A REVIEW ON DUAL AXIS SOLAR TRACKING SYSTEMS

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ABSTRACT:
Since the current energy sources are depleting due to the rising demand for energy, we want alternative energy sources like solar electricity, which is limitless and available everywhere. Solar panels use sunlight to generate electricity, however tracking systems can also be employed. In order to optimize solar radiation, these systems adjust the panel's orientation in anticipation of the sun's movement. The design boosts energy output by accurately determining the sun's position. The trackers optimize the amount of energy brought together by accurately predicting the ideal tilt and orientation angles. Analogous sensor-based and optimization algorithm-based solar tracking systems are evaluated. These include dual-axis trackers, which move in two directions to follow the sun. These trackers are frequently installed on platforms. Solar photovoltaic (SPV) technology uses PV cells to convert sunlight into electrical energy. The renewable energy source that has gained popularity due to its clean and sustainable nature. The aim of this paper performance analysis and the basic design function model of dual axis solar tracking system. By using microcontroller programmed with the C language, LDR sensors which are Detect the intensity of sun light by these servo motors continuously moves the solar panels in the direction of source of sunrays. The solar panel also attached with the Inverted battery it preserves the DC current converts into AC, which is then supplied. In this project, compare and analyze the Single axis and Dual axis Solar tracking systems. The system that the maximum amount of radiations of the sun capturing, transforms into power supply utilization for the harvesting applications.

Keywords :
Arduino Microcontroller, LDR Sensor, Solar PV, DC Servo Motors.

Introduction:

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 that 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. Different techniques have been developed for solar tracking system. A solar tracker is a device that orients a payload toward the Sun. Payloads are usually solar panels, parabolic troughs, Fresnel reflectors, lenses or the mirrors of a heliostat. For flat-panel photovoltaic systems, trackers are used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel. This increases the amount of energy produced.

