DECLARATION A

I NGUELE Keny Declare that This research study is my original work and has not been presented for a Degree or any other academic award in any University or Institution of Learning". No part of this research should be reproduced without the authors' consent or that of ULK Polytechnic Institute.

Student name: __________________

Sign: __________________________ Date: ________________

DECLARATION B

I, do declare this research project entitled **Design and implementation of dual-axis solar tracker simulator in southern Rwanda** prepared and submitted by NGUELE Keny in partial fulfillment of the requirement for award of advanced diploma (A1) in Electrical Technology.

Name and Sig. of Supervisor: ___________________________

Date of Comprehensive Examination: _____________________

DEDICATION

A special dedication to my family especially my grandparents who have been played a significant role in my social life and studies.

Also, I dedicate this work to my close friends who are always being presented in the good and bad times but also for our awesome relationship we maintain one another.

To my church members, I am so much grateful started my spiritual life here with some kind brethren who help me to be close with Jesus Christ in my daily life.

ACKNOWLEDGEMENT

First and foremost, I would like to thank God for his never-ending grace, mercy, and provision during what ended up being one of the toughest times of my life.

I have an acknowledgement for my family members for the wonderful love, encouragement and financial aid as well as going ahead with my vision. By the same token this acknowledgement goes to my special family that I have found here I mean all the brothers, sisters from Gabon and Rwanda too who contributed financially or socially during my staying.

I sincerely acknowledge all the great job done by ULK Polytechnic members in the sense where they have been more than lecture or administrator but for playing the role parents for us through some advice and through their will of guiding us perfectly academically.

ABSTRACT

This research aims at determining the effectiveness of tracking system, which has two axes in enhancing the solar energy collection in the southern part of Rwanda. As the world becomes conscious of pollution and the usage of fossil fuels becomes deemed unsustainable, there is hope in other forms of energy such as solar energy. However, the effectiveness of solar panel depends on the fact of their capacity to follow the movement of the sun during the day. For the sake of improvement of the orientation of the solar panels, this research links a dual axis tracking technique to it. In the research, the orientation of solar geographical location of the southern part of RWANDA, the coordinates of latitude and longitude and climate. A number of simulations and empirical data collecting are provided to estimate the effectiveness of dual-axis tracking system in comparison with the fixed-mount solar panels. This study shows that great advances were made in terms of energy production and efficiency where the tracking system has been installed especially during the times of low sun position and in the fluctuations of season. In addition, economic and environmental consequences are analyzed and current economic opportunities and potential impacts of this technology on energy security and carbon neutrality goals of Rwanda are also described. To policymakers, energy planners as well as investors who intend to support renewable energy systems in Rwanda and other regions with high solar irradiation, this study holds a lot of potentials.

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LIST OF ACCRONYMS AND ABBREVIATIONS

LDR: Light Dependent Resistor
REG: Rwanda Energy Group
PV: Photovoltaic
ADC: Analog Digital Converter
CSP: Concentrated solar Power
EDCL: Energy Development Corporation Ltd
SHS: Solar Home System
MATLAB: Mathematic Laboratory
CO_2: Dioxygen Carbon
SWOT: Strength Weakness Opportunity and Threat
SAM: System Advisor Model
NPC: Net Present Cost
NGOs: Non-Governmental Organizations
SME: Small and Medium Enterprise
SD Card:
PCB: Printed Circuit Board
SPSS: Statistical Package for the Social Science

CHAPTER 1: GENERAL INTRODUCTION

1.0 Introduction

Renewable energy has gained significant attention globally due to its potential to provide clean and sustainable power. Solar energy, in particular, is a promising alternative to conventional fossil fuels. This study focuses on a dual-axis solar tracking system implemented in the southern region of Rwanda.

1.1 Background of the Study

Rwanda, located near the equator, receives ample sunlight throughout the year, making it an ideal location for solar energy projects. However, the efficiency of solar panels can be significantly enhanced by utilizing tracking systems that follow the sun's path. dual-axis tracking systems adjust both the azimuth and elevation angles of the solar panels, ensuring they are optimally positioned to capture maximum sunlight throughout the day. This study examines the effectiveness of a dual axis tracking solar system in the south of Rwanda, aiming to contribute to the nation's renewable energy initiatives.

1.2 Problem Statement

Despite Rwanda's high solar potential, many solar energy projects in the region still rely on fixed solar panels, which do not utilize the available solar radiation effectively. This leads to suboptimal energy generation and higher costs per unit of electricity produced. There is a need to explore and implement more efficient solar tracking systems to maximize energy output and reduce costs. This study addresses this gap by evaluating the performance and benefits of a dual-axis tracking system in the south of Rwanda.

1.3 Research Objectives

1.3.1 Main objectives

The main objective of this research is design and implementation of dual axis tracking sun in southern Rwanda.

1.3.2 Specific Objectives

A dual axis solar tracker in southern Rwanda could have the following key objectives:

- **To maximize solar energy absorption**: By continuously adjusting the panel's orientation to track the sun's position throughout the day, a dual axis tracker can increase the amount of solar energy captured compared to a fixed panel. This is especially important in southern Rwanda where the sun's position varies significantly.
- **To improve energy generation efficiency**: Studies have shown that dual axis trackers can increase the energy output of a solar panel by 55.38% compared to a fixed system. This efficiency boost is critical for maximizing the power generated from a small panel.
- **To provide reliable off-grid power**: In rural areas of southern Rwanda, access to grid electricity is limited. A dual axis solar tracker could be used to power critical loads like lighting, communications, and small appliances in off-grid homes and businesses.
- **To demonstrate solar tracking technology**: Deploying a small-scale dual axis tracker could help raise awareness and interest in solar energy in southern Rwanda. It could serve as an educational tool to showcase the benefits of tracking systems and encourage further adoption of solar power.
- **To gather performance data**: Instrumenting the tracker to monitor parameters like solar irradiance, panel temperature, current and voltage could provide valuable data on its real-world performance.

1.3.3 Research Questions

- What are the most effective strategies and technologies for optimizing the efficiency of solar panels in order to maximize energy absorption throughout the day?
- What innovative technologies and methods can be implemented to enhance the energy generation efficiency of solar panels in residential and commercial applications?
- What are the key components and considerations for designing an effective off-grid power system that ensures reliable energy supply in remote areas?
- How does the implementation of dual-axis solar tracking technology enhance the efficiency and energy output of solar photovoltaic systems compared to fixed installations?
- What are the most effective methods and tools for collecting and analysing performance data from solar panel systems to ensure optimal energy production and system efficiency?

1.4 Scope and Limitations

This study will focus on the performance and impact of a dual-axis solar tracking system in the southern region of Rwanda. The time scope of the study will span from the initial installation and testing phase through a full year of operational data to account for seasonal variations in solar radiation. The research will cover a period from July 2024 to August 2024, allowing for a comprehensive analysis of the system's performance across different seasons.

1.5 Significance of the Study

This study is significant for several reasons:

•It provides valuable data on the performance and efficiency of dual-axis solar tracking systems in Rwanda, which can inform future renewable energy projects.

•It offers insights into the economic and environmental benefits of adopting more advanced solar technologies.

•The findings can help policymakers and stakeholders make informed decisions regarding the promotion and implementation of solar energy solutions in Rwanda.

1.6 Organization of the Study

Chapter One or General Introduction provides an overview of the study, including the background, problem statement, objectives, research questions/hypotheses, scope, significance, and organization of the study. Literature Review reviews existing literature on solar energy, solar tracking systems, and their applications. In Research Methodology, this chapter outlines the research design, data collection methods, and analytical techniques used in the study. Chapter Four presents the findings of the study and discusses their implications and the chapter Five concludes the study and offers recommendations for future research and policy-making.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

This chapter presents a comprehensive review of the literature on dual axis solar tracking systems, focusing on their application and potential benefits in the southern region of Rwanda. It covers key concepts, expert opinions, theoretical perspectives, and related studies to establish a foundation for understanding the significance and implementation of a dual axis solar tracking system in this context.

