Faculty of Electrical Technology and Engineering

DEVELOPMENT OF DUAL AXIS SOLAR PANEL TRACKING DEVICES

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Bachelor of Electrical Engineering Technology (Industrial Power) with Honors

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APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology (Industrial Power) with Honours.

Signature : ....

Supervisor Name : Puan Nurul Kausar Binti Ab Majid

Date : 27/12/2024

DEDICATION

This project is dedicated to my beloved mother Zurainah Binti Zulkifli, whose continually love, support, and encouragement have always provided me with strength. Your efforts and prayers provided the foundation for my education and achievements. Your belief in me, even during my most difficult times, has motivated me to endure and strive for perfection. This effort reflects your commitment to my accomplishment, and I am eternally thankful for your direction and attention.

To my great lecturer Madam Nurul Kausar Binti Ab Majid, I am deeply grateful for your mentorship and assistance along this journey. Your dedication for teaching and commitment to growing young minds have been genuinely inspirational. Your knowledge and encouragement have greatly influenced my understanding as well as implementation of the concepts underlying this project. Thank you for encouraging me to think critically and pushing me to achieve my best potential.

Finally, I dedicate my effort to a great siblings and friend who has provided inspiration and guidance during this journey. Your unwavering trust in my abilities, as well as your companionship during late-night conversations about ideas, meant everything to me. You have been a great partner in this journey, not just a friend. Thank you for your understanding, confidence, and constant support when I needed you the most.

ABSTRACT

Through the creation of a solar panel tracking device, this study presents a fresh strategy for improving the efficiency of solar energy systems. The device employs a combination of sensors and actuators to dynamically modify the alignment of solar panels, with the objective of maximizing sunshine exposure and optimizing energy production from solar systems. The project aims to create a durable solar panel tracking device that can precisely track the sun's position throughout the day. Furthermore, the project aims to assess the performance and efficiency enhancements of the tracking device in comparison to stationary solar panel installations. The project follows a methodological approach that encompasses early design and prototype stages, followed by a series of rigorous testing and optimization rounds. These iterations are specifically designed to assure the reliability and efficacy of the tracking device. It combines the processing of sensor data, control mechanisms for actuators, and algorithmic decision-making to accomplish accurate alignment of solar panels with the sun's path. An anticipated outcome is a substantial improvement in the effectiveness and productivity of solar panels, resulting in heightened energy generation and enhanced overall performance of solar energy systems. The tracking gadget endeavors to achieve constant optimum energy production by maximizing solar exposure and reacting to environmental conditions. This technological innovation contributes to the progress and broad use of renewable energy technology. In summary, the advancement of this solar panel tracking system exhibits potential for transforming solar energy production via enhanced dependability and effectiveness, hence aiding the shift towards a more environmentally sustainable energy landscape.

ABSTRAK

Melalui penciptaan peranti Peranti penjejak panel solar, kajian ini membentangkan strategi baru untuk meningkatkan kecekapan sistem tenaga solar. Peranti ini menggunakan gabungan sensor dan penggerak untuk mengubah suai penjajaran panel solar secara dinamik, dengan objektif memaksimumkan pendedahan cahaya matahari dan mengoptimumkan pengeluaran tenaga daripada sistem solar. Projek ini bertujuan untuk mencipta peranti pengesanan panel solar tahan lama yang dapat mengesan kedudukan matahari dengan tepat sepanjang hari. . Selain itu, projek ini bertujuan untuk menilai prestasi dan peningkatan kecekapan peranti pengesanan berbanding dengan pemasangan panel solar pegun. Projek ini mengikuti pendekatan metodologi yang merangkumi peringkat reka bentuk awal dan prototaip, diikuti dengan satu siri pusingan ujian dan pengoptimuman yang ketat. Lelaran ini direka khusus untuk memastikan kebolehpercayaan dan keberkesanan peranti penjejakan. Ia menggabungkan pemprosesan data sensor, mekanisme kawalan untuk penggerak, dan pembuatan keputusan algoritma untuk mencapai penjajaran panel solar yang tepat dengan laluan matahari. Hasil yang dijangkakan adalah peningkatan yang besar dalam keberkesanan dan produktiviti panel solar, menghasilkan penjanaan tenaga yang tinggi dan peningkatan prestasi keseluruhan sistem tenaga solar. Alat pengesan berusaha untuk mencapai pengeluaran tenaga optimum yang berterusan dengan memaksimumkan pendedahan solar dan bertindak balas terhadap keadaan persekitaran. Inovasi teknologi ini menyumbang kepada kemajuan dan penggunaan teknologi tenaga boleh diperbaharui yang luas. Secara ringkasnya, kemajuan sistem pengesanan panel solar ini mempamerkan potensi untuk mengubah pengeluaran tenaga solar melalui kebolehpercayaan dan keberkesanan yang dipertingkatkan, sekali gus membantu peralihan ke arah landskap tenaga yang lebih mampan alam sekitar.

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LIST OF ABBREVIATIONS

V	-	Voltage
A	-	Ampere
%	-	Percent
W	-	Watt
LDR	-	Light Dependent Resistor
PV	-	Photovoltaic

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, there has been an important growth in the use of solar energy as a renewable and sustainable form of electricity generation. The use of solar photovoltaic (PV) systems, which consist of solar panels, has grown in popularity in both residential and business environments because of their positive impact on the environment and their potential for long-term financial savings. Nevertheless, the effectiveness of solar panels may be limited by other variables, including their alignment with respect to the sun and changes in meteorological conditions. The development of solar panel tracking devices has been identified as a possible approach to tackle these difficulties and improve the performance of solar systems.

1.2 Addressing Global Warming Through Weather Sensing Project

In this current day, the urgent problem of global warming requires creative strategies to reduce its effects. One undertaking entails the execution of weather sensing initiatives with the objective of comprehending and predicting climate trends. Using advanced technologies such as sensors and data analytics, these initiatives provide significant contributions to the understanding of weather dynamics. This, in turn, facilitates the ability to make well-informed decisions aimed at reducing the negative effects of climate change.

1.3 Problem Statement

Despite the considerable availability of solar energy, standard fixed solar panel systems often fall short of fully harnessing their potential because of insufficient placement during the day. The lack of efficiency leads to the underutilization of excess sunlight and a decrease in energy production. Moreover, the issue is compounded by the introduction of unpredictability in solar radiation levels due to uncertain weather conditions. Therefore, it is essential to develop an innovative method that can effectively modify the alignment of solar panels to optimize energy production, while also accommodating fluctuations in climatic conditions.

1.4 Project Objective

The primary objective of this project is to design and implement a solar panel tracking device capable of optimizing energy generation from solar installations. Specifically, the objectives are as follows:

a) To design and develop a solar panel tracking with dual axis system.

b) To analyze how well the solar tracking devices use dual axis system with monocrystalline and polycrystalline solar panel.

1.5 Scope of Project

The scope of this project is as follows:

a) A solar tracking system that uses Light Dependent Resistor (LDR) sensors to accurately determine the sun's position during daytime hours.

b) To measure power output of the solar tracker and fixed solar panel (45°) 8 am until 5 pm.

c) This project focuses on dual axis that can rotate following the position of the sun.

d) Using monocrystalline and polycrystalline solar panel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will present a comprehensive collection of all the research conducted on the issue, with specific emphasis on theoretical and fundamental concepts. The project scope facilitated the collection of essential data and information from many sources. Literary works, scholarly publications, written materials, Organizations, as well as websites, are both included in this category. A literature review is necessary to compare the current effort with previous studies that have attempted to address the same problem. Based on the results, there is ample opportunity for substantial progress, resulting in improved conclusions and recommendations for further investigation. Conducting a literature review will offer more evidence for comparing concepts, regardless of whether the ideas being examined are theoretical or practical. The presentation will address prior efforts that have pursued similar objectives, namely the translation of sign language into written and audible forms. More precisely, it will encompass the endeavors that have pursued comparable goals in previous instances.

2.2 Solar Tracking Technologies

Solar tracking systems are engineered to dynamically adjust solar panels, aligning them with the sun's trajectory throughout the day. This guarantees that the panels optimise sunshine absorption, hence enhancing energy efficiency. The project paper from RCC Institute of Information Technology [1] highlights the utilisation of Light Dependent Resistors (LDRs) and servo motors for the automatic adjustment of solar panels. The system employs several LDR sensors to ascertain the direction of sunlight, transmitting signals to the controller, which subsequently adjusts the motors to realign the solar panels. This method guarantees that the panels maintain an appropriate angle in relation to the sun, which is essential for maximising energy output.

The project [2] provides a pragmatic, hands-on manual for constructing a DIY solar tracker with an Arduino microcontroller. The Arduino interprets inputs from LDR sensors to determine the sun's direction depending on light intensity. It subsequently transmits commands to the servo motors to modify the panel's alignment. The advantages of this technology are evident: enhanced solar energy capture (20-30% improvement), user-friendliness, and cost-effectiveness. Nonetheless, while the RCC project emphasises academic and theoretical learning, the project [2] guide streamlines the process for novices, prioritising cost-effectiveness and simplicity in design. Solar tracking systems are engineered to modify the orientation of solar panels in real-time, synchronising them with the sun's trajectory during the day.

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2.2.1 Energy Storage and Smart Grids

Energy storage and smart grid integration are crucial for renewable energy, especially for solar systems that provide fluctuating outputs based on weather conditions and time of day. The ScienceDirect research [3] explores the optimisation of energy storage in microgrids, which are small-scale power grids that can function autonomously or in combination with the primary grid. This study underscores the significance of equilibrating energy supply and demand through the dynamic management of stored energy. The primary objective is to enhance energy storage systems to guarantee that surplus energy produced during peak sunlight hours is stored effectively and utilised when solar generation is minimal.

The IET Research report [5] further explores the incorporation of artificial intelligence (AI) into smart grid systems. The study investigates the capacity of AI algorithms to enhance energy distribution through the prediction of load demand and the real-time adjustment of power output. This degree of control is essential for maintaining grid stability, particularly when including renewable energy sources such as solar power, which are intrinsically variable. The document emphasises the significance of smart grids in effectively regulating energy distribution, enhancing dependability, and minimising energy waste.

2.2.2 Comparative Performance of Fixed vs. Tracking Systems

The IEEE study [4] offers an extensive evaluation of the efficacy of stationary solar panels compared to automated tracking methods. Fixed panels are constrained in their capacity to optimally gather sunlight throughout the day due to their constant angle. Conversely, dual axis tracking systems can adjust both horizontally and vertically to more precisely follow the sun's trajectory, leading to markedly enhanced energy capture. The research indicates that dual-axis trackers can enhance energy efficiency by as much as 40%, especially in areas with fluctuating sunlight availability. The results correspond with those of the RCC [1] and Instructable projects [2], which documented analogous enhancements in energy harvesting via automated tracking systems.

2.2.3 Automation and Control Systems

A common subject in these articles is the growing significance of automation and control systems in enhancing solar energy efficiency [4]. Solar trackers utilise microcontrollers, such as Arduino, to analyse sensor data and execute real-time choices concerning the orientation of solar panels. These systems incessantly modify the panels to maintain alignment with the sun, hence maximising energy production throughout the day. Automation is paramount in smart grids. Algorithms powered by artificial intelligence regulate energy flows, forecast load demand, and optimise energy storage and distribution to reduce waste and maintain grid stability.

Although all studies underscore the significance of automation, there are considerable variations in the complexity and extent of the systems examined. The RCC [1] and Instructables [2] projects emphasise straightforward, economical solutions for small-scale solar installations, whereas the ScienceDirect [3] and IET papers [5] examine large-scale, intricate energy systems necessitating sophisticated AI and machine learning algorithms for energy distribution management on a broader scale.

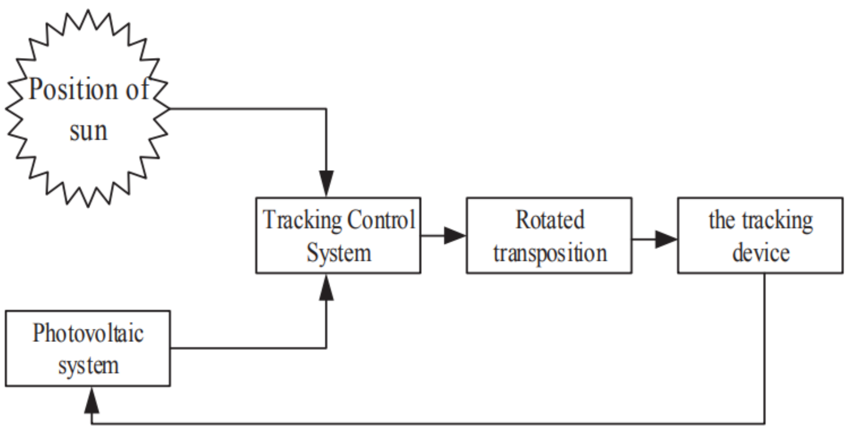

Figure 2.1 Automation and Control Systems

2.2.4 Economic and Environmental Impact

The advantages of solar trackers and smart grids, both economically and environmentally, are indisputable. Automated tracking systems enhance the efficiency of solar panels, hence decreasing the total cost of solar installations by minimising the payback period. The augmented energy production from solar trackers, along with enhanced energy storage and distribution technologies, necessitates less panels to satisfy energy requirements. Moreover, smart grid technologies diminish dependence on fossil fuels by effectively managing renewable energy sources, so further decreasing carbon emissions.

Table 2.1 Summary of Key Findings

Topic	(RCC Project) [1]	(Instructables Project) [2]	(ScienceDirect) [3]	(IEEE Paper) [4]	(IET Research) [5]
Core Technology	Solar tracker with LDR, servo motors	Arduino-based tracker with sensors	Microgrid optimization	Fixed vs. dynamic panels	AI-based smart grid management
Control System	Microcontroller, LDR sensors	Arduino, LDR sensors	Dynamic energy control	Real-time panel adjustment	AI-driven grid energy management
Efficiency Improvement	~20% (single axis)	20-30% (dual axis)	Optimized energy storage	40% improvement with dual axis	Enhanced energy distribution
Automation Complexity	Medium	Low to Medium	High	High	Very High
Cost Effectiveness	Moderate	Low	Moderate	High	High

2.3 Solar Tracking Systems with IoT and Hybrid Integration

Solar energy is an essential resource in the global transition to renewable energy, providing a cleaner substitute for fossil fuels. Solar tracking systems, particularly dual-axis systems with IoT integration, are increasingly emphasised in research and development for their capacity to enhance energy efficiency by optimising the location of solar panels. This literature review analyses essential findings from five primary sources, each addressing various facets of solar tracking, Internet of Things applications, and hybrid energy systems.

2.3.1 IoT-Enabled Solar Trackers for Optimization

The second study, "IoT-Based Solar Tracking Systems" (MDPI) [7], emphasises the incorporation of the Internet of Things (IoT) in the monitoring of renewable energy. The Internet of Things (IoT) is essential in solar tracking systems, offering real-time data, predictive maintenance, and automatic placement of solar panels. This paper demonstrates how IoT integration facilitates improved energy capture, automated modifications, and effective energy consumption monitoring. Furthermore, IoT facilitates reduced expenses and enhanced system dependability. This study illustrates the technological progress achieved in optimising renewable energy via the Internet of Things (IoT).

2.3.2 Dual-Axis Solar Tracker with IoT Monitoring

The third article from ResearchGate, entitled "Dual-axis Solar Tracker with IoT Monitoring System using Arduino," [8] offers a technical analysis of the design and implementation of an IoT-enabled solar tracking system. This device uses an Arduino microcontroller to automate the movement of solar panels along two axes, optimising sunshine exposure throughout the day. The integration of IoT functionalities facilitates real-time monitoring and data acquisition, hence enhancing the ability to assess system performance and pinpoint areas for enhancement. The study illustrates that dual axis tracking systems far surpass stationary solar arrays regarding energy efficiency.

2.3.3 Fabrication and Design of Solar Tracking Systems

The fourth source from the International Journal of Scientific Research in Engineering and Management (IJSREM) [9] examines the design and analysis of dual-axis solar tracking systems. The research examines the mechanical and material constraints encountered in the manufacture of these systems, highlighting the necessity for resilient designs capable of enduring environmental degradation. Furthermore, it examines economical materials and techniques for the construction of resilient and efficient solar trackers. The source emphasises the significance of material selection in guaranteeing both efficiency and enduring durability of solar tracking systems.

2.3.4 Hybrid Energy Systems and Solar Tracking

The final study from ScienceDirect [10] examines the utilisation of hybrid energy systems, which integrate solar and additional renewable energy sources, like wind. The incorporation of dual-axis solar tracking devices into hybrid vehicles facilitates a more adaptable and efficient energy provision. Hybrid systems are particularly advantageous in off-grid or isolated locations, where reliable power generation from a singular energy source may be difficult. By employing solar tracking, these systems may optimise solar energy capture, hence enhancing overall efficiency and sustainability

Table 2.2 Comparative Analysis of Key Features

Topic	Wiley [6]	MDPI [7]	ResearchGate [8]	IJSREM [9]	ScienceDirect [10]
Focus	Sustainable electric systems with solar integration	IoT-enabled smart energy monitoring	Design of dual-axis solar tracking with IoT monitoring	Fabrication and analysis of solar trackers	Review of hybrid energy systems and solar tracking
Technology Highlight	Solar PV systems, energy storage	IoT-based monitoring, energy optimization	Arduino-based IoT integration	Design and material considerations	Hybrid systems including wind and solar
Energy Efficiency	Emphasis on sustainable electricity storage	Optimization through IoT integration	Improved solar capture efficiency	Dual-axis systems enhance efficiency by 30-45%	Comparison of hybrid and tracking systems
Cost Analysis	Discusses cost-efficiency in renewables	Cost reduction through automation and IoT monitoring	Low-cost implementation with Arduino systems	Highlights affordability and materials selection	Compares costs between hybrid and single systems
Challenges	Storage, grid integration, sustainability	Need for reliable data communication and management	Precision in solar tracking, mechanical challenges	Maintenance, material durability, system stability	Integration and control of hybrid renewable systems

2.4 Design and Development of a 10 WP Solar Panel Tracking System Based on RTC and Arduino

This research aims to create an economical, compact solar tracking system, specifically designed for low-power applications like residential or educational setups [11]. The system employs a Real-Time Clock (RTC) and an Arduino as the control unit. The RTC monitors the sun's position by configuring the solar panel's tilt to align with solar time, so guaranteeing the panel continually faces the sun throughout the day. This design is pre-programmed to follow the sun's anticipated trajectory, in contrast to more intricate systems that depend on sensors such as Light Dependent Resistors (LDRs) for sunlight detection

The primary benefit of this method is its simplicity and affordability. The necessity for real-time sunshine sensing, depending instead on precise temporal modifications. This approach presupposes clear weather conditions, as the system fails to consider cloudy or diffuse light scenarios. Nonetheless, the design has demonstrated an enhancement in energy capture by roughly 25% relative to fixed solar panels, rendering it a compelling choice for small installations that do not necessitate optimal efficiency.

