MOI UNIVERSITY

SCHOOL OF ENGINEERING

ELECTRICAL AND COMMUNICATIONS DEPARTMENT

ELECTRICAL AND ELECTRONICS ENGINEERING

ENGINEERING PROJECT I

ECE 493

TOM ODHIAMBO

EC/1551/20

AUTOMATIC SOLAR TRACKING SYSTEM

ABSTRACT

The generation of power from the reduction of fossil fuels is the biggest challenge for the next half century. The idea of converting solar energy into electrical energy using photovoltaic panels holds its place in the front row compared to other renewable sources. But the continuous change in the relative angle of the sun with reference to the earth reduces the watts delivered by solar panel. Of all the renewable energies, solar energy is the only energy gained its popularity and importance quickly. Through the solar tracking system, we can produce an abundant amount of energy which makes the solar panel's workability much more efficient. Perpendicular proportionality of the solar panel with the sun rays is the reason lying behind its efficiency. Pecuniary, its installation charge is high provided cheaper options are also available. This project is discussed all about the design and construction mechanism of the prototype for the solar tracking system having a single axis of freedom. The main control circuit is based upon NodeMCU microcontroller. Programming of this device is done in the manner that the LDR sensor, in accordance with the detection of the sun rays, will provide direction to the DC Motor that in which way the solar panel is going to revolve. Through this, the solar panel is positioned in such a manner that the maximum amount of sun rays could be received. In comparison with the other motors, DC motor is the simplest and the suave one, the torque of which is high and speed of which is slow enough. We can program it for changing the direction notwithstanding the fact that it rotates only in one direction subject to exception as far as programming is concerned. 1985, first time ever it was witnessed for production of the silicon solar cells with an efficiency of 20%. Though a hike in the efficiency of the solar panel had a handsome increase still perfection was a far-fetched goal for it. Below 40%, most of the panels still hover to operate. Consequently, peoples are compelled to purchase a number of panels in order to meet their energy demands or purchase single systems with large outputs. Availability of the solar cells types with higher efficiencies is on provided they are too costly to purchase. Ways to be accessed for increasing solar panel efficiencies are a plethora in number still one of the ways to be availed for accomplishing the said purpose while reducing costs, is tracking. Tracking helps in the wider projection of the panel to the Sun with increased power output. It could be dual or single axis tracker. Duality ragged up with better compatibility as far as tracking of the sunlight from both the axis is concerned. Commercially single tracker is cheaper to use through booming of power is considerable and therefore a minuscule increase in the price is worthy and acceptable, provided maintenance cost should float around on an average level.

Table of Contents

CHAPTER 1

INTRODUCTION

General Background

Energy day by day is put to use at its best to fulfil the desires and ambition of the peoples at large. Each and every corner of our life is caged with various layers of impediment and in this response, energy is becoming an indispensable factor. Therefore, the source of energy needs to be endless in order to carry this colossal population ahead. Our aim is to endeavour in forwarding such noble goal of energy conservation.

With the present scenario, it is evident that conventional sources of energy such as coal, natural gas, oil, etc. are at the edge of catastrophic reduction. Solar energy stands as a beacon of hope in our quest for sustainable and renewable energy sources. With its abundance and environmental friendliness, solar power has emerged as a frontrunner in the transition towards a greener future. However, the efficiency of solar panels in harnessing this abundant energy source hinges on their ability to capture sunlight optimally throughout the day. Traditional fixed solar panels, while effective to some extent, fail to fully exploit the sun's energy potential due to their static orientation. Enter the automatic solar tracker system – a technological marvel designed to revolutionize solar energy harvesting by dynamically aligning solar panels with the sun's path. No other energy is more abundant than solar energy as per as its availability and freeness are concerned, utilization of which, compounded with rest of the fact of its conversion into electrical energy. Historically, the first solar panel was invented in 1881, Later on, all through the hands of Russell Ohl in the year, 1941 concept of the solar cell was conceived and subsequently workability of a solar panel has also advanced in comparison with the earlier span. Though it is improbable still it is not impossible as per as tracking of the mother energy is concerned in furtherance to which attempt has been taken through this project to confine every drop of energy from being left out.

The significance of automatic solar tracker systems lies in their ability to address the limitations of fixed solar panels. While fixed panels remain stationary throughout the day, automatic solar trackers continuously track the sun's movement, adjusting panel orientation to maintain optimal alignment. This dynamic response to solar irradiance variations ensures that solar panels operate at peak efficiency, thereby maximizing energy generation.