2.1 Experts Opinions

In this section, we explore the fundamental concepts and expert insights related to dual axis solar tracker systems and their relevance to solar energy utilization in Rwanda.

Dual axis solar trackers follow the sun's movement across the sky, adjusting both horizontally and vertically to maximize solar energy capture throughout the day. In contrast to fixed and single-axis systems, dual axis trackers can significantly increase energy output by maintaining optimal panel orientation to the sun, resulting in up to 40% more energy production. Recent innovations in tracking mechanisms, sensors, and control algorithms have improved the efficiency and reliability of these systems. Solar energy is a critical component in addressing energy shortages in developing regions, providing a sustainable and reliable power source. But key challenges include high initial costs, lack of technical expertise, and infrastructural limitations. then, the decreasing cost of solar technology and increased investment are mitigating these issues. Rwanda has a growing demand for electricity, with efforts to expand access to renewable energy sources. The southern region, in particular, presents opportunities due to its high solar insolation levels. In addition, initiatives like the Rwanda Energy Group (REG) and the National Strategy for Transformation emphasize the expansion of renewable energy to achieve universal access by 2024. Experts highlight the potential of dual axis trackers to optimize solar energy capture in regions with variable weather conditions, making them suitable for Rwanda's climate. Additionally, interviews with Rwandan energy sector professionals underscore the importance of tailored solutions that consider local socio-economic conditions and infrastructure.

2.2 Theoretical Perspective

The Light Dependent Resistor (LDR), also known as a photoresistor, is a light-sensitive component that exhibits a change in resistance based on the intensity of light falling on it. Typically, LDRs have a high resistance in darkness (often exceeding 1 megaohm) and a significantly lower resistance in bright light (around 1.8kΩ to 4.5kΩ at 10 lux). They are commonly used in various applications, such as automatic lighting systems, light meters, and solar trackers, due to their ability to detect light levels effectively. The peak sensitivity of LDRs is usually around 600 nm, which corresponds to the visible spectrum, making them ideal for detecting ambient light changes.

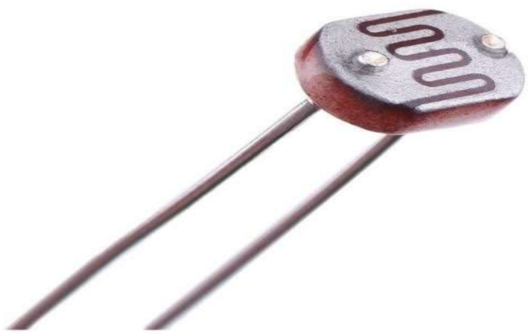

FIGURE 1: LIGHT DEPENDENT RESISTOR

The SG95 servo motor is a small, lightweight servo widely used in hobbyist projects and robotics. It operates on a standard voltage of 4.8 to 6.0 volts and provides a rotation range of approximately 180 degrees. The SG95 is known for its reliable performance and ease of use, making it suitable for applications such as robotic arms, remote-controlled vehicles, and solar tracking systems. Its compact size and affordability contribute to its popularity among makers and engineers, allowing for precise control of angular position based on pulse width modulation (PWM) signals sent from a microcontroller.

FIGURE 2: SERVO MOTOR

The Arduino Uno is a versatile microcontroller board based on the ATmega328P, featuring 14 digital input/output pins, 6 analog inputs, and a USB connection for programming. It operates at a voltage of 5V and is widely used in various electronic projects due to its user-friendly interface and extensive community support. The Arduino Uno allows users to easily interface with sensors, actuators, and other components, making it an ideal choice for projects like the dual-axis solar tracker. By reading input from LDRs and controlling servo motors, the Arduino Uno can automate the positioning of solar panels to maximize energy capture throughout the day.

FIGURE 3: ARDUINO UNO R3

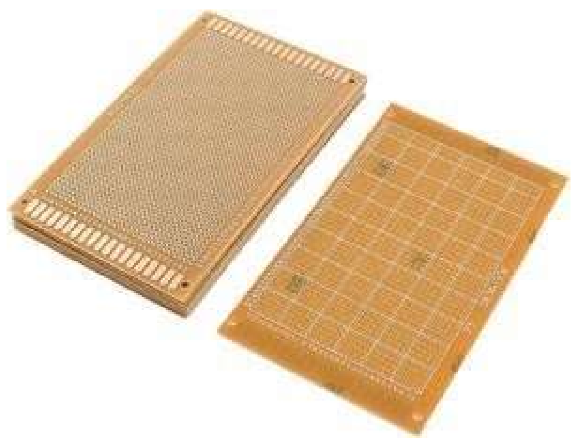

FIGURE 4: PRINTED CIRCUIT BOARD

The PCB (9cm x 15cm) is a standard rectangular shape with no cut outs or irregular edges. This simplifies manufacturing and allows for more efficient use of board space.

The 9cm x 15cm size strikes a good balance between available space and overall board size. It provides enough room for complex circuits while still being compact and cost-effective to manufacture. The rectangular shape is simple and versatile for a wide range of applications.

FIGURE 5: SOLAR PANEL

Voltage: 5V

Power:

Current: 500mA

Size: 130mm x 150mm (5.12" x 5.91")

Weight: 92g (3.2 oz)

Conversion efficiency: 17%

Operating temperature: -20°C to +85°C (-4°F to 185°F)

A 5V/ solar panel is a compact, encapsulated solar panel that can generate 2.5 watts of power at 5 volts. With a conversion efficiency of 17%, it can effectively convert sunlight into electrical energy.

The panel measures 130mm x 150mm and weighs only 92g, making it portable and suitable for a variety of applications.

FIGURE 6: 3D BODY PARTS

A dual axis solar tracker typically consists of the following 3D printed parts:

Base: The base provides a stable foundation for the entire tracker. It may have mounting holes for securing it to a surface.

Altitude Axis: This part rotates on the base to adjust the altitude (elevation) angle of the solar panel. It connects the base to the azimuth axis.

Azimuth Axis: Mounted on the altitude axis, this component rotates to adjust the azimuth (horizontal) angle of the panel. It provides the connection point for the panel frame.

Panel Frame: The frame securely holds the solar panel. It attaches to the azimuth axis and allows the panel to tilt with the altitude axis.

Linkages: These are the connecting rods between the various axes and the panel frame. They transfer the rotational motion from the motors to the panel.

Motor Mounts: Specialized mounts are used to attach the stepper motors that drive each axis. They ensure the motors are securely positioned.

Sensor Mounts: Brackets for mounting the light sensors that detect the sun's position. They are typically placed at the center of the tracker.

Limit Stops: These are small protrusions or attachments that prevent the axes from rotating beyond their limits and damaging the tracker.

The specific design and dimensions of these parts can vary based on the size of the solar panel, the motors used, and the desired range of motion. But in general, these are the key 3D printed components that make up the mechanical structure of a dual axis solar tracker.