2.4.1 Design and Development of a Single-Axis Solar Tracking System

The present study introduces a conventional single-axis solar tracking system that use light-dependent resistors (LDRs) to measure sunlight intensity and modify the panel's orientation accordingly [12]. The device is engineered to track the sun from east to west, enhancing the energy capture of the photovoltaic panel by maintaining a perpendicular orientation to the sun's rays. The utilisation of LDRs enables the system to execute real-time modifications according to the sun's actual location, instead of depending on pre-established timetables.

This design's principal strength is its performance under diverse lighting conditions. The LDRs continuously assess sunshine intensity, enabling the system to modify its orientation to optimise sunlight absorption, even during partially overcast conditions. This adaptability renders the system more efficient than time-based trackers, such as the one outlined in the initial paper. The study indicates that the system's energy efficiency can improve by up to 30% compared to fixed panels, rendering it suitable for medium-scale applications like commercial solar farms. The utilisation of a singular axis, however, constrains the system's capacity to maximise energy capture, as it adjusts solely in one direction.

2.4.2 Development and Comparison of Various Solar Tracking Systems

This ScienceDirect article offers a comprehensive evaluation of several sun tracking systems, including fixed, single-axis, and dual-axis configurations [13]. The authors evaluate these systems for performance and cost, offering critical insights into their suitability for applications. This research indicates that dual axis tracking systems provide the greatest potential for energy gain, although they are also the most costly and intricate to deploy.

This study revealed that fixed panels had the lowest efficiency, capturing merely 70% of the energy that a fully optimised system might harness. Single-axis systems, which modify the panel's orientation along a single axis (either east-west or north-south), provide a compromise option, enhancing energy capture by around 30%. Dual-axis systems, which orient the panel in two directions to optimise alignment with the sun's varying altitude and azimuth, demonstrated the greatest energy gains, capturing up to 40% more energy than fixed systems.

2.4.3 Design of a Dual-Axis Solar Tracker with Efficient Power Management

This research, published in MDPI Applied Sciences, explores the design and development of a dual-axis solar tracker utilising both sensor-based and astronomical data-based tracking methods [14]. In contrast to the previously examined single-axis trackers, dual-axis systems monitor the sun's trajectory in two dimensions: east to west (azimuth) and vertically (altitude). This enables the solar panels to maintain alignment with the sun continuously, hence enhancing energy capture efficiency significantly.

This study's dual-axis tracker employs a mix of LDR sensors and pre-programmed sun positions to maintain precise tracking, regardless of variations in ambient conditions. During overcast conditions, the system may utilise astronomical data to ascertain the sun's position, thereby maintaining alignment despite the absence of direct sunlight. The outcome is an enhancement in energy efficiency of up to 40%, representing a substantial advancement compared to fixed or single-axis systems.

Notwithstanding the efficiency improvements, the study indicates that dual-axis systems entail heightened complexity and expense, including both the necessary hardware and the software algorithms utilised for control. Moreover, dual-axis trackers are more prone to mechanical degradation owing to the greater quantity of moving components, potentially elevating long-term maintenance expenses.

2.4.4 Performance of Single and Dual-Axis Tracking Systems in Different Climates

The concluding study, published in MDPI Energies, assesses the efficacy of single and dual axis tracking devices under various environmental circumstances [15]. The study indicates that single-axis systems excel in clear weather, whereas dual-axis systems demonstrate enhanced performance in settings with diffuse sunlight, including cloudy or partially cloudy environments.

The research evaluates the energy capture of two tracking system types over diverse geographic regions, encompassing sunny, temperate, and overcast temperatures. Single-axis systems can enhance energy capture by approximately 30% in sunny climes, whilst dual-axis systems can provide up to a 40% gain in regions with changing weather conditions. This is especially significant in areas where diffuse sunlight, caused by cloud scattering, is common, as dual-axis devices can pivot in both directions to maximise light collection under suboptimal conditions.

Table 2.3 Comparative Table

Feature	10 WP Solar Panel Tracking (RTC & Arduino) [11]	Single-Axis Solar Tracking System [12]	Comparison of Tracking Systems [13]	Dual-Axis Solar Tracker [14]	Performance in Different Climates [15]
Type of Tracking	Single-Axis	Single-Axis	Single & Dual-Axis	Dual-Axis	Single & Dual-Axis
Control Mechanism	RTC & Arduino	LDRs & Microcontroller	Feedback Loops & Sensors	Hybrid: LDRs + Astronomical Data	Sensors & Astronomical Data
Efficiency Improvement	~25%	~30%	Single: 30%, Dual: 40%	Up to 40%	Single: ~30%, Dual: ~40%
Complexity	Low	Medium	Single: Medium, Dual: High	High	Medium to High
Cost	Low	Medium	Single: Medium Dual: High	High	Varies by Region
Maintenance Needs	Minimal	Moderate	Varies	High	Moderate to High
Best Applications	Small Installations	Small to Medium Installations	Medium to Large Installations	Large Installations	Location-Specific

2.5 Solar Tracking Technologies

The Journal article provides an overview of sun tracking technology, encompassing both single-axis and dual-axis systems [16]. Single axis tracking systems rotate solar panels along a singular axis, generally aligning with the sun's trajectory from east to west. Dual-axis systems are more sophisticated, enabling the solar panel to shift both horizontally and vertically to more precisely track the sun's position throughout the day and year. The chapter highlights that dual-axis systems provide greater energy efficiency, enhancing energy absorption by as much as 40%, however they are costlier and more intricate than single-axis systems. This chapter discusses the significance of microcontrollers in achieving accuracy in solar panel positioning, particularly within active tracking systems. Passive systems, which depend on natural phenomena such as solar heat for panel movement, are recognised as less efficient and less precise, yet considerably more economical. Hybrid systems integrate both active and passive components to optimise cost and performance.

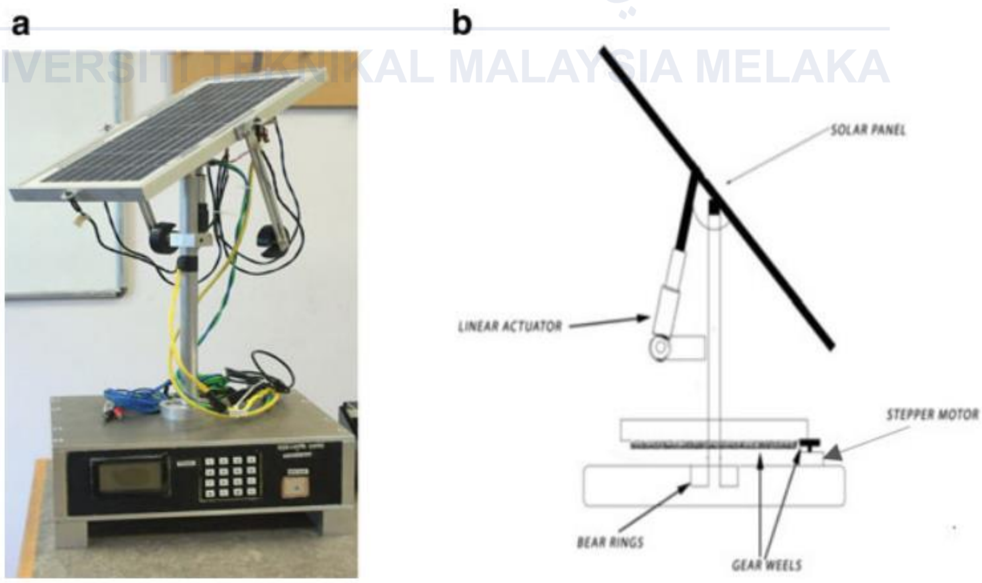

Figure 2.2 Design solar tracker

2.5.1 Development of Sun-Tracking Solar Panel Using Arduino

The research provides a straightforward yet efficient approach for creating a sun-tracking system utilising Arduino microcontrollers [17]. Arduino is a widely used open-source platform enabling developers to construct cost-effective and customisable projects. The sun-tracking system employs light-dependent resistors (LDRs) as sensors and servo motors to modify the solar panel's orientation according to the direction and intensity of sunlight. The principal benefit of this system is its cost-effectiveness and simplicity of deployment, rendering it suitable for small-scale or individual solar energy initiatives. The study indicates that the Arduino-based system enhances energy efficiency by around 20–30% relative to static solar panels. Nevertheless, it lacks the accuracy and efficacy of more sophisticated systems, especially those employing dual axis tracking and machine learning algorithms.

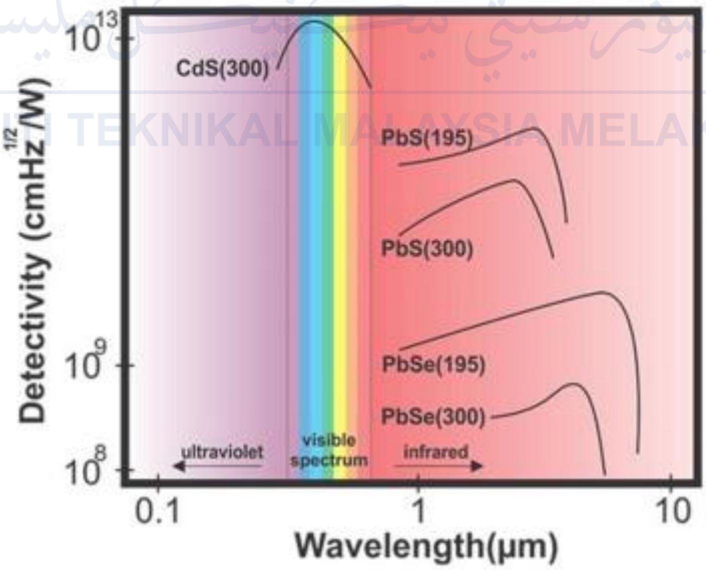

Figure 2.3 Wavelength of Light Dependent Resistor (LDR)

2.5.2 IoT and AI-Integrated Solar Tracking Systems

The document introduces a sophisticated method for solar tracking with the incorporation of Internet of Things (IoT) technology and artificial intelligence (AI) [18]. This study enhances dual-axis solar trackers with IoT-based systems that monitor real-time weather conditions, solar irradiance, and temperature to optimise the positioning of solar panels. Predictive AI algorithms enhance the system's efficiency by anticipating solar patterns, thereby guaranteeing optimal panel positioning even without direct sunlight. This integration results in enhanced accuracy and energy improvements of up to 45% compared to static systems. The heightened complexity and dependence on data processing and internet connectivity render the system more costly and necessitate constant maintenance, especially for the AI and IoT components. However, the enduring advantages of energy conservation and operational efficacy render this technology appealing for extensive solar farms and commercial solar power facilities.

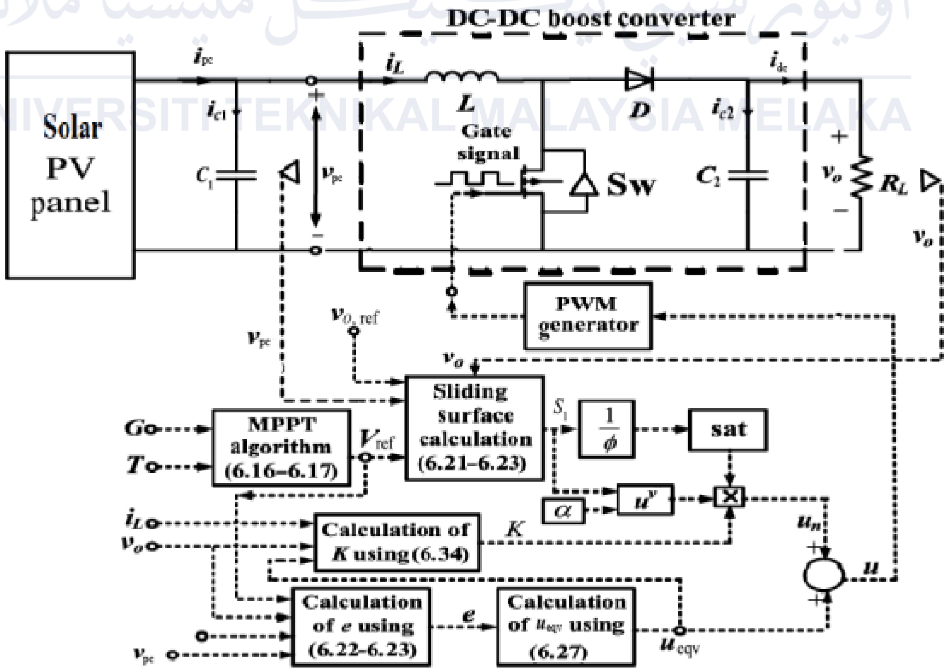

Figure 2.4 IoT and AI-Integrated Solar Tracking Systems

2.5.3 Solar Energy Optimization Using Sun Tracking

This paper assesses the efficacy of several sun tracking systems and their role in energy optimisation [19]. The emphasis is on dual-axis tracking systems, which have repeatedly demonstrated superior performance compared to single-axis and stationary systems. The paper presents a comprehensive examination of the energy gains gained by dual-axis systems, which can achieve up to 45% under some situations, especially in regions with significant sunshine variability. The research highlights the significance of automation and sensor precision in enabling the panels to adapt swiftly and effectively to varying illumination conditions. It also addresses the possible drawbacks, including elevated installation expenses and the necessity for frequent calibration and maintenance, particularly in regions with severe weather conditions. Although dual-axis tracking is exceptionally efficient, it may lack cost-effectiveness for smaller installations due to the elevated initial expenses linked to complex control systems and sensors.

2.5.4 AI-Powered Solar Tracking

The work expands on prior studies by incorporating machine learning methods to enhance solar panel location [20]. This system forecasts solar patterns using historical data and weather predictions, rather than depending exclusively on real-time sensor data, enabling it to anticipate variations in sunshine and make necessary adjustments. This predictive capacity results in enhanced energy efficiency, with the study indicating benefits of up to 50% in certain instances. This automatic system optimises performance in areas with variable illumination circumstances, including frequent cloud cover or seasonal changes, by reducing the necessity for human intervention. Nonetheless, the expense and intricacy of deploying such a system continue to pose considerable obstacles, constraining its viability for system.

Table 2.4 Comparative Insights

Feature	Springer Chapter	UniKL Paper (Arduino)	IEEE Paper (IoT + AI)	Sci. Direct (2017)	Sci. Direct (2018)
Tracking Type	Single/Dual Axis	Single axis (Arduino)	Dual axis (IoT, AI integration)	Dual axis	Dual axis
Control Method	Active/Passive	Arduino-based (LDR, Servo Motors)	AI + IoT Algorithms	Automated (based on sensors)	Predictive algorithms (ML)
Efficiency Improvement	20-40%	20-30%	45-50%	45%	40-50%
Complexity	Moderate	Low	High	High	Very High
Cost	Moderate	Low	High	Moderate	High

2.6 Summary

The primary objective of the literature review is to establish a theoretical framework and background for the study, while also identifying areas where information is lacking and opportunities for further research. The review focuses on literature relevant to stationary photovoltaic (PV) panels and PV panels equipped with tracking systems. The text thoroughly explores a range of subjects, such as performance assessment, sun tracking technologies, and solutions for solar tracker. The literature review provides a thorough evaluation of the theories, methodology, and conclusions of prior studies. It highlights their significance in the field and addresses any discrepancies or differing viewpoints. The findings obtained from this review will form the foundation for the following chapters, directing the formulation of the project's research hypotheses, methodology, and data analysis procedures.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss the techniques and approaches that will be used for this project. The methodology is a structured set of principles that must be adhered to to successfully accomplish a task or project. This chapter will provide a comprehensive overview of the entire project process, starting from the first stages and concluding with the final stages. This chapter will thoroughly analyze each procedural process to enhance understanding. The method must be rigorously adhered to guarantee the successful completion of the project. This chapter will also include the project's timeline and regimen. The project plan and schedule will provide a comprehensive outline of all necessary tasks and their corresponding timelines for completion. This chapter is essential for ensuring the project is completed on schedule.

3.2 System design

The effectiveness of a solar power system depends on a carefully designed framework. This part reveals the complexities of this pivotal stage, offering a clear path to comprehend the sequential procedures of the suggested system. An elaborate schematic diagram Explores the complex relationship between stationary and mobile solar panels, emphasizing their smooth incorporation.

However, efficiency goes beyond hardware alone. The Software part focuses on the careful selection of instruments that will coordinate the evaluation of the system. By explaining the strategic decisions involved in choosing software, we reveal the computational engine that powers the project's analytical capabilities.

Transparency and assertiveness are of utmost importance. In this part, the use of the passive voice highlights the methodological approach used to ensure an accurate and professional analysis of the factors that influence the evaluation of both fixed and tracking solar panels.

3.2.1 Flow Chart

The solar tracker system is activated by detecting environmental conditions using the LDR sensor, voltage sensor, and current sensor. The system determines if it is daytime by comparing the data from the Light Dependent Resistor (LDR) to a specific threshold value. If the answer is yes, the system calculates the best position for the monocrystalline solar panel by considering the intensity of sunlight and the angle at which it hits the panel. It uses stepper and servo motors to adjust the panel's azimuth and tilt, respectively. The system simultaneously monitors the levels of voltage and current and presents them on the 7-segment display. This procedure continuously loops to guarantee that the solar panel remains aligned with the sun throughout the day, hence maximizing energy efficiency.