At the heart of an automatic solar tracker system lies sophisticated sensor technology coupled with intelligent control algorithms. Light sensors, such as light-dependent resistors (LDRs), serve as the eyes of the system, detecting sunlight intensity in real-time. These sensors provide crucial input data to a microcontroller, which acts as the brain, processing sensor readings and determining the sun's position relative to the solar panels. The microcontroller then orchestrates the movement of actuators – typically servo motors– to adjust the orientation of the solar panels accordingly. By continuously monitoring sunlight intensity and dynamically adjusting panel orientation, the automatic solar tracker system ensures that solar panels are always aligned perpendicular to the incoming sunlight, thereby maximizing energy capture.

Through this research endeavour, it seeks to unravel the potential of automatic solar tracker systems in enhancing the efficiency and viability of solar energy harvesting. By elucidating the underlying principles, design considerations, and performance metrics of these systems, we aim to provide valuable insights into their practical implementation and impact on renewable energy infrastructure.

The goal of this project is to build a prototype of light tracking system at smaller scale, but the design can be applied for any solar energy system in practice. It is also expected from this project a quantitative measurement of how well tracking system performs compared to system with fixed mounting method. In that sense we have to ensure the sunlight rays are falling perpendicularly on the solar panel to give the maximum solar energy. Normally a solar panel converts only 30 to 40 per cent of the incident solar radiation in to electrical energy. An automated system is required to get a constant output, which should be capable to constantly rotate the solar panel. The sun tracking system was made as a prototype to solve the problem. It will be automatic and keeps the panel in forward-facing of sun until that is visible. The unique characteristic of this system is that instead of taking the earth as its reference, it takes the sun as a guiding source. The sunlight is monitored by the active sensors and rotates the panel towards the direction where the intensity of sunlight is maximums.

CHAPTER 2

LITERATURE REVIEW

Project Background

The concept of solar tracking systems traces its roots back to the early days of solar energy research, driven by the quest to maximize energy capture from photovoltaic (PV) panels. Over the years, researchers and engineers have explored various approaches and technologies to develop efficient solar tracking systems, aiming to enhance the performance and viability of solar power generation. In this literature review, we delve into the key advancements, challenges, and insights gleaned from previous studies in the field of automatic solar tracker systems.

Fossil fuels have been facing reduction with passing time and generation of power is becoming a bigger challenge. Talking about renewable sources, the conversion of solar energy into electrical energy is prioritized. The watts delivered by the solar panel are directly proportional to the relative angle of the sun in reference to the earth. Thus, the delivery of the watts is reduced when tis relative angle changes. In this regard the efficiency of the solar panel can be increased by using solar tracking system. The pay load is moved towards the sun by solar trackers throughout the day. This project highlights different forms of tracking system as well as their pros. The main types of tracking systems are either a single axis solar tracker or a dual axis solar tracker.

Evolution of Solar Tracking Systems

The evolution of solar tracking systems can be traced through a series of advancements in sensor technology, control algorithms, and mechanical design. Early solar tracking systems relied primarily on manual or single-axis tracking mechanisms, which adjusted panel orientation along one axis to follow the sun's apparent motion across the sky. However, these systems were limited in their ability to capture sunlight optimally, especially during periods of rapid sun movement or changes in cloud cover. The advent of automatic solar tracking systems marked a significant leap forward in solar energy harvesting technology. Automatic trackers utilize sensors to detect sunlight intensity and microcontrollers to dynamically adjust panel orientation in response to changing solar conditions. This autonomous operation enables continuous optimization of energy capture, leading to higher overall efficiency compared to fixed or manual tracking systems.

Previous Work

Sobuj Kumar Ray et al. [36] presented two ways of rotating freedom solar tracker by using microcontroller. The work includes the design of two ways rotating freedom solar tracker based on microcontroller.PIC16F72 microcontroller is used to activate the motors to get two ways rotation. LDC sensors are used to get the information about sun radiation. The results are compared with conventional solar tracker without microcontroller and also with fixed panels. The difference is almost 37% between fixed panel and tracking system with microcontroller.

Yousif El-Tous et al. [37] studied the thermal evaluation of a sun tracking solar cooker using microcontroller. The work contains the implementation of tracking system developed for getting the solar heating using solar cooker. A microcontroller is used for rotating the solar heater with the movement of the sun. PLC system is used as control system. A comparison between fixed and sun tracked cooker showed that the use of sun tracking increased the heating temperature by 36%

Haneih (2009) conducted a study in Amman Jordan focusing on the demand of the sun tracking for solar panels. This study basically discussed about increasing efficiency of PV panels in dessert regions. The author explained that by using part of the power output of the solar panel two degrees of freedom orientation can be achieved. If we consider the symmetry of the system, the kinematics of the system can be controlled using astronomic calculation. Solar tracking sensors and feedback control loops can be used to add close loop control to the system. This solves the problem of cloudy days. The author further explained that special consideration should be given to the grid arrangement of panels in the collecting plants.

