IMPROVEMENT OF PHOTON QUANTA USING A SOLAR TRACKING DEVICE

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Cover page

DEPARTMENT OF MATERIALS AND METALLURGICAL ENGINEERING,

UNIVERSITY OF BENIN.
BENIN CITY.

FEBRUARY, 2025

IMPROVEMENT OF PHOTON QUANTA USING A SOLAR TRACKING DEVICE

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A PROJECT SUBMITTED TO THE
DEPARTMENT OF MATERIALS AND METALLURGICAL ENGINEERING IN
FULFILMENT OF REQUIREMENT FOR BACHELOR OF ENGINEERING
UNIVERSITY OF BENIN,
BENIN CITY, EDO STATE.

Title page

FEBRUARY, 2025

CERTIFICATION

This is to certify that this work was carried out by **OGBOKO DAVID** and **UZEBU UHUNOGHARIEGIE** of the Department of Materials and Metallurgical Engineering, University of Benin, Benin City, in partial fulfillment of the requirements for Bachelor in Engineering Degree.

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DEDICATION

This project work is dedicated to God Almighty for his love, grace, wisdom and knowledge he bestowed upon us throughout our stay in University of Benin.

ACKNOWLEDGEMENTS

We give thanks to God almighty for his grace upon our life and for seeing us through this project work. Our profound gratitude goes to our supervisor Engr. J. Jesumirhewe for his concern, constructive and supportive idea which has aided this project work. Special thanks to the Head of Department, Materials and Metallurgical Engineering, Dr. Mrs. U. G. Unueroh also to the entire staff of the department for investing so much in our academic development.

We appreciate our Project Coordinator, Engr. (Dr.) W. A. Irogue and for his massive assistance in the course of this project.

We are extremely thankful to our parents, for their support and prayers and other family members for their sincere cooperation, motivation and providing a friendly atmosphere during the course of this work.

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ABSTRACT

This project addresses the challenge of optimizing solar energy capture through the design and implementation of a single-axis solar tracking device. Traditional fixed solar panels are limited by their stationary nature, resulting in suboptimal energy harvesting as the sun moves across the sky. The research aims to develop a cost-effective, efficient solar tracking system that continuously adjusts panel orientation to follow the sun's path.

The methodology involved evaluating multiple design concepts, including passive liquid-based trackers, Raspberry Pi-controlled systems, and an Arduino Nano-based solution with Light Dependent Resistors (LDRs). The final design utilized Arduino Nano microcontroller, servo motors, and LDRs to detect sunlight intensity and adjust panel orientation accordingly.

Testing revealed that the tracking system outperformed stationary panels in energy output during an 8-hour evaluation period. The tracked panel maintained consistently higher voltage readings throughout the day. Challenges encountered included ambient light interference with sensors and software-related overtilting issues, which were addressed through design modifications.

The study concludes that single-axis solar tracking represents a viable approach to enhancing solar energy efficiency, with recommended future improvements including more robust components, advanced tracking algorithms, dual-axis capabilities, and power supply optimization for increased durability and performance.

CHAPTER ONE

INTRODUCTION

1. 1 Background of the Study

The global need of clean and renewable energy has rapidly grown on account of the environmental pollution and to secure alternatives of fossil fuels. Solar energy has become one of the most realistic means to address these challenges, given its inexhaustible, renewable and eco friendly nature. Though very efficient, conventional solar panel systems are usually rigid, hence restricting the amount of light they can harness during the day, thereby decreasing total system efficiency (EIA, 2021).

Solar tracking systems have been designed to circumvent this constraint. Solar tracking systems enable solar panels to track the sun's movement throughout the sky, hence keeping the panels in maximum irradiation positions to absorb sunlight during the day (from dawn to sunset).This is as a result of the reality that a solar panel operates with solar radiation and not with the thermal radiation—and there is a widespread misunderstanding as regards this. Studies show that solar tracking systems can increase energy capture by 20% to 30% compared to fixed systems, making them a critical innovation in the field of solar energy (Mukund and Patel, 2005).

There are two main types of solar tracking devices: single-axis and dual-axis trackers. Single-axis trackers track the sun east to west throughout the day, whereas dual-axis trackers track the sun in both directions vertically and horizontally to follow the sun's path more accurately. While dual-axis trackers are more efficient, they are more complex and harder to manufacture and manage than single-axis systems (Solanki, 2015).

Research into solar tracking technology focuses on improving efficiency, reducing costs, and developing more reliable and durable systems. Innovations in material, sensor and control algorithm technologies have resulted in modern solar trackers being more efficient at the capture of solar radiation, particularly in high solar radiation areas (Liu and Wang, 2017).

Fulfilling the potential of solar tracking devices on a large scale would vastly increase solar energy production worldwide. By increasing the energy output of photovoltaic systems, solar tracking technology contributes to reducing the overall cost of solar energy, making it more competitive with conventional energy sources like coal and natural gas, therefore, this work seeks to design and fabricate a single-axis solar tracker.

1. 2 Statement of the problem

Solar energy has become increasingly popular as a clean replacement for traditional energy sources because of its environmental advantages and its source of renewable energy. Yet fixed arrays of solar panels generally under-perform because they cannot follow the sun as it moves

across the sky throughout the day causing great energy loss during low light hours of the day (EIA, 2021).

Although photovoltaic (PV) panels are highly efficient, the stationary character of panels impedes on their capability to capture maximum light under changing angles, in particular, in areas where sun hours and light intensity vary. Solar tracking devices have been introduced to mitigate this issue by enabling panels to continuously adjust their orientation to face the sun directly, maximizing energy absorption throughout the day. Still, there remain challenges in enhancing the performance and stability of such tracking systems. (Solanki, 2015).

Thus the challenge is to design a solar tracking device at an affordable, efficient, and long life-time cost, while maximizing the energy capture. Unless such developments occur, solar energy systems could still fall short of providing the maximum of renewable energy needed to supply the increasing global energy demand (Mukund and Patel, 2005).

1.3 Aim and objectives of the project

1.3.1 Aim of the project

The aim of this project is to design and construct an efficient solar tracking device that optimizes the capture of solar energy by continuously adjusting the orientation of solar panels to track the sun's movement.

1.3.2 Objectives of the project

The following are objectives of this project:

1. Design a solar-tracking system based on single-axis tracking devices.

2. Assess and choose sensors and control systems to accurately and effectively track the sun's position from morning through afternoon.

3. Fabrication of a prototype of solar tracking device and testing its performance.

1. 4 Scope of the Project

The scope of this project encompasses the design, development, and testing of a solar tracking device aimed at improving the energy efficiency of photovoltaic systems. It covers the following:

1 Design and Development.

2. Component Selection and Integration

3. Cost-Benefit Analysis

4. Prototype Development and Testing

5. Evaluation of Durability and Environmental Impact Implementation Feasibility

1. 5 Significance of the project

The work is notable for its ability to tackle several of the most important properties of solar energy systems. Firstly, it boosts the efficiency of energy capture by allowing solar cells to follow the sun's movement from morning to afternoon, which could increase the yield compared with a fixed solar cell by 20% to 30% (Solanki, 2015). This efficiency boost translates directly into reduced energy costs, as more electricity is generated without the need for additional panels, making solar energy more competitive with traditional energy sources (Mukund and Patel, 2005).

CHAPTER TWO

LITERATURE REVIEW

Photovoltaic (PV) systems, ranging from small, basic devices like pocket calculators to complex, high-powered systems such as those used in space stations, operate based on a process known as the photovoltaic effect. This phenomenon involves converting solar energy into direct current (DC) electricity in specific semiconductor materials. To fully grasp this process, one must understand several key concepts from physics, including photons and solar radiation, the structure of semiconductors, and the conversion mechanisms between solar radiation, chemical energy, and electrical energy (Green, 1982).

This project focuses on the development of a solar tracking module, where the detailed explanation of the photovoltaic effect is not the primary focus. Instead, this section will delve into the practical engineering aspects of PV systems, such as their structure, key subsystems and components, mechanical designs, and other factors that affect system performance and efficiency. In particular, the structure and operation of solar tracking systems will be discussed, alongside some basic physics principles relevant to their functionality (Luque and Hegedus, 2011).

2.1 Photovoltaic Principles

2.1.1 The Photovoltaic Effect

The photovoltaic effect is the fundamental physical process through which solar energy is directly converted into electrical energy, forming the basis for the operation of photovoltaic (PV) cells. Discovered by French physicist Alexandre Edmond Becquerel in 1839, the photovoltaic effect involves the creation of electric current in a material when it is exposed to light, typically sunlight. This effect is crucial for solar energy applications, as it enables the direct transformation of solar radiation into usable electricity (Becquerel, 1839).

