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DESIGN AND CONSTRUCTION OF A SINGLE-AXIS LDR-BASED SOLAR TRACKER FOR ENHANCED SOLAR ENERGY HARVESTING

By

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MAY, 2026

DECLARATION

I, **Chemonges Ivan,** do hereby affirm that this project work is my own original work and no part of this project work and report has been copied or submitted to any institution of higher learning for any academic award.

Signature: ……………… Date 26/08/2026………………

Chemonges Ivan

BU/UP/2021/1563

APPROVAL

The project work and report produced by this candidate has been directly under my supervision and with my approval, it’s now ready to be submitted.

Supervisor

Signature .... Date 26/08/2026

DR MICHAEL ROBSON ATIM

DEDICATION

This piece of work is dedicated to my beloved parents, my dad Chemonges Augustine and my mother Chebet Grace for all the sacrifices they made to nurture me and their continuous support. I pray that the good Lord may always bless you in whatever you are doing, grant your hearts desires and may He increase your faith, love and hope in Him in your old age

ACKNOWLEDGEMENT

I extend my sincere gratitude to the Almighty God for guidance and strength. I am deeply thankful to my supervisor, Dr. Michael Robson Atim, for his patience, direction, and critical feedback. I also appreciate the technical staff at the Faculty of Science and Education for allowing me access to the electronics lab. Finally, I thank my fellow students for their encouragement and assistance during the construction phase.

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ABSTRACT

This project designed and constructed a simple single-axis solar tracker to improve the energy output of a small solar panel. The system used two Light Dependent Resistors (LDRs), a comparator circuit based on the TPA2822M IC, and a servo motor to orient a 9V solar panel toward the sun. A fixed panel of similar rating was used as a control. Results showed that the tracking panel generated approximately 30% more power on average compared to the fixed panel, with peak gains of over 60% during morning and evening hours. The tracker performed best between 9:00 AM and 3:00 PM. This low-cost design (approximately 45,000 UGX excluding the panel) is suitable for small-scale rural applications in Uganda, including phone charging, and science education demonstrations.

CHAPTER ONE: INTRODUCTION

1.0 Background of the study

Solar energy is an abundant, renewable resource, yet the efficiency of stationary PV panels is reduced because they cannot maintain a perpendicular angle to the sun as it moves, leading to energy loss in the early morning and late evening. A solar tracker is an electromechanical device that orientates a solar panel toward the sun (Al-saadi et al., 2022). A single-axis tracker is a low-cost, effective solution that tracks the sun across the daily east-west path, increasing power generation by 20-30% compared to fixed panels.

Demand of electrical energy is increasing day by day. So many different power sources are being used in modern power system. Researchers are trying to make power system more and more efficient. Solar tracking system is also a part of this research to make power sources more efficient. Solar tracking is used to extract more power from solar panels by giving solar panels maximum appearance to sun light (Deb & Roy, 2012)**.** Different techniques have been developed for solar tracking system.

Uganda possesses a significant and underutilized renewable energy potential, estimated at 5.3 GW, with solar energy being a particularly abundant resource due to its location on the equator. The country experiences high solar radiation throughout the year, with an average of 5.1 kWh/m^2 per day and a gross energy potential of 11.98×10^8 MWh. These immense potential positions solar power as a key driver for Uganda's socio-economic transformation and a central technology in the nation's Energy Transition Plan, which aims for universal energy access by 2030.

Despite this potential and a robust policy framework, a critical disparity in electricity access persists, particularly between urban and rural areas (Balachandra, 2011). While the government aims to boost rural access to 60% by 2027, current grid electricity access in rural Uganda stands at a mere 9.1%. This is starkly lower than the national average of 25.3% and urban access of 49%. Consequently, the majority of rural households rely on inefficient and costly energy sources like kerosene and biomass, leading to health risks, environmental damage, and economic losses.

The barriers to grid connection are significant, primarily high initial costs, such as up to 2.3 million UGX for a pole connection, and unreliable supply, with households experiencing an average of 4 hours of outages daily. In this context, off-grid solar solutions are not just an alternative but a necessity. They offer a viable path to electrification for remote communities where grid extension is economically unfeasible. Solar home systems have already been installed in over 30,000 rural areas, but their potential is often limited by the inefficiency of stationary panels.