In another study conducted by Rao et al (2012) a project using ARM7 TDMI processor was explained. The processor did the task of gather input from sensor and giving command to the motor to track the sun. ARM7 TDMI processor was used to design and implement closed loop algorithm which form the bases of monitoring controller. This resulted in maximum current from solar panel to increase the energy production.

A difference between solar tracking device and a stationary collector was noted by Kancevica et al (2012). The author discussed that n a solar tracking device the solar radiation struck flat plate collector perpendicularly as compare to stationary collector of same size. This produced average 1.4 times more heat energy.

Generally, solar panels are motionless and do not monitor the movement of the sun. In this project a solar tracker device that tracks the movement of sun throughout the sky and tries to maintain the solar panel perpendicular to the rays, ensuring that the maximum quantity of sunlight is incident on the panel during the day. The automatic solar tracking system starts following the sun right from sunrise, in the course of the day until night, and starts all over again from the dawn next day. The solar panels are powerful means of storing energy, their performance at doing so is immediately associated with their perspective with the sun. Because PV cells get the maximum power from facing the solar, a stationary solar panel collects less sunlight one which follows the sun throughout the sky. In this project the **dual axis system is used that includes both a horizontal and vertical axis.**

Solar cells,

Also known as photovoltaic cells are used to convert light energy into electricity. Photovoltaic cells work on the principle of the photovoltaic effect, which is similar to the photoelectric effect. Differences being that the electrons in photovoltaic are not emitted instead contained in the material around the surface, creating a voltage difference. Solar cells are forged with crystalline silicon. It is the most commonly used material in a solar cell. The use of silicon in the solar cell has been very efficient and low cost. Two forms of crystalline silicon can be used to make solar cells. Other than silicon, solar cells can be fabricated with cadmium telluride (CdTe), Copper indium gallium (di)selenide (CIGS) etc. the fabrication of solar cells with materials other silicon is slightly expensive, thus making silicon the best material to be used in solar tracking systems. One of the finest and extensively used material, monocrystalline silicon has an efficiency of about 15-20%. While under high temperature the performance of the cell material drops by 10-15% of the initial. Polycrystalline silicon is another form, cheaper than the latter but has the same band gap as that of monocrystalline silicon. Though it has the same band gap energy, it lags in efficiency, hence this material is used in low-cost products. Amorphous silicon cells can work under extremely high temperatures, but the efficiency of these cells is comparatively lower than the other silicon forms. The technologies which use CdTe, CIGS, Amorphous Thin-Film Silicon (a-Si, TF-Si) in the fabrication of solar cells are known as thin film photovoltaic modules. These thin-film solar cells are relatively cost-effective than the solar cells of crystalline silicon.

There are several other factors on which the efficiency of a solar cell depends.

- Cell temperature
- Energy Conversion Efficiency
- Maximum power point tracking

Solar panels

Are a cumulative orientation of photovoltaic cells. The PV cells are arranged in a solar panel or a PV array such that is serves the purpose of exciting the electron of the material consisting inside the solar cells using photons. The average amount of sunlight received by solar panels particular depends on the position of the sun. A part of this source of natural energy is received by the solar panel. Certain ways have been developed to utilize this energy source as an alternative to other nonrenewable sources. Considering its multitudinous flourishing ways in which it can be applied to bring about the change in conserving other resources, the manipulation of the energy source is encouraged. Solar panels are hence used to utilize solar power in electrical means. They are aligned different arenas to collect maximum solar power. Though, solar panels can be used to absorb or collect solar power, there work is bounded to certain hours of the day and the sunlight pouring directly on them, i.e., the angle between the sunrays and the panel is orthogonal. While at other hours of the day, the angle of the sunrays is different, hence the amount of the solar power captured is very less. To overcome such pitfalls, and encapsulate the maximum available of solar energy the solar tracking systems were introduced. A solar tracking system is designed with the intention of keeping the angle between the sunrays and the solar array 90°.

The solar tracking system have three different modules-

- The mechanism
- Driving motors
- The tracking controller.