2.3 Related Studies

Energy crisis is one of the biggest problems in the third world developing country like Bangladesh. There is a big gap between generation and demand of Electric energy. Almost 50% population of our country is very far away from this blessing. Renewable energy is the only solution of this problem to be an energy efficient developed country. Solar energy is one of the great resources of the renewable energy which can play a crucial role in developing a power deficient country like Bangladesh. This paper provides a proposal of using dual axis solar tracker instead of solar panel. This encompasses a design of ideal solar house model using azimuth-altitude dual axis solar tracker on rooftop. It has been proved through mathematical calculation that the solar energy increases up to 50-60% where dual axis solar tracker is used. Apart from the mentioned design, this paper presents a structure and application of a microcontroller-based azimuth-altitude dual axis solar tracker which tracks the solar panel according to the direction of the solar radiation. A built-in ADC converter is used to drive motor circuit. To minimize the power consumption by dual axis solar tracker, we are in favor of using two stepper motor especially during the seasonal change. The proposed model demonstrates that we require a very small amount of power from national grid if we can install dual axis solar tracker on rooftops of our residence; this is how increasing energy demand can effectively be met. Now-a-days present world is facing crucial energy deficiency. Power is mostly generated using fossil fuels, which emit tons of carbon dioxide and other toxic materials. As the deposits of fossil fuel are dwindling and environment pollution has become a great threat to mankind, solar energy has become the most effective alternative to fossil fuels. Solar energy can be exploited averting environmental pollution and managing atmospheric emission. To make the best use of solar energy, we introduce a model in which both the direct and diffused solar radiation are utilized. This paper puts forward a design of an improved model of dual axis solar tracker combining with concentrated solar power (CSP) and photovoltaic (PV) technology. To increase the optimal energy generation, we propound a system which consists of dish Stirling engine and PV panel. The PV panel is attached on the periphery of the parabolic dish. Apart from the mentioned design, this paper presents a structure and application of a microcontroller-based azimuth-altitude dual axis solar tracker which tracks the system according to the direction of the solar radiation to increase the input to the Stirling engine. An approximate cost evaluation shows that the model will be cheaper than typical solar panel based dual axis tracker.

In Rwanda, electricity access is still low especially in rural villages and 82.79% of the population lives in rural areas. The government decentralized the education where the student's study, and back home at the evening time. Electricity access in rural areas is only 12%, this is a challenge for the students to revise the lessons and also a challenge for families in general to meet households' demand, this leading them to use biomass energy that covers about 85% of primary energy use in Rwanda and this results in various health hazards, environmental pollution, etc. The use of Solar Energy Technology rationally may contribute effectively to solutions of the above problem. The Energy Development Corporation Ltd (EDCL) has signed with 21 Solar companies to facilitate the people getting the solar home systems (SHS) easily, However, some installed SHS fail to give the expected power output to meet home electricity demand and others are not functioning. This causes shortage of electric power and limits electricity extension works. This research evaluated the performance of SHS by measuring the output values of the system components with the help of Multimeter and tape meter for measuring the dimension of panels and make a comparison between calculated and installed efficiencies. Also, the data further collected through visiting 32 SHS, interviewing their owners and personal observation. SPSS software used to display collected data using frequency tables, pie charts, and bar charts. MATLAB Software/ Simulink used for modelling, and run simulation to analyze the effect of some factors on I-V and P-V characteristics curves of selected solar panel the calculated efficiencies of panels were 10.7% and 9.7% while their installed efficiencies are 16% and 17% respectively, which shows that SHS are not properly working. The study found that the performance of SHS is mostly affected by the output of PV module, as its efficiency is affected by irradiance of the Area, roof form and inclination angle, maintenance activities etc. The measures taken focused on inspection and maintenance of SHS components especially PV module. The formulated solutions including: cutting tree leaves blocking sun rays from reaching panel, checking and cleaning the panel surface periodically, changing its direction for daily hours, Keeping battery in adequate area (dry area at room temperature), etc. The follow of guidance solutions boosts the efficiency of SHS and the periodic maintenance is the key factor for sustaining the components lifespan. The use of optimal SHS result in CO2 reduction and satisfy users through enough power for lighting, charging telephones, and help some of them to start small business

The energy sector of today's Rwanda has made a remarkable growth to some extent in recent years. Although Rwanda has natural energy resources (e.g., hydro, solar, and methane gas, etc.), the country currently has an installed electricity generation capacity of only 226.7 MW from its 45 power plants for a population of about 13 million in 2021. The current national rate of electrification in Rwanda is estimated to 54.5% (i.e.; 39.7% grid-connected and 14.8% off-grid connected systems). This clearly demonstrates that having access to electricity is still a challenge to numerous people not to mention some blackout-related problems. With the ambition of having electricity for all, concentrated solar power (CSP) and photovoltaic (PV) systems are regarded as solutions to the lack of electricity. The production of CSP has still not been seriously considered in Rwanda, even though the technology has attracted significant global attention. Heavy usage of conventional power has led to the depletion of fossil fuels. At the same time, it has highlighted its unfriendly relationship with the environment because of carbon dioxide (CO_2) emission, which is a major cause of global warming. Solar power is another source of electricity that has the potential to generate electricity in Rwanda. Firstly, this paper summarizes the present status of CSP and PV systems in Rwanda. Secondly, we conducted a technoeconomic analysis for CSP and PV systems by considering their strengths, weaknesses, opportunities, and threats (SWOT). The input data of the SWOT analysis were obtained from relevant shareholders from the government, power producers, mini grid, off-grid, and private companies in Rwanda. Lastly, the technical and economical feasibilities of CSP and PV microgrid systems in offgrid areas of Rwanda were conducted using the system advisor model (SAM). The simulation results indicate that the off-grid PV microgrid system for the rural community is the most cost-effective because of its low net present cost (NPC). According to the past literature, the outcomes of this paper through the SWOT analyses and the results obtained from the SAM model, both the CSP and PV systems could undoubtedly play a vital role in Rwanda's rural electrification. In fact, PV systems are strongly recommended in Rwanda because they are rapid and cost-effective ways to provide utility scale electricity for off-grid modern energy services to the millions of people who lack electricity access.

In the present study, performance results of two double axis sun tracking photovoltaic (PV) systems are analyzed after one year of operation. Two identical 7.9 kWh PV systems with the same modules and inverters were installed at Mugla University campus in October 2009. Measured data of the PV systems are compared with the simulated data. The performance measurements of the PV systems were carried out first when the PV systems were in a fixed position and then the PV systems were controlled while tracking the sun in two axis (on azimuth and solar altitude angles) and the necessary measurements were performed. Annual PV electricity yield is calculated as 11.53 MWh with 1459 kWh energy rating for 28 fixed tilt angles for each system. It is calculated that 30.79% more PV electricity is obtained in the double axis sun-tracking system when compared to the latitude tilt fixed system. The annual PV electricity fed to grid is 15.07 MW h with 1908 kWh for the double axis sun tracking PV system between April-2010 and March-2011. The difference between the simulated and measured energy values are less than 5%. The results also allow the comparison of different solutions and the calculation of the electricity output.

CHAPTER 3: RESEARCH METHODOLOGY

3.0 Introduction

Research methodology will essentially tackle upon the following points Research Design, Research Population, Sample Size, Sampling Procedure, Research Instrument, Validity and Reliability of Instrument, Data Gathering Procedures, Data analysis and Interpretation, Ethical Consideration, and Limitations of the study.

3.1 Research Design

A block diagram and graph of dual axis tracking sun will bring an explicit investigation and provide a justification of the choice.