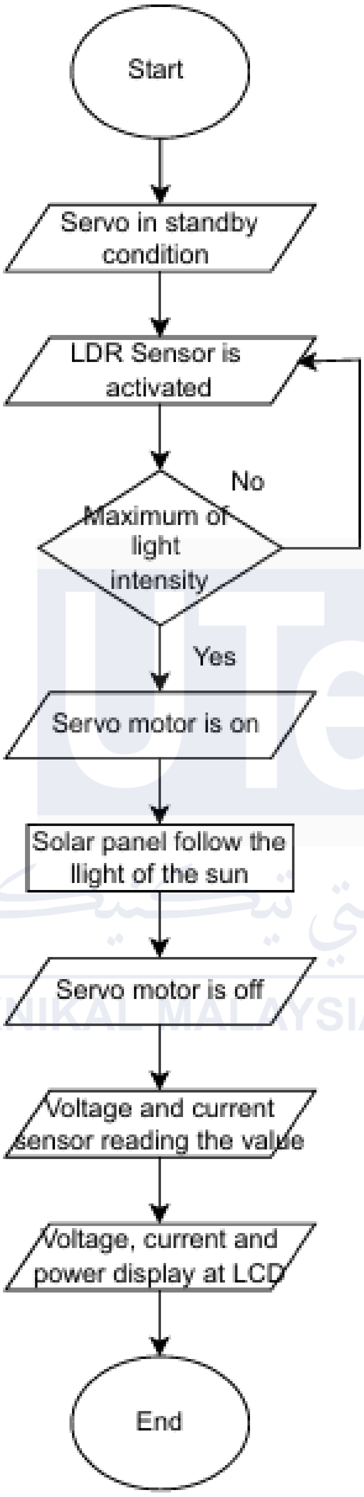

Figure 3.1 Flowchart of Solar Panel Tracking Devices

3.2.2 Block Diagram

The block diagram depicts the operation of a dual-axis solar panel tracking system, which captures sunlight through the solar panel. The system comprises multiple sensors: a voltage sensor, a Light Dependent Resistor (LDR) sensor, and a current sensor, which assess the panel's output and the intensity of sunlight. The sensor data undergoes processing by an Arduino controller, which subsequently regulates the movement of the solar panel via a servo motor, enabling positional adjustments for optimal sunlight exposure throughout the day. A Liquid Crystal Display (LCD) is employed to present real-time data, including voltage, current, and efficiency, thereby offering feedback on the system's performance. This configuration guarantees optimal alignment of the solar panel to enhance energy capture via dual-axis tracking.

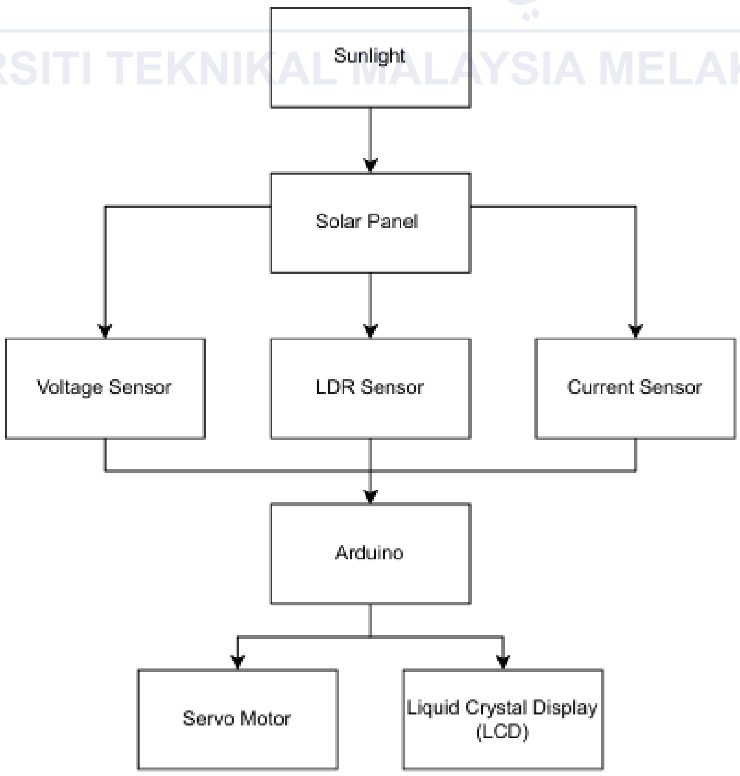

Figure 3.2 Block Diagram of Solar Panel Tracking Devices

3.2.3 Software Decision

There are three software used to succeed in this project.

a) Arduino IDE

b) Proteus 8 Professional

c) SolidWorks

3.2.3.1 Arduino IDE

The Arduino Integrated Development Environment (IDE) plays an important role for enabling the successful execution of this project. It serves as the programming platform for the Arduino microcontroller board, enabling the development and execution of control algorithms for the solar tracker. Using the IDE, the microcontroller may get data from various sensors, including those on the stationary PV panel and the PV panel with a tracking device, environmental sensors, and light sensors. This allows for the collection of performance-related data. Furthermore, the Arduino IDE simplifies the exchange of information between the microcontroller and other devices, such as a central control unit or data logging module. It also enables data recording and analysis, which assists in assessing the performance of both the stationary PV panel and the PV panel equipped with a tracking device over a period.

Figure 3.3 Arduino IDE

3.2.3.2 Proteus 8 Professional

A solar tracker is a device used in solar energy systems to optimize the efficiency of solar panels by constantly aligning them with the sun's position throughout the day. The dynamic orientation of the solar panels ensures that they are positioned to receive the highest amount of sunlight, hence maximizing energy production. Proteus 8 Professional, a widely-utilized software for electronics simulation and design, allows for the virtual simulation and testing of a solar tracker to assess its performance under different circumstances. Engineers can utilize the Proteus environment to incorporate sensors, motors, and control algorithms, enabling them to build, simulate, and improve solar tracker systems before to their actual implementation in real-world scenarios. This feature enables the effective creation, identification and improvement of solar tracking systems, ultimately aiding the progress of renewable energy technologies.

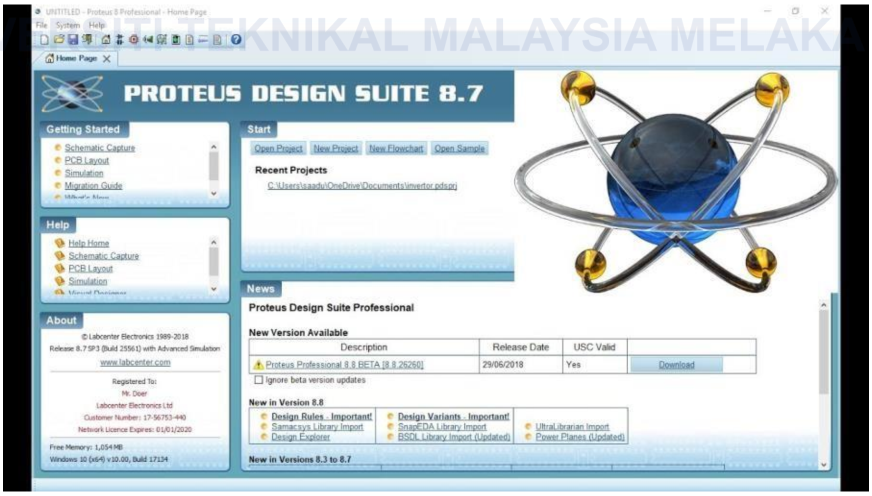

Figure 3.4 Proteus 8 Professional

3.2.3.3 SolidWorks

SolidWorks is robust software used for designing solar trackers, which are essential elements in solar energy systems for maximizing energy capture. Engineers can utilize SolidWorks software to generate accurate 3D models of solar tracker mechanisms, integrating diverse elements such as motors, sensors, gears, and mounting structures. The software enables comprehensive examination of mechanical strain, range of motion, and effectiveness, guaranteeing that the design fulfils performance criteria and endures environmental circumstances. The simulation capabilities of SolidWorks allow engineers to analyze and evaluate the performance and endurance of the tracker by testing numerous scenarios, such as variable sunlight angles and wind loads. Moreover, SolidWorks enhances teamwork by offering a platform for exchanging designs, making modifications, and guaranteeing smooth interaction with other components of the solar energy system. In summary, SolidWorks is crucial in the creation and improvement of effective and dependable solar trackers, hence aiding the progress of renewable energy technologies.

Figure 3.5 SolidWorks

3.3 System Development

Solar tracker systems are crucial for maximizing the effectiveness of solar panels by continuously synchronizing them with the sun's position throughout the day. The solution we propose employs a blend of hardware components and sensors to accomplish accurate sun tracking. The system primarily integrates a monocrystalline solar panel renowned for its exceptional efficiency in converting sunlight into electricity. An Arduino Mega 2560 microcontroller is used to regulate the movement of the solar panel, acting as the central processing unit of the system and synchronizing the functions of different components.

The Light Dependent Resistor (LDR) sensor is crucial for the solar tracking feature as it measures the intensity of sunlight. Arduino utilizes data from the LDR sensor to compute the most advantageous orientation for the solar panel, ensuring optimal exposure to sunlight. The provided information is used to control the SG90 servo motor, which is responsible for precisely regulating the tilt angle of the solar panel. This ensures that the solar panel perfectly tracks the sun's path throughout the day. Furthermore, a stepper motor is utilized to spin the solar panel on its axis, ensuring that it stays aligned with the sun's east-west movement.

To oversee the system's operation and guarantee safety, the design incorporates voltage and current sensors. These sensors offer immediate input on the electrical output of the solar panel, enabling changes to maximize power generation and avoid overloading. The information gathered from these sensors can be exhibited for user convenience using a 7-segment display, offering valuable understanding into the functioning and energy generation of the system.

In summary, solar tracker system utilizes high-tech hardware components, including monocrystalline solar panels, Arduino microcontrollers, servo and stepper motors, as well as sensors such as LDR, voltage, and current sensors. This combination ensures an effective and dependable solution for optimizing the collection of solar energy. The technology maintains optimal energy generation throughout the day by continuously aligning the solar panel with the sun's path, thereby contributing to sustainable and eco-friendly power generation.

3.3.1 Hardware Decision

There are 8 hardware used to succeed in this project.

a) Monocrystalline Solar Panel

b) Polycrystalline solar panel

c) Arduino Mega 2560

d) LDR sensor

e) MG 995 Servo motor

f) Voltage sensor

g) Current sensor

h) Liquid Crystal Display (LCD)

3.3.1.1Monocrystalline Solar Panel

By integrating monocrystalline solar panels with a solar tracker, one can achieve an optimal solution to enhance energy generation. Monocrystalline panels, known for their exceptional efficiency and compact design, are especially suitable for this purpose. Their intrinsic efficiency guarantees the highest level of electricity generation, maximizing the utilization of the available sunshine. Moreover, their robust structure can endure various weather conditions, making them perfect for outdoor installations, which are often seen with solar trackers. Furthermore, monocrystalline panels provide a superior power density, resulting in a greater amount of power generated per square meter. This is a significant benefit in situations when space is limited. Although the initial expenses may be more, the long-term advantages, particularly when combined with solar trackers, frequently surpass the initial capital outlay. The appeal of monocrystalline panels for solar tracker applications is further enhanced by their compatibility with the chosen tracker system and the solid guarantee and support provided by their maker.

Figure 3.6 Monocrystalline Solar Panel

3.3.1.2 Polycrystalline Solar Panel

Using a polycrystalline solar panel for your final year project to create a dual-axis solar tracking system is a realistic and cost-effective option. These panels are noted for being less expensive than monocrystalline equivalents, making them perfect for applications on a tight budget. While their efficiency, which normally ranges between 15% and 17%, is slightly lower than that of monocrystalline panels, they still give adequate performance for experimental settings. Polycrystalline panels also work well in a variety of lighting settings, which is useful when testing the tracking system. By incorporating a dual axis tracking mechanism, the project can maximise the panel's energy output by ensuring that it is constantly aligned with the sun, illustrating the effectiveness of solar tracking technology in enhancing energy efficiency.

Figure 3.7 Polycrystalline Solar Panel

3.3.1.3 Arduino Mega 2560

The Arduino Mega 2560 microcontroller board is a robust platform suitable for developing a solar tracker system. The Mega 2560 has many digital and analogue input/output pins, allowing it to easily connect with different sensors, such as light-dependent resistors (LDRs) or photovoltaic cells. This enables the detection of both the intensity and direction of sunlight. By incorporating this data with precision servo motors or stepper motors regulated by the Maga’s PWM outputs, the solar panels may be precisely aligned with the sun's position throughout the day, optimizing their energy collection. Furthermore, the Mega 2560's computational capacity allows for the execution of algorithms that enhance tracking techniques by considering variables like time of day, season, and geographical location. The Arduino Mega 2560 is an ideal option for creating efficient and customizable solar tracking solutions due to its versatility and the extensive community of developers and resources available.

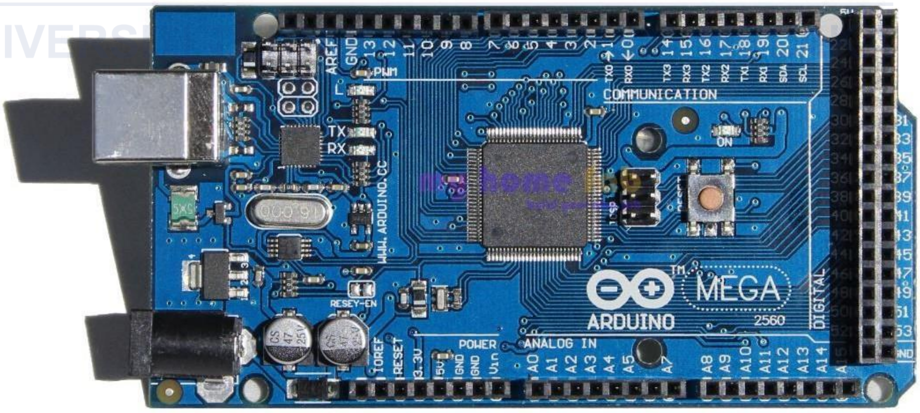

Figure 3.8 Arduino Mega 2560

3.3.1.4 Light Dependent Resistor Sensor (LDR)

A Light Dependent Resistor (LDR) is an essential element used in solar trackers to maximize the effectiveness of solar panels. Within the realm of solar tracking systems, an LDR functions as a sensor that discerns alterations in luminous intensity. The LDR is strategically positioned, typically on top of the solar panel array, to continuously measure the intensity of incoming light. The solar tracker continuously monitors changes in light intensity throughout the day and adjusts the orientation of the solar panels appropriately. This ensures that the panels are always positioned at the most favorable angle to receive the highest amount of sunshine. This adaptive modification improves the total energy production of the solar panels, hence increasing the efficiency and cost-effectiveness of the system. The LDR's capacity to precisely measure light levels in real-time enables the solar tracker to adjust to dynamic environmental factors, such as cloud cover or varying sun angles, hence optimizing the conversion of solar energy into electricity.

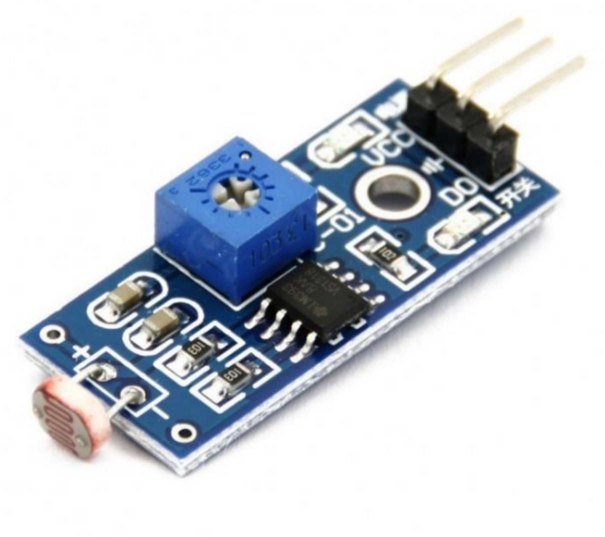

Figure 3.9 LDR sensor

3.3.1.5 MG 995 Servo Motor

The SG90 servo motor is widely favored for solar tracker systems because of its small size, cost-effectiveness, and high efficiency. The SG90 servo motor is essential in a solar tracker application since it is responsible for altering the position of solar panels to accurately monitor the sun's movement throughout the day. The tracker optimizes energy generation by continuously aligning the solar panels with the sun, maximizing the amount of sunlight captured. The SG90 servo motor provides precise control and seamless motion, making it ideal for correctly altering the position of solar panels. The lightweight design of the solar tracker system also decreases its overall weight, facilitating installation and maintenance. Moreover, the SG90 servo motor is renowned for its minimal power consumption, making it highly beneficial for solar-powered applications that priorities energy efficiency. The SG90 servo motor is a highly recommended option for solar tracker systems because to its exceptional dependability, precision, and cost-effectiveness.

Figure 3.10 Servo Motor

3.3.1.6 Voltage Sensor

Voltage sensors are essential components in solar tracking systems, as they are responsible for guaranteeing the highest level of performance and efficiency. These sensors play a crucial role in measuring the voltage output of solar panels or arrays. Through the continual measurement of voltage levels, they offer crucial feedback to the solar tracker system, enabling it to precisely alter the position of the panels to optimize sunshine exposure.

Voltage sensors are commonly placed at multiple locations throughout the solar array to precisely measure voltage measurements. They identify variations in electrical potential resulting from alterations in the brightness of sunlight, obstructing objects, or external conditions. The real-time data allows the solar tracker to make accurate modifications, guaranteeing that the panels are consistently positioned at the most advantageous angle to gather the most possible quantity of sunshine throughout the day.

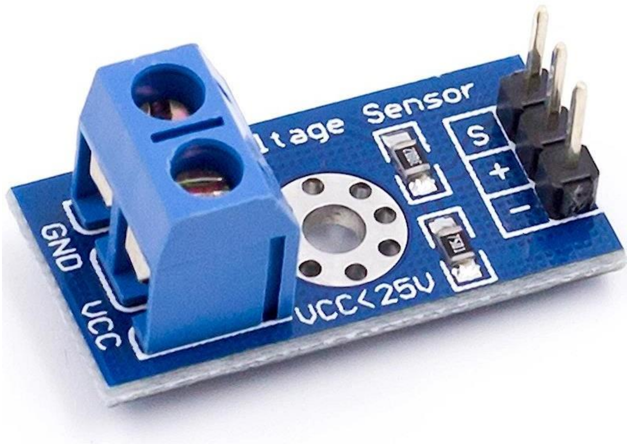

Figure 3.11 Voltage Sensor

3.3.1.7 Current Sensor

The current sensor is a vital element in a solar tracker system, as it plays a critical role in maximizing the efficiency of solar panels. These sensors generally gauge the electrical current passing through the panels, offering crucial input to the tracking system regarding the quantity of sunlight received and the effectiveness of power generation. The tracker continuously monitors the current and adjusts the orientation of the solar panels to ensure they are always positioned at the best angle in relation to the sun, hence maximizing energy output. Contemporary current sensors frequently employ sophisticated technology, such as Hall effect sensors or shunt resistors, to precisely and reliably detect electric current. In addition, certain sensors may include temperature adjustment capabilities to adjust for ambient variables that may impact the panels' functionality. In solar tracker systems, the current sensor plays a vital role in enhancing energy production and efficiency.

