTAL ENERGY CONSUMED					6KWH

Table 3.0 Total power consumption for water heater

3.2.4. HOT PLATE

LOCATION	QUANTITY	WATT PER UNIT	TOTAL POWER RATING(WATT)	HOUR USAGE PER DAY	ENERGY CONSUMED IN KWH
Kitchen	1	1200	1200	3	3600
TOTAL ENERGY CONSUMED					3.6KWH

Table 4.0 Total power consumption for Hot Plate

3.2.5. TV

LOCATION	QUANTITY	WATT PER UNIT	TOTAL POWER RATING(WATT)	HOUR USAGE PER DAY	ENERGY CONSUMED IN KWH
Sitting Room	1	200	200	8	1600
Master Bedroom 1	1	200	200	1	200
Master Bedroom 2	1	200	200	1	200
TOTAL ENERGY CONSUMED					2KWH

Table 5.0 Total power consumption for TV

TOTAL POWER RATING IN THE 2 BEDROOM APARTMENT = 12675.65W

TOTAL ENERGY CONSUMED IN THE 2 BEDROOM APARTMENT = 24,811.3WH

The total power rating above is the load the house owner would use if he consumes 100% of all his appliances at once. In most cases, this is not an ideal way of using power as it is not feasible for a home owner to use all appliances at once even on grid power supply.

To improve the lifespan of this renewable energy supply, the home owner may need to use his/her loads at interval or at a percentage and that percentage determines the Inverter rating.

If the homeowner decides to power 35% of his total power requirement at a time, i.e.

0.35 × 12675.65 = 4,436.4775W

In inverter design, it is important to give a 25% allowance for the sake of the inverter lifespan, running it at 100% would drastically shorten the lifespan. Therefore, 25% of the total required power = 0.25 × 4436.4775 = 1,109.119W

Total required power = 4436.4775 + 1,109.119 = 5,545.59W

Most inverters have a power factor of 0.8-0.9. Since most of the loads are not resistive loads, it's important to factor in power factor to get the actual power the inverter is supplying.

Recall,

$$APPARENT\ POWER(KVA) = REAL\ POWER(KW) + REACTIVE\ POWER(KVR) \ldots\ldots\ldots\ldots \text{i}$$

$$Power\ Factor(p.f) = \frac{Real\ Power(KW)}{Apparent\ Power(KVA)} \ldots\ldots\ldots\ldots\ldots\ldots \text{ii}$$

If we assume a p.f of 0.85,

$$Apparent\ Power(KVA) = \frac{5545.59}{0.85} \ldots\ldots\ldots\ldots\ldots\ldots \text{iii}$$

$$\text{Apparent}\ Power(KVA) = 6524.23VA \ldots\ldots\ldots\ldots\ldots \text{iv}$$

This is the actual power the inverter is capable of delivering to the load therefore, we need a 6.5KVA at 48V.

3.3. BATTERY CAPACITY

From our calculation thus far, we've seen the maximum power the inverter can actually supply i.e. 6.5KVA. In order for us to constantly supply this amount of power, we need a battery that can store this energy in form of electrical energy and supply to the inverter when needed.

3.3.1 Case Study for Battery: For this case study we are assuming batteries rated 12V**,** 200AH. For the sake of clarity, 200AH simply means that the battery can only supply a maximum of 200A to a device rated 200A for 1-hour if used for 1-hour i.e. if we have a load of 20A we could power that load for as much 10-hours.

$$Power\ Rating\ of\ Batteries = volatge\ of\ battery\ \times current\ of\ battery\ \times number\ of\ batteries ..\text{i}$$

$$Power\ Rating\ of\ Batteries = 12\ \times 200\ \times 4\ \ldots..\ \text{ii}$$

$$Power\ Rating\ of\ Batteries = 9600WH\ \ldots\ldots\text{iii}$$

This simply means that if we have a load that consumes 9600W with this battery, the load can only consume that for as much as 1-hour.

The total load the homeowner consumes for a day is 24.8113KWH. Therefore, we need to determine the amount of current needed to be consumed at the energy rate for that period time at 12V.

Recall,

$$Power = Current \times Voltage$$

$$Current = \frac{24811.3}{48}$$

$$current = 517AH$$

The current above give the total current needed to be able to supply that energy of 24.81KWH. Available batteries in the marketplace are 200AH and 220AH. For this research we would be using 200AH.

Thus,

$$the\ number\ of\ batteries\ needed = \frac{517}{200}$$

$the\ number\ of\ batteries\ needed$ = 2.585 ≈ 4 Batteries.