The mechanism

Is accountable to furnish with accurate movements, in the sake of following the footsteps of the sun throughout the day. The prototype of the device is made durable enough to withstand unfavourable weather condition. This mechanism of the solar tracking systems classifies themselves into two segments single axis tracker, dual axis tracker. Single axis tracking can be considered as one of the handy systems or prime solution in terms of small-scale photovoltaic power plants. Single axis tracking can be done using three different arrangements, which are based on the different axes of tracking-

- Inclined shaft installation
- South-North axis horizontal installation
- East-West axis horizontal installation.

Single axis tracker tracks in a single cardinal direction. The tracker has a single row tracking configuration. The above maintained methods are the different arrangements in which single axis tracker can be implemented. The working mechanism of all the maintained methods is at par with each other. The angle of the sun with the surface of the collector is computed and examined, the collectors are thus charged to track down the movement of the sun to meet the expectations of captivating a greater percentage of solar radiance.

There are numerable other imposition of single axis tracking tracker, including-

- Horizontal Single Axis Tracker (HSAT) • Horizontal Single Axis Tracker with Tilted Module (HTSAT)
- Vertical Single Axis Tracker (VSAT)
- Tilted Single Axis Tracker (TSAT)
- Polar Aligned Single Axis Tracker (PSAT)

The rotational axis in the **dual axis tracker** is orthogonal to each other. One of the axes is fixed in accordance with the ground level. This axis is known as the primary axis and the other axis is hence called the secondary axis. Dual axis trackers moved along two cardinal directions, horizontal and vertical. There are many applications of the dual axis tracker, the two most common being-

- Tip-Tilt Dual Axis Tracker
- Azimuthal Altitude Dual Axis Tracker.

The efficiency of these tracker is much more than any single axis tracker. It conventionally follows the movement of the un and hence captivates maximum solar energy.

On the basis of the driving mechanism solar trackers can again be of two kinds **active solar trackers** and **passive solar trackers**. The mechanism which makes use of electric motors such as DC motor, can be termed as active driving mechanism. The passive ones are simply controlled by the movement of the earth that is the gravitational forces.

Solar tracking controller can also categories solar trackers into two different modules.

1. <u>Open loop control</u>- The approach followed requires microprocessor. This method has an inbuild prototype which is based upon the records of the movement of sun throughout the day. Hence, the microcontroller computes the time and determines the position of the sun at that particular hour. The control system is not affected by any geographical conditions.
2. <u>Closed loop control/Feedback controllers</u>- This control system utilizes photosensor to compare the light intensity. These sensors are fixtures at the side of panel and helps in detection of the position of the sun.

The prototype used in this research, is that of a horizontal single axis tracker. The tracking system utilizes photosensitive sensors to track down the movement or the path of the sun. This type of tracking technique is classified as active solar tracking. It is based on feedback control system or closed loop controlling. The intensities of light in our system are compared and the solar panel is charged to move in the direction of maximum available intensity. Thus, the system works on the feedback of the weather condition.

Effect of light intensity

Variation in the intensities of light plays a significant role in depicting the amount of power output. This change in intensities monitors all the technical criterions such as voltage, circuit current, efficiency, shunt resistance etc. As a result, higher the intensities of light, greater is the power output. For PV modules that collect solar energy on the Earth's surface level, the incoming solar radiation consists of three main components: -

- Direct beam that reaches straight to the Earth's surface without scattering
- Diffuse radiation that scatters when passing through the atmosphere of the Earth
- Albedo radiation that reflects from the Earth's surface.

Of the first two components, direct beam holds about 80% to 90% of the solar energy in ideal condition (clear sky). It is the major source of energy for the operation of PV generator. For maximum collection of solar energy, solar panels need to maintain alignment with the Sun's direct beams as long as possible. This concept is quantitatively explained by measuring the incident angle between the direct beams and the panels **i**. For the same amount of incoming direct beams, the effective area of solar panel that collects this radiation is proportional to the cosine of **i**. As a result, the power P collected by solar panels can be calculated using equation 1:

$$\mathbf{P = Pmax * cos(i)} \qquad \mathbf{(1)}$$

where **Pmax** is the mmaximum power collected when solar panel is correctly aligned.

From equation (1) we can calculate the **loss of power a**:

$$\mathbf{a = [Pmax - Pmax * cos(i) / Pmax] = 1 - cos(i).} \qquad \mathbf{(2)\ .}$$

Equation (2) tells that the more misaligned angle is; the more sunlight energy is lost.

The efficiency of solar panel

The efficiency is one of the most significant criteria which defines the quality of the output of a certain device. There are many factors which alter the efficiency of a solar panel. Efficiency can be described as the ration of the input energy through the solar cell to the energy of the sun. The efficiency of the solar panel is monitored by the light intensity, material of the solar cell, temperature etc.