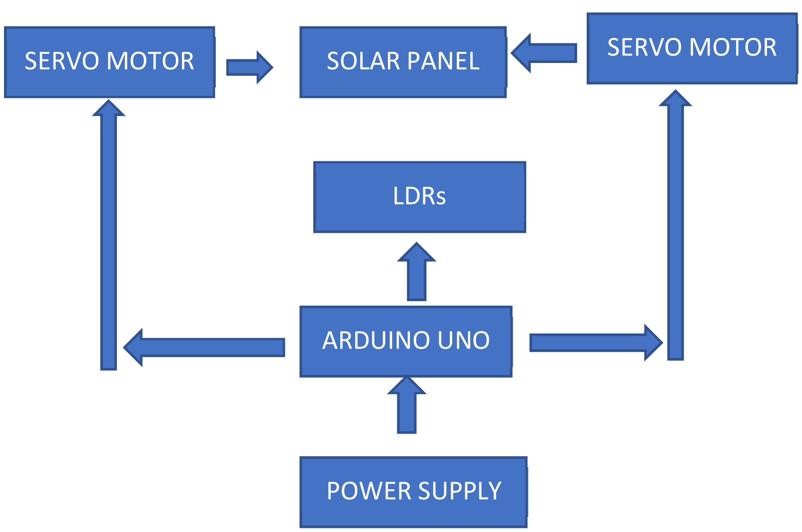

FIGURE 7: BLOCK DIAGRAM

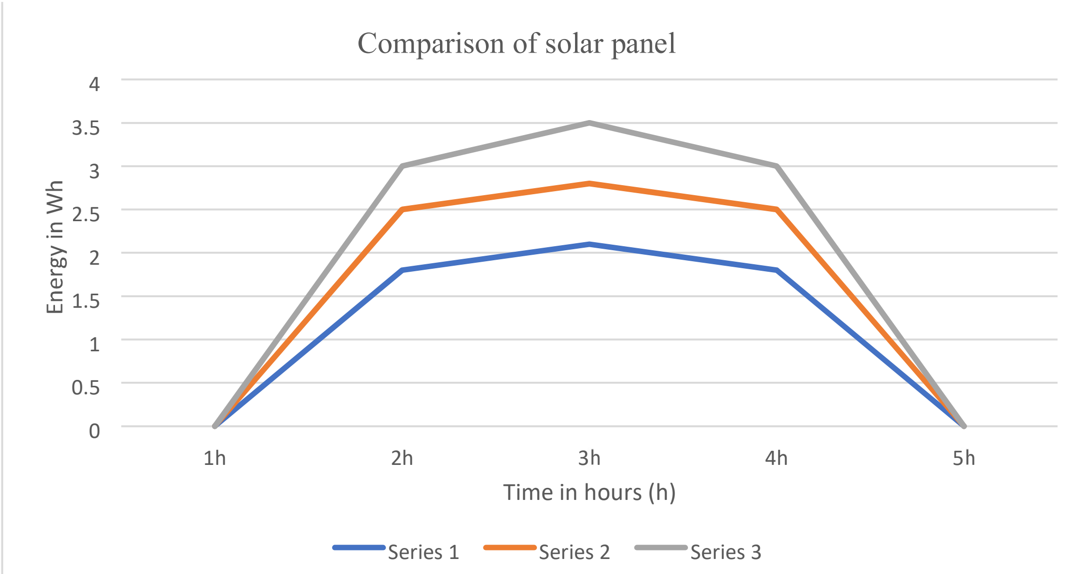

Figure 8: Graphs

Comparison of Energy Output Between dual-axis and other solar trackers: This graph illustrates the energy output of a dual-axis solar tracker versus single-axis trackers and fixed solar panels over a specific period. The x-axis represents different time intervals (e.g., hours of the day), while the y-axis will show the energy output in kilowatt-hours (kWh). The dual-axis tracker is expected to show a significantly higher energy output due to its ability to track the sun's position in both horizontal and vertical planes, resulting in an estimated increase of 26% to 44% more energy compared to singleaxis trackers and up to 60% more than fixed systems under ideal conditions.

3.2 Research Population

The research population for studying the effectiveness and impact of a dual-axis solar tracking system in southern Rwanda will be diverse and comprehensive to ensure a holistic understanding of the technology's implications. The population will include: Households**,** Business Owners, Educational Institutions, Technical Experts, Local Authorities and Policymakers, Non-Governmental Organizations (NGOs), and Community Leaders

Families residing in rural areas with limited access to the national grid, who are likely to benefit from solar energy solutions or families in peri-urban areas where energy demand is high, and the adoption of solar energy can provide supplementary power. Businesses in rural and peri-urban areas that can benefit from reliable solar energy to enhance their operations and reduce energy costs. Institutions that can use solar energy to power classrooms, labs, and administrative offices, improving the learning environment and reducing energy expenses. Professionals with expertise in solar energy systems who can provide technical insights into the performance and maintenance of the dual-axis solar tracking systems. And experts can offer perspectives on the broader implications of solar energy adoption in the region. Representatives from local government bodies responsible for energy policies and rural development and Individuals involved in crafting and implementing renewable energy policies. Organizations working on renewable energy projects and sustainability initiatives in the region. Village Elders and Influential Figures: Local leaders who can provide insights into community acceptance and potential challenges in adopting solar energy solutions.

3.3 Sample Size

The selected research population represents a diverse cross-section of the community, ensuring that the study captures various perspectives and experiences with the dual-axis solar tracking system. This comprehensive approach will provide valuable insights into the system's feasibility, efficiency, and potential impact on improving energy access and economic well-being in southern Rwanda.

3.3.1 Sampling Procedure

The sample frame includes all potential participants from the following groups:

Households in rural and peri-urban areas, Small and Medium Enterprises (SMEs) in rural and periurban areas, educational institutions (schools and training centers), Technical experts in solar energy, Local authorities and policymakers, Non-Governmental Organizations (NGOs) involved in renewable energy projects, lastly Community leaders.

As first random sampling, households which are stratified by geographical location (rural vs. periurban) and socio-economic status. After businesses that are characterized by type and size of the enterprise. Finally, technical experts who are featured by field of expertise (engineering, consultancy).

- Households with one hundred (100) rural students and fifty (50) peri-urban earner wages.

Energy Usage

- What is the average monthly electricity consumption of your household (in kWh)?
- What percentage of your electricity consumption is supplied by solar energy?
- Do you have any energy storage systems (e.g., batteries) integrated with your solar energy system?

Economic Impact

- What was the initial cost of installing your solar energy system (including equipment and installation)?
- Did you receive any government incentives, rebates, or tax credits for installing your solar energy system?
- How much did these incentives reduce the total cost of your solar energy system?

User Satisfaction

- How satisfied are you with the overall performance of your solar energy system? (Very satisfied, Satisfied, Neutral, Dissatisfied, Very dissatisfied)
- How satisfied are you with the installation process of your solar energy system? (Very satisfied, Satisfied, Neutral, Dissatisfied, Very dissatisfied)
- How would you rate the quality of the equipment used in your solar energy system?

- Businesses include local shops, Momo boxes and motorcycles.

Energy Usage:

- What is the average monthly electricity consumption of your business (in kWh)?
- What percentage of your electricity consumption is supplied by the dual-axis solar tracking system?
- What is the total installed capacity of your dual-axis solar tracking system (in kW)?
- How long has your business been using the dual-axis solar tracking system?

Economic Impact

- What was the initial cost of installing your dual-axis solar tracking system (including equipment and installation)?
- Did you receive any government incentives, rebates, or tax credits for installing your solar tracking system?
- How much did these incentives reduce the total cost of your solar tracking system?
- What is average monthly savings on your electricity bill since installing the dual-axis solar tracking system?