4 Batteries in series will output 200AH and 48V, but since our system needs about 517AH, we need 2 more sets of 4 batteries in series and then the two finally connected in parallel to give out 48V and 600AH making a total of 12 batteries

It is important to know that the batteries were connected in series and the reason for that would be discussed under result in chapter 4.

3.4 SOLAR PANELS REQUIRED

Once we have our load requirement and the battery to meet that load requirement, it is of importance to calculate the number of panels that can supply that amount of power or meet the load requirement. Ideally, solar panels are rated in watts according to the amounts of electricity they can produce in a single hour of direct sunlight. This simply means that, if we needed 1000Wh of power to our load, we need a 100watt solar panel that has been exposed to sunlight for 10 hours, shown by the calculation below.

$$Required\ panel\ wattage = \frac{Required\ load\ in\ KWh}{amount\ of\ direct\ sunlight\ in\ hours}$$

$$Required\ panel\ wattage = \frac{1000}{10}$$

$Required\ panel\ wattage\ =\ 100watt$ (This simply tells us we need a 100watt panel to deliver 100W in 10 hours).

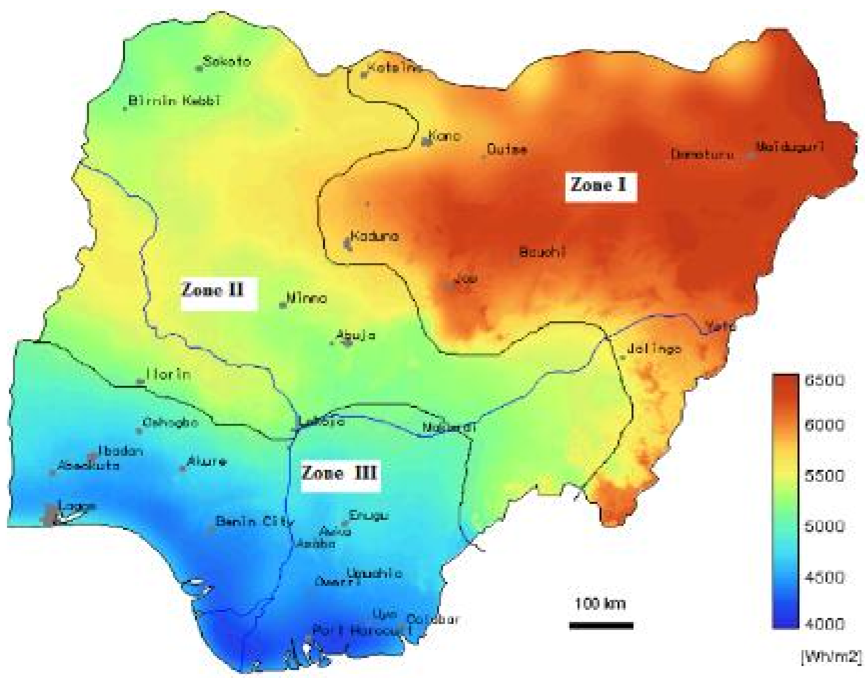


Fig 3.0 Heat Map of different zones in Nigeria

Zones	Annual average of global solar radiation ($kWh/m^2/day$)	Sunshine duration (h/day)	Annual average of solar energy intensity ($kWh/m^2/year$)	States
Zone I	5.7–6.5	6.0	2,186	Borno, Yobe, Jigawa, Kano, Kaduna, Bauchi, Gombe, Adamawa, Plateau and Katsina
Zone II	5.0–5.7	5.5	2,006	Sokoto, Zamfara, Kebbi, Niger, FCT (Abuja), Nassarawa, Taraba, Kwara, some section of Plateau, Benue, and Katsina
Zone III	<5.0	5.0	1,822	Lagos, Oyo, Osun, Ekiti, Kogi, Benue, Rivers, Delta, Imo, Anambra, Abia, Enugu, Edo, Ondo, Bayelsa, Akwa-Ibom, Cross Rivers, Ebonyi

Fig 3.1 Daily Sun readings(In hours) of different zones in Nigeria

From their research (Abam, 2014), Nigeria have an average amount of 5-6 hours daily sunlight daily.