For the calculation of the energy, we calculate the maximum power, which is defined as the product of open-circuit voltage (VOC), short-circuit current (ISC) and fill factor (FF).

$$Pmax = \boldsymbol{VocIscFF}$$

The efficiency (η) is then calculated as: -

$$\eta = \boldsymbol{VocIscFF\ /Pin}$$

Where, $\boldsymbol{Pin}$ is the total input power.

The sunlight is observed at different angles depending on the place on the earth and the angles of the sun. The sun's angle can be classified into the following: -

- Elevation
- Zenith Angle
- Azimuth Angle

The elevation angle

is the angle made by the sun with the horizon. The elevation angle is 0 degree at sunrise and 90 degrees around noontime, at the equator. The elevation angle is different at a different time of the day and different for different latitudes. The depicted formula can be used to determine the elevation angle.

$\alpha = 90 + \varphi - \delta$

When the equation above gives a number greater than 90° then subtract the result from 180°. It means the sun at solar noon is coming from the south as is typical the northern hemisphere. φ is the latitude of the location of interest (positive for the northern hemisphere and negative for the southern hemisphere). δ is the declination angle, which depends on the day of the year.

Zenith angle

is akin with elevation angle. The only difference being it is measured along the vertical. Therefore, it's the angle between the sun and the vertical i.e., Zenith Angle = 90° – elevation angle.

$\zeta = 90° - \alpha$

Azimuthal Angle

This is the compass direction from which the sunlight is coming. At solar noon, the sun is directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day. At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude. Therefore, the azimuth angles are 90 degrees at sunrise and 270 degrees at sunset.

Sunrise and Sunset time can be formulated by the following formulas

Sunrise= $12 - 1/15° \cos^{-1}(-\tan\varphi \tan\delta) - TC/60$

Sunset= $12 + 1/15° \cos^{-1}(-\tan\varphi \tan\delta) - TC/60$

Where φ being the latitude of the place, δ being the declination angle and TC is the Time Correction.

Types	Specification
Active Solar Tracker	• It uses motors and gear trains or direct drive actuators, to follow the movement of the sun. • Directed by a controller. • Deactivates during darkness based on the design of the system.

	• It uses a light sensor to locate the angle at which maximum sunlight can be absorbed. • The MCU directs the solar panel to change the angle.
Passive Solar Tracker	• It uses a liquid, easily compressible and boiled. • It is driven by the solar heat. • The fluid moves when heated, like a teeter-totter and hence the solar panel moves.
Chronological Solar Tracker	• Works with the rotation of the earth. • Have no sensors. • Depends on the geographical location. • Uses a controller to calculate the moment and position of the earth with respect to the sun at a given time and location.

Challenges and Future Directions

Despite the significant advancements in automatic solar tracker technology, several challenges and opportunities for improvement remain. One major challenge is the cost-effectiveness and scalability of solar tracking systems, particularly for small-scale and residential applications. Addressing cost barriers through innovation in sensor technology, control algorithms, and manufacturing processes will be crucial for widespread adoption of solar tracking technology.

Another challenge is the integration of solar tracking systems with emerging trends such as smart grids, energy storage, and distributed generation. By leveraging data analytics, machine learning, and Internet of Things (IoT) technologies, solar tracking systems can be integrated into intelligent energy management systems to optimize energy production, storage, and consumption in real-time.