In photovoltaic materials, typically semiconductors like silicon, the absorption of photons—particles of light—excites electrons from a lower energy state (in the valence band) to a higher energy state (in the conduction band). The energy difference between these two states is referred to as the "band gap." When the energy of the incoming photon matches or exceeds the band gap energy, electrons gain enough energy to break free from their atomic bonds and move into the conduction band, leaving behind a positively charged "hole" in the valence band. The movement of these free electrons and holes generates an electric current, which can be captured and used as electrical power (Nelson, 2003).

For this process to occur efficiently, the PV cell is typically constructed with two layers of semiconductors—one doped with a material that has excess electrons (n-type) and the other with a deficiency of electrons (p-type). When sunlight strikes the cell, it creates electron-hole pairs. The internal electric field created by the p-n junction drives the electrons towards the n-type side and the holes towards the p-type side, generating a flow of current that can be harnessed as direct current (DC) electricity (Green, 1982).

Different materials can be used for PV cells, and the choice of semiconductor material affects the efficiency of the photovoltaic effect. Silicon, for instance, is widely used due to its relatively optimal band gap for solar energy conversion, abundance, and technological maturity. Other materials like gallium arsenide (GaAs) and cadmium telluride (CdTe) are also used in specialized PV applications for higher efficiency or lower-cost production (Sze and Ng, 2006).

Despite advances in materials and designs, the efficiency of PV systems is limited by factors such as recombination (where excited electrons lose energy and fall back into the valence band), thermalization losses (where excess energy from photons is dissipated as heat), and reflection losses. However, ongoing research in material science and cell architecture continues to improve the performance and cost-effectiveness of PV technologies (Luque and Hegedus, 2011).

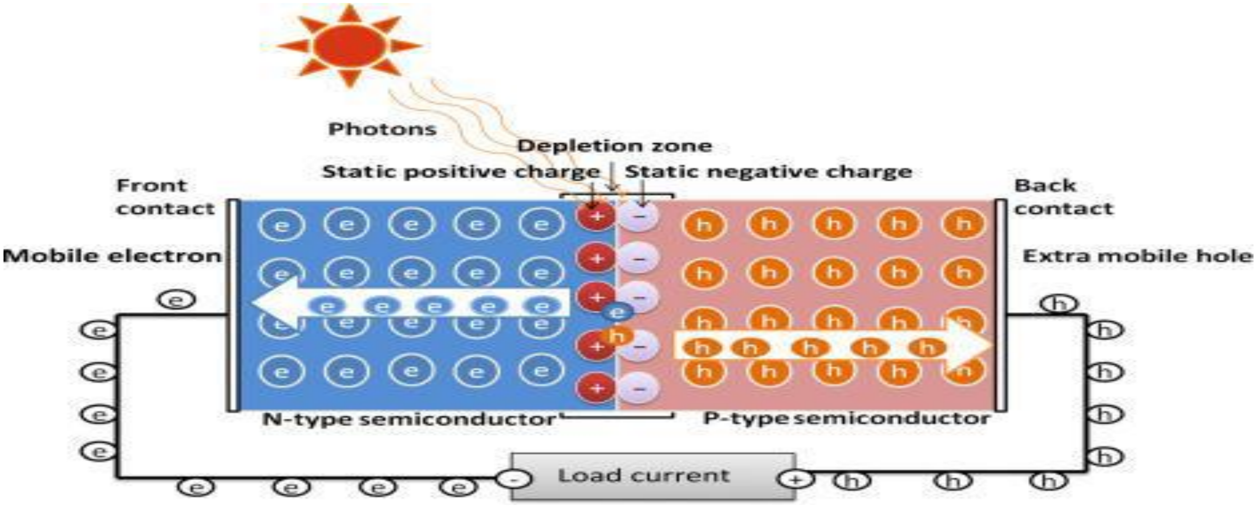
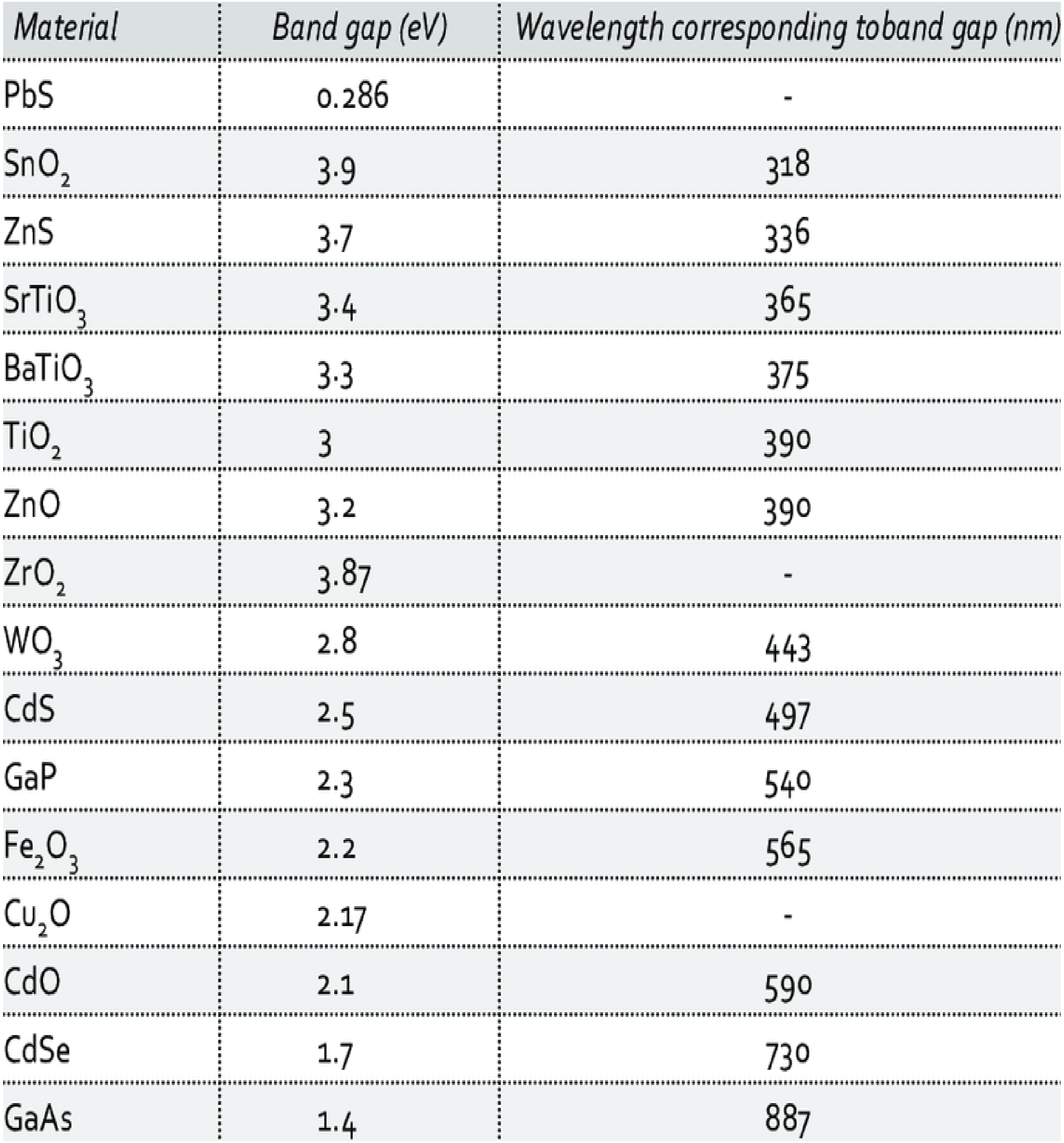


Figure 2.1: Schematic representation of a simple photovoltaic cell**.**

2.1.2 Photovoltaic Materials and Solar Cells:

Popular photovoltaic (PV) materials, such as Silicon (Si), Indium Phosphide (InP), Gallium Arsenide (GaAs), Cadmium Telluride (CdTe), and Cadmium Selenide (CdSe), are commonly used in solar cells due to their ability to effectively capture the solar radiation spectrum. These materials have band gaps that correspond to the wavelengths of light within the solar spectrum, making them ideal for converting sunlight into electricity. Solar cells, which are the fundamental components of photovoltaic systems, rely on these materials for efficient performance. By integrating different materials into multi-junction solar cells, a broader range of the solar spectrum can be absorbed, enhancing the overall efficiency of the cell (Green et al., 2020).

Table 2.1: List of selected semiconductor materials with specified band gap energy and corresponding light's wave-length values.