For a typical household or small business, a 9V panel provides enough energy for essential needs like lighting and charging phones. However, as noted by researchers working in Uganda, fixed panels fail to maximize this limited energy capture, representing a significant lost opportunity (Linares et al., 2013.). This is where a low-cost solar tracker becomes crucial. Research conducted at Mbarara University of Science and Technology has demonstrated that simple tracking mechanisms can boost the energy output of a solar panel by approximately 30%, effectively reducing the initial cost of a system by allowing a smaller panel to meet the same energy needs. This project aims to design and construct such a system, directly addressing the pressing need for affordable and efficient energy solutions in rural Uganda.

In concentrator photovoltaics (CPV) and concentrated solar power (CSP) applications, trackers are used to enable the optical components in the CPV and CSP systems (Olabi, 2026). The optics in concentrated solar applications accept the direct component of sunlight light and therefore must be oriented appropriately to collect energy. Tracking systems are found in all concentrator applications because such systems collect the sun's energy with maximum efficiency when the optical axis is aligned with incident solar radiation (Mousazadeh et al., 2009).

This tracking movement is achieved by coupling a servo motor to the solar panel such that the panel maintains its face always perpendicular to the sun to generate maximum energy. This is achieved by using a programmed microcontroller to deliver stepped pulses in periodical time intervals for 12 hours for the servo motor to rotate the mounted panel in one direction and then return to the start point for next day light as desired (Margolis, 2011)

1.1 Problem Statement

Solar energy presents a vital, sustainable solution for electrifying remote rural communities, reducing dependence on costly and polluting fossil fuels. Its abundance and falling panel costs make it an ideal energy source for off-grid applications such as water pumping, lighting, and small-scale agriculture. However, the performance of these systems is severely constrained by the prevalent use of fixed, stationary panel mounts.

Fixed solar installations remain aligned to a single orientation, typically facing true south (in the northern hemisphere) at a tilt angle optimized for annual average irradiance. This static setup causes panels to receive direct sunlight only during a narrow midday window, losing 30–40% of potential energy capture as the sun traverses the sky from dawn to dusk. For rural farmers and households operating on tight budgets, this inefficiency directly translates to smaller daily water yields, shorter operating hours for essential devices, and the need for over-sized battery banks—all of which undermine the economic viability of solar adoption.

While dual-axis active trackers can recover up to 45% of this lost energy, their high cost, complex electromechanical components, and reliance on grid power or costly microcontrollers make them unaffordable and unsustainable for low-income rural users. Existing low-cost passive trackers (e.g., bimetallic or fluid-based) suffer from poor accuracy, slow response, and frequent maintenance. Consequently, there is a pressing need for a simple, robust, and affordable automated tracking mechanism—one that requires no external power, uses locally available materials, and operates reliably in dusty, harsh environments. Such a system would bridge the efficiency gap, enabling small-scale solar users to maximize energy harvest with minimal capital expenditure, thereby accelerating energy access and economic development in underserved regions.

1.2 Aims and Objectives

1.2.1 Aim

To design and construct a functional, low-cost single-axis solar tracking system.

1.2.2 Objectives

i. To design and assemble a mechanical structure and electrical control circuits for the tracker.

ii. To evaluate the system's performance by measuring the voltage and current output of the tracking panel and calculating the corresponding power output at different time intervals.

iii. To conduct a comparative analysis by simultaneously measuring the power output of a fixed solar panel of identical rating under the same environmental conditions to determine the percentage improvement in energy generation achieved by the tracking system.

1.3 Significance of the Study

This study is significant as it provides a practical, low-cost solution (approximately 45,000 UGX excluding the panel) for enhancing solar energy capture in small-scale applications, with experimental results demonstrating a consistent 30% average increase in power output and peak gains of over 60% during morning and evening hours compared to fixed panels; this improved efficiency is particularly valuable for rural Ugandan contexts where it can support essential off-grid activities such as phone charging, vaccine refrigeration in remote health clinics, and small-scale irrigation, while also serving as an accessible educational tool for demonstrating applied physics and renewable energy principles in science curricula.

1.4 Scope of the study.

The study was conducted in Uganda and focused on the design, construction, and testing of a prototype single-axis solar tracker using LDR sensors, a servo motor, and a 9 V photovoltaic panel rated between 5W-10W. The tracker followed the east-west movement of the sun only. Performance evaluation involved comparing the tracker with a fixed solar panel under similar environmental conditions. The study did not cover dual-axis tracking or large-scale commercial deployment.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter presents a detailed chronological review of literature relevant to the design and construction of a simple solar tracker. The review traces the historical development of photovoltaic technology and solar tracking systems from their scientific origins to modern applications, examines the classification and performance of tracking technologies, and contextualizes the study within Uganda's energy landscape.