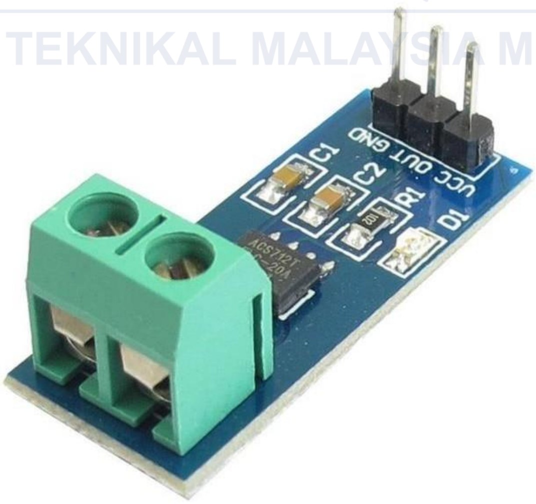

Figure 3.12 Current Sensor

3.3.1.8 Liquid crystal display (LCD)

In the creation of a dual-axis solar panel tracking device, a Liquid Crystal Display (LCD) is critical for real-time monitoring and data visualisation. The LCD displays important parameters such as current, voltage, and power generated by the solar panel system. This real-time data is critical for determining the tracking system's performance because it allows users to see how well the panel is orientated towards the sun to maximise energy output. The display has a user-friendly interface that allows for smooth interaction with the system, making it more practical and usable for monitoring and optimising solar energy performance.

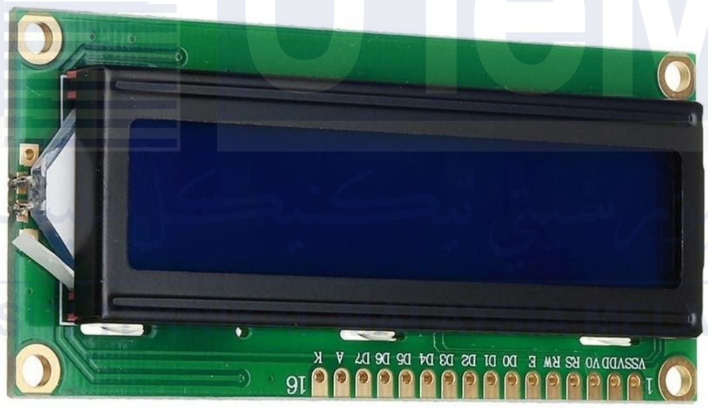

Figure 3.13 LCD Display

3.4 System Analysis

The advancement of dual-axis solar panel tracking systems has demonstrated efficacy in improving the energy efficiency of solar power generation. The dual-axis tracker maintains the solar panels' alignment with the sun's position throughout the day, from 8 AM to 5 PM, by altering their orientation along two axes: azimuth (horizontal) and elevation (vertical). This regular alignment enhances energy absorption by the solar panels, resulting in a substantial boost in energy output relative to fixed panels. The dual-axis device can enhance solar energy production by roughly 30-40% throughout the day. Nonetheless, although the system delivers enhanced efficiency, it entails elevated initial installation expenses and more intricate maintenance demands owing to the moving components involved.

Conversely, stationary solar panels, usually positioned at a 45° angle, do not follow the sun's trajectory and consequently function at suboptimal angles during certain times of the day, particularly in the early morning or late afternoon. The efficiency of fixed panels is rather static, and their energy output is generally worse, particularly in comparison to tracking systems. Fixed panels are more straightforward, economical, and necessitate minimal maintenance; however, they only harness optimal sunlight during periods, notably around midday when the sun is positioned directly overhead.

The efficacy of solar panels is contingent upon the specific type of panel employed. Monocrystalline panels typically exhibit more efficiency than polycrystalline panels. Monocrystalline panels generally provide superior conversion efficiencies (15-20%) and enhanced performance in low-light settings, yielding more energy output from 8 AM to 5 PM, particularly during the morning and late afternoon when sunlight is less direct. Conversely, polycrystalline panels, albeit marginally less efficient (13-17%), are more economical and exhibit superior performance in elevated temperature conditions.

Data obtained on solar irradiance, current, and voltage throughout the day, from 8 AM to 5 PM, reveals significant variations in energy output. The dual axis tracking system with monocrystalline panels is expected to demonstrate a superior total energy yield during the day, since it adapts to maintain the panels' alignment with the sun's shifting position. In contrast, the permanent 45° solar panels exhibit peak energy output around midday but experience a substantial decline in the early morning and late afternoon when the sun's angle is sharper.

In conclusion, dual axis tracking systems, especially when combined with monocrystalline panels, surpass fixed systems, particularly in areas with considerable fluctuations in solar angles during the day. Nonetheless, they entail increased expenses and maintenance demands. Fixed systems, however less efficient, provide a more straightforward and cost-effective solution, especially in areas with a stable solar trajectory or where initial installation expenses and maintenance simplicity are prioritised. The selection between these two systems is contingent upon criteria including installation budget, maintenance capability, spatial availability, and the geographic position of the solar installation.

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CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This study's results and discussion focus on the effectiveness of dual-axis solar panel tracking systems relative to fixed solar panels positioned at a 45-degree tilt, utilising both monocrystalline and polycrystalline solar panels. Solar irradiance fluctuates throughout the day, generally reaching its zenith at midday and diminishing during the morning and evening. Dual axis tracking systems, which adjust both horizontally and vertically to follow the sun, are anticipated to achieve superior alignment with the sun's position throughout the day, leading to enhanced solar energy capture compared to fixed panels that are inadequately aligned during non-peak hours. Monocrystalline panels, recognised for their superior efficiency, are anticipated to generate larger current and voltage compared to polycrystalline panels under identical conditions, resulting in enhanced energy production. Conversely, polycrystalline panels, while less efficient, are more economical and yet deliver a satisfactory energy output, particularly in scenarios where cost factors take precedence over efficiency. The efficacy of the dual axis tracking system will be most apparent during early morning and late afternoon when stationary panels are sub optimally orientated. The dual axis tracking system with monocrystalline panels is expected to yield the maximum overall energy output, sustaining elevated energy production levels throughout the day. This study emphasises the benefits of integrating advanced tracking technology with high-efficiency monocrystalline panels for superior solar energy performance; however, additional research may investigate the integration of tracking systems with polycrystalline panels to achieve a more cost-effective yet efficient solution.

4.2 Project Design

Solar power has become a crucial element of sustainable energy solutions due to the rapid expansion of renewable energy technology. Solar tracking systems have garnered considerable interest due to their capacity to improve the efficiency of photovoltaic (PV) panels. A dual-axis solar tracker enhances the alignment of solar panels by modifying both the horizontal and vertical axes, so maximizing the absorption of solar energy throughout the day and across different seasons. The objective of this final year's project is to create and construct a dual-axis solar tracker using SolidWorks, a prominent computer-aided design (CAD) software. The objective of the research is to develop a practical and effective tracking system that can greatly enhance the energy generation of solar panels. Using SolidWorks' sophisticated modelling and simulation features, our goal is to create a durable and dependable tracker that can endure different climatic conditions while keeping accurate alignment with the sun.

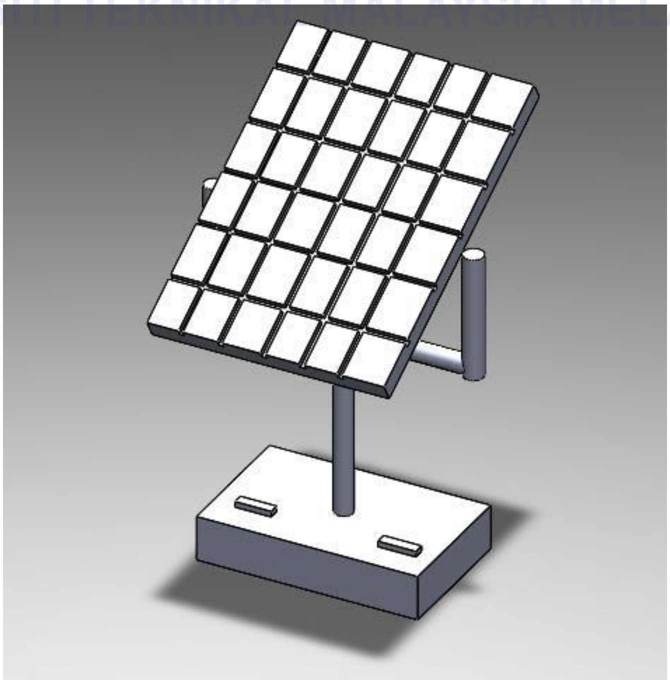

Figure 4.1 SolidWorks 3D View

4.3 Circuit Design

The growing need for renewable energy has spurred progress in solar technology, rendering solar trackers indispensable for optimizing energy acquisition. The objective of this project is to create a dual-axis solar tracker using Proteus 8 simulation software. This tracker improves the efficiency of solar panels by altering their position along two axes to track the movement of the sun. A microcontroller utilizes light-dependent resistors (LDRs) as sensors to process sunlight data and regulate motors responsible for adjusting the panels. Proteus 8 enables comprehensive simulation and testing of circuit designs, guaranteeing functionality prior to actual implementation. The objective of this project is to develop a prototype of a solar tracker that is both cost-effective and efficient, showcasing its practical use in renewable energy.

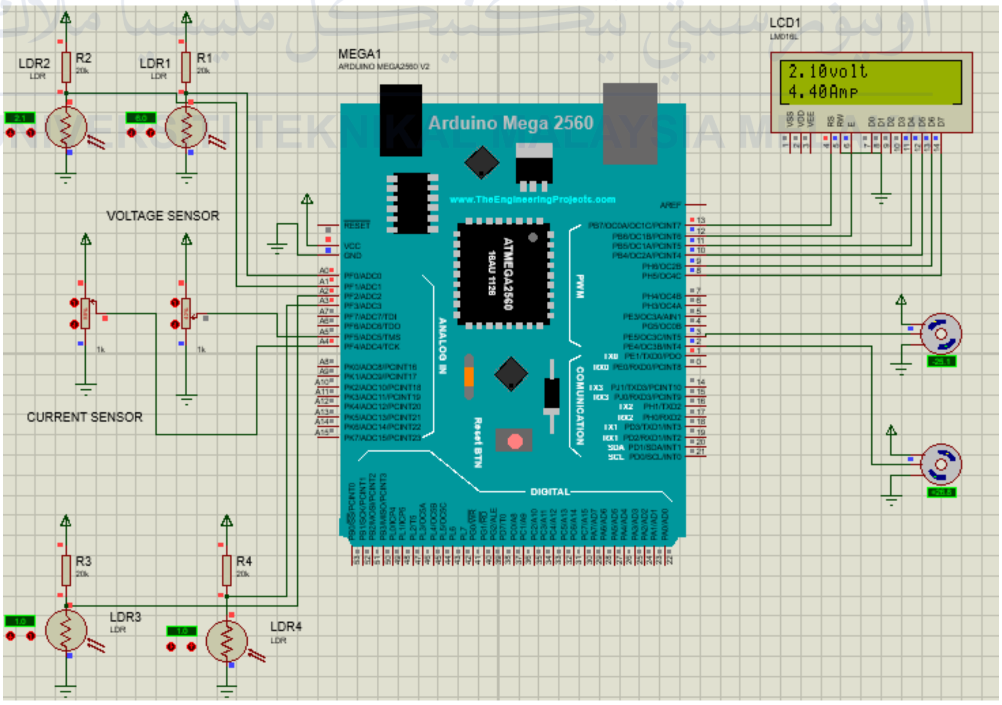

Figure 4.2 Proteus 8 Circuit Diagram

4.4 Project Development

This study focusses on the construction and comparison of two solar panel systems. A stationary solar panel configuration and a dual-axis solar tracking system. The fixed system will orient solar panels at a 45° angle, a standard configuration for optimising solar energy collection year-round. The dual axis tracking technology will alter the solar panels' angles both horizontally and vertically to align with the sun's movement, so optimising exposure and energy generation. The objective is to evaluate the performance of two systems utilising Monocrystalline and Polycrystalline solar panels throughout the day, from 8 AM to 5 PM, by monitoring solar irradiance, current, and voltage data.

The project seeks to ascertain which configuration yields the greatest efficiency in energy capture by assessing the energy output of both panel types and tracking devices under real-world situations. Monocrystalline panels, recognised for their superior efficiency, will be evaluated against the more economical Polycrystalline panels. The collected data will yield insights into the additional energy generated by a dual-axis tracker vs a fixed-position system, as well as the response of each panel type to fluctuating irradiance levels throughout the day. The findings will enhance the optimisation of solar energy systems, providing critical insights for the development of more efficient solar power solutions.

Figure 4.3 Project Development of Polycrystalline Solar Tracker

Figure 4.4 Project Development of Monocrystalline Solar tracker

4.5 Polycrystalline solar panel

Polycrystalline solar panels are constructed from silicon crystals that are fused and subsequently cooled in a mould. This technique yields a less homogeneous structure in contrast to monocrystalline panels, which utilise a single silicon crystal. Consequently, polycrystalline panels generally exhibit marginally poorer efficiency compared to monocrystalline panels, however they are usually less expensive to produce.

The efficiency of polycrystalline solar panels typically varies from 15% to 20%, contingent upon the quality of materials and the technologies employed in their manufacture. These panels are distinguished by their azure tint and unique textured surface. Although polycrystalline panels require more area to produce equivalent power compared to monocrystalline panels, they remain a favoured option for residential and commercial solar installations because of their reduced cost and reliable performance.

Polycrystalline solar panels exhibit durability and has an extended lifespan, generally ranging from 25 to 30 years. Their comparatively low cost and effective performance in diverse weather conditions render them a feasible choice for numerous solar energy systems, including those employing tracking devices to optimise solar exposure.

4.5.1 Analysis of Polycrystalline Tracking Solar Panel and Fixed Solar Panel (45°)

The irradiance research indicates that the solar tracker constantly obtains superior values throughout the day in comparison to the stationary solar panel. The solar tracker attains its maximum irradiance of 614 W/m² at 1:00 PM, whilst the fixed panel obtains a high of 590 W/m² at the same time. The fixed panel underperforms in the early morning and late afternoon because of its static orientation, while the solar tracker optimises irradiance capture by continuously adjusting to the sun's position.

Regarding voltage, both systems show comparable performance at peak hours; however, the solar tracker retains a marginal edge throughout the day. The solar tracker achieves a peak voltage of 6.63 V at 1:00 PM, whilst the fixed panel attains a maximum value of 6.64 V. Although their peak values are comparable, the solar tracker maintains a greater voltage output for an extended duration, enhancing its overall efficacy in power generation.

The solar tracker demonstrates a distinct advantage over the stationary solar panel, especially around midday. The solar tracker attains a peak current of 1.17 A at 1:00 PM, while the fixed panel generates merely 0.96 A at that time. This trend persists throughout the day, as the tracker attains elevated current levels by optimising irradiance exposure. The increased current output immediately enhances the tracker's exceptional power generation.

The solar tracker markedly exceeds the stationary solar panel in electricity output. The solar tracker attains its maximum power of 7.76 W at 1:00 PM, whilst the stationary panel only produces 6.37 W. The solar tracker consistently achieves elevated power levels throughout the day, especially in the afternoon when the output of the fixed panel significantly decreases due to suboptimal alignment with the sun. At the conclusion of the day, the solar tracker generates a total energy output of 55.0 W, which is 20.8% greater than the fixed panel's 45.52 W, illustrating the distinct benefit of employing a tracking system to enhance solar energy gathering.

Table 4.1 Polycrystalline Solar Tracker Data

Time	Solar Tracking Device			
	Irradiance, (W/m^2)	**Voltage, V**	**Current, A**	**Power, W**
8:00 AM	320	5.68 V	0.71 A	4.03 W
9:00 AM	336	5.75 V	0.78 A	4.49 W
10:00 AM	341	6.02 V	0.80 A	4.82 W
11:00 AM	373	6.37 V	0.85 A	5.41 W
12:00 PM	535	6.59 V	1.12 A	7.38 W
1:00 PM	614	6.63 V	1.17 A	7.76 W
2:00 PM	370 (CLOUDY)	6.47 V	1.01 A	6.53 W
3:00 PM	223 (CLOUDY)	6.34 V	0.96 A	6.09 W
4:00 PM	196 (CLOUDY)	6.01 V	0.75 A	4.50 W
5:00 PM	159 (CLOUDY)	5.87 V	0.68 A	3.99 W

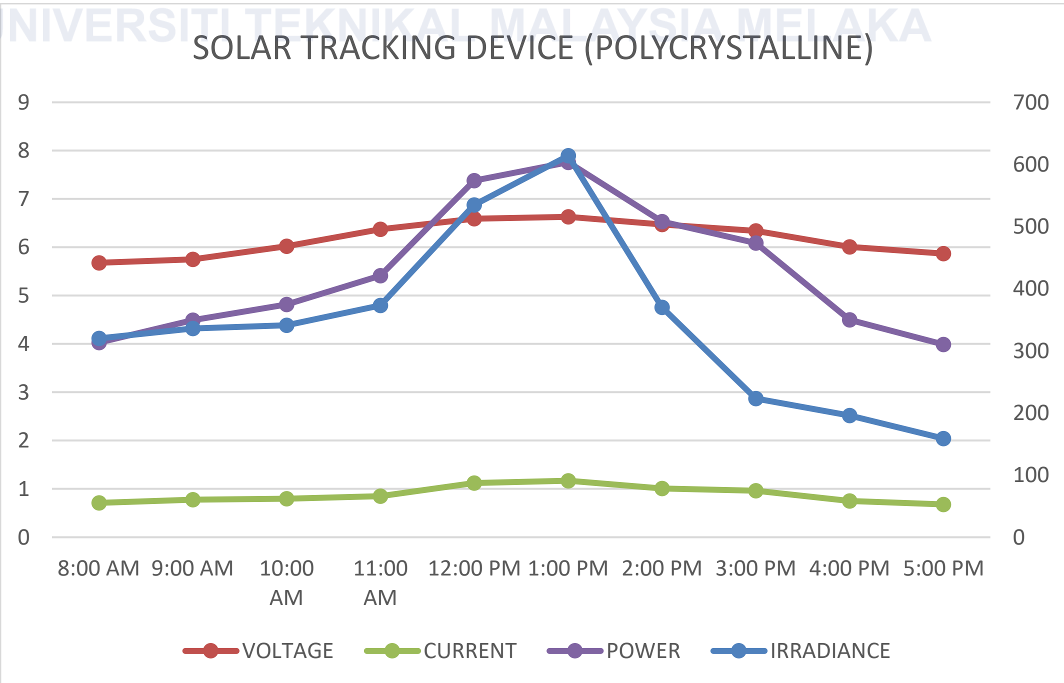

Figure 4.5 Polycrystalline Solar Tracker Data Graph

Table 4.2 Polycrystalline Fixed Solar Panel Data

Time	Fixed Solar Panel (45°)			
	Irradiance, (W/m^2)	Voltage, V	Current, A	Power, W
8:00 AM	102	5.99 V	0.59 A	3.53 W
9:00 AM	140	6.59 V	0.63 A	4.15 W
10:00 AM	367	6.48 V	0.69 A	4.47 W
11:00 AM	410	6.57 V	0.70 A	4.59 W
12:00 PM	530	6.46 V	0.91 A	5.87 W
1:00 PM	590	6.64 V	0.96 A	6.37 W
2:00 PM	217 (CLOUDY)	6.10 V	1.03 A	6.28 W
3:00 PM	211 (CLOUDY)	6.31 V	0.85 A	5.36 W
4:00 PM	100 (CLOUDY)	5.01 V	0.65 A	3.26 W
5:00 PM	93 (CLOUDY)	3.81 V	0.43 A	1.64 W