Material	Band gap (eV)	Wavelength corresponding toband gap (nm)
PbS	0.286	-
SnO_2	3.9	318
ZnS	3.7	336
$SrTiO_3$	3.4	365
$BaTiO_3$	3.3	375
TiO_2	3	390
ZnO	3.2	390
ZrO_2	3.87	-
WO_3	2.8	443
CdS	2.5	497
GaP	2.3	540
Fe_2O_3	2.2	565
Cu_2O	2.17	-
CdO	2.1	590
CdSe	1.7	730
GaAs	1.4	887

Among the materials mentioned in figure 2.2, Silicon (Si) is by far the most widely used material in the production of solar cells, primarily due to its well-established manufacturing processes, abundance, and favorable electronic properties. With a band gap of 1.1 eV, Silicon efficiently absorbs sunlight in the visible to near-infrared region of the electromagnetic spectrum, making it highly effective for converting solar energy into electricity. Silicon-based solar cells are typically divided into three types: monocrystalline, polycrystalline, and amorphous silicon cells, each with varying levels of efficiency and cost-effectiveness. Monocrystalline silicon, known for its high purity and efficiency, remains the dominant choice for commercial applications. Silicon's relatively low cost, long lifespan, and ability to perform well in diverse environmental conditions further enhance its appeal in the solar industry. Despite some limitations, such as lower absorption in the UV spectrum and the energy-intensive manufacturing process, Silicon remains the cornerstone of the global photovoltaic market (Green et al., 2020).

2.2 Solar Photovoltaic System Structure

The photovoltaic (PV) generator is the core component of any PV system, but it must be integrated with several other parts to ensure reliable and efficient performance. A complete PV system consists of multiple components and subsystems, each carefully designed and interconnected to achieve optimal power production.

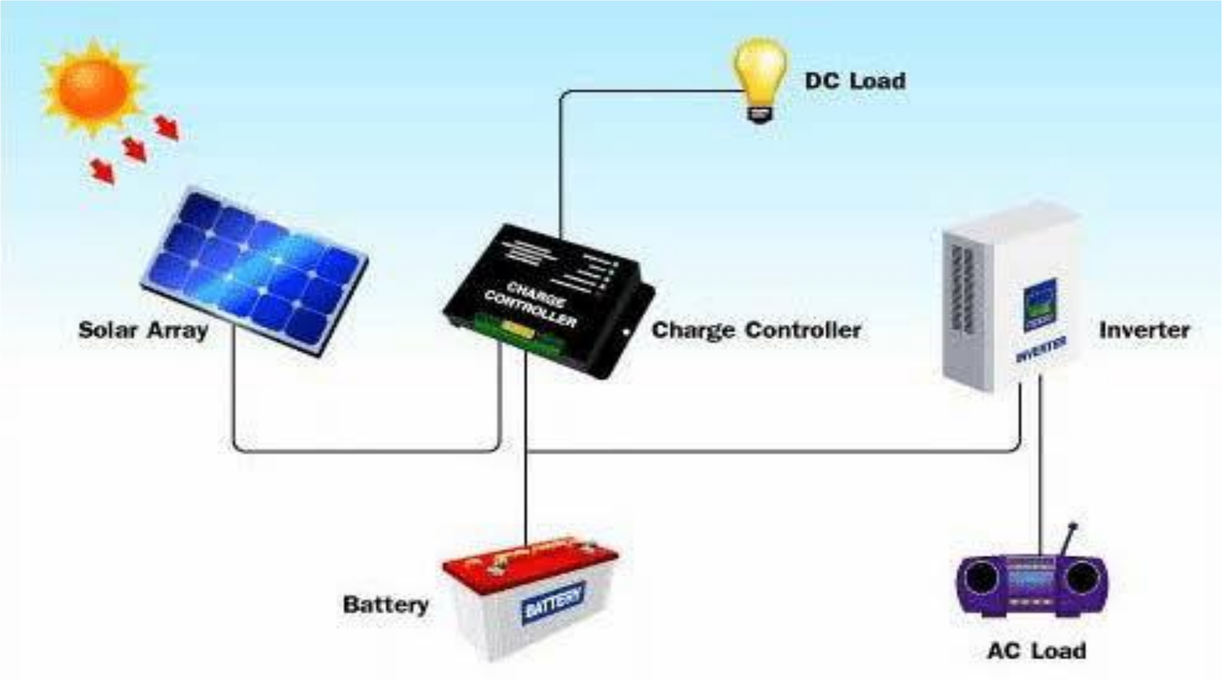


Figure 2.2 Typical components/subsystems of a solar PV system.

As illustrated in Figure 2.2, the PV generator is the heart of the system, made by connecting multiple photovoltaic modules into solar panels. These panels can be further combined to form a solar array for higher power output. The generator is supported by mechanical modules, which may either keep the panels fixed in place or use a tracking mechanism to rotate and follow the sun (Barker et al., 2019).

The PV generator converts sunlight into direct current (DC) electricity, which can be utilized in various applications. In smaller PV systems, this DC output is either consumed directly by a load or stored in batteries for later use. For larger-scale systems, such as those in industrial or residential grid-connected settings, inverters are used to convert the DC power into alternating current (AC), enabling its use for more substantial energy demands (Liu et al., 2020).

Ensuring the reliable operation of the PV generator requires protecting the individual cells in shaded conditions. Since the cells are connected in series, a shaded cell can act as a load due to forward bias, causing the current from other cells to heat up the shaded one, potentially leading to its failure. To prevent this, bypass diodes are employed to provide an alternative current path for the affected cell. Additionally, when PV systems are used to charge batteries, a blocking diode is often incorporated to prevent the PV cells from discharging the battery when they are inactive, such as in shaded conditions (Barker et al., 2019; Liu et al., 2020).

Given that solar energy varies throughout the day and seasons, energy storage is often necessary. Chemical batteries are commonly used to store this energy. To ensure efficient charging and protect the batteries, a charge regulator is implemented. The performance and functionality of the entire system, including solar panel protection, charge regulation, and light-tracking modules, are managed by a control unit. This ensures that the system operates effectively (Barker et al., 2019).

All components within a PV system are supported and connected by mechanical systems designed to meet the specific needs of the application and environmental conditions. Special mechanical systems, such as tracking mechanisms, can significantly enhance system efficiency by improving how well the PV generator captures sunlight. The following section will explore in greater detail the importance of mechanical modules in optimizing solar panel performance (Liu et al., 2020).

2.3 Solar Module’s Performance and Solar Tracking System

2.3.1 Solar Panel’s Performance by Fixed Mounting

For photovoltaic (PV) modules located at the Earth's surface, incoming solar radiation is comprised of three main components:

Direct beam radiation: Travels directly from the Sun to the Earth’s surface without scattering.

Diffuse radiation: Scatters while passing through the Earth's atmosphere.

Albedo radiation: Reflects off the Earth's surface.

Under ideal conditions, with a clear sky, the direct beam accounts for about 80% to 90% of the solar energy, making it the primary energy source for PV systems. For optimal energy collection, it is essential that solar panels remain aligned with the Sun’s direct beams as much as possible. This is measured by the incident angle (i) between the direct beams and the panel's surface (Barker et al., 2019).

The power (P) collected by a solar panel is proportional to the cosine of this incident angle. The relationship is expressed in the following formula:

$$P = P_{max} * \cos(i)$$

Where Pmax is the maximum power collected when the panel is perfectly aligned. The loss of power (a) due to misalignment can be calculated using the formula:

$$a = 1 - \cos(i)$$

This equation shows that as the incident angle increases, more sunlight is lost, reducing the power collected by the solar panel. The impact of misalignment is further illustrated in Figure 2.3

Maintaining the correct orientation is key to minimizing energy losses and maximizing the efficiency of fixed solar panels.