Thus, going by this figure,

$$Required\ panel\ wattage = \frac{Required\ load\ in\ KWh}{amount\ of\ direct\ sunlight\ in\ hours}$$

$$Required\ panel\ wattage\ = \frac{24811.3}{5.5}$$

$Required\ panel\ wattage\ = 4511W$ (Delivers this wattage in 1 hour)

3.4.1 Case study for solar panel: Panels are usually rated from 100W to 800W. On the assumption that 400W panel is used for this design, the number of panels required equates to:

$$Number\ of\ required\ panels = \frac{4511}{400}$$

$$Number\ of\ required\ panels = 11.28 \approx 12\ panels$$

3.4.2 PARAMETERS OF THE 400W PANEL BEING USED

- Power Output, P_{out} = 400W
- Current Maximum Power, I_{mp} = 33A
- Voltage Maximum Power, V_{mp} = 12V
- Short Circuit Current, I_{sc} = 35A
- Open Circuit Voltage, V_{oc} = 21.5V
- Module Dimension = 1960 × 990 × 42mm
- Cell Technology = Monocrystalline
- Maximum System Voltage = 1500VDC

To fully charge the battery, each panel delivers 33A for 1hour at 400W, i.e. for 12 panels,

$$total\ current\ delivered\ to\ the\ battery = 33 \times 3$$

The battery voltage must match the solar panel voltage. Since we have 12 panels at 12V each, connecting 4 in series gives us 48V and 33A. Since there are 3 sets of 48V and 33A, the aim is to maintain 48V and increase the current. Therefore, connecting the 48V in parallel gives us 48V and 99A

$$total\ current\ delivered\ to\ the\ battery = 99Ah$$

Since we need a total of 600Ah,

$$Time\ taken\ to\ full - battery = \frac{600}{99}$$

$$Time\ taken\ to\ full - battery = 6\ Hours$$

This means at full 6 hours of direct sun, the 12 batteries would be fully charged to deliver 24811.3W of power to the load.

It is important to know that the panels were connected in parallel and the reason for that would be discussed under result in chapter 4.

3.5 SIZING OF SOLAR PANEL MPPT CHARGE CONTROLLER

The Maximum Power Point Tracking (MPPT) is a powerful component of the solar design system. They take charge in managing the charging of the battery bank from the solar panels and also ensure to convert higher voltage of the solar array to lower voltage of the battery bank. This done to prevent overcharging of the battery since the panels doesn't know when stop when the battery is fully charged. The MPPT charge controller is usually rated in primary ratings.

- First Rating: This simply tells the voltage battery bank the charge controller is designed to work with.
- Second Rating: This is the voltage input
- Third Rating: This is the output current

To get the rating of our MPPT charge controller,

$$Charge\ Controller\ Current\ \ Rating = \frac{Total\ Power\ from\ Solar\ Panel}{Volatge\ Supplied}$$

$$Charge\ Controller\ \ Current\ Rating = \frac{12V\ \times 400W}{48V}$$

$$Charge\ Controller\ \ Current\ Rating = \ 100A$$

For safety and efficiency, charge controllers need to be able to handle full load demand of the battery bank. If the charge controller isn't rated for full capacity of the battery bank, it could overheat or fail when batteries are being charged. So, it's always best to choose a charge controller of higher rating and amperage than the required. Based on our calculated value of charge controller, the next best rating of the charge controller is the 120A charge controller.

3.6. SOLAR PANEL CIRCUIT BREAKER

The solar panel array has a short circuit of I_{sc} of 35A. The number of available panels is 12.

$$Panel\ Circuit\ Breaker\ Rating = 145\%\ \times Solar\ Panel\ in\ parallel \times\ I_{sc}$$

$$Panel\ Circuit\ Breaker\ Rating = 1.45\ \times\ 3 \times 35 =\ 152.25A$$

Common values of circuit breakers: 5A, 10A, 15A, 20A, 30A, 45A, 60A, 100A, 125A, 150A, 200A, 220A, 300A, 400A.

From the list above, the next possible circuit breaker to use is the 200A circuit breaker.

3.7 SOLAR PANEL CABLE SIZING

Cable Cross-sectional Area	2 cables single phase AC or DC		3 or 4 Cables, three phase AC	
	Current Carrying Capacity	Volt-drop per ampere per meter	Current carrying capacity	Volt-drop per ampere per meter
mm^2	A	mV	A	mV
1.0	14	42		
1.5	17	28	14	24
2.5	24	17	21	15
4	32	11	29	9.2
6	45	7.1	37	6.2
10	55	4.2	1	3.7
16	74	2.7	6	2.7
25	97	1.7	7	1.5
35	119	1.3	6	1.1
50	145	0.97 AC	25	0.84

		0.91 DC		
70	185	0.71 AC 0.63 DC	60	0.62
95	230	0.56 AC 0.45 DC	95	0.48
120	260	0.48 AC 0.36 DC	20	0.42

Table 6.0 Ratings of different cables

The maximum current that can flow through any conductor is the short-circuit current. At short circuit, we have seen that the DC current that can flow through a conductor is 152.2A. From the table above, the conductor that can carry such amount of current is the 70mm^2 cable.