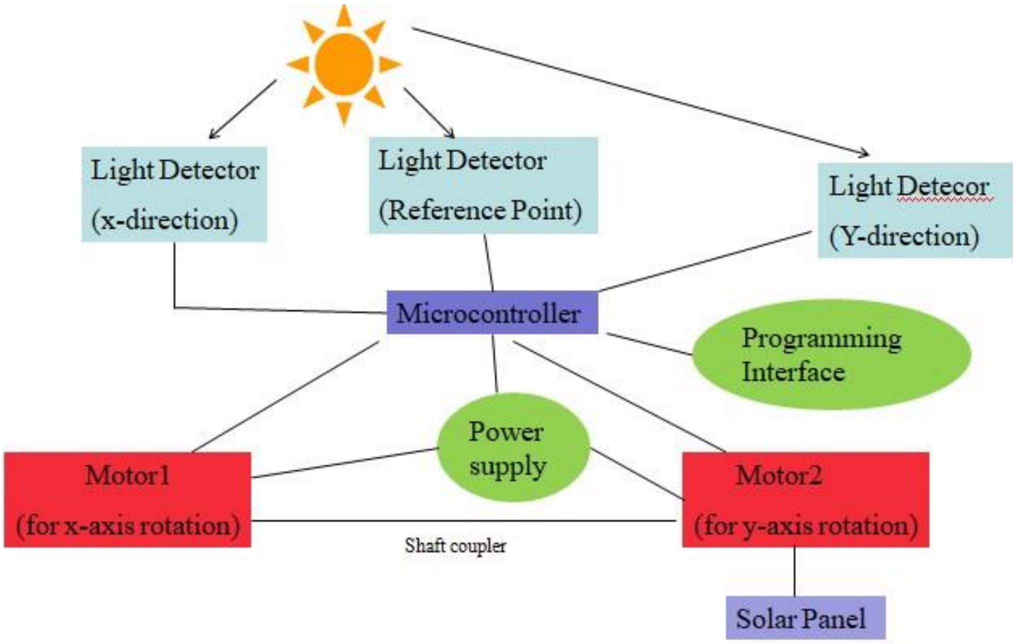

Fig.1 Block Diagram of Dual Axis Solar Tracking System

from a fixed amount of installed power generating capacity. In standard photovoltaic applications, it was predicted in 2008-2009 that trackers could be used in at least 85% of commercial installations greater than one megawatt from 2009 to 2012. In concentrator photovoltaic (CPV) and concentrated solar power (CSP) applications, trackers are used to enable the optical components in the CPV and CSP systems. The optics in concentrated solar applications accepts 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. This tracking movement is achieved by coupling a stepper 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 stepper motor to rotate the mounted panel in bidirectional and then return to the start point for next day light as desired.

Human civilization is moving towards renewable energy due to the impacts of global warming and rising carbon emissions after Covid-19. As renewable energy becomes cheaper, India aims to achieve 500 GW of non-fossil energy by 2030. A dual-axis solar tracker is highlighted for its efficiency in collecting solar energy through photovoltaic (PV) modules. These trackers, optimized by AI techniques like fuzzy logic and neural networks, adjust to maximize energy collection. The shift to renewable energy has increased worldwide interest, especially in PV models for electricity generation. Traditional solar methods are less efficient (below 40%), but solar tracking improves efficiency significantly. Dual-axis tracking outperforms single-axis tracking and fixed systems, though factors like temperature and dust can affect performance. This technology is particularly beneficial for developing countries like Bangladesh, where many people lack electricity. Historical advancements in solar technology have improved power collection efficiency, and the costs and maintenance of trackers are important considerations. Different tracking systems, including open-loop, closed-loop, and hybrid systems, help maximize energy collection. Solar energy also aids in water supply solutions, and countries like Morocco promote solar water heating technologies. Solar concentrators and active tracking systems are crucial for maximizing efficiency, ensuring optimal alignment with the sun.

Solar panels are typically positioned with a fixed angle of inclination, facing the sun. Sun tracking systems are classified into passive and active types. Passive trackers are mechanical systems that require manual adjustments to maintain the sun's direction. They are more affordable but not widely recognized due to maintenance issues. Examples for passive trackers are ground mounted system,

floating solar panels and gravity based trackers and fluid filled trackers. Active trackers are controlled by microprocessors or microcontrollers based on the date and time of the day. They use photo-resistors or light-dependent resistors to detect light and send commands to DC motors to spin the panel. Programmable logic controller (PLC)-based solar tracking system (STS) uses pre-computed position data to control the motor, ensuring optimal solar energy collection. Examples for Active trackers are single axis solar tracking system and dual axis solar tracking system. A dual-axis STS is proposed to precisely determine the sun's location, allowing solar panels connected to the tracker to receive the most solar energy. This closed-loop system consists of a power system and a mechanical mechanism. The system includes a solar tracker PV system, tracker control circuit, and battery bank. The sensor-based feedback controller measures sunlight intensity and produces feedback error voltage. The E-W control algorithm continuously tracks the sun's position and modifies the azimuth angle of solar panels or mirrors, determining the system's alignment and direction.
The azimuth angle is a critical concept in solar energy and many other fields involving direction and orientation. It refers to the angle between a reference direction and the direction of an object, measured clockwise from the reference direction. The key advantage of a dual-axis STS is that the installation is not location-based and solar panels are always perpendicular to the direction of sun light.