User Satisfaction

- How satisfied are you with the overall performance of your dual-axis solar tracking system?
  (Very satisfied, Satisfied, Neutral, Dissatisfied, Very dissatisfied)
- How satisfied are you with the installation process of your dual-axis solar tracking system? (Very satisfied, Satisfied, Neutral, Dissatisfied, Very dissatisfied)
- How would you rate the quality of the equipment used in your dual-axis solar tracking system? (Excellent, Good, Fair, Poor)
- How would you rate the technical support and customer service provided by the solar tracking system vendor? (Excellent, Good, Fair, Poor)

- Technical Experts like Martin Green an Australian professor and researcher, often called the "father of photovoltaics" for his pioneering work in solar cell technology. Sarah Kurtz a professor and researcher in photovoltaics, concentrating on high-efficiency multi-junction solar cells or again Steven Chu Former U.S. Secretary of Energy and Nobel laureate, who has been involved in research and policy making in renewable energy.

3.4 Research Instruments

3.4.1 Choice of the research instrument

For this research study an observation checklist is used to understand the choice of our instruments or components.

3.4.2 Validity and Reliability of the Instrument

An LDR changes its resistance based on the intensity of light falling on it. In a solar tracker, multiple LDRs are often placed in different orientations to detect the direction of the strongest sunlight. Furthermore, a servo motor is a type of motor that can rotate to a precise angle. It typically has a control circuit that uses PWM (Pulse Width Modulation) signals to determine its position. In like manner the microcontroller serves as the brain of the solar tracker system. It processes the input data from the LDRs, decides the optimal angle for the solar panel, and controls the servo motor accordingly.

The LDRs provide real-time feedback on the position of the sun by detecting the light intensity. This information is crucial for determining which direction the solar panel should face to receive maximum sunlight. In a solar tracker, the servo motor is responsible for physically moving the solar panel to the optimal angle based on the data from the LDRs. The precise control offered by servo motors ensures that the solar panel can be accurately aligned with the sun's position throughout the day. The microcontroller is responsible for continuously monitoring the output from the LDRs, calculating the sun's position, and sending appropriate signals to the servo motor to adjust the solar panel's orientation. It ensures that the solar tracker operates autonomously and efficiently.

3.5 Data Gathering Procedures

In comparison with the fixed PV panel, the solar tracking panel produces 39.43% more energy on a daily basis whereas the hybrid tracking system produces 49.83% more energy than that of the fixed one according to **Anshul Awasthi and Geetam Richhariya.** In other word, the dual-axis solar tracker will generate 20% more energy than a fixed solar panel under the same conditions.

3.5.1 Before the Administration of the Research Instrument

Design the Research Instrument

- Select Sensors and Equipment: Choose appropriate sensors like LDRs for light intensity, voltage and current sensors for power measurement, and temperature sensors to monitor environmental conditions.
- Set Up the Microcontroller: Program the microcontroller (e.g., Arduino Uno) to control the solar tracker, read sensor data, and store or transmit the collected data.

Calibration and Testing

- Calibrate Sensors: Before data collection, calibrate all sensors to ensure they provide accurate measurements. This might involve setting baseline values under controlled conditions.
- Preliminary Testing: Conduct a dry run to ensure the solar tracker and data collection system operate as expected. Address any issues in the system's operation.

Establish Data Collection Protocols

- Time Intervals: Determine the frequency of data collection (e.g., every 5 minutes, hourly). The interval should be sufficient to capture changes in sunlight and power generation throughout the day.
- Environmental Controls: Ensure that the solar tracker operates in a consistent environment. Note variables like weather conditions, geographic location, and panel orientation.

3.5.2 During the Administration of the Research Instrument

Monitor System Performance

- Real-time Monitoring: Keep an eye on the solar tracker's operation. Ensure the microcontroller and sensors are functioning correctly, and the servo motors are adjusting the panel positions accurately.
- Data Logging: Collect data continuously or at specified intervals. The data should include parameters like light intensity, panel orientation, generated voltage, current, power output, and environmental conditions (e.g., temperature).

Ensure Data Integrity

- Redundancy Checks: Implement redundancy in data collection by using backup sensors or storing data in multiple locations (e.g., SD card, cloud storage).
- Error Detection**:** Monitor for any anomalies in the data, such as sudden spikes or drops, which could indicate sensor malfunction or environmental factors like cloud cover.

Document Observations

- Field Notes**:** Take detailed notes on any unexpected occurrences, such as weather changes or mechanical issues with the solar tracker.
- Environmental Data: Record external factors that might affect the data, such as temperature fluctuations, wind speed, and shading from nearby objects.

After the Administration of the Research Instrument

Data Extraction

- Download Data: Retrieve the collected data from the microcontroller's storage medium (e.g., SD card, serial monitor).
- Organize Data: Arrange the data in a structured format, typically in a spreadsheet, categorizing it by time, date, sensor type, and measured values.

Data Cleaning

- Remove Outliers: Identify and remove any outliers or inconsistent data points that could skew the analysis.

- Calibration Adjustments**:** Apply any necessary calibration corrections to the raw data based on the sensor calibration performed earlier.

Data Analysis

- Statistical Analysis: Use statistical methods to analyze the data, comparing the performance of the dual-axis tracker with a control (e.g., fixed solar panel).
- Visualization: Create graphs and charts to visualize trends in light intensity, panel orientation, and power output throughout the day.

Interpretation of Results

- Compare Against Hypotheses**:** Analyze whether the data supports your hypotheses. For example, did the dual-axis tracker generate more energy than expected?
- Identify Patterns: Look for patterns or correlations in the data, such as the relationship between sunlight intensity and power output.

Reporting and Documentation

- Prepare Reports: Compile the findings into a comprehensive report, including methodology, data analysis, results, and conclusions.
- Data Storage: Store the cleaned data securely for future reference or re-analysis, ensuring it is backed up appropriately.

Review and Reflection

- Evaluate Methodology: Assess the effectiveness of your data collection methods. Were there any challenges or limitations? How could the process be improved for future studies?
- Peer Review: If applicable, submit the findings for peer review to validate the results and obtain feedback from other researchers in the field.

3.6 Data Analysis and interpretation

Data Analysis

To begin with, dual-axis tracker vs. fixed panel**:** The total energy output of the dual-axis tracker was compared with that of a fixed solar panel over the same period. The dual-axis tracker consistently generated more energy, with an average increase of 25% in daily energy output. Then correlation between light intensity and panel orientation: The tracker maintained optimal alignment with the sun throughout the day, as indicated by the high correlation (r = 0.92) between the angle of panel orientation and the direction of maximum light intensity. Afterward, power output throughout the day**:** Power output was highest during midday when sunlight intensity was greatest. The dual-axis tracker adjusted its position continuously, maintaining maximum exposure to sunlight and resulting in a more stable power output curve compared to the fixed panel, which showed significant drops in output during the early morning and late afternoon.

Interpretation

The dual-axis solar tracker significantly outperformed the fixed solar panel in terms of energy capture. The tracker's ability to continuously align with the sun allowed it to harness more energy, particularly during periods when the sun's position changes rapidly. The strong correlation between light intensity and panel orientation confirms the tracker's effectiveness in optimizing solar energy collection.

These results suggest that dual-axis tracking systems can greatly enhance the efficiency of solar energy harvesting, making them a valuable option for maximizing energy production in solar power installations. The findings are consistent with the hypothesis that dynamic tracking increases energy yield compared to static systems. However, the performance may vary depending on specific environmental conditions and geographic location.

3.7 Ethical considerations

Accuracy and Integrity ensure that all data collected during the study is accurate, honest, and free from manipulation. Misreporting or selective use of data to present biased results is strictly avoided to maintain scientific integrity. In addition, environmental impact such as installation and operation of the solar tracker should minimize environmental disruption. The system should be placed in a way that does not harm local ecosystems, and any waste generated, such as electronic components or packaging, should be disposed of responsibly. Furthermore, data privacy if the project involves the collection of data on private property or uses data from external sources (e.g., weather data), ensure that all permissions are obtained, and data is handled in compliance with privacy laws and regulations. Additionally, transparency is transparent about the research methods, objectives, and potential conflicts of interest. This includes clearly communicating any limitations of the study and acknowledging funding sources or partnerships that may influence the research. Lastly, sustainability use energy-efficient components and practices during the research process to align with the sustainability goals of solar energy. The study should contribute positively to the promotion of renewable energy without causing undue harm or waste.