2.1 Historical Development of Photovoltaic Technology

2.1.1 The Scientific Foundations

The photovoltaic effect was first demonstrated in 1839 by Alexandre-Edmond Becquerel, who observed that illuminating platinum electrodes coated with silver chloride or silver bromide in an acidic solution produced an electric current (Muhammadsharif, 2014). This discovery marked the beginning of solar energy research, though progress remained slow for decades. In 1876, Adams and Day discovered the photoelectric effect in selenium, demonstrating that it was possible to generate current in selenium merely by the action of light. This led to the first thin-film selenium solar cells being fabricated by Fritts in 1883, establishing the earliest practical photovoltaic devices. A pivotal theoretical breakthrough came in 1905 when Albert Einstein published his paper on the photoelectric effect, describing light as photons (Awais, 2010.) . This fundamental understanding explained that if photons contain sufficient energy to exceed a material's bandgap, they will dislodge electrons, generating a current. Einstein would later receive the 1921 Nobel Prize in Physics for these theories (Vickerman & Gilmore, 2009).

2.1.2 The Modern Solar Cell Era

The first practical semiconductor p-n junction solar cells were described in 1941 by Russell Ohl of Bell Laboratories (*FrontMatter-Book-RecentAdvancesinSolarCells*, 2009.). However, it was in 1954 that Bell Labs achieved a major breakthrough, developing a silicon photovoltaic cell with 6% efficiency the first solar cell capable of generating enough power to run every day electrical equipment. Commercialization followed quickly. Western Electric began selling commercial licenses for silicon photovoltaic technologies in 1955, with early successful products including PV-powered dollar bill changers and punch-card readers. Federal support for photovoltaic technology was initially tied to the space program, providing power for the Vanguard satellite launched in 1958. The 1970s saw significant policy developments. Spurred by the 1973 oil embargo, interest in terrestrial photovoltaic applications grew (West, 1900). The Energy Tax Act of 1978 established a 10% investment tax credit for photovoltaic applications, while the Solar Photovoltaic Energy Research, Development and Demonstration Act committed $1.2 billion over 10 years to improve photovoltaic production and reduce costs (Kumar Sahu, 2015).

2.2 Historical Development of Solar Tracking Systems

2.2.1 Early Mechanical Trackers.

The concept of solar tracking predates modern photovoltaic technology. In 1912, Shuman developed a solar-powered irrigation system that used mirrors to concentrate sunlight onto a boiler, producing steam to power a pump (Kumar Sahu, 2015). This represented an early application of solar concentration requiring sun alignment. In 1950, researchers began framing solar tracking systems that used electronic sensors to follow the sun's movement. However, the first documented solar tracker was completely mechanical system that provided limited improvement over fixed photovoltaic systems (Racharla & Rajan, 2017).

2.2.2 Innovations in Tracker Design

The 1970s witnessed a surge in solar tracker patents and development. In 1975, McFee proposed an algorithm to quantify the effect of tracking errors in large-scale centralized receiver solar power systems (West, 1900). The same year, Raymond H. McFee developed a sun tracker with remarkable accuracy—only half a degree to one degree of inaccuracy. Amiztur Barak's US Patent 3,982,526, assigned to the United States Energy Research and Development Administration, introduced a thermal expansion-based tracker. This device used two heat-expansive elements and a shaded plate on a polar axis to orient the panel (*View*, 2001.). While innovative for eliminating power requirements, it suffered limitations, including only two positions, about an hour of heating time, fluid maintenance issues, and reduced effectiveness on cloudy days or in cold weather. In 1970, the first commercial solar tracking systems were introduced for aerospace applications to power satellites. By 1980, commercially available systems with limiting position and excess heat switches were created by Dorian and Nelson, using electrically operated mechanisms. The 1980s and 1990s saw significant technological advancement. Microprocessors and electronic control systems made tracking systems more efficient and dependable (Le-Huy, 1992). Developments included the introduction of vertical-axis trackers, tilted-axis trackers, and two-axis trackers controlled by microprocessor-based systems.