Literature review:
Y Yao, Y Hu, S Gao., (2014) Solar tracking systems are more efficient than fixed solar panels, as they can boost energy collection by up to 40% by following the sun's path. There are single-axis and dual-axis trackers, with dual-axis ones being more effective as they track both horizontal and vertical sun angles. Recent studies focus on using microcontrollers like Arduino to improve the precision of these tracking systems. These controllers, paired with sensors and motors, make the tracking process more efficient. Comparative studies show that dual-axis trackers can increase power output by 25-30% compared to fixed systems, supporting the findings of the current study.
HS Akbar, AI Siddiq et al., (2017) Dual-axis solar tracker designed with ATmega 328 controller for efficiency. Two-axis tracker follows sun's altitude and east-west movement. System tracks sun in azimuth and altitude axes for optimal energy generation. Temperature and covers reduce solar panel output power. Colored cellphone affects solar panel output power based on color.
M Abdollahpour, MR Golzarian., (2018) The proposed tracking system utilizes image processing to determine the sun's position. By capturing the shadow of a bar, Testing showed that the tracker could follow the sun with an accuracy of ±2°, which is within the acceptable range for the stepper motors used.The system calculates the angles necessary to orient the solar panel towards the sun. The angles are derived from the shadow's characteristics, which are processed and analyzed **.**The key objective is to demonstrate that the system can be implemented at a low cost while consuming minimal energy.
YM Safan, S Shaaban., (2018) Uses the Sun Position Algorithm (SPA), based on time, date, and geographical location, which is accurate for calculating the sun's position.Closed-loop controller Uses a sun position sensor that consists of four photodiodes to capture the actual position of the sun and provide real-time feedback.The MDOF controller combines the outputs of both controllers by assigning different adaptive weights to each, depending on the real-time error between the actual sun position and the calculated position. Instead of switching between control modes, both are used simultaneously, but with dynamically adjusted contributions.
EK Mpodi, Z Tjiparuro., (2019) Active solar trackers, especially dual-axis ones, greatly enhance the efficiency of PV panels. However, active systems need extra power and may lose efficiency in cloudy weather, while passive systems can be less accurate in extreme conditions. Further research is needed, but dual-axis active trackers are currently the best choice for PV systems.
NA Kelly, TL Gibson., (2019) The study developed a method to optimize solar module orientation, including a new technique for overcast days. It stressed the need for efficient PV systems to aid hydrogen production for fuel-cell electric vehicles (FCEVs) and aimed to reduce the size and cost of

solar energy systems. The research highlighted enhancing both solar and electrolysis systems to boost overall efficiency.
ALR Nadia.,et al. (2020) The system incorporated with the ANFIS principle for minimize the error, maximize energy of efficient solar tracking system. The models show superior results when utilizing five membership functions, leading to enhanced performance for both single-axis and dual-axis solar tracking systems ANFIS controllers efficiently predict solar tracking angles with high accuracy (2020).
A Awasthi, AK Shukla., (2020) Solar PV system design and performance analysis of dual axis solar trackers and solar cell electricity generation. It classified based on control system, driving system and degree of freedom. The design methodology was based on mechatronics concept and VDI 2206 standard. Maintenance is required due to rotating components in solar tracking system, which have complex design and control mechanism.
Mehmet Das., (2021) It investigate that the Two SACs of equal size were designed for the experiment. One was fixed at a tilt angle of 38° South-East, while the other was equipped with a two-axis PLC solar tracking system. Performance was analyzed under identical conditions, focusing on output temperature, energy efficiency, and heat transfer values. Under three mass flow rates with three different Nu correlations which enhance solar air collector performance and energy efficiency.
P Muthukumar,S Manikan.,et al. (2023) System uses IOT and microcontrollers for sun tracking and dual axis solar tracking enhances energy output by tracking sun movement and adjust panel position. (1) It monitors tracker performance through IOT connectivity and IOT connected via Wi-Fi to track monitor performance. IOT monitors PV panel output and alerts for system adjustment and responds within 0.2 seconds and monitors for 24 hours of data set and utilize more effectively.
ML Bharathi.,et al. (2022) The research developed a dual-axis solar tracking system using a programmable logical controller (PLC) to automate panel alignment with the sun. It employed a multi-quadrant photoelectric detector for accurate tracking, combining open-loop and closed-loop controls for precise adjustments. Various sensors, including light-dependent resistors (LDRs), were integrated to optimize energy capture. The system showed a 30% increase in energy generation, with high tracking accuracy and adaptability to environmental changes. Trials confirmed the feasibility of the system for practical solar energy applications.
U Mamodiya, N Tiwari., (2023) The system is designed using the SIMULINK platform and validated through simulation and optimization which it delivers a greater current output. Wind load effects are analyzed using Solid Works software SP-13. The 335-Watt solar tracker system is safe from critical wind speeds and has sufficient strength. The investigation revealed that wind speed rises with tracker system height and that surface-specific friction coefficient values impact wind speed at various heights
QJ Abdul-Ghafoor, SH Abed.,et al. (2024) Linear Fresnel Reflector Technology this technology consists of mirror rows fixed at specific angles to reflect solar radiation towards an absorber tube. Fresnel solar reflector using multi-walled carbon nanotubes (MWCNTs) in distilled water. Their one-dimensional model showed that a 0.3% volume ratio of MWCNTs resulted in the highest thermal efficiency of 33.8%, highlighting the benefits of using nanofluids.
Hossein Mousazadeh et Al., (2011) The system investigated maximization of collected energy from an on-board PV array, on a solar assist plug-in hybrid electric tractor (SAPHT). Using four light dependent resistive sensors a sun tracking system on a mobile structure was constructed and evaluated. The experimental tests using the sun-tracking system showed that 30% more energy was collected in comparison to that of the horizontally fixed mode. Four LDR sensors were used to sense the direct beams of sun. Each pair of LDRs was separated by an obstruction as a shading device. A microcontroller based electronic drive board was used as an interface between the hardware and the software. For driving of each motor, a power MOSFET was used to control the actuators. The experimental results indicated that the designed system was very robust and effective.
K.S. Madhu et al., (2012) The states that a single axis tracker tracks the sun east to west, and a two-axis tracker tracks the daily east to west movement of the sun and the seasonal declination movement of the sun. Concentrates solar power systems use lenses or mirrors and tracking systems to focus a