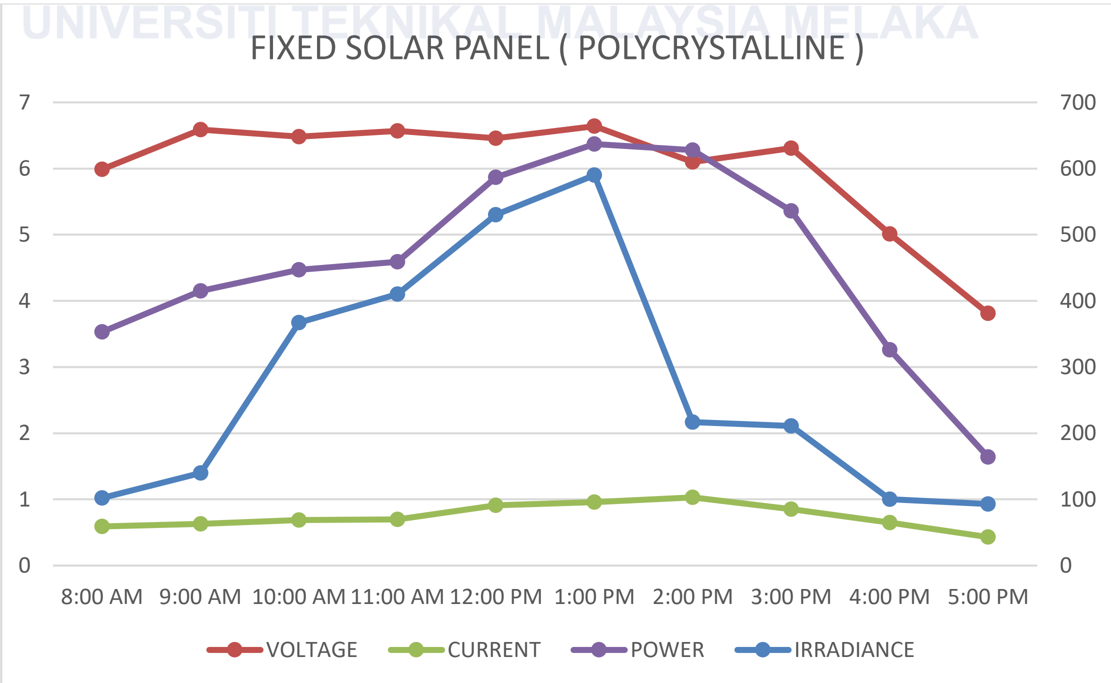

Figure 4.6 Polycrystalline Fixed Solar Panel Data Graph

4.5.2 Effect Of Sun Elevation on Light Intensity for Polycrystalline Solar Tracker

The effect of solar elevation on light intensity is distinctly evident through the LDR values measured at various periods throughout the day. At 8:00 AM, when the sun's elevation angle is 20°, the LDR values are comparatively low (e.g., LDR1 = 200), signifying diminished light intensity due to the sun's lower position. As the sun ascends in the sky, the elevation angle rises, resulting in a consistent increase in LDR measurements. At 12:00 PM, when the elevation angle peaks at 60°, the LDR values attain their maximum (LDR1 = 450, LDR2 = 420), indicating heightened light intensity. This pattern indicates that elevated sun angles produce increased light intensity, as sunlight strikes the sensors more directly, hence diminishing the angle of incidence.

In the afternoon, when the sun sets, the elevation angle diminishes, resulting in a corresponding decrease in LDR values. At 4:00 PM, with the sun at an elevation angle of 40°, the LDR values decrease to lower levels (LDR1 = 250, LDR2 = 230). At 5:00 PM, when the elevation angle reverts to 30°, the LDR values further diminish (LDR1 = 200). This trend demonstrates a distinct association between the sun's elevation angle and light intensity, with LDR values reaching their zenith at midday and diminishing in the early morning and late afternoon. For dual-axis solar panel tracking systems, comprehending this relationship is crucial, since optimising panel orientation with elevated sun angles can markedly enhance light absorption and total energy efficiency.

Table 4.3 Light Intensity and Elevation Angle for polycrystalline Solar Tracker Data

Time	Polycrystalline Solar Tracker				
	LDR 1	**LDR 2**	**LDR 3**	**LDR 4**	**Elevation Angle**
8:00 AM	200	150	180	130	20°
9:00 AM	300	270	250	230	30°
10:00 AM	350	300	290	260	40°
11:00 AM	400	350	340	310	50°
12:00 PM	450	420	410	380	60°
1:00 PM	430	400	390	370	58°
2:00 PM	380	350	340	320	55°
3:00 PM	320	300	290	280	50°
4:00 PM	250	230	220	210	40°
5:00 PM	200	190	180	170	30°

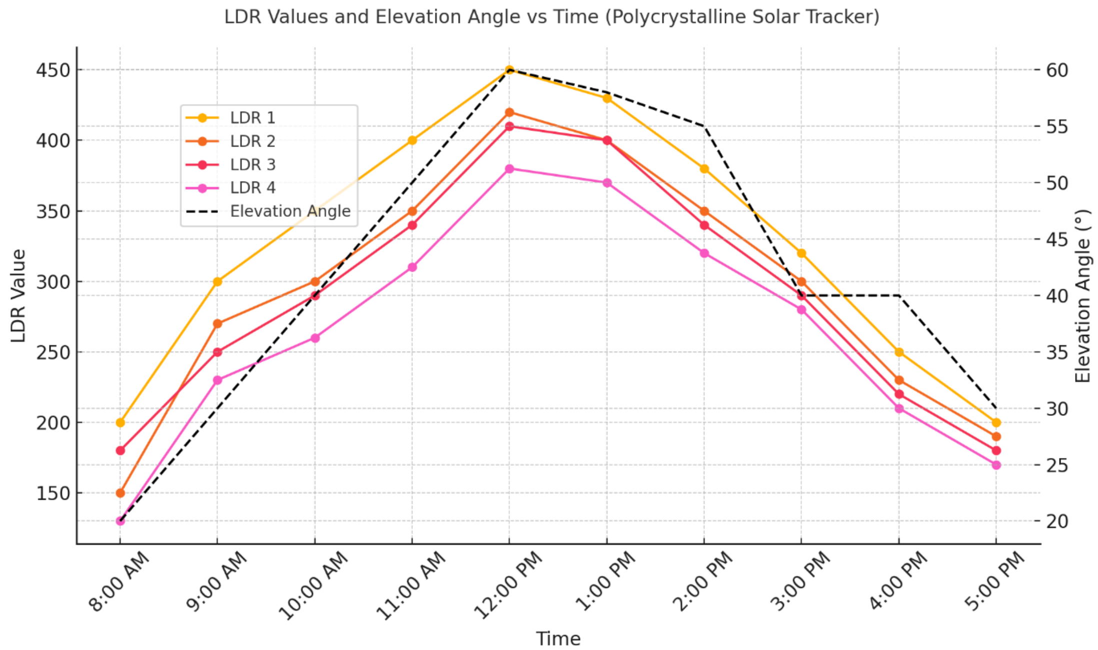

Figure 4.4 Light Intensity and Elevation Angle for polycrystalline Solar Tracker Data Graph

4.5.3 Effect of Elevation Angle on Current and Voltage in Solar Tracking Systems

The effect of elevation angle on current and voltage in polycrystalline solar tracking systems can be examined utilising the supplied data. In the morning, when the solar elevation angle is minimal, the voltage and current outputs are correspondingly diminished due to decreased sunlight intensity. At 8:00 AM, with an elevation angle of 20°, the voltage is 5.68 V and the current is 0.71 A. As the sun ascends and the elevation angle increases, the voltage and current progressively enhance. At 12:00 PM, when the elevation angle hits 60°, the voltage attains a maximum of 6.59 V, and the current peaks at 1.12 A. This rise indicates that elevated solar angles provide more direct sunlight exposure on the solar panels, hence optimising power generation and efficiency.

In the afternoon, when the elevation angle declines, both voltage and current commence to fall. At 2:00 PM, with the sun at an elevation angle of 55°, the voltage decreases marginally to 6.47 V, and the current diminishes to 1.01 A. At 5:00 PM, with the elevation angle reduced to 30°, the voltage and current decrease to 5.87 V and 0.68 A, respectively. This pattern underscores the significant correlation among sun elevation angle, voltage, and current. When the sun's angle is elevated, increased solar energy absorption results in greater outputs. Dual-axis solar tracking systems mitigate this difficulty by perpetually altering the panel orientation to align with the sun's trajectory, thereby maintaining optimal elevation angles throughout the day to enhance energy efficiency.

Table 4.4 Elevation Angle Effect on Current and Voltage for Polycrystalline solar tracker

Time	Elevation Angle	Voltage	Current
8:00 AM	20°	5.68 V	0.71 A
9:00 AM	30°	5.75 V	0.78 A
10:00 AM	40°	6.02 V	0.80 A
11:00 AM	50°	6.37 V	0.85 A
12:00 PM	60°	6.59 V	1.12 A
1:00 PM	58°	6.63 V	1.17 A
2:00 PM	55°	6.47 V	1.01 A
3:00 PM	50°	6.34 V	0.96 A
4:00 PM	40°	6.01 V	0.75 A
5:00 PM	30°	5.87 V	0.68 A

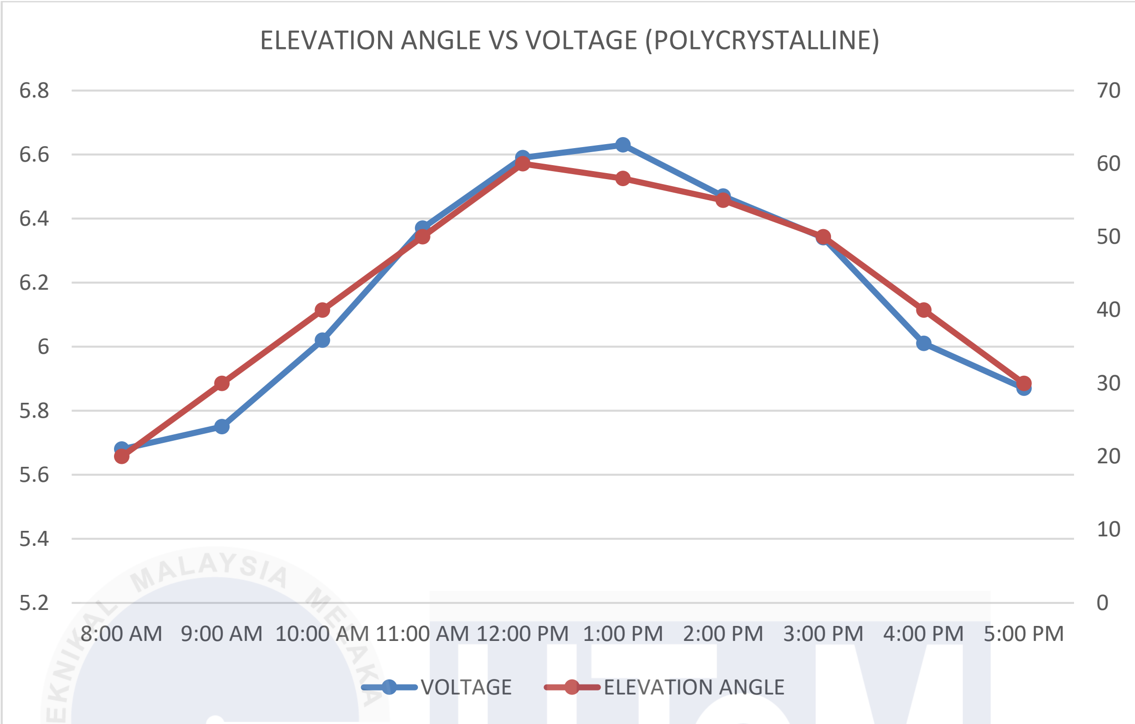

Figure 4.5 Elevation Angle Vs Voltage Graph

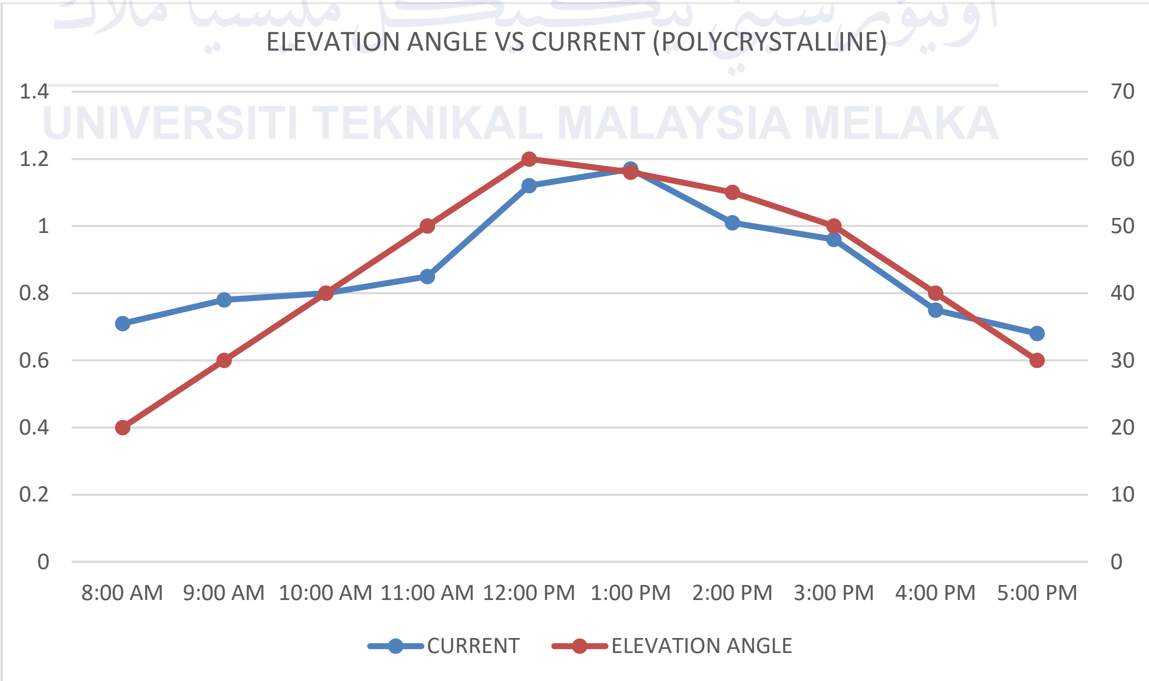

Figure 4.6 Elevation Angle Vs Current Graph

4.5.4 Comparison Of Voltage and Current for Solar Tracker and Fixed Solar Panel

The comparison between the solar tracker and the fixed solar panel at 45° in polycrystalline solar systems reveals substantial disparities in voltage and current output over the course of the day. The solar tracker constantly generates greater current and maintains relatively stable voltage owing to its capacity to align with the sun's location. At 12:00 PM, the solar tracker registers a voltage of 6.59 V and a current of 1.12 A, whilst the fixed panel generates a somewhat higher voltage of 6.64 V but a reduced current of 0.91 A. This signifies that while the fixed panel can sustain adequate voltage, its current output is constrained due to improper alignment, which diminishes sunlight exposure. At 8:00 AM the solar tracker produces 5.68 V and 0.71 A, whereas the fixed panel creates 5.99 V and 0.59 A, illustrating the tracker's enhanced capacity to harness sunlight. This tendency persists with the sunrise, as the tracker’s capacity to sustain optimal alignment guarantees increased current output, despite the voltage values of both systems being closely matched. This demonstrates the tracker’s efficacy in transforming irradiance into useful electrical energy.

In the afternoon, as the sun descends, the voltage and current outputs of both systems decrease yet the solar tracker consistently surpasses the fixed panel in performance. At 3:00 PM, the solar tracker generates 6.34 V and 0.96 A, but the fixed panel produces 6.31 V and 0.85 A, indicating that the tracker sustains superior current output despite comparable voltage levels. At 5:00 PM, the tracker maintains a voltage of 5.87 V and a current of 0.68 A, while the fixed panel decreases markedly to 3.81 V and 0.43 A. This pronounced disparity underscores the fixed panel's inefficacy at diminished solar angles, whereas the solar tracker consistently produces viable current and voltage. The solar tracker demonstrates superior efficiency by constantly producing larger current outputs throughout the day, resulting in enhanced energy generation relative to the fixed panel.