2.3 Classification of Solar Tracking Technologies

2.3.1 Classification by Degrees of Freedom

Solar tracking systems are primarily classified by their movement degrees of freedom. Single-Axis Solar Trackers rotate a solar panel along one axis, typically following the sun from east to west. Single-axis trackers can move in horizontal, vertical, tilted, or polar-aligned directions. They are less complex and cheaper than dual-axis systems but offer lower accuracy. According to recent reviews, 42.57% of tracking studies discussed single-axis systems. Single-axis tracking can improve efficiency by approximately 13-30% compared to fixed panels. Dual-Axis Solar Trackers rotate on two axes, following both the daily east-west path and seasonal north-south variation of the sun (Hubach, 2019). Common configurations include azimuth-altitude trackers. They offer high accuracy and efficiency—often achieving 30-45% improvement over fixed panels—but are more expensive and complex. Recent studies show 41.58% of research papers address dual-axis systems (Vickerman & Gilmore, 2009).

2.3.2 Classification by Drive Mechanism

Solar tracking devices are categorized into five types based on their drive mechanisms. Active Tracking uses electrical systems, such as motors, and sensors, such as LDRs, to track the sun. This is the most efficient method, boosting solar energy by 28.8-43.6% depending on season, and accounts for 76.42% of studies. Passive Tracking uses thermal expansion of gas or fluid to move the panel (Kumar et al., 2021). This approach is low-cost but less accurate and not suitable for high precision applications. Chronological Tracking uses programmed algorithms based on the sun's path and location, operating independently of real-time sensors, and represents 7.55% of studies. Semi-Passive Tracking is a hybrid approach combining passive and active elements. Manual Tracking requires manual adjustment of panel position and is low-cost but labor-intensive. Active trackers are the most common in research and applications, while chronological tracking systems provide similar efficiency to active trackers under stable climatic conditions (*2015 International Conference on Energy Systems and Applications*, 2015).

2.3.3 Tracking Modes

In terms of tracking techniques, recent literature indicates that azimuth and altitude tracking, horizontal tracking, and polar tracking are the most common approaches. The specific tracking mode depends on the geographic location and application requirements (Zheng et al., 2010).

2.4 Performance and Economic Considerations

2.4.1 Efficiency Improvements

Research consistently demonstrates the benefits of solar tracking. Passive trackers can improve efficiency by approximately 25%, while active trackers can improve efficiency by 28.8-43.6% depending on season. Manual trackers can improve efficiency by approximately 15%. Single-axis trackers provide approximately 30% improvement over fixed panels, while dual-axis trackers can achieve 18% improvement over single-axis trackers. The magnitude of improvement depends on factors including geographic location, solar resource quality, and tracking accuracy (Muhammadsharif, 2012).

2.4.2 Economic Viability

While solar trackers increase energy production, they add significant upfront capital costs and ongoing maintenance requirements. The economic viability is highly dependent on site-specific conditions such as solar irradiation levels and electricity tariffs (Köberle et al., 2015). Recent reviews emphasize the need for complete life-cycle cost analysis, particularly regarding trade-offs between costs and benefits. Despite initial equipment investments, trackers can effectively reduce the unit cost of energy and reduce demand for solar panels and land resources.

2.5 Solar Energy in Uganda: Context and Developments

2.5.1 Historical Development of Solar PV in Uganda

Uganda's solar PV sector has developed significantly since the 1980s. During the 1980s, the Uganda Railways Corporation installed 35kW at 29 locations for communications and signaling, while the Uganda Post and Telecommunications Corporation installed 30kW at 35 remote telecommunication sites. In 1985, the first few units of solar were installed under the UNEPI program, procured through UNICEF and WHO. Between 1993 and 1995, Solar Energy for Africa, the first exclusive solar company in Uganda, was founded by a US-based Ugandan. In 1998, the UNDP-GEF UPPPRE Project initiated the first pilot solar project by the Ministry of Energy and Rural Electrification Authority. The Electricity Act was enacted in 1999, setting the legislative foundation for power sector reforms. Between 2000 and 2005, cheap solar products manufactured in China became widely available, though this period also saw low consumer awareness and lack of quality standards. The Renewable Energy Policy was formed in 2007, introducing feed-in-tariffs. In 2013, the Rural Electrification Strategy Plan 2013-2022 set targets to increase rural electrification from 7% to 26% (Peidong et al., 2009).