large area of sunlight into a small beam. PV converts light into electric current using the photoelectric effect. Solar power is the conversion of sunlight into electricity. Test results indicate that the increase in power efficiency of tracking solar plate in normal days is 26 to 38% compared to fixed plate. And during cloudy or rainy days it's varies at any level.

M Abdollahpour, MR Golzarian., et al. (2018) The research developed a cost-effective dual-axis solar tracking system using image processing of a bar shadow. It includes a shadow-casting object, webcam, electronic circuits, computer controls, and stepper motors to adjust the panel's position. The tracker uses the shadow length to determine the zenith angle, keeping the panel perpendicular to solar irradiation. A stepper motor enhances accuracy and reduces costs. The system functions independently of initial settings and geographical location. Its performance was evaluated by comparing predicted angles with actual values for both east-west and north-south angles.The system achieved an accuracy of ±2°, making it accessible and efficient without the need for daily initial settings. While some existing systems offer higher accuracy with specialized equipment, the proposed system is cost-effective and practical. One identified error source is the ratio of object diameter to length, inversely affecting accuracy, providing insights for future improvements.

NA Kelly, TL Gibson., (2019) The research measured solar irradiance during cloudy periods to optimize energy capture, focusing on the difference between direct and diffuse radiation. It proposed an improved tracking algorithm that uses a 2-axis system on clear days and a horizontal configuration on cloudy days to maximize diffuse solar irradiance. Comparative analysis showed this method's effectiveness over fixed horizontal orientations during cloudy conditionsThe research showed that orienting solar modules horizontally during cloudy conditions can boost energy capture by about 50%, vital for meeting energy needs in poor solar conditions. It emphasized maximizing diffuse radiation capture to reduce storage needs and stabilize output. This approach benefits applications like hydrogen production for fuel-cell vehicles, using algorithms and sensors to adjust solar modules based on cloud cover.