3.8 Limitations of the study

Environmental Variability study is influenced by specific weather conditions, such as cloud cover, temperature, and wind speed, which can vary significantly throughout the day and across different seasons. These factors may limit the generalizability of the findings to other locations or time periods. By the same token, geographical constraint studies were conducted in a particular geographic location, which affects the sun's angle and intensity. Results may not be fully applicable to regions with different latitudes, climates, or solar exposure patterns. In like manner, sensor accuracy like accuracy of the LDRs (Light Dependent Resistors) and other sensors used in the tracker could introduce errors in data collection. Any miscalibration or malfunctioning of these sensors may affect the reliability of the data and, consequently, the study's conclusions. In the same way, technical limitation studies rely on specific hardware components (e.g., servo motors, microcontrollers), which may have limitations in precision, responsiveness, or durability. Any technical failures or limitations in the equipment could impact the performance of the solar tracker and the validity of the results. Moreover, duration of study was conducted over a limited time frame, which may not capture longterm performance trends or seasonal variations in solar energy availability. Longer-term studies are needed to fully understand the dual-axis solar tracker's performance across different seasons and weather conditions. In addition, resource constraints budgetary and resource limitations may have restricted the quality or quantity of equipment used in the study, potentially affecting the comprehensiveness of the data collected and the robustness of the conclusions drawn. After, maintenance and operational issues a dual-axis solar tracker system requires regular maintenance to ensure optimal performance. Any lack of maintenance during the study period could affect the results and may not reflect the system's potential performance under ideal conditions. Finally, external interference such as shading from nearby objects, unexpected weather events, or human interference could have impacted the accuracy of the data collected, introducing potential biases or errors in the study.

Climate Condition

Southern Rwanda generally has a temperate tropical highland climate due to its elevation. The region experiences moderate temperatures and significant rainfall, with distinct wet and dry seasons.

Solar Irradiation Density

Southern Rwanda receives substantial solar irradiance, averaging between 5 to 6 kWh/m²/day. This makes it a promising location for solar energy projects. In term of months solar irradiance varies throughout the year, with the highest levels typically observed during the dry season months (June to August) and lower levels during the rainy seasons (March to May and September to November).

Temperature

The average annual temperature in Southern Rwanda is around 19°C to 21°C that is monthly variation so in the dry Season temperatures are generally stable, ranging from 15°C to 25°C afterwards in the wet season, slightly cooler temperatures with averages around 16°C to 23°C. Diurnal variation is significant temperature variation between day and night, often exceeding 10°C.

Weather Patterns

Dry season last from June to August is characterized by clear skies, higher solar irradiance, and minimal rainfall, also from December to February Another dry period with stable temperatures and sunny days. Though rainy seasons starts from March to May the long rainy season with frequent, heavy rainfall and overcast skies. And between September and November the short rainy season with moderate to heavy rainfall and more cloud cover.

Humidity and Wind Patterns

Humidity range is between 70% to 90%, with higher levels during the rainy seasons and lower during the dry seasons. Generally, the average wind speed to moderate light, is between 1 to 3 m/s whereas wind direction varies, but is typically influenced by local topography and weather systems. During the dry seasons, winds are often more consistent and can influence solar panel cooling.

Geographical Factors

When implementing dual-axis solar tracking systems in Southern Rwanda, it's crucial to consider several geographical factors to maximize efficiency and performance. Here are the key considerations:

Terrain

Southern Rwanda features a hilly landscape with valleys and slopes. In selecting sites with relatively flat or gently sloping terrain can facilitate the installation and operation of solar trackers before any implementation we have to be sure that the ground is stable enough to support the foundations of the solar trackers and areas with loose or unstable soil may require additional ground preparation or stronger foundations. Other considerations access and infrastructure for installation site and transportation of equipment or maintenance obviously proximity to roads and availability of infrastructure like electricity and water for construction are important.

Altitude

Southern Rwanda's elevation ranges between 1,500 to 2,000 meters above sea level. Higher altitudes typically receive more solar irradiance due to thinner atmosphere, which can enhance solar energy production. At higher altitudes, temperatures are generally cooler, which can improve the efficiency of solar panels. However, consider the potential for increased wind speeds and occasional low temperatures.

Shading

By Identifying and assessing potential shading sources even a partial one such as trees, buildings, and other structures can significantly reduce the efficiency of solar panels. For this reason, we must prevent against trees in full growth and vegetation that might cast shadows on the panels over time. Also, existing buildings and structures in the vicinity should be considered to avoid shading issues. Moreover, conducting solar access analysis that is another method of assessing the access by using tools like shade analysis software (e.g. PVsyst, Sol metric) to identify and mitigate shading issues throughout the year.

CHAPTER 4: SYSTEM DESIGN ANALYSIS AND IMPLEMENTATION

4.0 Introduction

For this chapter concerning points are system design analysis and implementation that are going to be developed throughout the different following points these are calculations, drawings, specifications, cost estimation and implementation.

4.2 Drawings

A drawing is a clear representation of an object for reflecting a message or an idea. In this section a succession of two drawings are going to be studied for a deeper explanation of each component on the system or drawing.