From the table it can be seen that for every 1 meter there's a corresponding 0.63×10^{-3}V drop. If we assume a 20m distance from the roof top to the point of connection;

$$Total\ Voltage\ Drop = Voltage\ Drop\ per\ meter\ \times total\ distance\ of\ cable\ \times current\ carrying\ capacity$$

$$Total\ Voltage\ Drop = 0.63\ \times 10^{-3} \times 15\ \times\ 185$$

$$Total\ Voltage\ Drop = 1.748V$$

3.8 BATTERY CABLE RATING

Inverter rating = 6.5KVA/48V

Battery's Voltage = 48V

$$\text{Current from battery} = \frac{Inveretr\ Battery\ wattage}{Voltage\ of\ battery}$$

$$\text{Current from battery} = \frac{6524.23}{48} = 136A$$

From the table above, a 50mm^2 cable can be used.

CHAPTER 4

RESULTS & ANALYSIS

In this chapter we'd consider the results before installation of the panels and after installation of the panels.

4.0 PANEL TYPE

There are two types of panels available for use in designs - Monocrystalline and Polycrystalline. The type of panel used is dependent on factors such as cost, effectiveness and space.

Pros of a Monocrystalline:

- Highly efficient at producing energy
- Panels requires less space
- Better heat tolerance

Cons of a Monocrystalline:

- Expensive
- Less sustainable production methods

Pros of a Polycrystalline:

- Less expensive than monocrystalline panels
- Lifespan comparable to that of monocrystalline panels yet at a lower cost

Cons of a Polycrystalline:

- Panels require more space
- Less efficient at producing energy
- Less sustainable production
- Less heat tolerance

For this research, after observation of the site, it was decided a monocrystalline panel is used. This is because given the amount of space available and the budget of the home owner, using a monocrystalline would be more efficient base on its pros and hence it's important we work with what will give the best result.

The results of using a monocrystalline go thus below.

4.1 RESULTS

Open circuit Results	**Short Circuit Results**
The open circuit result is dependent on the intensity level of the UV rays from the sun. At full intensity or midday we got 21.7V at 55^{o}C	It was also observed that on a full day supply of sun roughly about 7 hours, the short circuit current was about 34.5A at 55^{o}C at mid-day.

for a single panel and at early hours of the morning, we got 15V. Ordinarily, the output from the solar panels can only be controlled by the amount of sunlight we receive. If the amount of sunlight for the whole day averages 6 hours, that's a good enough time to charge up our battery i.e. the value of voltage increases as the temperature increases.	

4.1.3 Installation of Panels.

After observing that panels matched the rated parameters, it was necessary to look for the best location to mount our panels as the better tilted the panels are the better the intensity and the better the voltage supply to our battery.

Steps involved in installing the panel.

- The roof and the environment surrounding are first of devoid of all trees, obstructions that will act as a shade. That is why it is important to have a good location or positioning for the panels.
- The solar racks which act as a support for the solar panels are mounted on the roof.

- The panels are then tilted to get maximum sunlight from the sun. The wrong positioning could mean poor utilization of the sunlight. Thereafter they are positioned properly and screwed to the racks
- There are about 12 panels – 4 are connected in series thereby forming 3 set of 4 connected panels in series with each set reading 48V and then they are connected in parallel to increase the current output.
- Once the panels are mounted, we use the required cable to connect the panels and an MPPT charge controller.

On-Load Results	Upon mounting the panels and connecting our charge controller, it was observed that on a full day supply of sun roughly about 7 hours, it took the battery roughly 4 hours to get fully charged leaving us with an extra 3 hours. The Voltage supply to the battery from the charge controller was 19.5V and the current was 32.83A.

4.2 TOOLS USED DURING INSTALLATION

- Digital Multimeter: For measuring the voltage readings, current readings and other forms reading such as ohmmeter readings.

- Screwdrivers: Used for screwing screws to a fitting.

- Pliers: For separating insulation from wires, joining wires and cutting wires.

- Spanners: For fitting in bolts and nuts.