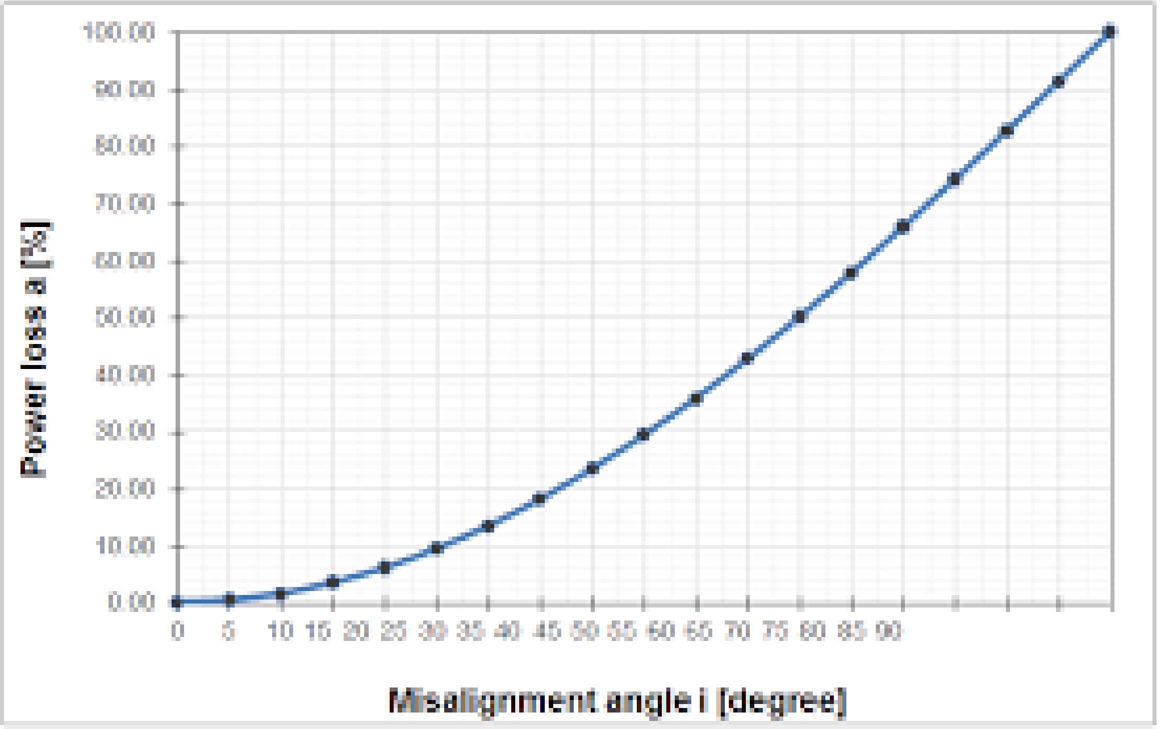
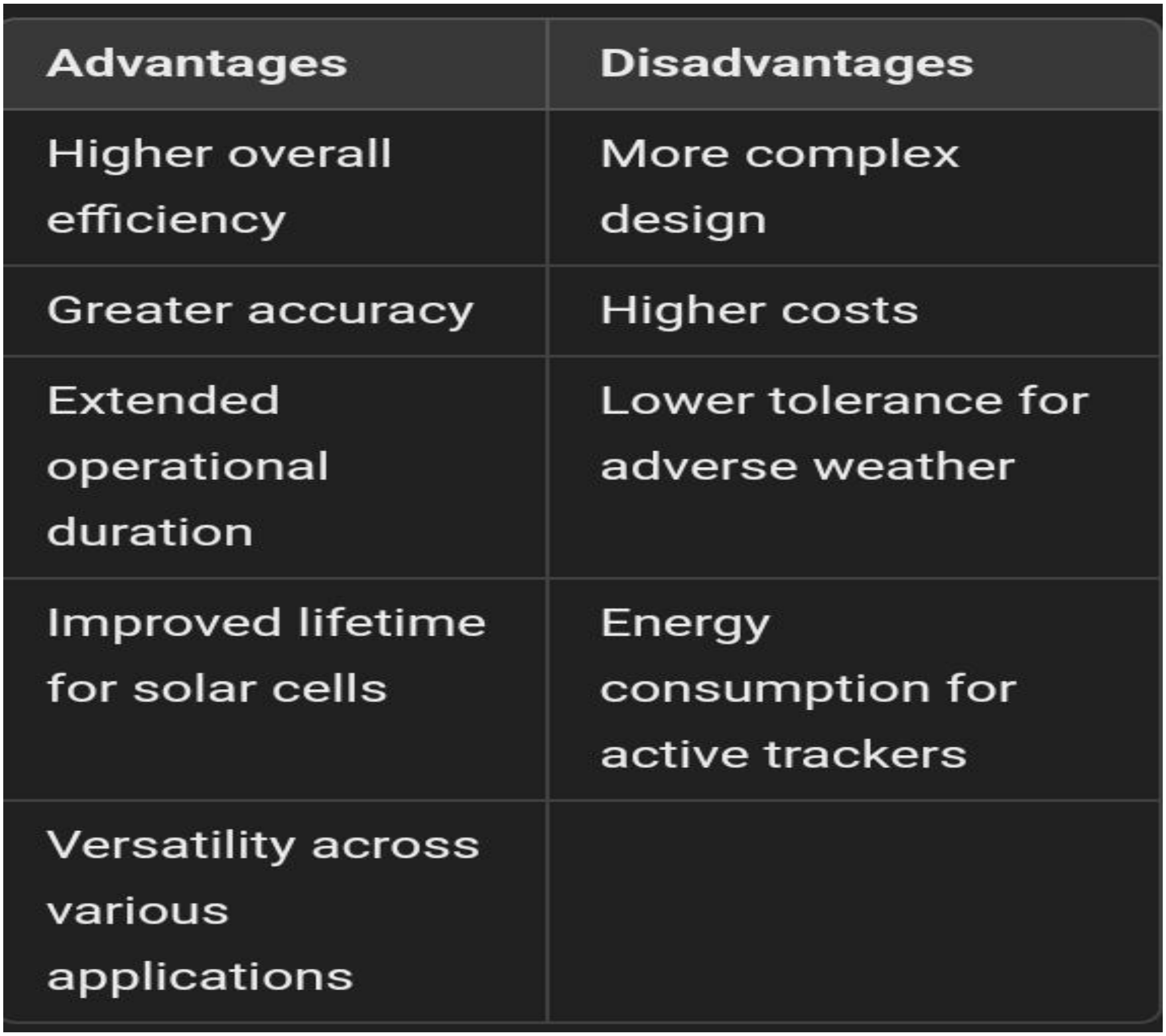


Figure 2.3 Power loss dependency on panel misalignment

2.3.2 Enhancement by Using Tracking Systems

As previously discussed, fixed mounting systems have several limitations in terms of optimizing the performance of a solar PV system. Solar trackers address the core issue by reducing the misalignment between the Sun's direct beams and the solar panels. Through various mechanical mechanisms, solar trackers can continuously adjust the orientation of the panels to ensure optimal alignment during operation. A comparison of solar trackers with fixed mounts is outlined in the Table 2.1.

Table 2.2 : Comparison of Solar Trackers and Fixed Panel



Advantages	Disadvantages
Higher overall efficiency	More complex design
Greater accuracy	Higher costs
Extended operational duration	Lower tolerance for adverse weather
Improved lifetime for solar cells	Energy consumption for active trackers
Versatility across various applications	

Solar trackers use either passive or active methods to adjust the angle of solar panels'passive trackers' function through thermal expansion. They rely on a two-phase fluid contained in canisters positioned on either side of the tracker, which expands and shifts weight as the Sun heats the fluid, causing the panels to pivot toward the sunlight. However, passive trackers are less commonly used due to their complex design and lower accuracy (Chen et al., 2018).

‘Active trackers’ on the other hand, use motorized systems to control the movement of solar panels, often operating in single- or dual-axis configurations. These trackers track the Sun’s position using sensors and are typically controlled by a computer system. Although active trackers involve higher upfront costs, they offer the greatest accuracy and efficiency. In fact, ‘dual-axis trackers’ (DAT) can increase energy collection by up to 40% annually compared to fixed systems (Johnson et al., 2020).

CHAPTER THREE

METHODOLOGY

3.1 Design Concepts

To create a reliable and cost-effective solar tracking system, multiple design concepts were explored before finalizing the best approach. Each concept aimed to improve efficiency by optimizing how the solar panels follow the sun’s path. These design ideas are categorized as development concepts. The focus of the designs was to enhance how the system tracks sunlight, adjusts the panels throughout the day, and maximizes energy generation.

These concepts will highlight advantages and disadvantages between them and the design concept we eventually went with. It will also highlight the reasons they weren't used as well as highlight situations where their usage is imperative.

These concepts include;

3.1.1 Concept one

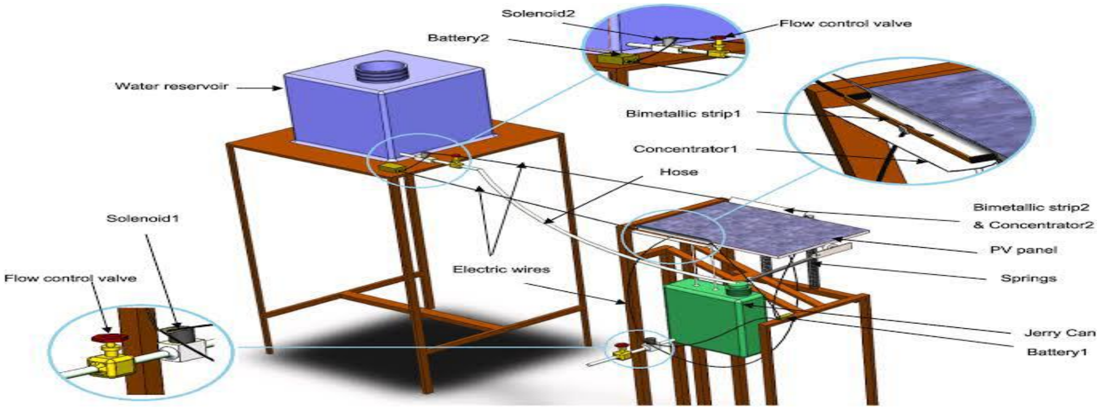


Figure 3.1: Isometric representation of design concept one

Passive Liquid-Based Solar Tracker (Thermal Expansion Fluid)

This design uses the thermal expansion of a liquid (usually a refrigerant or similar fluid) to move the solar panel. It exploits the fact that liquid expands when heated and contracts when cooled. By placing liquid containers on either side of the solar panel, the system can use the sun’s heat to track its movement across the sky.