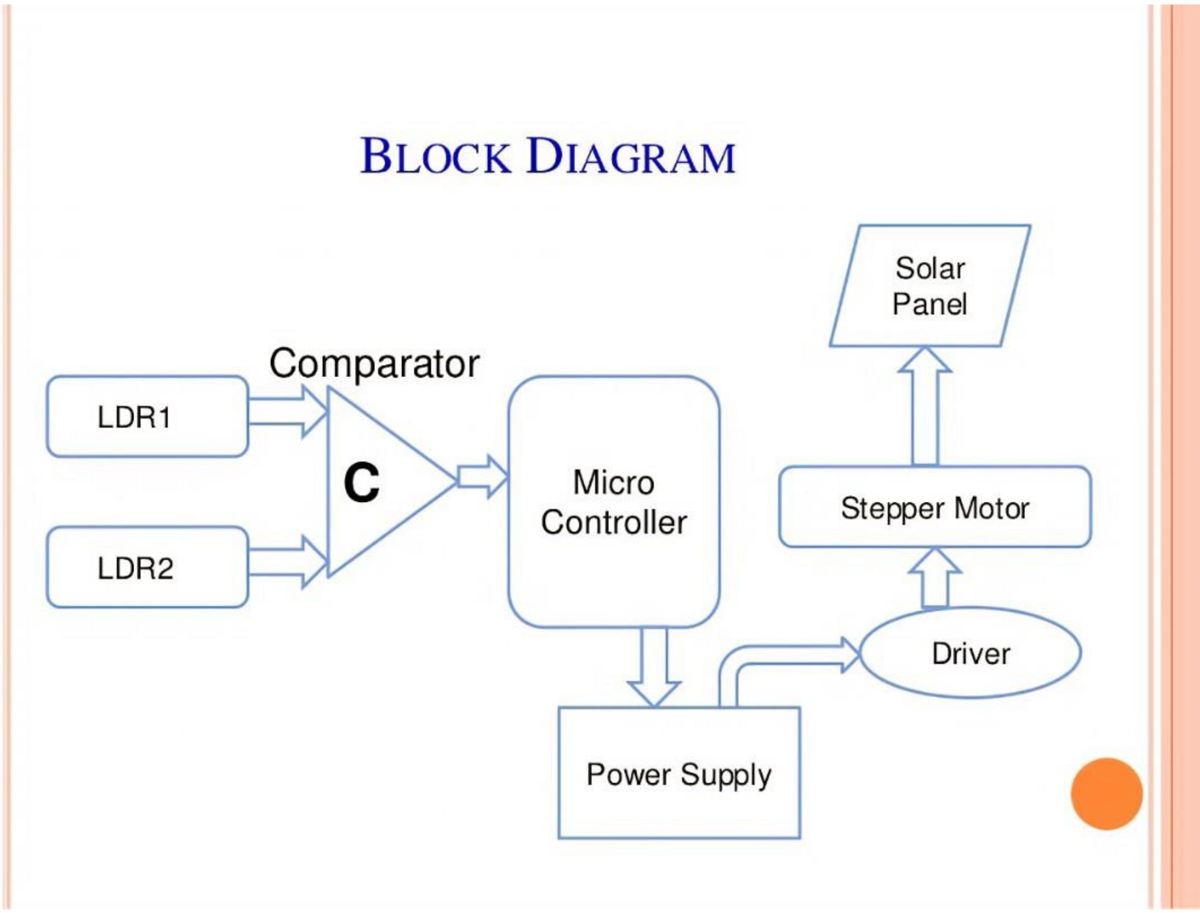
Future research directions in the field of automatic solar tracking systems include exploring advanced sensor technologies, enhancing control algorithms, and optimizing mechanical design for maximum efficiency and reliability. Additionally, interdisciplinary collaborations between researchers, engineers, and industry stakeholders will be essential for translating research findings into practical solutions and accelerating the adoption of solar tracking technology on a global scale.

CHAPTER THREE

METHODOLOGY

System Architecture

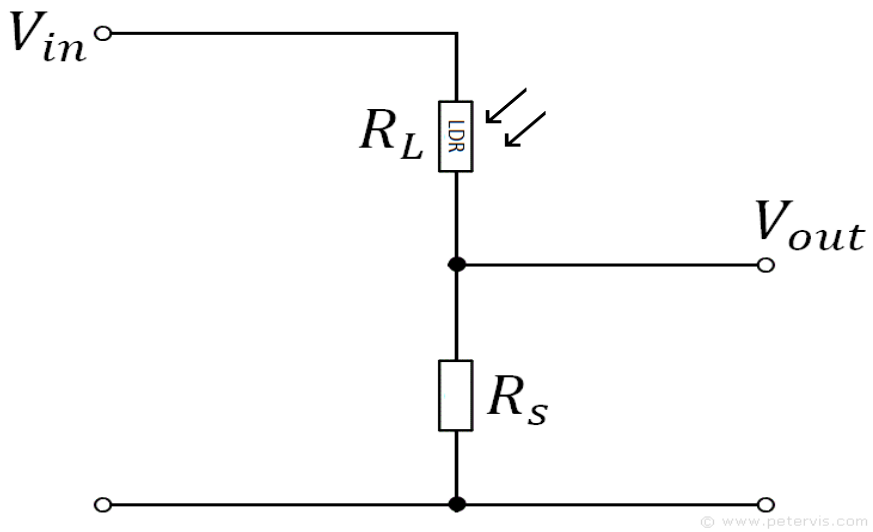
The architecture of an automatic solar tracker system comprises several key components, each playing a crucial role in ensuring its functionality and performance. This project is implemented using two **servo motors** with the main advantages being that they are fast, can sustain high torque, has precise rotation within limited angle and does not produce any noise. Arduino IDE is used for the coding. There is the design of an input stage that facilitates conversion of light into a voltage by the light dependent resistors (LDRs). There is comparison of the two voltages, then the microcontroller uses the difference as the error. The servo motor uses this error to rotate through a corresponding angle for the adjustment of the position of the solar panel until such a time that the voltage outputs in the LDRs are equal. The difference between the voltages of the LDRs is received as analog readings, which are then converted to digital values by an analog to digital converter, ADC port of the microcontroller, which is compared in order to get the difference value for motor movement. The difference is transmitted to the servo motor and it thus moves to ensure the two LDRs are an equal inclination. This means they will be receiving the same amount of light, and the Solar panel will receive the sunlight at 90° i.e., the plane of PV panel will make an angle 90° with the Sun, and the perpendicular drawn on the plane makes an angle 0° with the Sun, to ensure maximum illumination: (Lambert's cosine Law). The procedure is repeated throughout the day.