4.3 MATERIALS USED DURING INSTALLATION

Since the materials used is highly dependent on the requirement of the home owner, the following where used:

- 400W Solar panels
- 120A Felicity Charge Controller
- Battery Racks
- 200AH, 12V Battery
- Connecting cables
- 6.5KVA Inverter

4.4 PRECAUTIONS TAKEN DURING INSTALLATION

1. Insulated gloves was ensured to be worn while working with the solar module

2. The arrays before installation was checked for damage to avoid incorrect readings

3. All connections were ensured to be tight.

4. All test were carried out in the array before installation. Test such as open circuit test, short circuit test.

5. All solar precautions when installing panels were ensured to be followed.

BILL OF ENGINEERING MATERIALS & EVALUATION

S/N	ITEM	QTY	UNIT RATE	TOTAL AMOUNT
1	Digital Multimeter	1	1,000	1,000
2	Screws	80	50	4000
3	Control Switch	1	8,000	8,000
4	Tape	2	150	300
5	12V/200AH	12	190,000	2,280,000
6	6.5KVA	1	1,174,000	1,174,000
7	400W Monocrystalline Solar Panels	12	75,000	900,000
8	Charge Controller	1	200,000	200,000
9	Connecting Wires	35Yards	1,000	35,000
10	Trunking Pipes	4	750	3,000
11	Charge over	1	6,000	6,000
12	Connectors	4	1,200	4,800
13	35mm2	1 Coil	9000	9,000

14	16mm2	1 Coil	9000	9,000
15	10mm2	1 Coil	9000	9,000
16	Miscellaneous			40,000
TOTAL				4,647,100

Table 7.0 Bill of Engineering Materials & Evaluation

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.0 CONCLUSION

In conclusion, the research on solar panel design for a two-bedroom apartment has provided valuable insights into the feasibility and benefits of utilizing solar energy as an alternative power source in residential settings. Through rigorous analysis and experimentation, it has been demonstrated that solar panels can effectively meet the electricity demands of a typical two-bedroom apartment, thereby reducing dependency on traditional grid-based electricity and mitigating environmental impact.

The study highlighted the importance of various factors such as panel placement, orientation, and quality in maximizing energy generation efficiency. By optimizing these parameters, homeowners can harness the full potential of solar energy and reap the associated economic and environmental benefits.

Furthermore, the research emphasized the need for ongoing maintenance and monitoring of solar panel systems to ensure optimal performance over their lifespan. Regular upkeep, including cleaning and repairs, is essential to mitigate any efficiency losses and prolong the system's longevity.

Overall, the findings of this research support the adoption of solar panel systems in residential properties, offering a sustainable solution to energy needs while reducing carbon emissions and promoting environmental stewardship. It is hoped that the recommendations provided will guide homeowners, property developers, and policymakers in embracing solar energy technology to create a more sustainable and eco-friendly future.

5.1 RECOMMENDATION:

Based on the findings of the research on solar panel design for a two-bedroom apartment, it is recommended that the implementation of solar panels be seriously considered for residential applications. The data gathered demonstrates the significant potential for harnessing solar energy to meet the electricity demands of a typical two-bedroom apartment, thereby reducing reliance on non-renewable energy sources and contributing to sustainability efforts.

Furthermore, the study highlights the importance of proper panel placement and orientation to maximize solar energy absorption. To ensure optimal efficiency, it is advised to install the solar panels on a roof with unobstructed access to sunlight throughout the day. Additionally, incorporating technologies such as solar trackers and tilt mechanisms can further enhance energy generation by adjusting panel angles to follow the sun's path.

Moreover, it is crucial to invest in high-quality solar panels and accompanying components to ensure durability and long-term performance. While the initial costs may seem daunting, the long-term benefits, including reduced electricity bills and environmental impact, outweigh the upfront investment.

Lastly, ongoing monitoring and maintenance of the solar panel system are essential to ensure optimal performance over its lifespan. Regular inspections, cleaning, and prompt repairs can help mitigate any issues and maximize energy generation efficiency.

In conclusion, the research findings underscore the viability and benefits of incorporating solar panel systems in residential settings, particularly for two-bedroom apartments. By embracing solar energy technology, individuals can not only reduce their carbon footprint but also enjoy significant cost savings in the long run. It is recommended that homeowners and property developers explore the possibility of integrating solar panels into their properties to contribute to a sustainable future.

REFERENCES

Abam, F. N. (2014). Energy resource structure and on-going sustainable development policy in Nigeria. *International Journal of Energy and Environmental Engineering*, 6.