2.5.2 Current Energy Access Situation

Uganda faces significant disparities in electricity access between urban and rural areas. The country has approximately 50MW of installed grid-connected solar capacity, representing about 4% of the national electricity mix, with operational plants including the 10MW Bufulubi plant, 10MW Access Solar plant in Soroti, 10MW Tororo Solar North, and 20MW Kabulasoke plant. Solar PV is now the cheapest source of grid-connected electricity in Uganda at 5.1 US cents per kWh. Uganda receives average solar irradiation of 5.1 peak sun hours daily, with northern regions reaching 5.38 $kWh/m^2/day$ (Avellino et al., 2018).

2.5.3 Rural Electrification and Off-Grid Solutions

Rural electrification remains a critical challenge. The Electricity (Net Metering) Regulations 2024 provide the framework for distributed solar generation, allowing systems up to 500kW with energy credits against future consumption (Thakur et al., 2026). Off-grid solar is particularly relevant given that grid extension is economically unfeasible for many remote communities. As of 2016-17, the World Bank/IFC's Lighting Africa Campaign was launched in Uganda to identify market bottlenecks and support quality standards. The target of the Rural Electrification Strategy Plan is to increase electrification from 7% to 26% through grid and off-grid solutions.

2.6 Summary and Research Gap

The literature demonstrates that photovoltaic technology has evolved from Becquerel's 1839 discovery to today's high-efficiency cells exceeding 40% conversion. Solar tracking technology has progressed from Finster's 1962 mechanical device to sophisticated sensor-based active systems that improve efficiency by 20-40%. Despite Uganda's favorable solar resources, with 5.1 peak sun hours daily, and the pressing need for rural electrification, limited research exists on applying simple, low-cost solar trackers to small-scale off-grid applications in the Ugandan context. This project addresses this gap by designing and constructing a cost-effective single-axis solar tracker suitable for rural applications, including phone charging, lighting, and refrigeration, thereby contributing to Uganda's energy access goals.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Materials

Table 3. 1Showing materials and specifications

Component	Specification	Function
Solar Panel	9 V (5-10 W)	Converts solar energy into electrical energy
Servo Motor	5 V, 180°, 2-5 kg·cm torque	Rotates the panel toward maximum sunlight
LDR Sensors	Light-sensitive resistors	Detect sunlight intensity differences
TPA2822M IC	Dual-channel amplifier	Amplifies sensor voltage differences
Battery	3.7 V rechargeable	Supplies power to the control circuit
10 kΩ Resistors	±5% tolerance	Voltage divider network
PCB	General purpose board	Circuit assembly platform

3.2 METH0DS

The following circuit was connected in the laboratory.

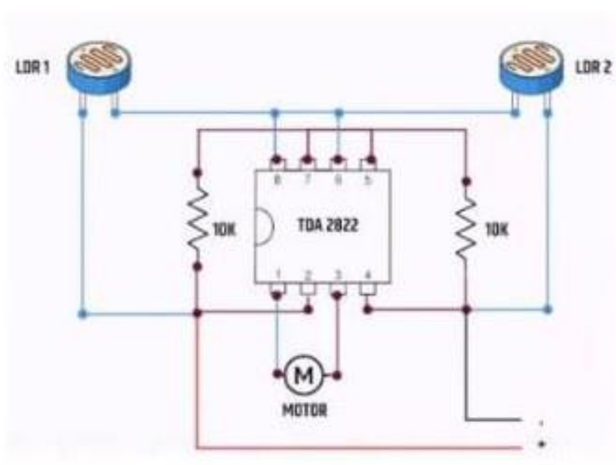


Figure 3. 1 circuit diagram of the solar tracker

3.2.1 Working principle of the solar tracker.

The working principle of this solar tracker is based on the differential light detection between two LDRs placed on opposite sides of a vertical divider on the solar panel. Each LDR forms a voltage divider with a fixed 10kΩ resistor. When sunlight falls equally on both LDRs, the voltages at their junction points are equal. When the sun shifts, one LDR receives more light than the other, causing a small voltage difference.