H Bentaher, H Kaich, N Ayadi., (2014) The research developed a simple solar tracking system using light-dependent resistors (LDRs) to monitor photovoltaic panels. Tested in the Sfax region, the system featured two axes of rotation for Azimuth and Elevation, with performance evaluated using an angular sensor and data-logger. The optimal angle between the LDRs was assessed both numerically and experimentally to enhance tracking precision. The tracking system demonstrated acceptable precision influenced by the angle between photo-resistors, with potential improvements using more precise components. It effectively followed the sun's Azimuth, especially during midday, though environmental factors like temperature, humidity, and dust affected its accuracy. The good agreement between numerical and experimental results suggests the system could be a reliable model for future solar tracking systems.

I Anshory, J Jamaaluddin., et al. (2024) The research developed a dual-axis solar tracker using the ESP8266 microcontroller and LDR sensors to optimize solar energy absorption. The system measures current, voltage, and temperature, transmitting data via the IoT platform for remote monitoring. Experimental tests assessed the system's efficiency and accuracy under varying solar heat and temperature conditions. The experimental results showed that the dual-axis solar tracker using the ESP8266 microcontroller and LDR sensors improved solar energy absorption efficiency by 65% over manual systems. The system maintained optimal alignment during peak solar intensity, while environmental factors like temperature and sunlight exposure affected panel performance. Effective thermal management and consistent tracking are crucial for stable energy output.

YM Safan, S Shaaban., et al. (2018) The study has been explained methodology involves designing a two-axis solar tracking system with a hybrid control system using an MDOF SUI PID controller, integrating both open-loop and closed-loop methods. Performance evaluation includes tracking accuracy and power output assessment. Simulations were conducted using MATLAB/Simulink for model validation. The hybrid solar tracking system (STS) achieved a pointing error of ±0.18° and tracking accuracy of ±0.12°, with a performance ratio of about 97%. Under cloudy conditions, it maintained a pointing error of -0.2° and high output power despite a 10° sun sensor error. Two evaluation methods were used to assess tracking accuracy and power production.

Methodology:
Resistance of LDR depends on intensity of the light and it varies according to it. The higher is the intensity of light, lower will be the LDR resistance and due to this the output voltage lowers and when the light intensity is low, higher will be the LDR resistance and thus higher output voltage is obtained. A potential divider circuit is used to get the output voltage from the sensors (LDRs).The LDR senses the analogue input in voltages between 0 to 5 volts and provides a digital number at the output which generally ranges from 0 to 1023. 5 Now this will give feedback to the microcontroller using the Arduino software (IDE). The servo motor position can be controlled by this mechanism which is discussed later in the hardware model.