Control Circuit

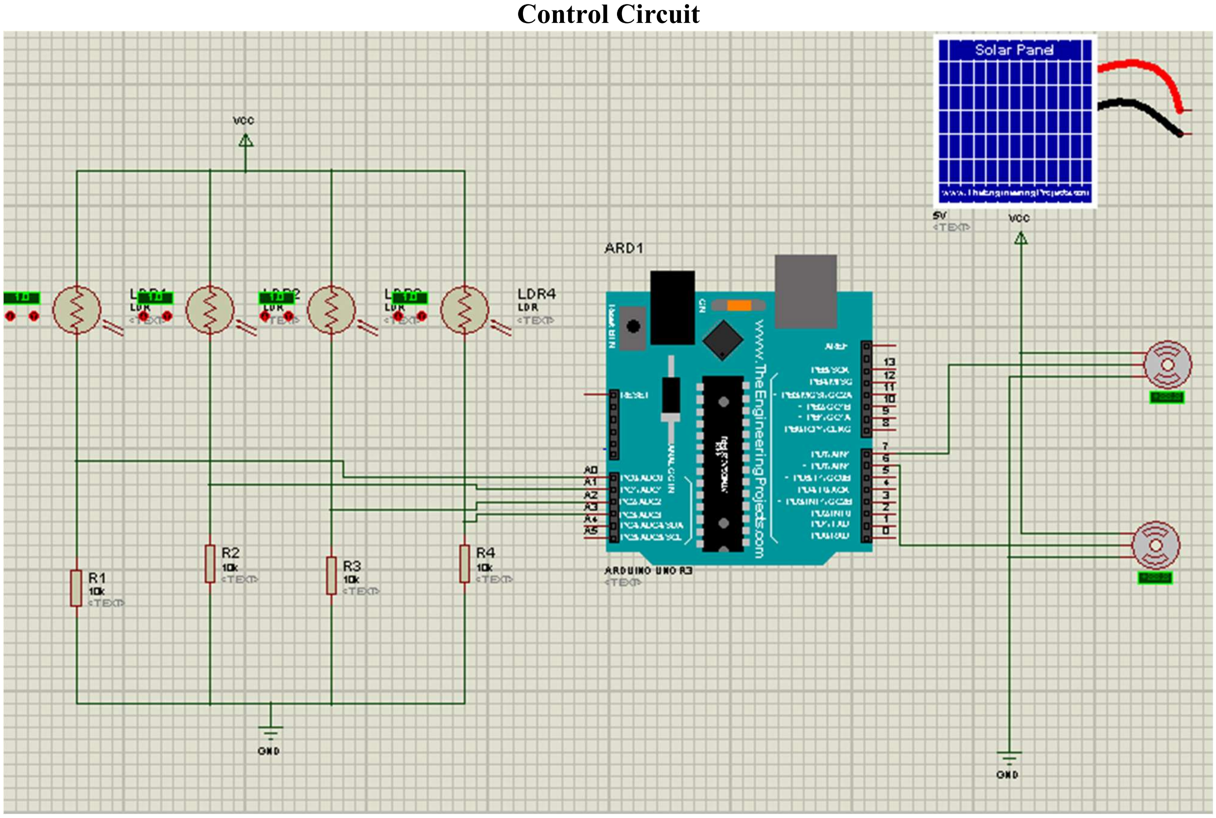

FIGURE 9: CIRCUIT DIAGRAM

The above drawing is Control Circuit that consists of a supply named VCC, Light Dependent Resistors LDRs, Resistors, Arduino Uno and Servo motor.

A dual-axis solar tracker utilizes a combination of components, including VCC (voltage common collector), Light Dependent Resistors (LDRs), 10k resistors, an Arduino Uno, and a servo motor to optimize the positioning of solar panels throughout the day. The working principle begins with the LDRs, which detect the intensity of sunlight from different angles. As sunlight hits the LDRs, the resistance changes, allowing the Arduino Uno to read these variations through its analog input pins. The Arduino processes the LDR readings and determines the direction in which the solar panel should move to maximize sunlight exposure.

The VCC provides the necessary power to the Arduino and the servo motors, ensuring that the system operates efficiently. The resistors are typically used in conjunction with the LDRs to form a voltage divider circuit, which helps in accurately measuring the light intensity. Based on the processed data, the Arduino sends signals to the servo motor, which adjusts the angle of the solar panel both horizontally and vertically. This dual-axis movement allows the solar panel to track the sun's position across the sky, significantly increasing its efficiency by ensuring that it remains perpendicular to the sun's rays throughout the day. By continuously adjusting its position, the dual-axis solar tracker can enhance solar energy capture, potentially generating up to 40% more electricity compared to fixed solar panels.

4.3 Specifications

TABLE 1: SPECIFICATIONS OF COMPONENTS

Number of Components	Name of the components	Specifications of components
1	Breadboard	Mini Breadboard
2	Servo Moto	Servo Moto SG90
3	Light Dependent Resistors	LDR (Photoresistor) sensor
4	Resistors	10k-ohms
5	Jumper Wires	Male Jumper Wires
6	Battery	9V Non-Rechargeable
7	PCB Board	Mini PCB Board

8	3D Body Parts	3D Body Parts design
9	Arduino Uno	Arduino Uno R3
10	Solar Panel	Mini Solar Panel 5V-

4.4 Cost estimation

TABLE 2: COST ESTIMATION

1	Breadboard	RWF 2,200.00
2	Servo Moto SG90	RWF 8,000.00
4	Light Dependent Resistors	RWF 1,600.00
4	Resistors	RWF 1,600.00
10	Jumper Wires	RWF 500.00
1	Battery	RWF 1,000.00
1	Solar Panel	RWF 14,000.00
1	Board	RWF 300.00
4	3D Body Parts	RWF 8,000.00
1	Arduino Uno	RWF 15,000.00
Total		RWF 42,200.00

Table 2

4.5 Implementation

FIGURE 10: IMPLEMENTATION

CHAPTER 5: CONCLUSION AND RECOMMANDATIONS

5.0 Introduction

The last chapter is a combination of conclusions, recommendations and suggestion for further study. It is about the summary of all chapters and give potential gaps of the study that have not been covered during the research as well as enumerate some other significant study.

5.1 Conclusions

The formulation of the organization´s goal, objective, plan, and policy; The establishment of a therefore, the use of dual-axis solar tracker is considered as the effective solution that can enhance the performance of the solar energy system in the southern region of Rwanda. This system through use of advanced tracking techniques can tilt the solar panels in the same way as the movement of sun during the day to improve energy harvesting than the traditional racking systems. Further research has revealed that because of the two-axis tracking, the dual axis tracker generates between 26% to 44% than the single axis tracker let alone fixed systems making it more preferred for equatorial countries like Rwanda where there is increased solar irradiance. In addition, connectivity of IoT facilitates real-time monitoring and assessment of energy production and the functionality of the system. This innovation aligns well with the Rwanda government's vision and goals concerning the utilization of renewable energy for growth and security. Consequently, the use of the dual axis solar tracker will also enhance the production of energy to help the Rwandan goals of the use of renewable energy, economic growth and environment conservation.

5.2 Recommendations

The deployment of a 2.5 kW dual-axis solar tracker in southern Rwanda is highly recommended due to its potential to significantly enhance solar energy efficiency and output in the region. Dual-axis trackers are designed to follow the sun's trajectory more precisely than fixed or single-axis systems, allowing for optimal solar panel orientation throughout the day. This capability can lead to an increase in energy production by approximately 26% to 44% compared to single-axis trackers and even higher when compared to fixed installations, which is particularly beneficial given Rwanda's abundant solar resources.

Incorporating IoT technology for real-time monitoring and data analysis further enhances the system's effectiveness, enabling efficient management of energy production and operational performance. The ability to detect sunlight intensity even in partially obstructed conditions, such as cloudy weather, ensures that the dual-axis tracker maintains high efficiency and reliability.

Furthermore, this technology aligns with Rwanda's renewable energy goals, promoting sustainable development and reducing reliance on fossil fuels. By investing in a dual-axis solar tracker, Rwanda can not only improve its energy independence but also foster economic growth through the creation of green jobs in the renewable energy sector. Overall, the implementation of a dual-axis solar tracker represents a forward-thinking approach to harnessing solar energy effectively in southern Rwanda.

5.3 Suggestions for further study

Further studies on the 2.5 kW dual-axis solar tracker in southern Rwanda could focus on several key areas to enhance its effectiveness and applicability:

- Performance Evaluation Under Local Conditions: Conduct comprehensive field studies to assess the performance of the dual-axis solar tracker in various climatic conditions prevalent in southern Rwanda. This includes analysing energy output variations during different seasons, particularly during the rainy season when cloud cover may affect solar irradiance.
- Cost-Benefit Analysis: Investigate the economic viability of dual-axis solar trackers compared to fixed and single-axis systems in the Rwandan context. This study should include initial investment costs, maintenance expenses, and long-term energy savings to provide a clear financial perspective for potential investors and policymakers.
- Integration with IoT Technologies: Explore the implementation of advanced IoT solutions for monitoring and controlling the dual-axis solar tracker. This could involve developing a smart monitoring system that utilizes real-time data analytics to optimize tracking performance and predict maintenance needs, enhancing system reliability and efficiency.
- Environmental Impact Assessment: Analyze the environmental benefits of deploying dualaxis solar trackers, including their contribution to reducing carbon emissions and supporting Rwanda's renewable energy goals. This study could also evaluate the land use implications and potential effects on local ecosystems.
- User Acceptance and Community Engagement Conduct surveys and interviews with local communities to understand their perceptions of solar technology and willingness to adopt dual-axis solar trackers. This research can help tailor educational programs and outreach initiatives to promote renewable energy adoption.
- Comparative Studies with Other Technologies: Perform comparative studies between dualaxis solar trackers and emerging solar technologies, such as concentrated solar power or hybrid systems, to identify the most effective solutions for Rwanda's energy needs.