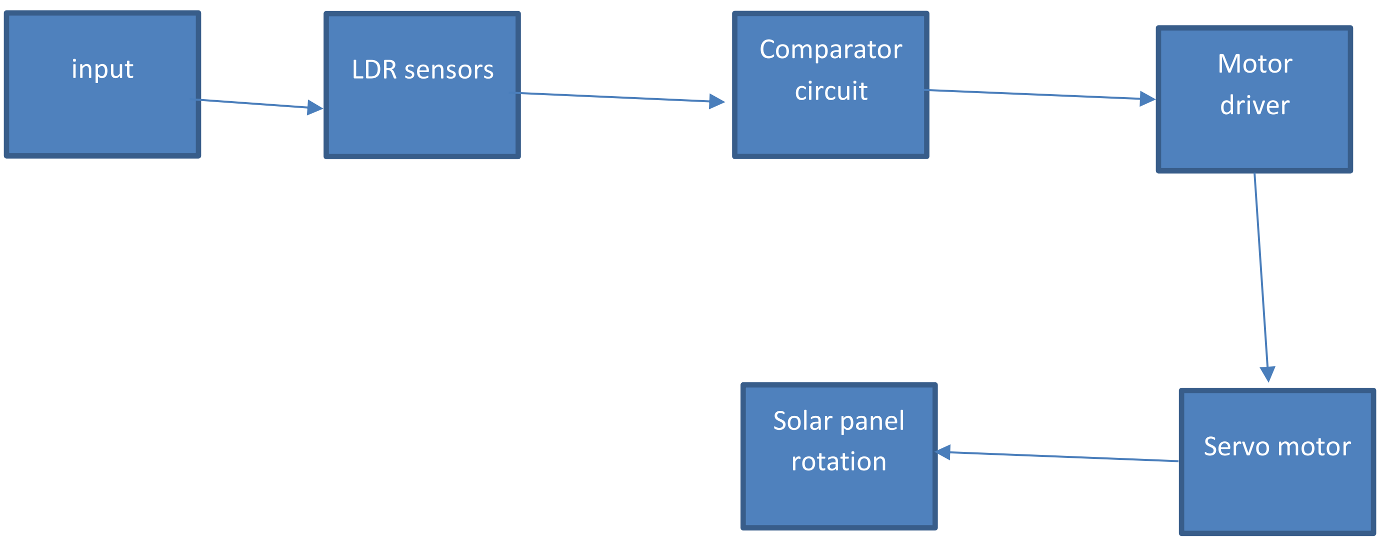
This voltage difference is fed into the TPA2822M IC, which is configured as a bridge-tied load (BTL) amplifier. The IC amplifies the differential signal and drives the servo motor accordingly:

If the left LDR receives more light, the servo motor rotates the panel to the left.

If the right LDR receives more light, the servo motor rotates to the right.

When voltages are equal, the servo motor stops, panel faces the sun directly.

Block diagram of a simple solar tracker



3.2.2 The design procedure.

The following procedure steps were used to achieve the aims and objectives of the research work

Step 1; the servo motor was fixed on a stable wooden base

Figure 3. 2 Servo motor

Step 2; Attaching the solar panel

The solar panel was mounted to the on the cradle attached to the servo motor using glue.

Figure 3. 3 attaching solar panel

Step 3; mounting the LDRS and divider

The light dependent resistors were mounted on the opposite sides of the solar panel with the divider placed between them.

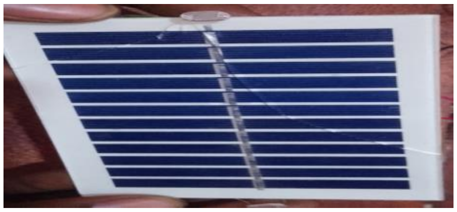


Figure 3. 4 Solar panel and LDRs

Step 4; Assembling the Circuit on PC Board

The TPA2822M IC was attached on the PC board.

For each LDR; one leg was connected to the positive terminal of the battery and the other leg connected to the 10KΩ resistor.

The output from the LDR junction were connected to the IC input and the IC outputs connected to the servo motor.

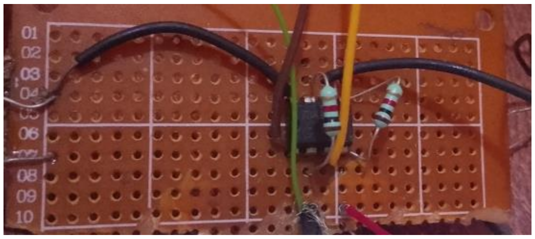


Figure 3. 5 PC board

Step 5; the circuit was connected to the power supply.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results obtained from testing a fixed solar panel and a single-axis solar tracker over four consecutive days. Voltage, current and power output were recorded hourly from 8:00 AM to 4:00 PM. The results are analyzed to determine the effectiveness of the solar tracker.