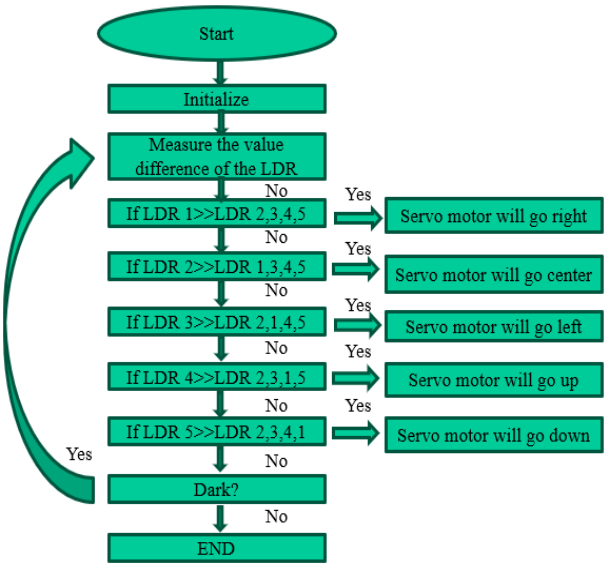

Fig.2 Flow chart of dual axis solar tracking system

As we see in the block diagram, there are three Light Dependent Resistors (LDRs) which are placed on a common plate with solar panel. Light from a source strikes on them by different amounts. Due to their inherent property of decreasing resistance with increasing incident light intensity, i.e. photoconductivity, the value of resistances of all the LDRs is not always same. Each LDR sends equivalent signal of their respective resistance value to the Microcontroller which is configured by required programming logic. The values are compared with each other by considering a particular LDR value as reference. One of the two dc servo motors is mechanically attached with the driving axle of the other one so that the former will move with rotation of the axle of latter one. The axle of the former servo motor is used to drive a solar panel. These two-servo motors are arranged in such a way that the solar panel can move along X-axis as well as Y-axis. The microcontroller sends appropriate signals to the servo motors based on the input signals received from the LDRs. One servo motor is used for tracking along x-axis and the other is for y-axis tracking. In this way the solar tracking system is designed.

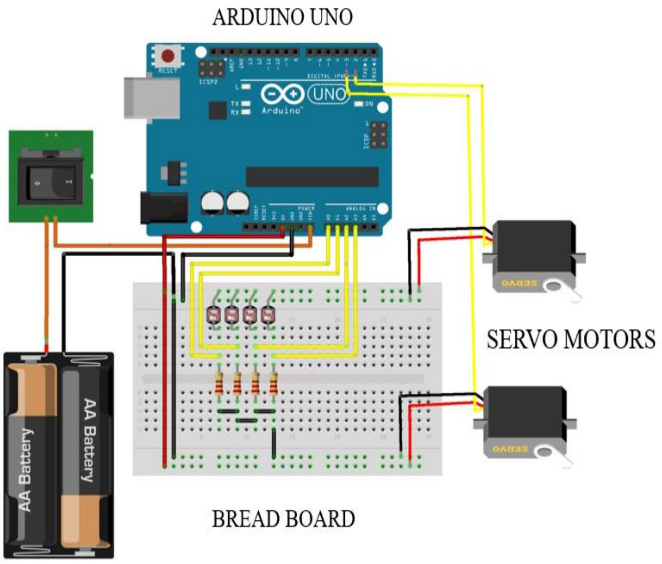

Fig.3 Circuit Diagram

Performance criteria:

TRACKING ACCURACY:

1.Azimuth and elevation angle:

- Azimuth angle : Azimuth is compass direction from sunlight coming with specific point on earth's surface. it is angle between projected vector of object on horizontal plane and the north direction.
- Azimuth angle(x) is measured from "0 when facing north", "90 when facing east", "180 when facing south", "270 when facing west".
- It is calculated by

$$Azimuth\ angle = \arccos\left(\sin(y) - \sin(z) * \sin(h) / \cos(z) * \cos(h)\right)$$

Where:

- y is declination angle of the sun.
- z is latitude of the observer.
- h is an hour angle.
- Elevation angle : It is a vertical angle between the observer's horizon and sun in the sky.
  0° when the object is on the horizon,
  90° when the object is directly overhead (zenith).

$$Elevation\ angle = \arcsin(\sin(l)) * \sin(x) + \cos(l) * \cos(x) * \cos(h))$$

Where:

L is the latitude of the observer,
x is the declination of the object(sun)
h is the hour angle

Energy consumption: Energy consumption refers to the total amount of energy used by a system, device, or process over a certain period of time. **kilowatt-hours (kWh)**

Formula: Energy Consumption (E)=$P \times t$

Where:

- P = Power in watts (1 W = 1 J/s),
- t = Time in seconds.

Energy output: Energy output refers to the total energy produced or delivered by a system, device, or process over a certain period of time.

Formula**:** $E=\eta\times E_{in}$

Where:

- E = Energy output.
- η = Efficiency of the system

- E_{in} = Energy input

Results & Discussions :

In this Dual Axis Solar Tracker, when source light falls on the panel, the panel adjusts its position according to maximum intensity of light falling perpendicular to it.

The objective of the project is completed. This was achieved through using light sensors that are able to detect the amount of sunlight that reaches the solar panel. The values obtained by the LDRs are compared and if there is any significant difference, there is actuation of the panel using a servo motor to the point where it is almost perpendicular to the rays of the sun.