Components:

1. **Fluid-Filled Cylinders:** Containers of refrigerant or another expanding fluid placed on both sides of the solar panel.
2. **Heat Absorbing Surfaces**: Surfaces that focus sunlight on the fluid containers to heat them up.
3. **Hydraulic or Pneumatic System**: The expanding fluid pushes pistons, which adjust the panel's orientation.
4. **Rotating Platform with Bearings**: Enables the solar panel to rotate smoothly as the fluid expands and contracts.

Working:

As sunlight hits one side of the panel, it heats up the fluid inside the corresponding cylinder.

The heated fluid expands and pushes a piston, tilting the panel toward the sun.

As the sun moves, the fluid in the other cylinder heats up, and the process continues, causing the panel to follow the sun throughout the day.

At night, the cooling of the liquid causes it to contract, resetting the system for the next day.

Advantages:

1. **Completely Passive**: Does not require any external power source, making it highly energy-efficient.
2. **No Electronics**: Fully mechanical, with no need for sensors, controllers, or electricity to operate the tracking system.

3. **Self-Regulating**: The system naturally follows the sun as the liquid expands and contracts, with minimal maintenance required.

Disadvantages:

1. **Less Precise**: Similar to the bimetallic design, this system is less precise than electronic trackers, especially during variable weather conditions (e.g., cloudy days).
2. **Slower Response**: The system may not react quickly to fast changes in sunlight intensity or the sun's position, as it relies on the heat absorption rate of the **fluid.**

3.1.2 Concept two

Figure 3.2: Diagrammatic representation of the Raspberry pi pico microcontroller

Raspberry Pi Pico Solar Tracker

The Raspberry Pi Pico is a versatile and powerful microcontroller that offers more computing power than the Arduino Nano, making it ideal for more complex solar tracking applications. In this design, the Raspberry Pi Pico is used for real-time solar tracking and can also be connected to additional sensors for environmental data.

Components:

Raspberry Pi Pico: A small but powerful microcontroller that handles the tracking logic.

Photodiodes or Phototransistors: Used instead of LDRs for more precise light detection.

Servo or Stepper Motor: Controls the movement of the solar panel.

BME280 Environmental Sensor (Optional): Measures temperature, humidity, and pressure, allowing for dynamic control of the solar panel in varying environmental conditions**.**

OLED Display (Optional): Displays real-time tracking data and sensor readings on the device itself.

Working:

The photodiodes detect the sunlight intensity and feed the data into the Raspberry Pi Pico.

The Pico processes the data and controls the motor to align the solar panel with the sun.

The BME280 environmental sensor can be used to adjust the solar panel based on weather conditions (e.g., wind or high temperatures).

The system can display real-time data on an OLED screen, such as sunlight levels, motor position, and environmental conditions.

Advantages:

1. **More Power and Flexibility:** The Raspberry Pi Pico is more powerful than many Arduino boards, enabling more complex processing and data handling.

2. **Multiple Inputs/Outputs:** It offers more GPIO pins and greater flexibility for additional sensors and actuators.

3. **Advanced Sensor Integration:** Can easily incorporate additional sensors like temperature, humidity, or even solar irradiance sensors to improve tracking performance.

Disadvantages:

1. **More Power consumption:** The Raspberry Pi Pico consumes more power compared to basic Arduinos like the Nano or Uno.
2. **Complexity:** Programming and wiring a Raspberry Pi Pico system can be more complex than with an Arduino-based design.
3. **Low Cost**: Uses inexpensive components like op-amps and relays.
4. **Simple Design**: Easy to implement for small-scale solar applications.

Disadvantages:

1. **Limited Features**: No programmability or advanced tracking features.
2. **Less Flexibility**: It's more difficult to integrate additional functionalities like seasonal adjustments without a microcontroller.

3.1.3 Concept three

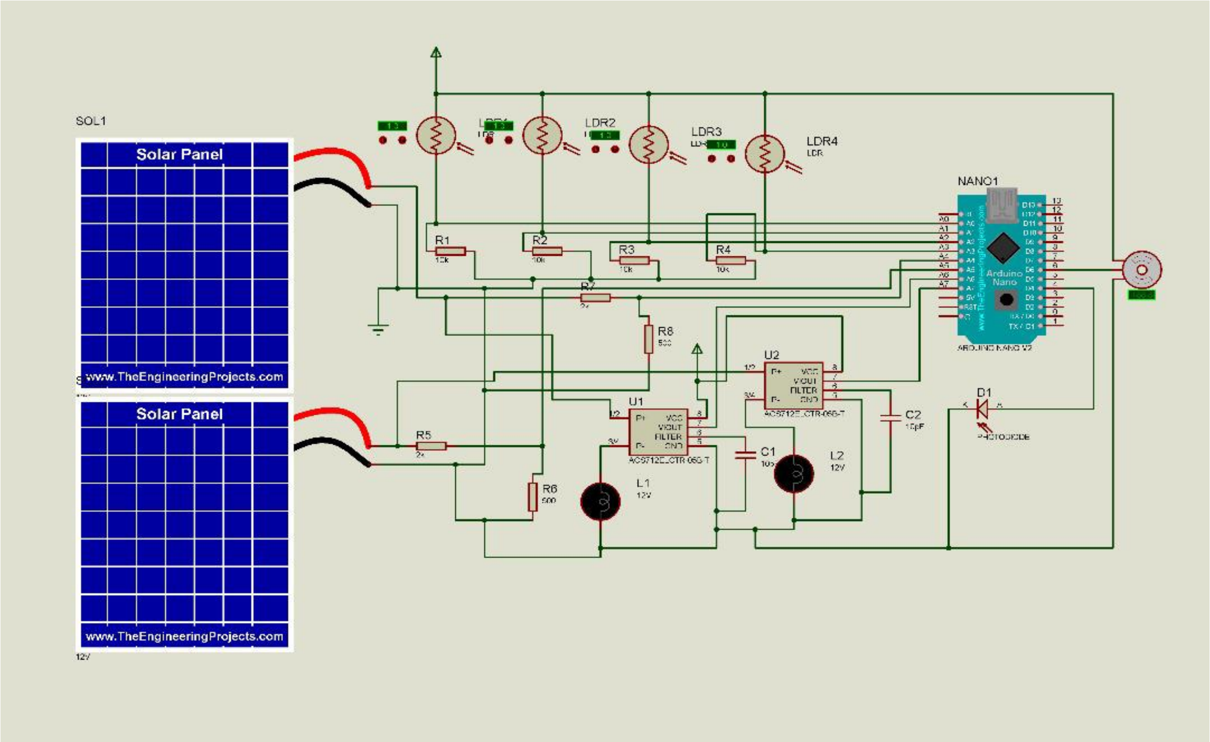


Fig 3.3 Block diagram of concept 3 using Arduino nano

3.2. Design equipment

- **Light Dependent Resistor (LDR) :** This is a component whose resistance decreases as the light intensity increases. It has high resistance in the dark and low resistance in bright light, making it useful in devices like automatic street lights and light sensors.

Figure 3.4 : Isometric representation of the light dependent resistor (LDR)

- **Servo motor:** A servo motor is a rotary or linear actuator that allows precise control of angular or linear position, velocity, and acceleration. It consists of a motor, a feedback sensor (usually a potentiometer), and control electronics. Servo motors are commonly used in robotics, remote-controlled vehicles, and automation systems to move parts to specific positions.

Figure 3.5: Servo motor

- **Arduino Nano:** This is a compact, microcontroller board based on the ATmega328 chip. It is small, breadboard-friendly, and used for building electronics projects. It has digital and analog input/output pins, and is programmable via USB, making it the ideal for DIY projects and prototyping.