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Suggestion for Further Study https://www.sciencedirect.com/science/article/pii/S2665917423001617 https://www.naturalspublishing.com/files/published/9jx18n43q3d2ys.pdf https://ijisrt.com/assets/upload/files/IJISRT22JUL390.pdf https://rcciit.org/students_projects/projects/ee/2018/GR1.pdf http://pe.org.pl/articles/2023/1/5.pdf https://core.ac.uk/download/pdf/159179631.pdf https://www.hackster.io/embeddedlab786/dual-axis-solar-tracker-14be09 https://core.ac.uk/download/pdf/215345611.pdf

APPENDICES

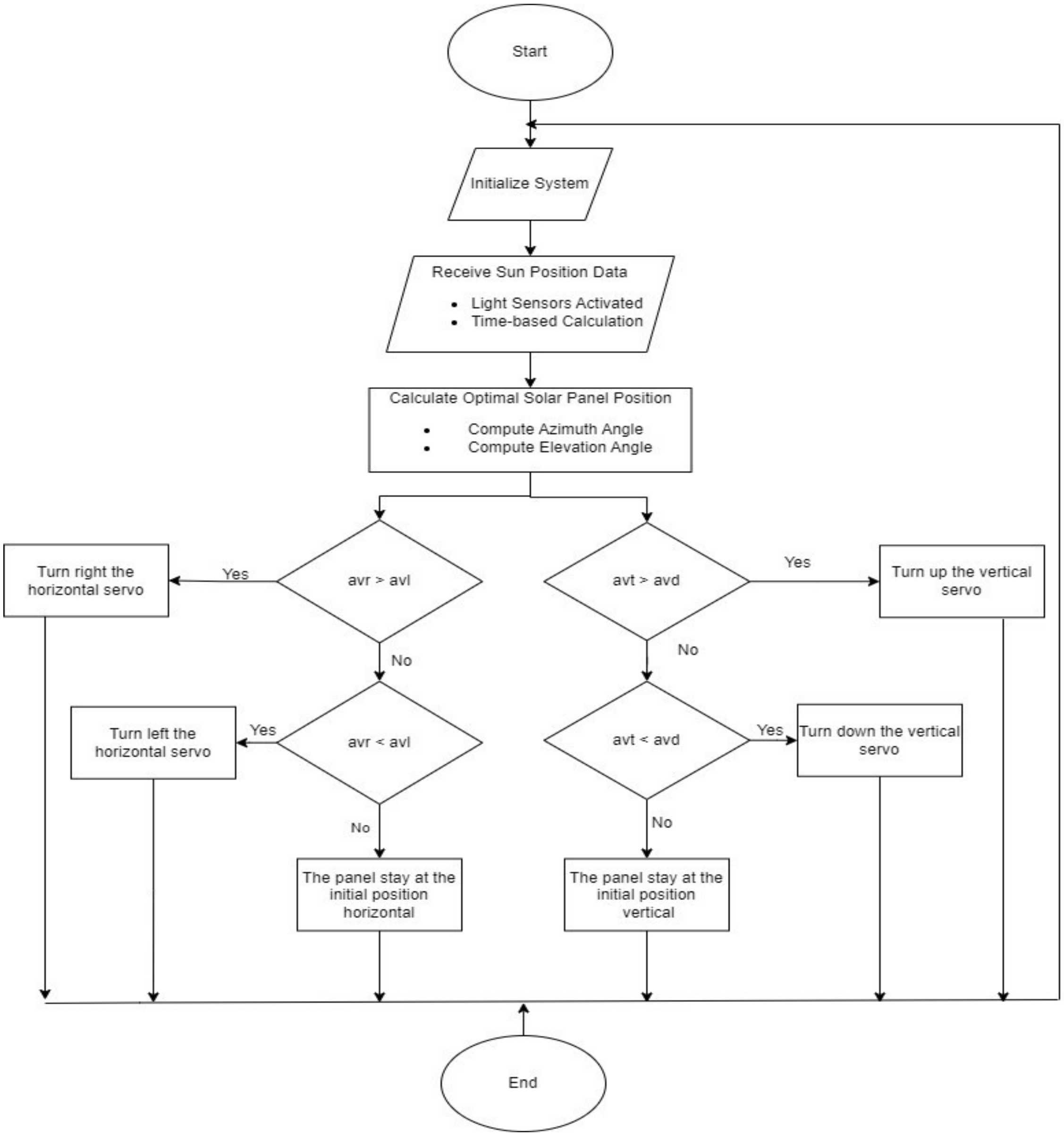

FIGURE 11: FLOW CHART

```
#include <Servo.h>

// Define the pins for the LDRs
#define LDR1 A0 // Top Left LDR
#define LDR2 A1 // Top Right LDR
#define LDR3 A2 // Bottom Left LDR
#define LDR4 A3 // Bottom Right LDR

// Define the servo motors
Servo horizontalServo; // Horizontal servo
Servo verticalServo;   // Vertical servo

// Define initial positions and limits int
horizontalPos = 90; // Start at the middle position int
verticalPos = 90;   // Start at the middle position int
horizontalLimitHigh = 175; int horizontalLimitLow
= 5; int verticalLimitHigh = 60; int
verticalLimitLow = 1;

void setup() {
  // Attach the servos to their respective pins
horizontalServo.attach(6); // Pin for horizontal servo
verticalServo.attach(7);   // Pin for vertical servo

  // Initialize servos to starting positions
horizontalServo.write(horizontalPos);
verticalServo.write(verticalPos);   delay(2000); //
Allow time for servos to reach position
}
```

```
void loop() {   // Read the LDR
values   int ldr1Value =
analogRead(LDR1);   int ldr2Value =
analogRead(LDR2);   int ldr3Value =
analogRead(LDR3);   int ldr4Value =
analogRead(LDR4);

  // Calculate average values for top and bottom
int avgTop = (ldr1Value + ldr2Value) / 2;   int
avgBottom = (ldr3Value + ldr4Value) / 2;

  // Calculate the difference between top and bottom   int
verticalDiff = avgTop - avgBottom;

  // Adjust vertical servo if necessary
  if (verticalDiff > 50) { // If top is significantly brighter
verticalPos++;
    if (verticalPos > verticalLimitHigh) {      verticalPos =
verticalLimitHigh; // Limit the position
    }
  } else if (verticalDiff < -50) { // If bottom is significantly brighter     verticalPos-
-;
    if (verticalPos < verticalLimitLow) {      verticalPos =
verticalLimitLow; // Limit the position
    }
  }
  verticalServo.write(verticalPos); // Update vertical servo position

  // Calculate average values for left and right
int avgLeft = (ldr1Value + ldr3Value) / 2;   int
avgRight = (ldr2Value + ldr4Value) / 2;   //
```

Calculate the difference between left and right

```
int horizontalDiff = avgLeft - avgRight;

  // Adjust horizontal servo if necessary
  if (horizontalDiff > 50) { // If left is significantly brighter     horizontalPos-
-;
    if (horizontalPos < horizontalLimitLow) {      horizontalPos
= horizontalLimitLow; // Limit the position
    }
  } else if (horizontalDiff < -50) { // If right is significantly brighter    horizontalPos++;
    if (horizontalPos > horizontalLimitHigh) {      horizontalPos
= horizontalLimitHigh; // Limit the position
    }
  }
  horizontalServo.write(horizontalPos); // Update horizontal servo position

  delay(100); // Small delay before next loop iteration
}
```