This was achieved using a system with three stages or sub systems. Each stage has its own role. The stages were;

- An input stage that was responsible for converting incident light to a voltage.
- A control stage that was responsible for controlling actuation and decision making.
- A driver stage with the servo motor. It was responsible for actual movement of the panel.

The data from morning to noon to create control charts and graphs based on the performance of the dual-axis solar tracking system

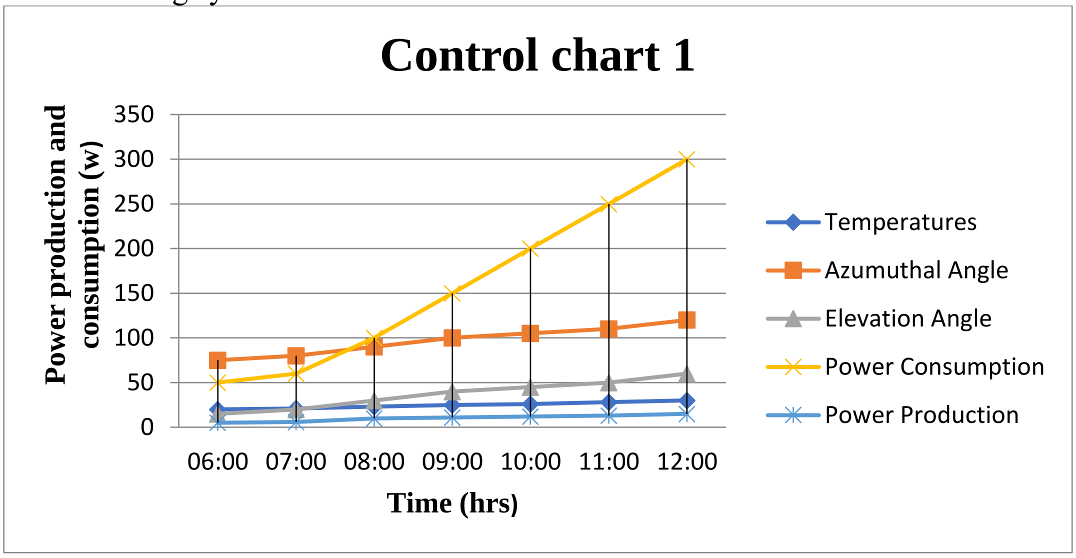

Fig.4 Time VS Energy Output

The temperature appears to increase steadily from morning to noon. Azimuth angle, which determines the solar panel's east-west orientation, shows an upward trend, suggesting the panel is tracking the sun's movement across the sky. Elevation Angle which controls the panel's tilt, also exhibits an upward trend, indicating that the panel's inclination is increasing to optimize solar capture.The power consumption curve is relatively flat, suggesting a consistent energy demand throughout the morning hours. The power production curve shows a significant increase from morning to noon, indicating that the solar tracking system is effectively capturing more sunlight as the day progresses.

There seems to be a positive correlation between temperature and power production. As the temperature rises, the solar panel's efficiency may increase, leading to higher power output.The increasing azimuth and elevation angles likely contribute to the rise in power production by keeping the panel aligned with the sun's position. Overall, the graph suggests that the dual-axis solar tracking system is functioning as intended. It effectively tracks the sun's movement, resulting in increased power generation throughout the morning. The specific values for each parameter would provide more precise information about the solar tracking system's performance. It would be interesting to see how the graph looks at different times of the day and year to assess the system's behaviour under varying solar conditions.