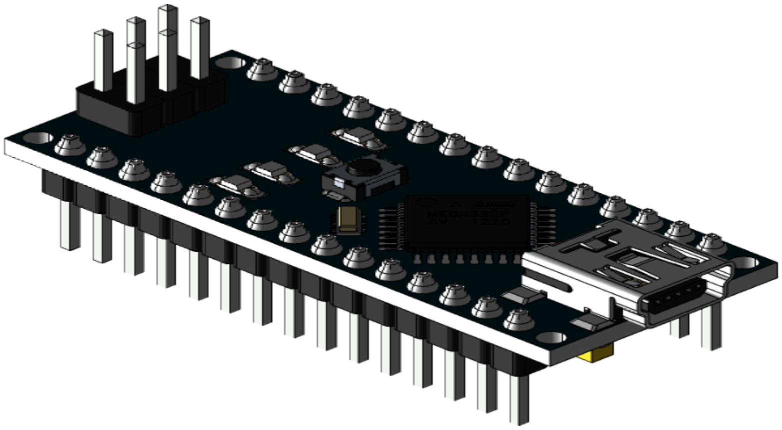


Figure 3.6 : Arduino nano

- **Solar panel :** This is a device that converts sunlight into electricity using photovoltaic (PV) cells. These cells capture sunlight and generate direct current (DC), which can be used to power devices or stored in batteries for later use. Solar panels are commonly used in renewable energy systems.

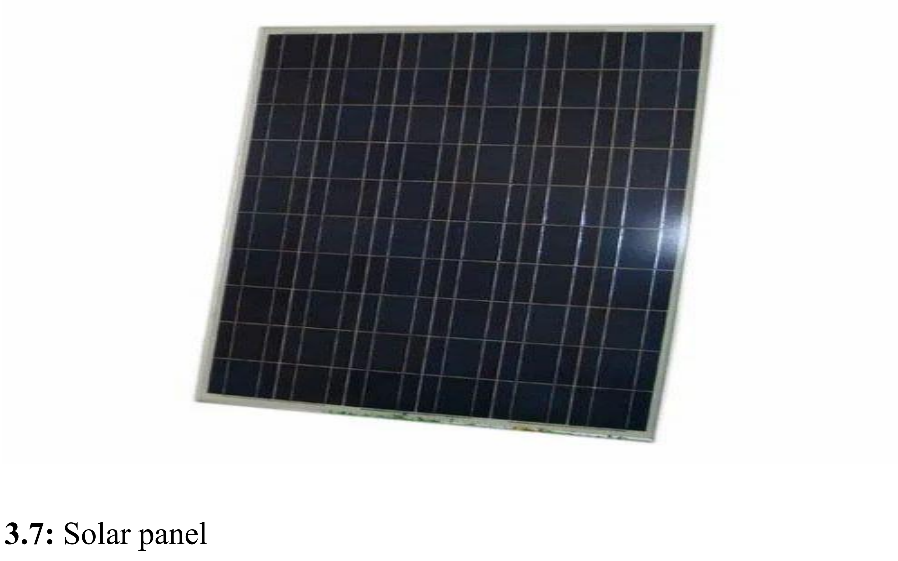


Figure 3.7: Solar panel

- **Housing unit**: This is a protective enclosure designed to house and safeguard electrical components, such as circuits, wiring, or devices. It shields them from environmental factors like dust, moisture, and physical damage, while also preventing accidental contact with live electrical parts. These units are commonly used for appliances like power supplies, switches, and controllers.

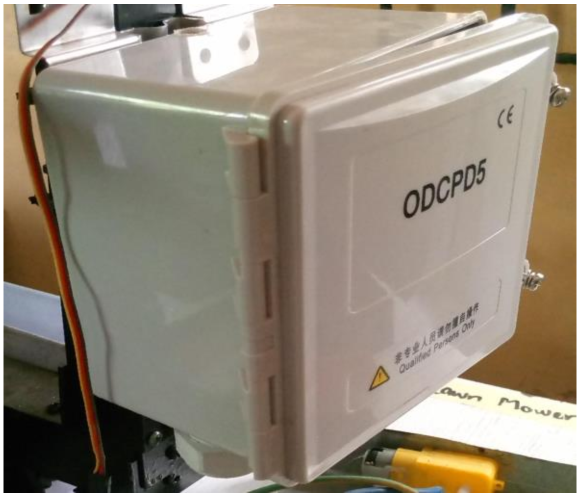


Figure 3.8 : PVC housing

- **Frame:** This is a structural support that provides shape and stability to an object.

Figure 3.9 : Aluminum frame

3.1.2 Design factor and consideration

In the development of the solar tracking device, several key factors were carefully evaluated. These include:

1. **Cost**: This encompasses the expenses for production, maintenance, and eventual disposal, ensuring affordability throughout its lifecycle.
2. **Safety**: The design prioritizes user safety, ensuring the device operates securely in various environmental conditions.
3. **Efficiency**: The device is designed to optimize the positioning of solar panels to capture the maximum amount of sunlight, improving energy output and overall performance.
4. **Sustainability**: The materials used are long-lasting and environmentally friendly. By utilizing recyclable components, the device contributes to a sustainable energy solution.
5. **Availability**: The materials and components for the device are readily accessible and can be sourced locally, ensuring ease of manufacturing and repairs.
6. **Portability**: The solar tracker can be easily assembled, disassembled, and transported, allowing flexibility in installation and maintenance.

3.3 Detailed design

3.3.1 Design dimension for the machine

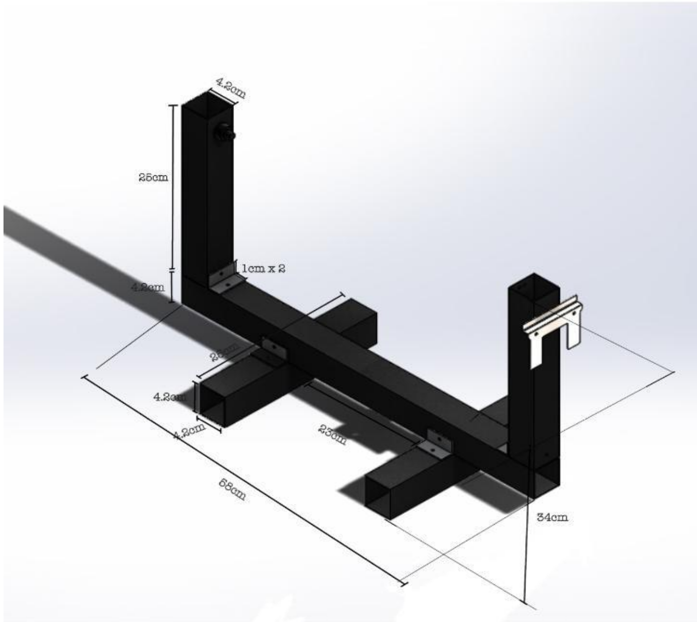


Figure 3.10: Design dimension of the machine

3.3.1. Design Calculation for the Machine

Microcontroller Unit (MCU)

The MCU reads the voltage from two analog pins connected to the LDRs using ADC (Analog to Digital Conversion). The conversion process translates analog voltage into digital values.

ADC Conversion:

- The ADC conversion range is from 0 to 1023, corresponding to 0V to 5V.

- Assuming 2V is fed into the MCU, the conversion bits can be calculated as follows:

5V = 1023 bits

2V = X bits

X = (2 * 1023) / 5

X = 409.2 bits

Thus, a 2V input would correspond to approximately 409 bits in the MCU's ADC

LDR Calculation for Tracking Movement:

The logic used for controlling the movement of the solar panel is based on the difference in light intensities between the two LDRs:

(Left LDR) - (Right LDR)

- If the light intensity on the Left LDR is higher than that on the Right LDR, the panel moves clockwise.
- If the light intensity on the Right LDR is higher, the panel moves counterclockwise.

Voltage Divider Calculation

The voltage divider is used to measure the voltage across the two LDRs. The output voltage, V(out), can be determined using the voltage divider formula:

V(out) = V * [R1 / (R1 + R2)]

Where:

- V = +5V (supply voltage)
- R1 = 10k ohms
- R2 = R(LDR) (resistance of the LDR, which varies with light intensity)

The formula becomes:

V(out) = 5 * [10k / (R(LDR) + 10k)]

The resistance of the LDR, R(LDR), varies between 0 ohms (in bright light) to 5M ohms (in darkness).

Maximum V(out):

For maximum V(out), R(LDR) = 0 ohms (brightest light):

V(out) = 5 * [10,000 / (10,000 + 0)]

V(out) = 5V

Minimum V(out):

For minimum V(out), R(LDR) = 5M ohms (darkness):

V(out) = 5 * [10,000 / (5,000,000 + 10,000)]

V(out) = ~0V

From Ohm's law, since voltage and resistance are inversely proportional, a lower resistance produces a higher voltage and a higher resistance produces a lower voltage.

In conclusion, the voltage output from the two LDRs is processed by the MCU to control the movement of the solar panel based on the difference in light intensity between the left and right sides.