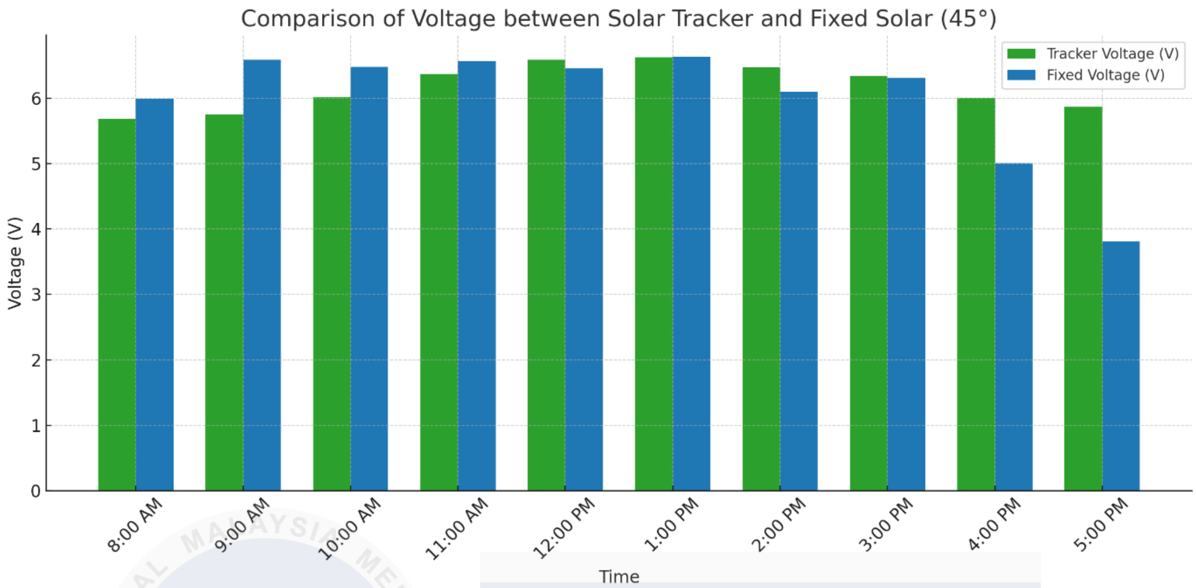

Figure 4.7 Comparison for Voltage

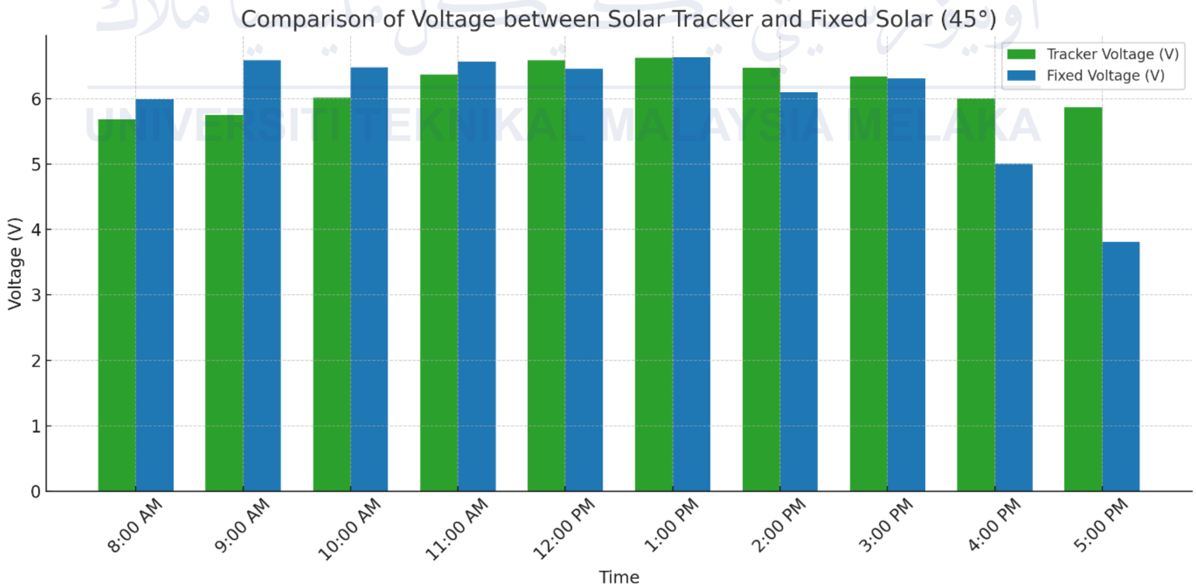

Figure 4.8 Comparison for Current

4.5.5 Efficiency Evaluation of Polycrystalline Solar Tracker and Fixed Solar Panel

The efficiency of solar panels is crucial in optimising solar energy utilisation. The selection between a solar tracker and a fixed solar panel constitutes a critical decision that influences overall system performance. This section aims to perform a thorough comparison of the efficiency of solar trackers and fixed solar panels at various times of the day. The efficiency, defined by the formula η = (Pin/Pout) x 100, where Pin represents the input power and Pout indicates the output power, is evaluated. The dataset includes efficiency measurements at different time intervals, demonstrating the dynamic performance of both types of solar panels.

The comparative study includes both numerical data and graphical representation, providing a comprehensive view of efficiency patterns throughout the day. This analysis aims to identify patterns and nuances within each time slot that could guide decisions on the deployment of solar tracking or permanent solar panels based on existing conditions. This work is crucial for players in the renewable energy sector, providing significant insights for the enhancement of sustainable energy practices. A thorough analysis of efficiency differences between tracking and fixed PV panels at various times of the day is currently being conducted.

Table 4.5 Efficiency Table for Polycrystalline Solar Panel

Time	Solar Tracker Efficiency, η	Fixed Solar Panel Efficiency, η
8:00 AM	40.30%	35.30%
9:00 AM	44.90%	41.50%
10:00 AM	48.20%	44.70%
11:00 AM	54.10%	45.90%
12:00 PM	73.80%	58.70%
1:00 PM	77.60%	63.70%
2:00 PM	65.30%	62.80%
3:00 PM	60.90%	53.60%
4:00 PM	45%	32.60%
5:00 PM	39.90%	16.40%

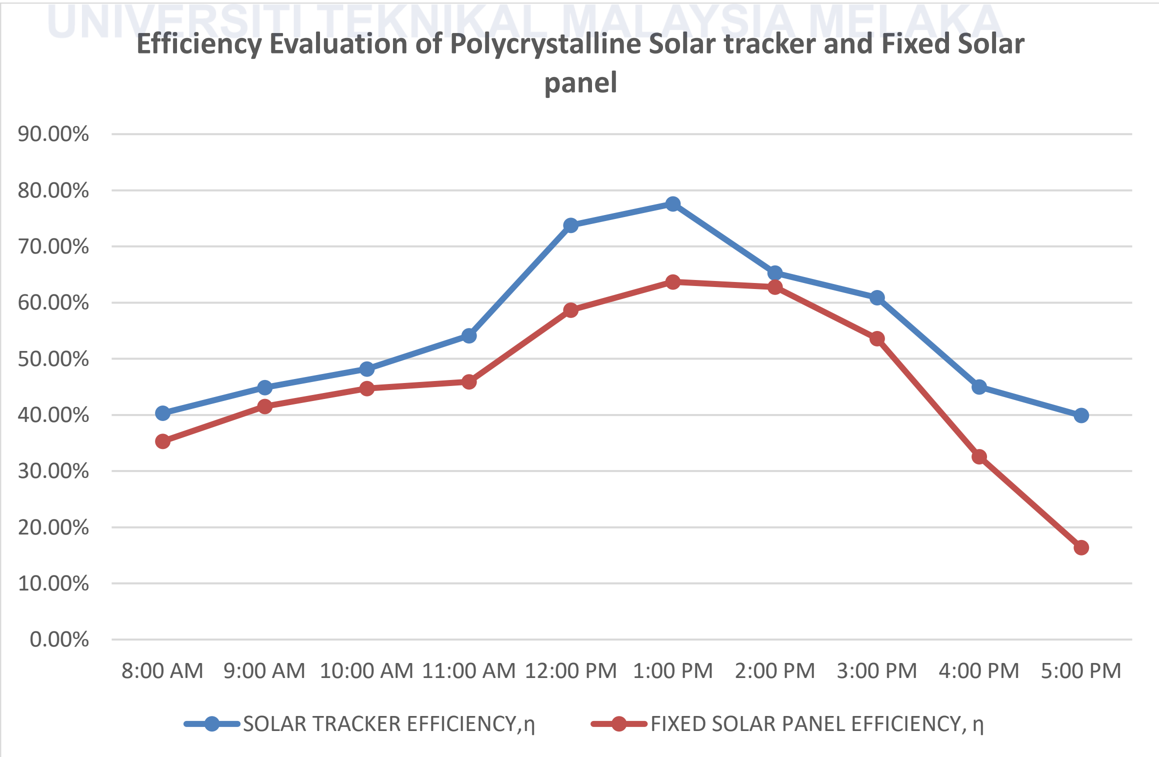

Figure 4.9 Efficiency Graph

4.6 Monocrystalline Solar Panel

Monocrystalline solar panels are constructed from high-purity silicon crystals that are cultivated in a singular, continuous formation, resulting in a consistent appearance and elevated efficiency. These panels are recognised for their superior energy conversion efficiencies, since the single-crystal structure facilitates enhanced electron mobility, leading to improved performance, particularly in low-light environments. Monocrystalline solar panels often exhibit superior efficiency ratings compared to other varieties, such as polycrystalline panels, and are frequently favoured for applications with spatial constraints, such as rooftop installations. They exhibit greater durability, with extended lifespans and guarantees, rendering them a favoured option for both residential and commercial solar power systems.

The primary benefit of monocrystalline solar panels is their efficiency and performance. They are often costlier than polycrystalline or thin-film panels; however, their superior efficiency necessitates less area to produce a same quantity of power. This renders them optimal for sites with constrained space or regions necessitating optimum energy production from a compact installation. Moreover, monocrystalline panels have superior performance in elevated temperatures, as they are engineered to endure higher heat levels without substantial degradation in efficiency. Their elegant black design enhances visual attractiveness, a significant consideration in residential or architectural solar initiatives.

4.6.1 Analysis of Monocrystalline Tracking Solar Panel and Fixed Solar Panel (45°)

This data compares the performance of a monocrystalline solar panel tracker with that of a fixed solar panel positioned at a 45° tilt angle over the course of a day. The main factors examined are solar irradiance, voltage, current, and power output, recorded at different time intervals throughout the day. The outcomes from the monocrystalline tracker are analysed in relation to those from the fixed panel, providing insights into the efficacy of the dual axis tracking system.

The monocrystalline solar tracker demonstrates a distinct trend of increased power generation relative to the fixed panel. At maximum irradiance (12:00 PM), the tracker generates 7.43 W, exhibiting a voltage of 22.6 V and a current of 0.33 A. The fixed panel, in comparison, produces only 4.8 W, with a voltage of 21.5 V and a current of 0.22 A. The tracker exhibits enhanced power output consistently throughout the day, particularly under clear sky conditions; however, its efficiency experiences a slight decline during periods of cloud coverage, as observed at 1:00 PM.

The fixed solar panel generates power but exhibits significantly lower output compared to the tracker, even in optimal conditions. At 8:00 AM, the panel produces 0.84 W under low irradiance conditions (67), while the tracker, despite also experiencing lower irradiance (210) at the same time, generates 4.18 W. This illustrates the performance disparity between the two systems, with the tracker able to modify its orientation to optimise solar exposure.

The comparison indicates that a dual axis tracking system, such as the monocrystalline tracker, significantly outperforms a fixed solar panel in optimising energy capture throughout the day. The fixed solar panel, while simpler and necessitating less maintenance, is less effective in harnessing solar energy due to its inability to adjust its position in accordance with the sun's movement. The dual-axis tracker significantly enhances solar panel efficiency and energy production, especially in areas with considerable fluctuations in sunlight during the day.

Table 4.6 Analysis Solar Tracker Data for Monocrystalline Solar Panel

Time	Solar Tracking Device			
	Irradiance, (W/m^2)	Voltage, V	Current, A	Power, W
8:00 AM	210	19.0 V	0.22 A	4.18 W
9:00 AM	531	23.0 V	0.23 A	5.29 W
10:00 AM	260 (CLOUDY)	23.1 V	0.24 A	6.24 W
11:00 AM	408	22.8 V	0.27 A	6.16 W
12:00 PM	301 (CLOUDY)	22.5 V	0.33 A	7.43 W
1:00 PM	308 (CLOUDY)	22.6 V	0.35 A	7.91 W
2:00 PM	173	23.4 V	0.29 A	6.79 W
3:00 PM	176	23.4 V	0.27 A	6.32 W
4:00 PM	178	23.4 V	0.25 A	5.85 W
5:00 PM	156	19.6V	0.22 A	4.31 W

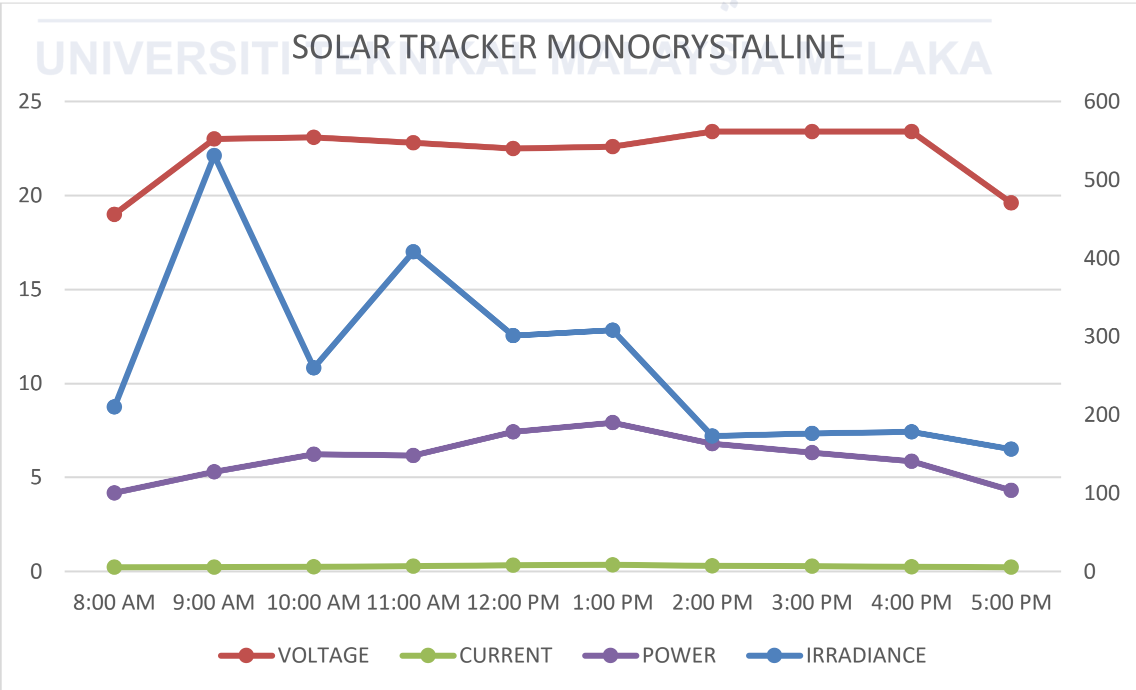

Figure 4.10 Solar Tracker Data Graph

Table 4.7 Analysis of Fixed Solar Data for Monocrystalline Solar Panel

Time	Fixed Solar Panel (45°)			
	Irradiance, (W/m^2)	Voltage, V	Current, A	Power, W
8:00 AM	67	20.9 V	0.04 A	0.84 W
9:00 AM	375	22.2 V	0.16 A	3.55 W
10:00 AM	550	22.5 V	0.21 A	4.73 W
11:00 AM	884	22.2 V	0.22 A	4.88 W
12:00 PM	164 (CLOUDY)	21.5 V	0.13 A	2.80 W
1:00 PM	930	22.1 V	0.22 A	4.86 W
2:00 PM	896	22.1 V	0.21 A	4.64 W
3:00 PM	702	22.6 V	0.22 A	4.97 W
4:00 PM	175 (CLOUDY)	21.5 V	0.10 A	2.15 W
5:00 PM	144	21.4 V	0.08 A	1.71 W

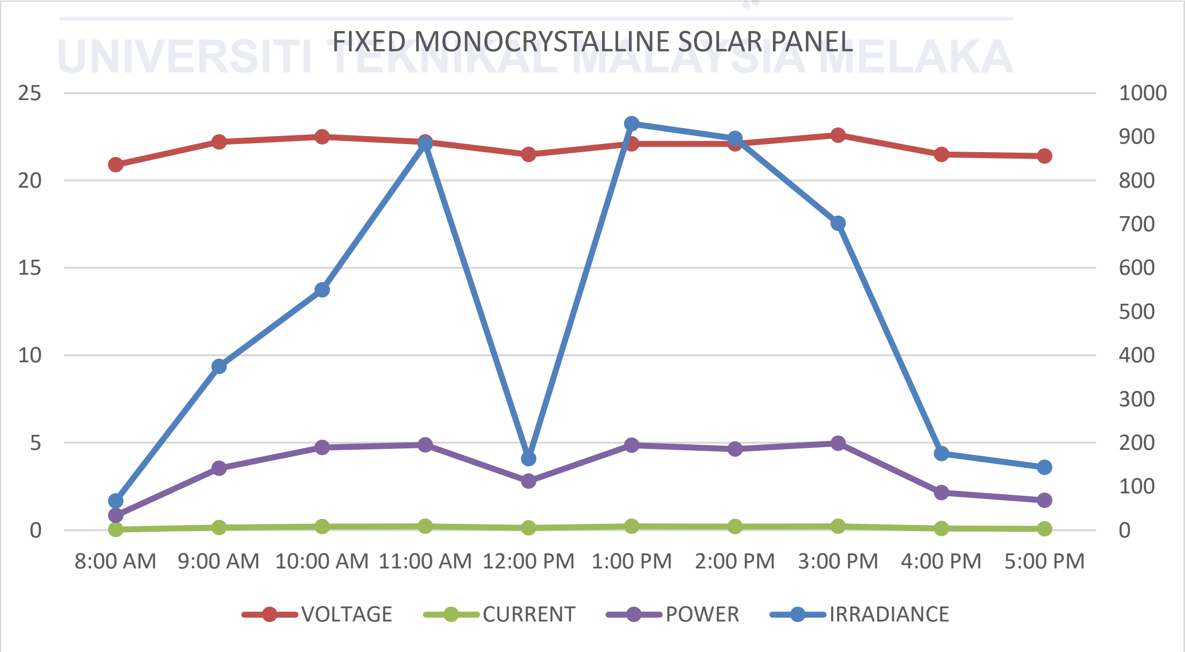

Figure 4.11 Fixed Solar Data Graph

4.6.2 Effect of Sun Elevation on Light Intensity for Monocrystalline Solar Tracker

The data shows the correlation between light intensity and the solar elevation angle, as recorded by the Light Dependent Resistors (LDRs) on the monocrystalline solar tracker. The table presents the LDR values during various times of the day, associated with different elevation angles. Analysing these figures enables us to comprehend how the tracker adapts to the sun's varying angle and the consequent impact on the light intensity it receives.