Agency, I. E. (2014). *International Energy Statistics.* International Energy Agency.

Alazraki R, H. J. (2007). Assessing the up take of small-scale photovoltaic electricity production in Argentina. *Clean Production*, 15(2):131–42.

Al-Hasan A, G. A. (2004). Optimizing electrical load pattern in Kuwait using grid connected photovoltaic systems. *Energy Conversion and Management*, 45(4):483–94.

B.J. Huang, F. S. (2006). Near-maximum-power-point-operation (nMPPO) design of photovoltaic power generation system. *Solar Energy*, 1003-1020.

Barton JP, I. D. (2006). A probabilistic method for calculating the usefulness of a store with finite energy capacity for smoothing electricity generation from wind and solarpower. *JPower Sources*, 162(2): 943-8.

C. Choudhury, H. G. (1991). Evaluation of a jet plate solar air heater. *Solar Energy*, 199-209.

D.B. Nelson, M. N. (2006). Unit sizing and cost analysis of stand-alone hybrid wind/PV/fuel cell power generation systems. *Renewable Energy*, 31(10): 1641-1656.

D.L. Zhao, Y. L. (2011). Optimal study of a solar air heating system with pebble bed energy storage. *Energy Conversion and Management*, 2392-2400.

Deshmukh M, D. S. (2008). Modeling of hybrid renewable energy systems. *Renew Sustain Energy Rev*, 12(1):235–49.

Dilip Jain, R. K. (2004). Performance evaluation of an inclined multi-pass solar air heater with in-built thermal storage on deep-bed drying application. *Journal of Food Engineering*, 479-509.

E.Cunow, B. G. (2001). The megawatt solar roof at the new Munich Trade Fair Centre – an advanced and successful new concept for PV plants in the megawatt range. *Solar Energy Materials and Solar Cells*, 67(1):459–67.

El-Tamaly, H. H. (2006). Impact of interconnection photovoltaic/wind system with utility on their reliability using a fuzzy scheme. *Renewable Energy*, 2475-2491.

Eman-Bellah S. Mettawee, G. M. (2006). Experimental study of a compact PCM solar collector. *Energy*, 2958-2968.

Herzog, A. V. (2001). Renewable energy sources. Encyclopedia of life support systems (EOLSS). *Forerunner Volume-Perspectives and overview of life support systems and sustainable development*, 76.

Katti PK, K. M. (2007). Alternative energy facilities based on site matching and generation unit sizing for remote area powersupply. *Renew Energy*, 32(8):1346–62.

Marwan M Mahmoud, I. H. (2003). Field experience on solar electric power systems and their potential in Palestine. *Renewable and Sustainable Energy Reviews*, 531-543.

Panwar N, K. S. (2011). Role of renewable energy sources in environmental protection. *Renew Sustain Energy Rev*, 15(3):1513–24.

Rehman S, B. M.-M. (2007). Cost of solar energy generated using PV panels. *Renew Sustain Energy Rev*, 11(8):1843–57.

S.M. Shaahid, M. E. (2008). Economic analysis of hybrid photovoltaic–diesel–battery power systems for residential loads in hot regions—A step to clean future. *Renewable and Sustainable Energy Reviews*, 12(2): 488-503.

Schlamadinger B, e. a. (1997). Towards a standard methodology for greenhouse gas balances of bioenergy systems in comparison with fossil energy systems. *Biomass Bioenergy*, 13(6):359–75.

So, J. H. (2006). Performance results and analysis of large scale PV system. *IEEE 4th World Conference on Photovoltaic Energy Conference* (pp. 2375-2378). IEEE.

Sopian, K. B. (2009). Output air temperature prediction in a solar air heater integrated with phase change material. *European Journal of Scientific Research*, 334-341.

T. Muneer, M. J. (2003). Generation and transmission prospects for solar electricity: UK and global markets. *Energy Conversion and Management*, 44(1):35–52.

Tanrioven, M. (2005). Reliability and cost–benefits of adding alternate power sources to an independent micro-grid community. *Journal of power sources*, 136-149.

Thanaa F. El-Shatter, M. N.-H. (2006). Energy flow and management of a hybrid wind/PV/fuel cell generation system. *Energy Conversion and Management*, 47(9-10):1264-1280.

Zhou X, e. a. (2009). Economic analysis of power generation from floating solar chimney powerplant. *Renewable and sustainable energy reviews*, 13(4):736–49.