3.5 Material Selection Technique for a Solar Tracking Device

The selection of materials for a solar tracking device is influenced by several factors, including the type and amount of stress the device components will endure, the need for flexibility or rigidity, and exposure to environmental elements such as sunlight, heat, and corrosion. Additionally, the material must be compatible with manufacturing techniques like molding, machining, or casting. The material chosen should fulfill requirements like strength, resistance to corrosion, lightweight, durability, cost-effectiveness, and ease of availability. Therefore, material selection will be guided by the following considerations:

1. Strength
2. Weight
3. Availability
4. Manufacturability
5. Cost Efficiency

3.5.1 Service Requirements

For the solar tracking device to function effectively, the materials used must meet specific performance criteria. These service requirements ensure the material can withstand the working conditions of the device. Some important characteristics include:

a) Toughness to handle stress from constant movement and wind.
b) Hardness to resist wear over time.
c) Sufficient strength to support solar panels under varying weather conditions.
d) Stiffness to maintain structural integrity.
e) Corrosion resistance to withstand outdoor exposure.
f) Heat resistance to endure prolonged sun exposure without degradation.

3.5.2 Fabrication Requirements

In the fabrication of a solar tracking device, materials must possess properties that allow easy processing and assembly. This includes being malleable enough to form the necessary shapes and ductile enough to be drawn into components like wiring or frames. Materials also need to be weldable for assembling different parts of the device, withstanding high temperatures during manufacturing without losing their key properties.

3.5.3 Precautions

1. Make sure all electrical components are sealed in airtight and waterproof housings to prevent damage

2. Make sure all individual components are functional before assembling them
3. Use corrosion resistant materials for the frame
4. Make sure the batteries capacity is sufficient to power the device for an extended period or time.
5. Do not buy substandard materials

3.6 Test procedure

Test procedures play a vital role in determining the performance, reliability, and durability of components in a single-axis solar tracking device. The procedures ensure that each component meets the required standards, functions as intended, and can withstand real environmental conditions. The following are the tests performed on the working parts of the solar tracking system and the significance of their results.

1. Servo Motor Testing

The servo motor was subjected to several tests to ascertain its ability to rotate the solar panel precisely and effectively. The torque test was effective to ensure that the motor had the ability to withstand the weight of the solar panel, including winds and other mechanical loads. Through the positioning accuracy test, the motor aligned the panel at certain angles, further asserting its ability to track the sun. The response time test indicated small actuation delays to achieve maximum energy capture. The constant duty test indicated that the motor was capable of being utilized for extended periods without deterioration. Overload protection was implemented to avoid damaging the motor in the case of mechanical resistance, and environmental testing proved the motor to be resilient to outdoor conditions.

2. Arduino Nano Testing

The Arduino Nano was also subjected to tests to verify that it worked as the control module for the solar tracker. Power consumption test showed that it operates using efficient power with minimal consumption, making it perfect for use in solar energy-powered applications. The I/O pin test also confirmed that the microcontroller was able to properly read from sensors and provide control signals to the motor. The sensor integration test demonstrated that the Arduino handled sunlight data effectively, with the appropriate adjustment to the panel. The test of signal response demonstrated rapid response to sensor input. The software test validated the efficiency and stability of the solar tracking algorithm, and the environmental test confirmed that the microcontroller was capable of operation under harsh temperatures.

3. Solar Panel Testing

The power output test of the solar panel verified that the solar panel would deliver the predicted electrical power under varied lighting conditions. Efficiency testing indicated that the panel was within its rated efficiency under standard conditions. The I-V curve test calculated the maximum power point (MPP), where the panel was most efficient. The temperature coefficient test showed how power output was influenced by temperature variations, and durability testing confirmed the panel's stability against weather conditions like rain, dust, and UV. Wiring integrity testing confirmed that the electrical connections on the panel were reliable and tight.

4. Light Sensor Testing

The sun-tracking light sensors were tested for sensitivity and did well even under low-light conditions. The response time test showed quick detection of changes in sunlight, enabling real-time system adjustment. Calibration testing was done to ensure accuracy of sensor readings to reduce tracking errors. The durability test showed that the sensors can withstand outdoor conditions without loss of performance.

5. Power Supply and Battery Testing

While, in the event that the system utilized the battery backup, the charge/discharge test confirmed that the battery had a capacity to sustain the tracker in low light conditions. Voltage regulation testing ensured that power supply supplied stable voltage, which suppressed the power ripples. Temperature testing ensured that the battery performance functioned under various weather conditions and that it is suitable for utilizing it outdoors.

After testing the components separately, they were tested as a whole unit to determine their functionality.

To carry this out , the components were assembled and taken outside and placed under the sun to test the functionality in accurately tracking the sun's location in the sky.

Some problems encountered during testing;

During the development and testing of the single-axis solar tracking device, several issues were encountered that affected the overall performance and functionality of the system. These problems include the following:

Interference of Ambient Light on the LDRs

The light-dependent resistors (LDRs) used for detecting sunlight were sometimes affected by ambient light from surrounding sources. This interference led to inaccurate readings, causing the system to misinterpret the sun's position and resulting in suboptimal tracking.

- Overtitling of the Solar Panel

Overtilting of the solar panel was observed during operation. This was traced back to an issue with the code on the Arduino Nano, which caused the servo motor to move the panel beyond its intended range, leading to excessive tilt and reduced tracking accuracy.

These challenges were identified during the testing phase of the project.

- Interference of Ambient Light on the LDRs

Ambient light is any surrounding light in the environment that does not come directly from the sun. It can be caused by various sources, such as reflections from nearby surfaces like buildings, water bodies, or even clouds. In the case of the solar tracking device, this ambient light created interference with the light-dependent resistors (LDRs), which were used to detect the sun’s position.

The LDRs work by measuring the intensity of light falling on them, which allows the system to adjust the position of the solar panel accordingly. However, when ambient light reflected off nearby objects or surfaces, it often hit both LDRs simultaneously, leading to inaccurate readings.

This interference caused the device to misinterpret the sun's position, resulting in suboptimal performance of the solar tracking system.

To correct this problem, two key modifications were implemented:

1.Covering the LDR Mount with Black Electrical Tape

The first solution involved covering the LDR mounts with black electrical tape. This was done to reduce the amount of stray light that could reflect off nearby objects and interfere with the sensors. The black electrical tape absorbed any ambient light, ensuring that the LDRs were only exposed to direct sunlight. This step minimized reflection and improved the reliability of the LDR readings.

2. Dividing the LDRs with a Black Shield

In addition to the tape, a black shield was placed between the two LDRs. The purpose of this shield was to physically block light that might reflect from one LDR to the other, especially during times when the sun's position was less direct. By ensuring that each LDR responded independently to the sunlight, the system became more accurate in tracking the sun’s position. This shield effectively prevented sunlight from reflecting onto both sensors at the same time, which had previously confused the tracking mechanism.

These measures significantly reduced the influence of ambient light and improved the accuracy of the solar tracking device, allowing it to perform its function more efficiently.

2.Overtilting of the Solar Panel

Initially, the panel was tilting a full 90 degrees on either side during operation, which led to inefficient tracking and mechanical strain on the system. This excessive tilt was traced back to the code on the Arduino Nano, which controlled the servo motor responsible for adjusting the panel’s angle.

The overtilting occurred because the code allowed the servo motor to rotate the panel too far, leading to unnecessary and extreme angles that went beyond the optimal range for sun tracking. This caused the panel to deviate significantly from its intended position, reducing the device’s effectiveness in capturing sunlight.

To resolve this issue, the code was updated to limit the tilt of the panel. The new code restricted the panel to tilt a maximum of 70 degrees on either side during a complete revolution, instead of the full 90 degrees. This adjustment provided a more controlled and precise movement, keeping the panel within a more suitable range for tracking the sun while preventing overtilting.

By modifying the tilt angle, the solar tracking device was able to operate more efficiently, with smoother and more accurate tracking of the sun's position.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

To evaluate the performance of the single-axis solar tracking device, a comparative analysis was conducted between the solar tracker and a stationary 20-watt solar panel, under identical environmental conditions. Both systems were tested over an 8-hour period, from 9:00 AM to 5:00 PM, with measurements taken to determine their respective energy outputs.

The results demonstrated that the solar tracking system outperformed the stationary panel in terms of energy generation. By dynamically adjusting its position to follow the sun throughout the day, the solar tracker maintained higher sunlight exposure, translating into increased energy output compared to the stationary panel, which experienced reduced exposure as the sun’s angle changed.

It is important to note that the primary advantage of a solar tracking system is not necessarily the instantaneous power boost, but rather the extended duration of time it spends optimally aligned with the sun. This prolonged exposure results in higher overall energy capture compared to a stationary panel, which remains fixed and experiences fluctuations in sunlight intensity throughout the day.