Tracker systems work on two simple principles together. One being, the normal principle of incidence and reflection on which our tracker works and the other is the principle on which the solar (PV) panel works, which will produce electricity. Both these principles can be combined and as a result of which it can produce nearly double the output that the panel specifies normally.

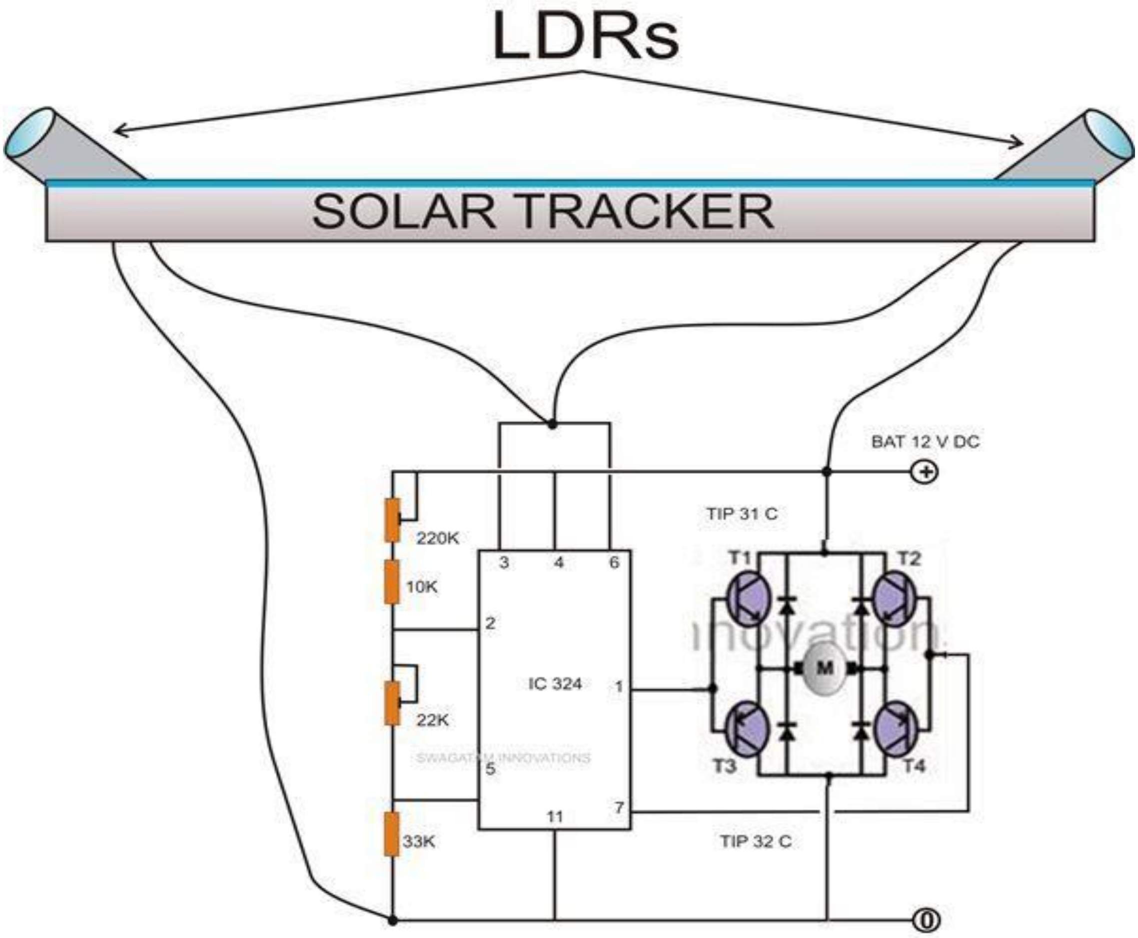
Working Principle