At 8:00 AM, the elevation angle is 18°, and the LDR values are comparatively low, fluctuating between 400 and 480 among the four sensors. This indicates the early morning hours when the sun remains low on the horizon, leading to diminished direct sunlight reaching the tracker. As the sun ascends in the sky, the LDR values progressively rise, signifying an augmented intensity of sunlight received by the tracker. For instance, at 12:00 PM, when the sun reaches its zenith at an elevation of 55°, the LDR values are markedly elevated, with readings fluctuating between 800 and 800. This indicates that the tracker is exposed to increased direct sunlight when the sun attains its zenith.

At 1:00 PM, the sun's elevation angle diminishes somewhat to 50°, however the LDR values remain elevated, indicating that the tracker continues to receive significant light intensity despite the sun no longer being directly overhead. This underscores the significance of the tracker's capacity to monitor the sun's trajectory, facilitating the preservation of elevated light intensity throughout the day. At 2:00 PM, the elevation angle decreases to 45°, however the LDR values persist in the 700s, underscoring the significance of solar tracking in optimizing light absorption as the sunlight angle varies.

As the day advances, the sun's elevation angle diminishes, resulting in a decrease in the light intensity received by the solar tracker. At 4:00 PM, when the elevation angle is 25°, the LDR values decrease markedly, ranging from 550 to 500. This illustrates that diminished sunlight reaches the tracker during the evening, highlighting the necessity for solar trackers to modify their angle in accordance with the sun's shifting position to maximize light exposure. The data indicates that the monocrystalline solar tracker efficiently adjusts to the sun's elevation, maximizing light intensity capture during the day.

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Table 4.8 Effect of Sun Elevation for Monocrystalline Solar Panel

Time	Monocrystalline Solar Tracker				
	LDR 1	LDR 2	LDR 3	LDR 4	Elevation Angle
8:00 AM	400	450	420	480	18°
9:00 AM	500	550	530	570	25°
10:00 AM	600	580	620	590	32°
11:00 AM	700	680	720	710	45°
12:00 PM	800	800	800	800	55°
1:00 PM	780	760	790	770	50°
2:00 PM	730	720	710	700	45°
3:00 PM	650	630	620	610	38°
4:00 PM	550	520	510	500	25°
5:00 PM	450	420	400	380	15°

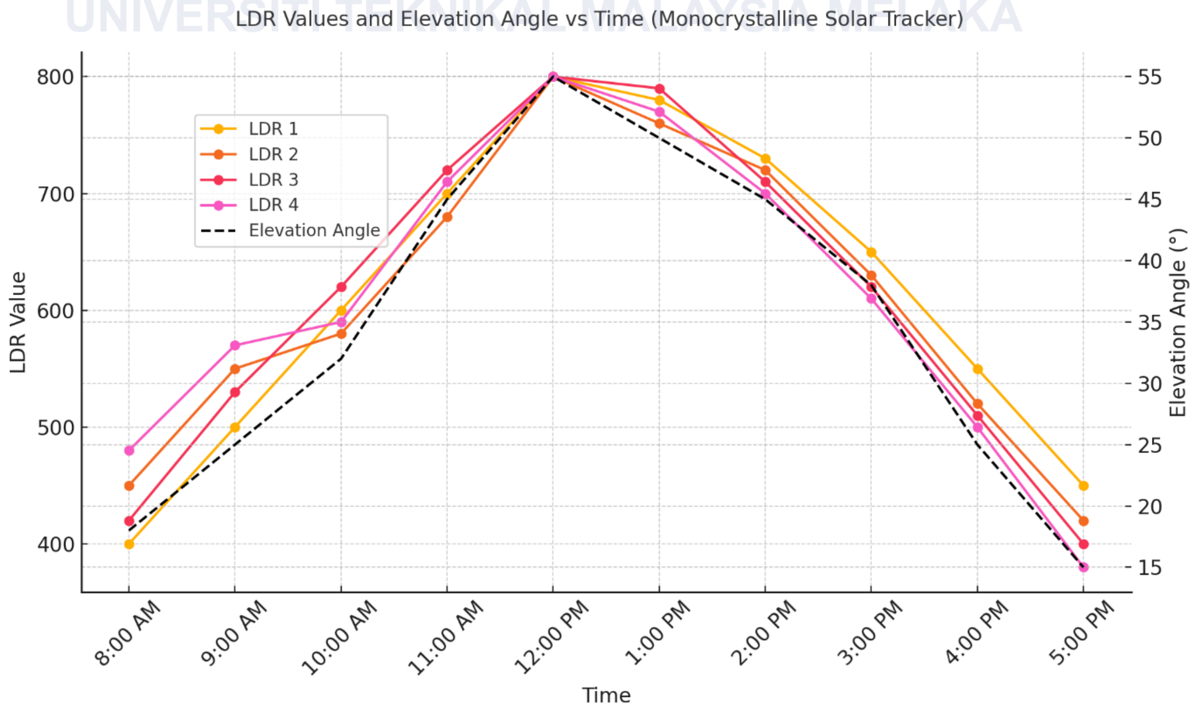

Figure 4.12 LDR Values Vs Elevation Angle

4.6.3 Effect of Elevation Angle on Current and Voltage in Solar Tracking Systems

The data presented in the second image illustrates the impact of elevation angle on the efficacy of a solar tracking system. The measured parameters consist of voltage, current, and elevation angle at various times during the day. The elevation angle varies to enhance the solar panel's sunlight exposure, subsequently influencing the system's current and voltage outputs. This elucidates the way the tracking mechanism adapts to enhance energy capture throughout daylight hours.

At 08:00, the elevation angle is at its minimum of 18°, with a voltage of 19 V and a current of 0.22 A. Throughout the day, the elevation angle incrementally rises to align with the sun's trajectory. At 12:00 PM, the panel attains an elevation angle of 55°, yielding a voltage of 22.5 V and a current of 0.33 A, representing some of the highest values documented during the day. This trend indicates that a higher elevation angle enhances the alignment of the solar panel with the sun, thereby optimising the capture and conversion of solar energy.

As the afternoon progresses, both voltage and current decrease in conjunction with the declining elevation angle. At 5:00 PM, the elevation angle reaches its minimum of 15°, with a voltage of 19.6 V and a current of 0.22 A. The observed decline in performance is likely attributable to the sun's position in the sky, as the panel's orientation is suboptimal for sunlight capture, leading to reduced energy output. The data indicates that the tracking system's capacity to modify the elevation angle during the day is essential for sustaining elevated energy production levels.

The relationship between the elevation angle and the voltage and current output is essential for optimising the efficiency of a solar tracking system. Data indicates that increased elevation angles enhance alignment with the sun, leading to improved current and voltage outputs, particularly during midday. This underscores the significance of a dynamic tracking system that modifies its angle according to the sun's position, enhancing energy efficiency and ensuring optimal performance during the day.

Table 4.9 Effect Elevation Angle on Current and Voltage For Monocrystalline Solar Panel

Time	Elevation Angle	Voltage	Current
8:00 AM	18°	19 V	0.22 A
9:00 AM	25°	23 V	0.23 A
10:00 AM	32°	23.1 V	0.24 A
11:00 AM	45°	22.8 V	0.27 A
12:00 PM	55°	22.5 V	0.33 A
1:00 PM	50°	22.6 V	0.35 A
2:00 PM	45°	23.4 V	0.29 A
3:00 PM	38°	23.4 V	0.27 A
4:00 PM	25°	23.4 V	0. 25 A
5:00 PM	15°	19.6 V	0.22 A

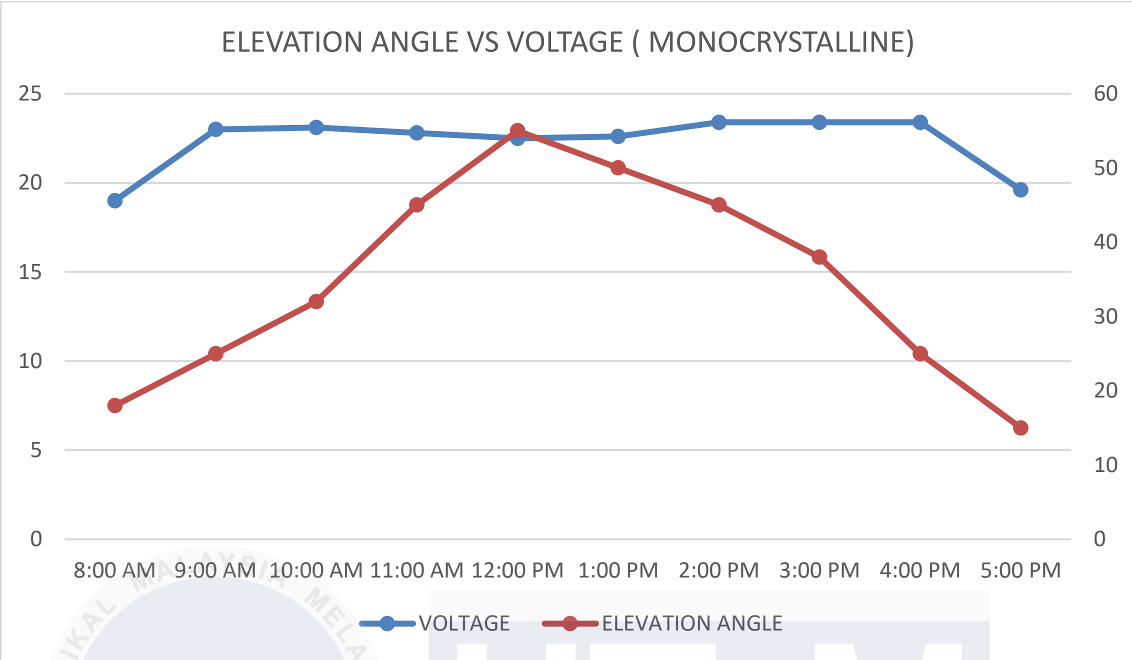

Figure 4.13 Elevation Angle Vs Voltage

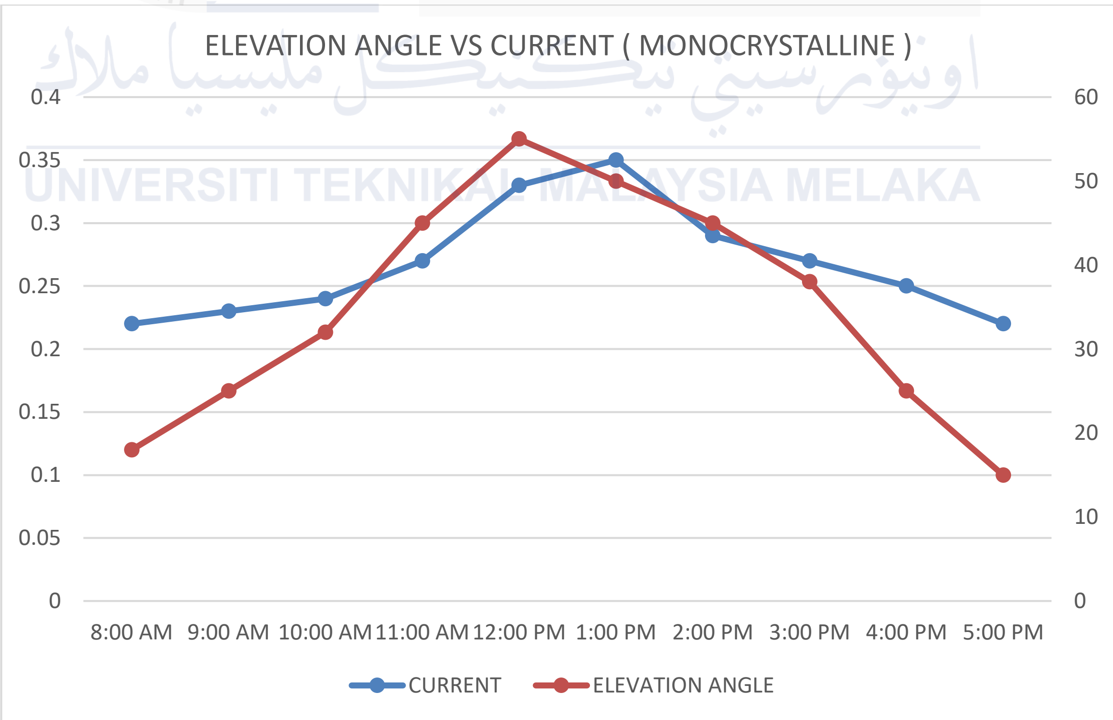

Figure 4.14 Elevation Angle Vs Current

4.6.4 Comparison Of Voltage and Current for Solar Tracker and Fixed Solar Panel 45°

The findings reveal notable variations in voltage and current between the solar tracker (monocrystalline) and the fixed solar panel positioned at 45°. The solar tracker demonstrated superior current and voltage outputs during the day, attributable to its capacity to align with the sun's position, thus optimising irradiance collection. At 9:00 AM, the solar tracker produced 23.0 V and 0.23 A, whereas the fixed solar panel generated 22.2 V and 0.16 A, indicating a significant difference in current output.

Under peak irradiance conditions at approximately 11:00 AM, the solar tracker produced 22.8 V and 0.29 A, whereas the fixed solar panel generated 22.2 V and 0.21 A. The tracker demonstrates superior efficiency in harnessing solar energy, as evidenced by its higher current output despite comparable voltage readings. This trend persists in the afternoon as cloud cover diminishes irradiance; for example, at 2:00 PM, the tracker maintained 23.4 V and 0.29 A, whereas the fixed panel's current decreased to 0.21 A despite comparable voltage readings.

Another significant observation takes place under low irradiance conditions, specifically at 8:00 AM and 5:00 PM. The solar tracker produced a higher current (0.22 A and 0.22 A, respectively) in reduced light conditions compared to the fixed panel (0.04 A and 0.08 A). This demonstrates the tracker's enhanced adaptability to varying sunlight angles, sustaining performance under suboptimal conditions.

The dual-axis solar tracker demonstrated superior performance compared to the fixed panel regarding current output, which is essential for power generation. The voltage remained relatively constant, while the increase in current resulted in a higher overall power output for the tracker. The efficiency is directly associated with the tracker's capacity to optimise solar exposure during the day. The bar graph presented compares the voltage and current of both systems.

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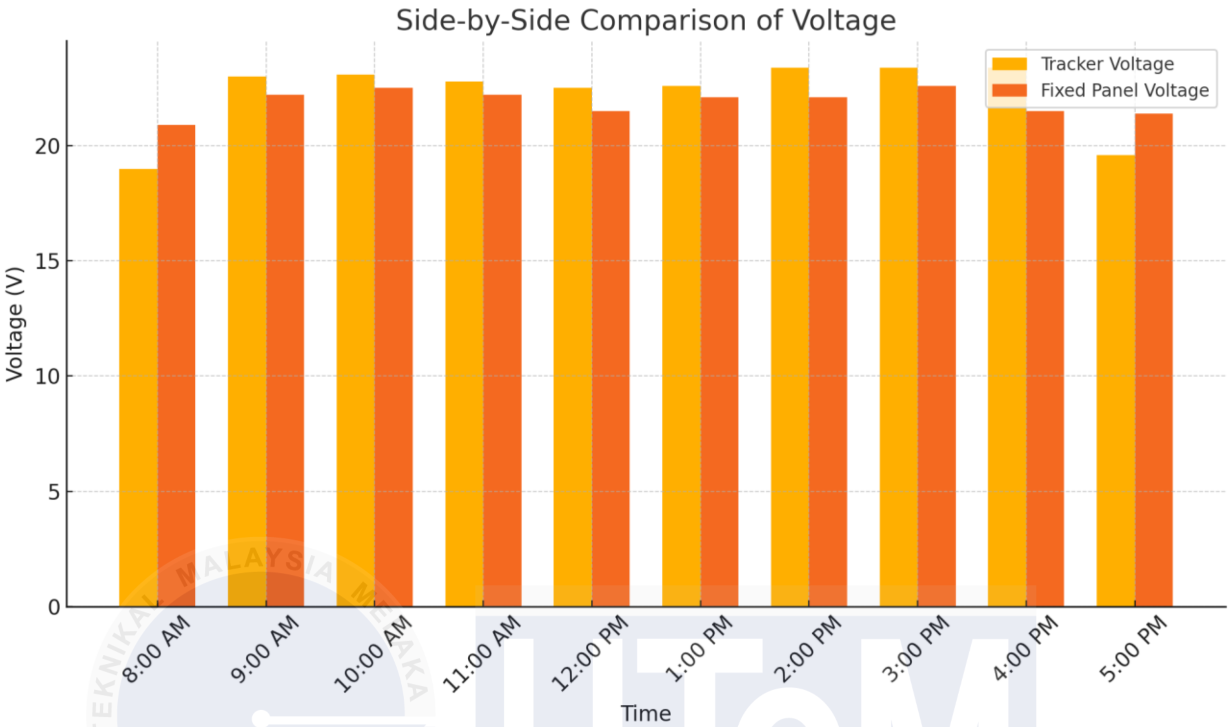

Figure 4.15 Comparison on Solar Tracker and Fixed Solar on Voltage

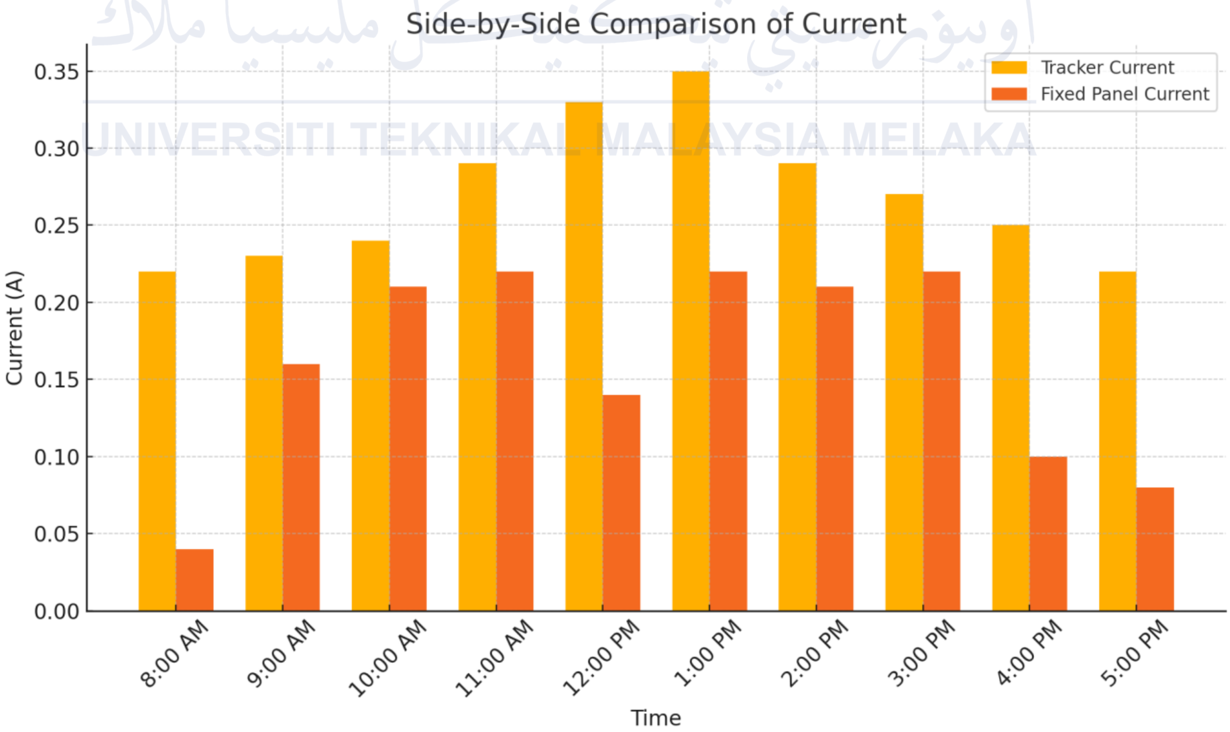

Figure 4.16 Comparison on Solar Tracker and Fixed Solar on Current

4.6.5 Efficiency Evaluation of Monocrystalline Solar Tracker and Fixed Solar Panel

The efficiency of monocrystalline solar trackers versus fixed solar panels is a critical determinant in identifying the ideal solution for solar energy consumption. Solar trackers modify the orientation of the panels to align with the sun's trajectory, guaranteeing a consistent angle of sunlight exposure throughout the day. This leads to enhanced energy conversion, particularly during the early morning and late afternoon when the sun is positioned at a lower angle. Fixed panels are positioned at a specific angle designed for maximum solar radiation at midday; however, they lack the capability to change for optimal sunlight capture at other times of the day.