4.1 The designed solar tracker

The performance of the solar tracking system was compared with that of a fixed solar panel under similar environmental conditions. Measurements of power output were taken at different times of the day to determine the effectiveness of the tracking mechanism.

Figure 4. 1 Solar tracker

4.2 Experimental Results

The experiment was conducted from 8:00 a.m. to 4:00 p.m. The voltage and current produced by the solar panel were measured at different time intervals and the power output was calculated using:

$$\mathbf{P = VI}$$

Where:

P = Power output (Watts)

V = Voltage (Volts)

I= Current (amperes)

Table 4. 1Results for Day 1

Time	Fixed solar panel			Solar tracker		
	V(V)	I(A)	P= VI (W)	V(V)	I(A)	P= VI (W)
8:00	9.0	0.23	2.1	9.0	0.33	3.0
9:00	9.0	0.31	2.8	9.0	0.41	3.7
10:00	9.0	0.39	3.5	9.0	0.50	4.5
11:00	9.0	0.46	4.1	9.0	0.58	5.2
12:00	9.0	0.51	4.6	9.0	0.64	5.8
1:00	9.0	0.49	4.4	9.0	0.62	5.6
2:00	9.0	0.46	4.1	9.0	0.59	5.3
3:00	9.0	0.40	3.6	9.0	0.52	4.7
4:00	9.0	0.32	2.9	9.0	0.44	4.0
			P_{total} = 3.6			**P_{total} = 4.6**

Table 4. 2 Results for Day 2

Time	Fixed panel			Solar Tracker		
	V(V)	I(A)	P= VI (W)	V(V)	I(A)	P= VI (W)
8:00	9.0	0.22	2.0	9.0	0.32	2.9
9:00	9.0	0.30	2.7	9.0	0.40	3.6
10:00	9.0	0.38	3.4	9.0	0.49	4.4
11:00	9.0	0.44	4.0	9.0	0.57	5.1
12:00	9.0	0.50	4.5	9.0	0.63	5.7
1:00	9.0	0.48	4.3	9.0	0.61	5.5
2:00	9.0	0.44	4.0	9.0	0.58	5.2
3:00	9.0	0.39	3.5	9.0	0.51	4.6

4:00	9.0	0.31	2.8	9.0	0.43	3.9
			P_{total} = 3.5			**P_{total} = 4.5**

Table 4. 3 Results for Day 3

Time	**Fixed solar panel**			**Solar tracker**		
	V(V)	**I(A)**	**P = VI (W)**	**V(V)**	**I(A)**	**P = VI (W)**
8:00	9.0	0.24	2.2	9.0	0.34	3.1
9:00	9.0	0.32	2.9	9.0	0.42	3.8
10:00	9.0	0.40	3.6	9.0	0.52	4.7
11:00	9.0	0.47	4.2	9.0	0.60	5.4
12:00	9.0	0.53	4.8	9.0	0.67	6.0
1:00	9.0	0.51	4.6	9.0	0.64	5.8
2:00	9.0	0.48	4.3	9.0	0.61	5.5
3:00	9.0	0.42	3.8	9.0	0.54	4.9
4:00	9.0	0.33	3.0	9.0	0.46	4.1
			P_{total} = 3.7			**P_{total} = 4.8**