These are the readings we got;

Table 4.1: Result of Readings

Time	**Fixed Parnel**		**Moving Panel**	
	Voltage (V)	**Current (A)**	**Voltage (V)**	**Current (A)**
9am	22.66	-0.18	24.17	-0.12
10am	22.74	-0.12	23.27	-0.06
11am	22.57	-0.18	23.37	0.06
12 pm	22.66	-0.18	24.15	-0.06
1pm	22.47	-0.29	24.02	0.00
2pm	22.37	-0.18	23.76	-0.12
3pm	22.18	-0.18	23.83	-0.18
4pm	22.35	-0.29	23.95	0.12
5pm	24.36	-0.23	23.90	-0.18

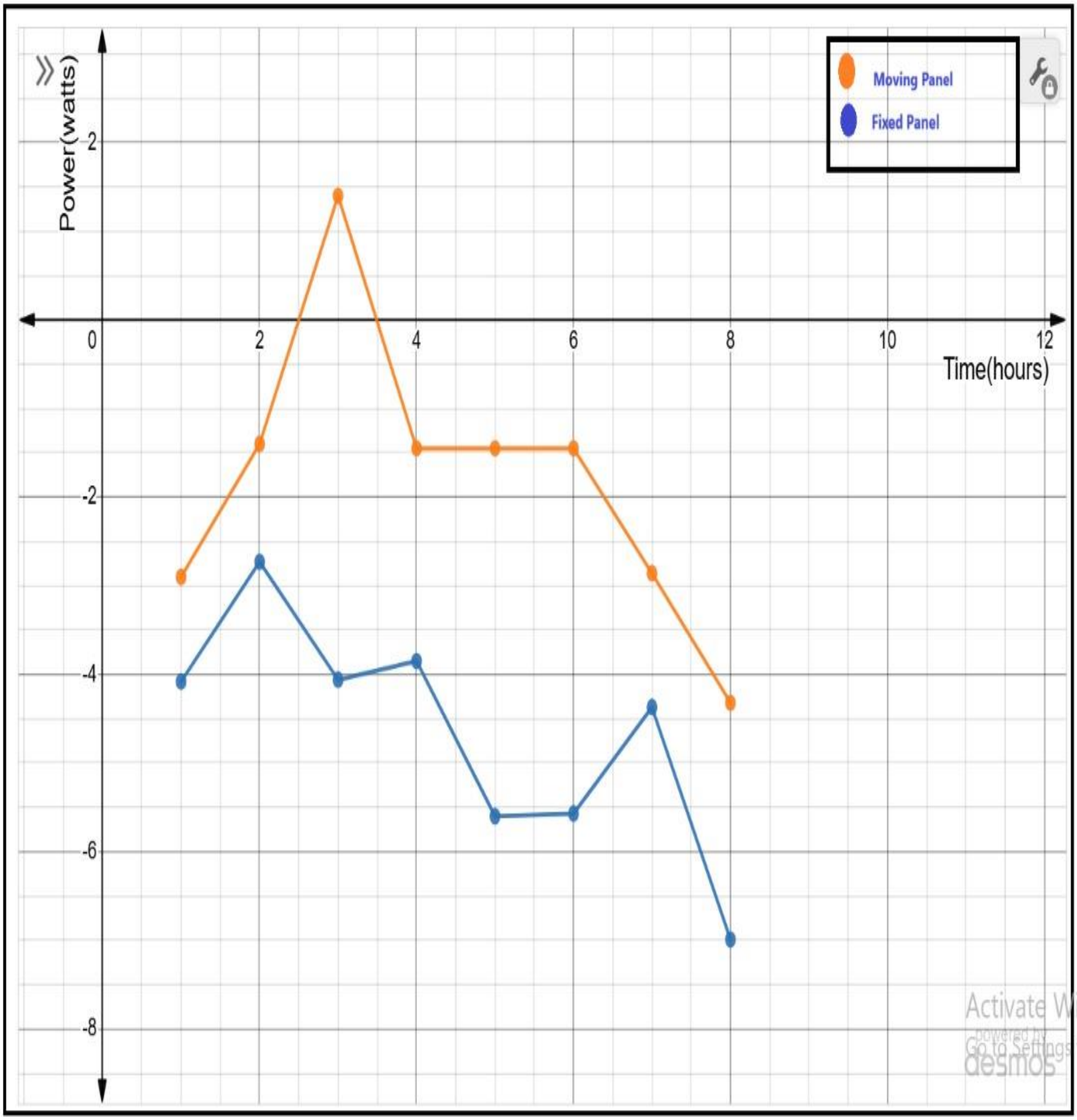


Figure 4.1: Graph of Power against Time

This graph was plotted with power against time because **P=IV**

4.2 Discussion

Inaccurate Sensor Readings

- Solar trackers rely on sensors like Light Dependent Resistors (LDRs) to detect sunlight intensity and adjust the solar panel's orientation.
- If the sensors are poorly calibrated, damaged, or exposed to environmental interference (e.g., reflections or shadows), they can misinterpret sunlight direction.
- This causes the panel to face a suboptimal angle, reducing energy capture and overall efficiency.
- Solution: Regularly calibrate sensors and shield them from unnecessary reflections.

Mechanical Limitations

- The tracking system often uses servo or stepper motors to move the solar panel.
- Limitations in motor torque, gear backlash, or over-tilting can prevent precise positioning.
- Wear and tear over time can also make the system sluggish, leading to missed sunlight positions.
- Solution: Use durable motors, ensure proper mechanical design, and perform regular maintenance.

Power Consumption of the Tracker

- The tracker itself consumes power for motors, control boards (like Arduino Nano), and sensors.
- If this consumption is too high, it offsets the gains from improved sunlight capture.
- Solution: Optimize motor movements (e.g., move less frequently), use energy-efficient electronics, and consider passive tracking designs where possible.

Environmental Factors

- Weather changes (like cloud cover, rain, or haze) reduce the available sunlight, limiting the maximum energy output regardless of tracking accuracy.
- Dust, dirt, or bird droppings on panels also block sunlight and lower efficiency.

- Solution: Schedule routine cleaning, and design panels to be tilted in a way that reduces dust accumulation.

Code or Software Inefficiencies

- Poorly written code that controls tracking timing and angles can result in delays or frequent unnecessary movements.
- This not only reduces efficiency but also increases energy use and wear on the motors.
- Solution: Optimize algorithms for smooth, calculated tracking updates and minimize motor activity.

These factors collectively explain why even advanced solar trackers may not reach 100% efficiency. Addressing them through better calibration, optimized design, and maintenance ensures maximum energy capture.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the design and testing of the single-axis solar tracking device have shown promising results in improving solar energy efficiency by enhancing the tracking accuracy of solar panels throughout the day. The system, incorporating components such as the servo motor, Arduino Nano, and solar sensors, performed within the expected parameters, providing valuable insights into the effectiveness of solar tracking technology. The testing procedures confirmed the reliability of key components, while addressing limitations such as mechanical wear and sensor calibration. Overall, the device has met the performance goals set out at the beginning of the project, demonstrating both its potential for increasing solar energy production and its viability for real-world applications.

However, challenges related to the durability of moving parts and environmental factors that affect the system's performance were identified. These limitations, along with opportunities for further refinement, will guide the next stages of development and optimization. Despite these challenges, the project has been successful in achieving its primary objective of improving solar panel performance through automated tracking and maximizing energy efficiency.

5.2 Recommendations

Based on the findings of this project, the following recommendations are made to ensure continued success and future improvements:

Enhanced Durability of Moving Parts: It is recommended to use more robust materials for components subject to mechanical stress, such as the servo motor and the arm mechanism. This would reduce wear and tear and increase the longevity of the device.

Advanced Tracking Algorithm: Future iterations of the project should incorporate a more advanced tracking algorithm to improve accuracy in low-light conditions or during cloudy weather. This could involve integrating more sophisticated sensors or using machine learning to predict sun movement more accurately.

Integration of Dual-Axis Tracking: While the single-axis tracking system is effective, the inclusion of a dual-axis tracking system could further increase energy efficiency by tracking the sun more precisely in both vertical and horizontal planes.

Power Supply Optimization: Enhancing the power supply system to include larger batteries or more efficient charging circuits could ensure consistent operation during cloudy days or at night, reducing the dependency on sunlight for power.

Regular Calibration and Maintenance: To maintain optimal performance, regular calibration of the sensors and periodic checks of the mechanical components should be incorporated into the maintenance schedule.

Cost Reduction: Exploring alternative materials or mass production techniques could reduce manufacturing costs, making the system more affordable and competitive with other solar panel tracking solutions.

Scalability and Commercialization: As the technology matures, it is recommended to consider the scalability of the device for commercial and industrial applications. With further optimization, this system could be adopted for use in larger solar farms, increasing its impact on renewable energy generation.

By implementing these recommendations, the solar tracking device can be refined to maximize its performance, durability, and cost-effectiveness, ensuring that it contributes to a sustainable future of energy production.

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APPENDICES

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F