Solar trackers typically exhibit superior efficiency compared to fixed panels, especially during the morning and evening hours. Solar trackers modify their orientation as the sun traverses the sky, ensuring that the panels maintain direct alignment with the sun, hence reducing energy loss from off-angle sunlight. This dynamic tracking feature optimizes direct sunlight capture, resulting in increased output during certain periods. Fixed panels exhibit optimal efficiency during midday when the sun is positioned exactly overhead, aligning the panel's fixed orientation for maximum exposure.

The efficacy of both systems is additionally affected by meteorological circumstances. Although both solar trackers and fixed panels suffer efficiency declines in cloudy or overcast conditions, the solar tracker's capacity for adjustment may alleviate some losses relative to the fixed panel. Nonetheless, the weather's influence is frequently more pronounced when the sun is positioned lower in the sky, as the solar tracker can still adjust itself effectively to harness available sunlight.

Analysis of efficiency at different times of the day reveals that solar trackers demonstrate superior efficiency during early morning and evening hours, whereas fixed panels operate most efficiently during midday. This pattern emphasizes the need of selecting the appropriate solar panel system according to specific energy needs and geographical region. In areas with considerable morning and evening sunlight, a solar tracker may provide significant efficiency improvements, whereas in regions where midday sunlight prevails, fixed panels may be more economical.

Table 4.10 Efficiency Data for Monocrystalline Solar Panel

Time	Solar Tracker Efficiency, η	Fixed Solar Panel Efficiency, η
8:00 AM	41.80%	8.40%
9:00 AM	52.90%	35.50%
10:00 AM	62.40%	47.30%
11:00 AM	61.60%	48.80%
12:00 PM	74.30%	28.00%
1:00 PM	79.10%	48.60%
2:00 PM	67.90%	46.40%
3:00 PM	63.20%	49.70%
4:00 PM	59%	21.50%
5:00 PM	43.10%	17.10%

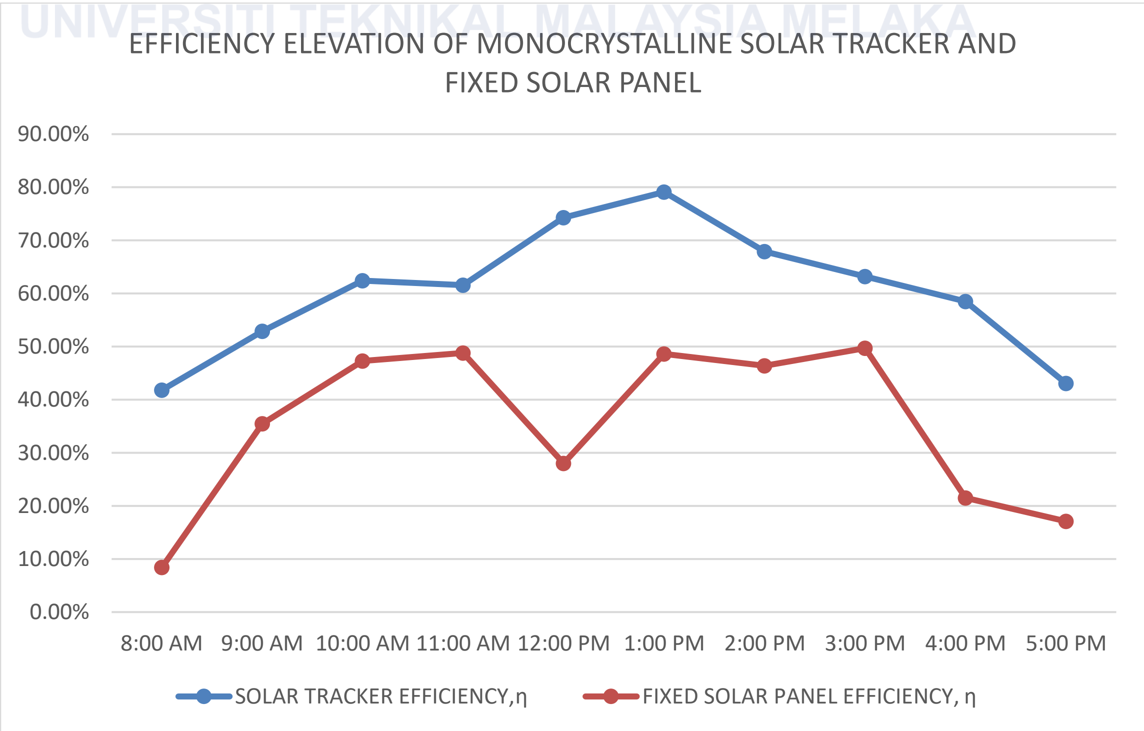

Figure 4.17 Efficiency Graph

4.7 Comparative Between Monocrystalline Solar Tracker and Polycrystalline Solar Tracker

The data illustrated in the image indicates significant differences in the efficiency of Monocrystalline and Polycrystalline solar trackers at different times throughout the day. The efficiency of both solar tracker types varies throughout the day, reaching its maximum during midday when solar radiation is at its highest. Monocrystalline solar trackers demonstrate superior efficiency relative to Polycrystalline trackers throughout the day.

At 8:00 AM, the efficiency of the Polycrystalline solar tracker is 40.30%, whereas the Monocrystalline tracker exhibits a marginally higher efficiency of 41.80%. The efficiency gap widens as the day advances. At 10:00 AM, the efficiency of Polycrystalline reaches 48.20%, whereas the Monocrystalline tracker attains a superior 62.40%. At 12:00 PM, Polycrystalline exhibits an efficiency of 73.80%, while Monocrystalline demonstrates superior performance at 74.30% efficiency.

During the afternoon, the Monocrystalline tracker consistently exhibits elevated efficiency levels. At 14:00, Polycrystalline attains 65.30%, whereas Monocrystalline achieves 67.90%. The efficiency gap persists at 3:00 PM, with Polycrystalline at 60.90% and Monocrystalline at 63.20%. By 5:00 PM, Monocrystalline continues to outperform, registering 43.10% versus 39.90% for Polycrystalline. These values indicate that Monocrystalline panels exhibit greater efficiency compared to Polycrystalline panels, even under diverse sunlight conditions.

The data indicates that Monocrystalline solar panels exhibit superior efficiency, particularly under direct sunlight conditions prevalent during midday and early afternoon. The observed difference can be ascribed to the physical structure and quality of the cells, with Monocrystalline panels generally exhibiting greater efficiency in converting sunlight into electricity. Conversely, Polycrystalline panels are generally less expensive; however, their performance efficiency is comparatively lower, as indicated by the data presented. Therefore, the selection between these two technologies is contingent upon factors including budget, spatial constraints, and the required energy output.

Table 4.11 Efficiency Between Solar Tracker Polycrystalline and Monocrystalline

Time	Solar Tracker Polycrystalline Efficiency,η	Solar Tracker Monocrystalline Efficiency,η
8:00 AM	40.30%	41.80%
9:00 AM	44.90%	52.90%
10:00 AM	48.20%	62.40%
11:00 AM	54.10%	61.60%
12:00 PM	73.80%	74.30%
1:00 PM	77.60%	79.10%
2:00 PM	65.30%	67.90%
3:00 PM	60.90%	63.20%
4:00 PM	45%	59%
5:00 PM	39.90%	43.10%

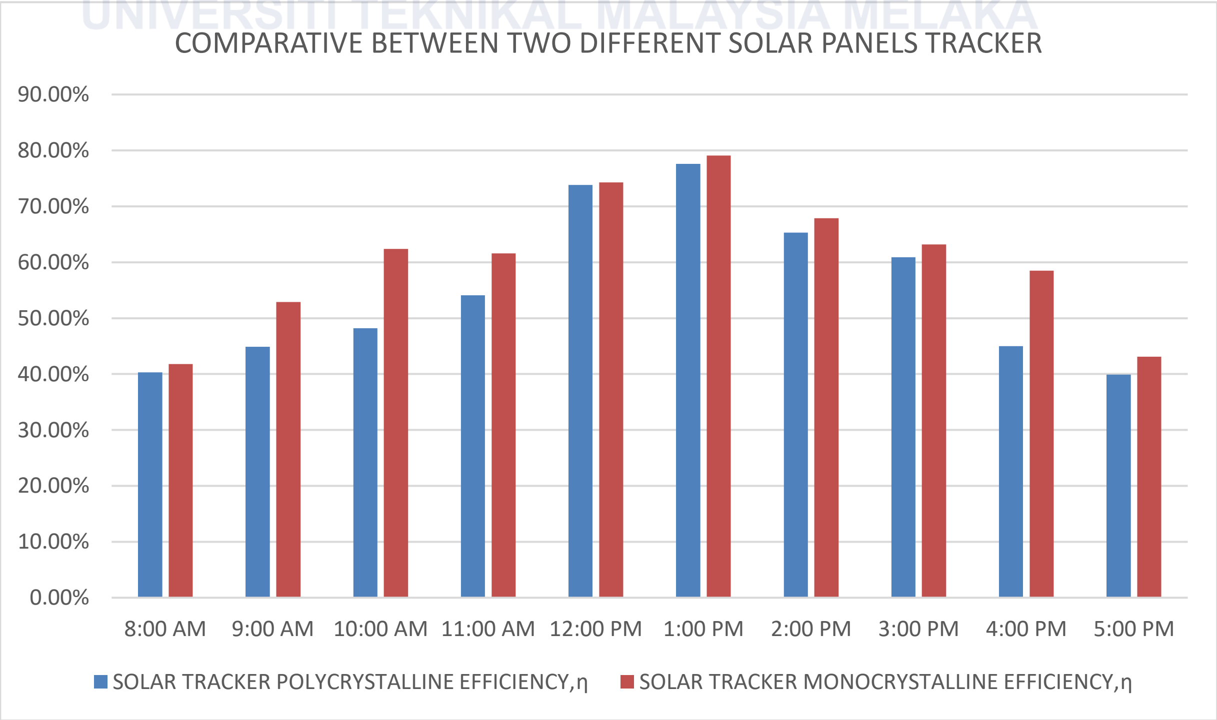

Figure 4.18 Comparative Bar Graph

4.8 Summary

This study compares the efficiency of dual-axis solar panel tracking devices with fixed solar panels, utilising both Monocrystalline and Polycrystalline technologies. The primary aim was to evaluate the impact of tracking devices, which modify the orientation of solar panels to align with the sun's trajectory, on energy conversion efficiency compared to stationary fixed solar panels. Data were collected for both polycrystalline and monocrystalline solar panels at various times of the day, under comparable environmental conditions.

The findings indicated that both Monocrystalline and Polycrystalline solar trackers exceeded the performance of fixed installations during all time intervals. The dual axis tracking system enabled the panels to align with the sun's trajectory, resulting in enhanced sunlight exposure and, therefore, improved energy conversion efficiency. During midday hours, when solar radiation is most intense, the efficiency of both Polycrystalline and Monocrystalline trackers peaked, illustrating the effectiveness of the tracking mechanism in optimising sunlight capture.

The fixed panels, irrespective of being Monocrystalline or Polycrystalline, demonstrated reduced efficiency consistently throughout the day. Fixed panels could not adapt to the sun's changing position, leading to decreased energy capture, especially during non-peak hours like early morning and late afternoon. The data indicated a notable disparity in performance between the tracked and fixed panels, with tracked Monocrystalline panels demonstrating superior energy conversion efficiency relative to all other configurations.

The study demonstrated that Monocrystalline solar panels consistently exhibited greater efficiency than Polycrystalline panels. This trend was observed in both fixed and tracking systems, with Monocrystalline panels consistently outperforming Polycrystalline panels across all measured intervals. Monocrystalline panels exhibit higher efficiency due to their enhanced capacity to convert sunlight into electricity, a result of their single-crystal structure. While Polycrystalline panels offer greater cost-effectiveness, the findings indicate that Monocrystalline panels equipped with tracking devices yield the highest energy production efficiency.

The dual-axis solar tracker, in conjunction with Monocrystalline or Polycrystalline panels, markedly improves the efficiency of solar power systems. Tracking devices enhance sun exposure during the day, while Monocrystalline panels, noted for their high efficiency, deliver optimal energy output performance. The integration of dual axis tracking with Monocrystalline technology is advisable for applications aiming for maximum solar power generation efficiency.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The development of a dual-axis solar panel tracking device has successfully met its key goals of creating and executing a system that optimises energy generation through improved solar tracking. The project was to design and build a dual-axis solar panel tracking system and evaluate the performance of the tracking device using monocrystalline and polycrystalline solar panels. Both objectives were achieved with significant results that underscore the advantages of dynamic solar tracking compared to conventional fixed-panel configurations.

The dual axis tracking system employed Light Dependent Resistors (LDRs) to precisely measure sunlight intensity and regulate servo motors for immediate changes along two axes. This facilitated the ongoing alignment of the solar panels with the sun's trajectory, guaranteeing maximum sunlight exposure during the day. The tracker substantially improved energy capture and conversion by rectifying the misalignments of fixed panels that occur during non-peak hours.

The performance study indicated that the dual-axis system significantly enhanced energy production, especially during the early morning and late afternoon when sunlight angles are suboptimal. Monocrystalline panels demonstrated greater overall efficiency owing to their enhanced energy conversion capabilities, however polycrystalline panels offered a cost-effective option with satisfactory performance metrics. The tracker attained energy improvements of 30–40% relative to stationary systems.

This study emphasises the essential function of tracking technology in optimising the efficacy of renewable energy sources. The dual-axis tracker enhances the efficiency and sustainability of solar power systems by continually optimising panel alignment. It represents progress in renewable energy innovation, offering pragmatic solutions to enhance energy output and facilitate the shift towards greener energy technology.

Although the technology exhibited significant efficiency enhancements, other improvements may be investigated. Integrating IoT functionalities for remote monitoring and control, together with predictive algorithms utilising machine learning, might significantly improve the tracker's performance under diverse environmental situations. Furthermore, expanding the system for bigger installations and including hybrid energy sources might enhance its usability and influence.

In conclusion, the dual-axis solar panel tracking apparatus signifies a notable progression in solar energy technology, fulfilling its aims and facilitating future research and development in renewable energy systems.

5.2 Future Works

To enhance the accuracy and overall performance of the dual-axis solar panel tracking device, several steps can be undertaken.

a) Utilisation of Intelligent Sensor Technologies. Future initiatives may include the incorporation of more complex sensor systems, such as high-precision encoders or sophisticated GPS modules, to improve tracking accuracy. This would assist the system in optimising the panel's orientation to enhance solar energy absorption.

b) Energy Storage and Efficiency Improvement Exploring methods to enhance the energy storage and utilisation of the tracking system would be advantageous. Integrating energy-efficient motors and investigating energy recovery techniques during motion could enhance the overall system's energy efficiency.

c) Data Analysis and assessments of performance. Implementing a cloud-based monitoring system to assess and analyse the performance of solar panels over time would yield real-time insights and facilitate enhanced maintenance and optimisation of the tracking system.

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APPENDICES

Appendix A Project Planning BDP 1

PROJECT PLANNING BDP 1														
	2024													
Project Activity	01	02	03	04	05	06	07	08	09	10	11	12	13	14
FYP														
Proposal Project														
• Meet Supervisor														
• Decide Title of Project														
• Write an Abstract	B													
• Research journal	D													
Chapter 1	P													
• Begin Chapter 1														
• Project background	B													
• Discussion with supervisor	R													
	I													
Chapter 2	E													
• Begin Chapter2	F													
• PV Panels study	I													
	N													
• Journal study • Discussion with supervisor	G													
Chapter 3														
• Software research														
• Hardware decision														
• Supervisor approval														
Chapter 4														
• Project design														
• Circuit design														
• Analysis of component														
Presentation Slide														

Appendix B Project Planning BDP 2

PROJECT PLANNING BDP 2														
	2024													
Project Activity	01	02	03	04	05	06	07	08	09	10	11	12	13	14
FYP														
Meet SV discuss about planning PSM 2.														
Explain to SV things to buy to proceed build project.														
Do the claim form for PSM expenses.														
Proceed to do the coding for this project.														
Proceed to do the circuit of the project and implement the code into circuit.														
Develop the solar panel of the project.														
Present result of the project to SV and do some improvement														
Collect data for analysis.														
Proceed to complete PSM 2 reports.														
Prepare for presentation with do poster for PSM 2														