The data from noon to evening to create control charts and graphs based on the performance of the dual-axis solar tracking system

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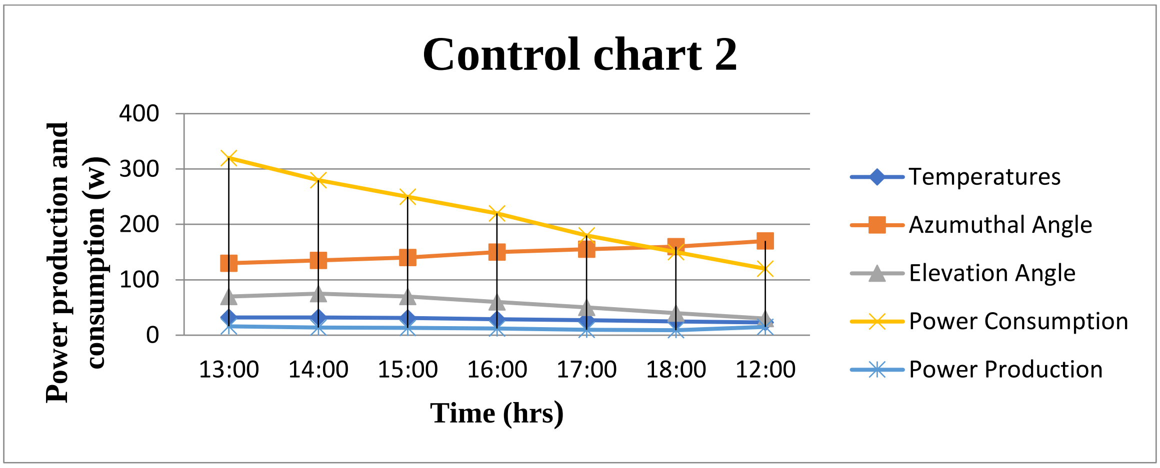

Fig.5 Time VS Energy Output

The temperature appears to decrease steadily from noon to evening. Azimuth angle, which determines the solar panel's east-west orientation, shows a downward trend, suggesting the panel is tracking the sun's movement towards the west. Elevation angle, which controls the panel's tilt, also exhibits a downward trend, indicating that the panel's inclination is decreasing as the sun lowers in the sky. The power consumption curve remains relatively flat, suggesting a consistent energy demand throughout the afternoon. The power production curve shows a significant decrease from noon to evening, reflecting the decreasing solar radiation as the sun sets.

There seems to be a negative correlation between temperature and power production. As the temperature decreases, the solar panel's efficiency may also decrease, leading to lower power output. The decreasing azimuth and elevation angles likely contribute to the decline in power production as the sun moves away from its zenith. Overall, the graph suggests that the dual-axis solar tracking system is functioning as intended, even as the sun moves towards the horizon. It effectively tracks the sun's movement, resulting in a gradual decrease in power generation as the day progresses. The specific values for each parameter would provide more precise information about the solar tracking system's performance during the afternoon. It would be interesting to compare the performance of this system with a fixed-tilt solar panel to assess the benefits of tracking.

The input stage is designed with a voltage divider circuit so that it gives desired range of illumination for bright illumination conditions or when there is dim lighting. The potentiometer was adjusted to cater for such changes. The LDRs were found to be most suitable for this project because their resistance varies with 39 light. They are readily available and are cost effective. Temperature sensors for instance would be costly. The control stage has a microcontroller that receives voltages from the LDRs and determines the action to be performed. The microcontroller is programmed to ensure it sends a signal to the servo motor that moves in accordance with the generated error. The final stage was the driving circuitry that consisted mainly of the servo motor. The servo motor had enough torque to drive the panel. Servo motors are noise free and are affordable, making them the best choice for the project.

Conclusion:

In this 21st century, as we build up our technology, population & growth, the energy consumption per capita increases exponentially, as well as our energy resources (e.g. fossils fuels) decrease rapidly. So, for sustainable development, we have to think alternative methods (utilization of renewable energy sources) in order to fulfill our energy demand. In this project, Dual Axis Solar Tracker, we've developed a demo model of solar tracker to track the maximum intensity point of light source so that the voltage given at that point by the solar panel is maximum. After a lot of trial and errors we've successfully completed our project and we are proud to invest some effort for our society.

This project was implemented with minimal resources. The circuitry was kept simple, understandable and user friendly.

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