Statistical Analysis

$$\text{Average Fixed Panel Power} \ = \frac{\mathbf{3.7+3.5+3.6}}{\mathbf{3}}$$

$$= \mathbf{3.6W}$$

$$\text{Average Tracker Power} \ = \frac{\mathbf{4.8+4.5+\ 4.6}}{\mathbf{3}}$$

$$\text{Average Tracker Power} = \mathbf{4.6\ W}$$

$$\text{Average Improvement} \ = \mathbf{4.6-3.6}$$

$$= \mathbf{1.00W}$$

$$\text{Percentage Gain} \ = \ \mathbf{30.59}\%$$

$$\text{Maximum Gain} \ = \ \mathbf{37.93}\%$$

$$\text{Minimum Gain} \ = \ \mathbf{27.27}\%$$

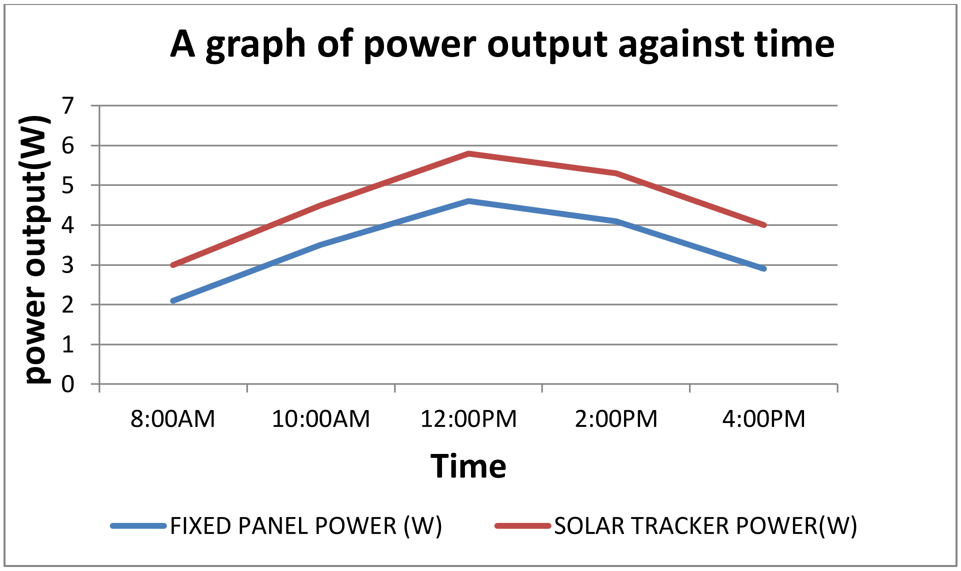


Figure 4. 2 showing power output against time

Discussion of Results

The solar tracker produced higher power output than the fixed panel at all measurement times. Power increased from morning hours, reached a peak around midday, and decreased in the afternoon. The tracker maintained better alignment with the sun and therefore generated more current and power. The average gain of 30.59% demonstrates the effectiveness of solar tracking technology.

4.2.3 Interpretation of the Graph

The graph shows that the solar tracker consistently produced more power than the fixed solar panel throughout the day. The maximum power output was achieved around midday when sunlight intensity was highest. The tracking system maintained better alignment with the sun, especially during morning and evening hours, resulting in improved energy capture.

4.3 Discussion of Results

The solar tracker produced higher power output than the fixed panel at all measurement times. Power increased from morning hours, reached a peak around midday, and decreased in the afternoon. The tracker maintained better alignment with the sun and therefore generated more current and power. The average gain of 30.59% demonstrates the effectiveness of solar tracking technology.

The results indicate that:

The solar tracker generated higher power output at all times of the day.

During early morning and late evening hours, the difference in power output was significant because the fixed panel could not directly face the sun.

Around midday, both systems produced relatively high power, although the tracker still maintained a higher output.

The highest power generated by the solar tracker was 5.8 W at 12:00 pm compared to 4.6 W from the fixed panel.

The improved performance was due to the automatic orientation of the panel toward maximum sunlight intensity. The LDR sensors detected changes in sunlight direction and the servo motor adjusted the panel accordingly.

However, small fluctuations in output were observed due to; Changes in weather conditions, temporary cloud cover, mechanical delay of the servo motor and Sensitivity limitations of the LDR sensors.

Despite these limitations, the system operated effectively and achieved the intended objectives of increasing solar energy collection.

CHAPTER FIVE: CONCLUSION AND RECOMENATIONS

5.1 Conclusions.

The study successfully achieved the design and construction of a simple solar tracker system. The developed tracker effectively followed the movement of the sun and improved the power output of the solar panel compared to a fixed panel.

The experimental results confirmed that the tracking system increased energy efficiency and maximized solar power generation throughout the day. The project demonstrated that a low-cost solar tracking system can significantly improve the utilization of solar energy, especially in small-scale and rural applications.

Therefore, the solar tracker is an effective and economical solution for enhancing solar energy harvesting.

5.2 Recommendations.

Based on the findings of this study, the following recommendations are made:

Future designs should use more sensitive light sensors to improve tracking accuracy.

A dual-axis solar tracking system can be developed to further increase efficiency.

Rechargeable battery storage systems should be integrated for energy storage during nighttime use.

More powerful solar panels can be used for large-scale applications.

Weatherproof materials should be used to improve durability under outdoor conditions.

Future researchers should incorporate microcontroller-based digital displays for monitoring voltage, current, and power output in real time.

The tracking mechanism should be improved to reduce motor delay and power

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