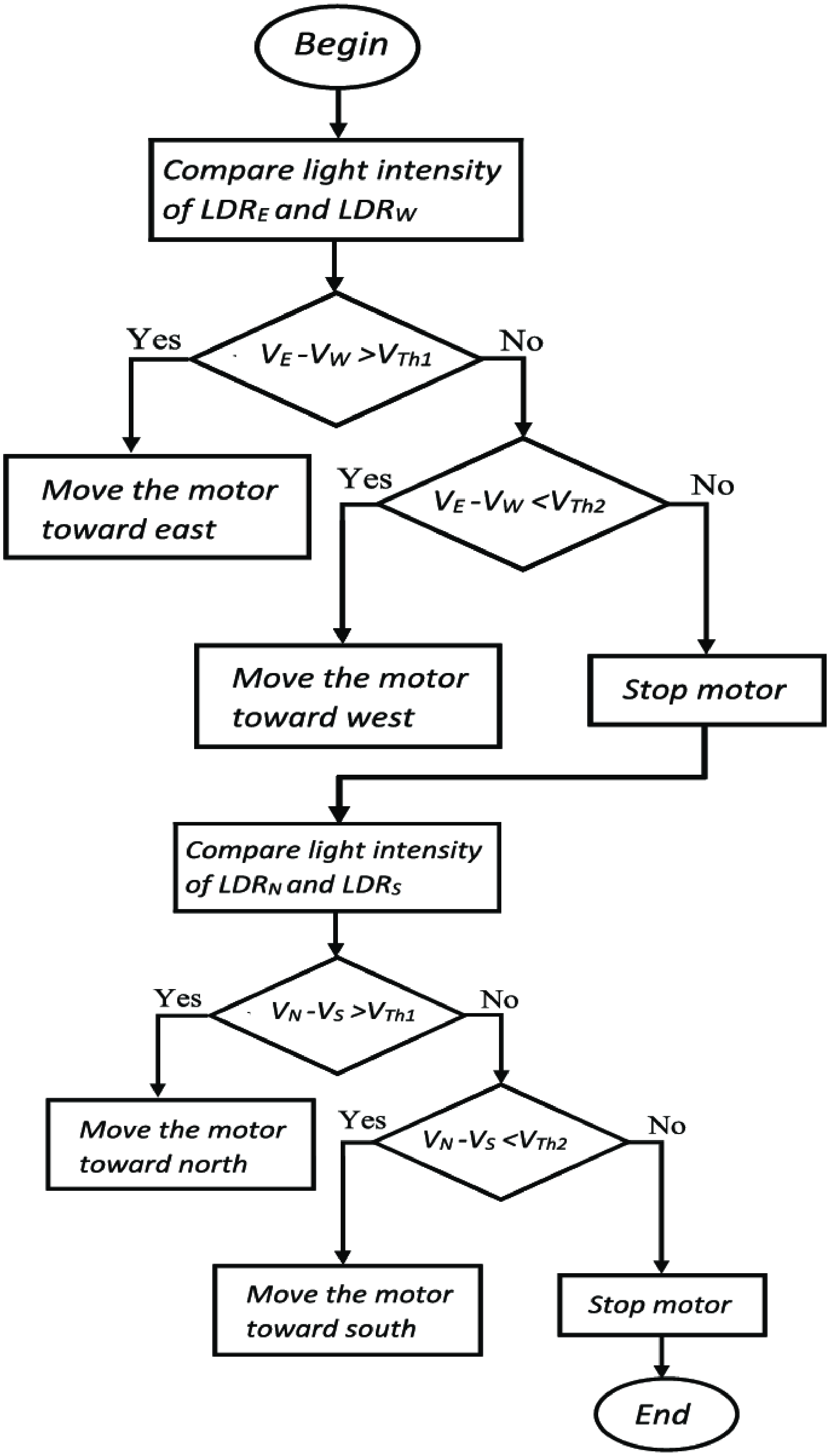
Resistance of LDR depends on intensity of the light and it varies according to it. The higher is the intensity of light, lower will be the LDR resistance and due to this the output voltage lowers and when the light intensity is low, the higher the LDR resistance and thus higher output voltage is obtained. A potential divider circuit is used to get the output voltage from the sensors (LDRs). The circuit is shown here:



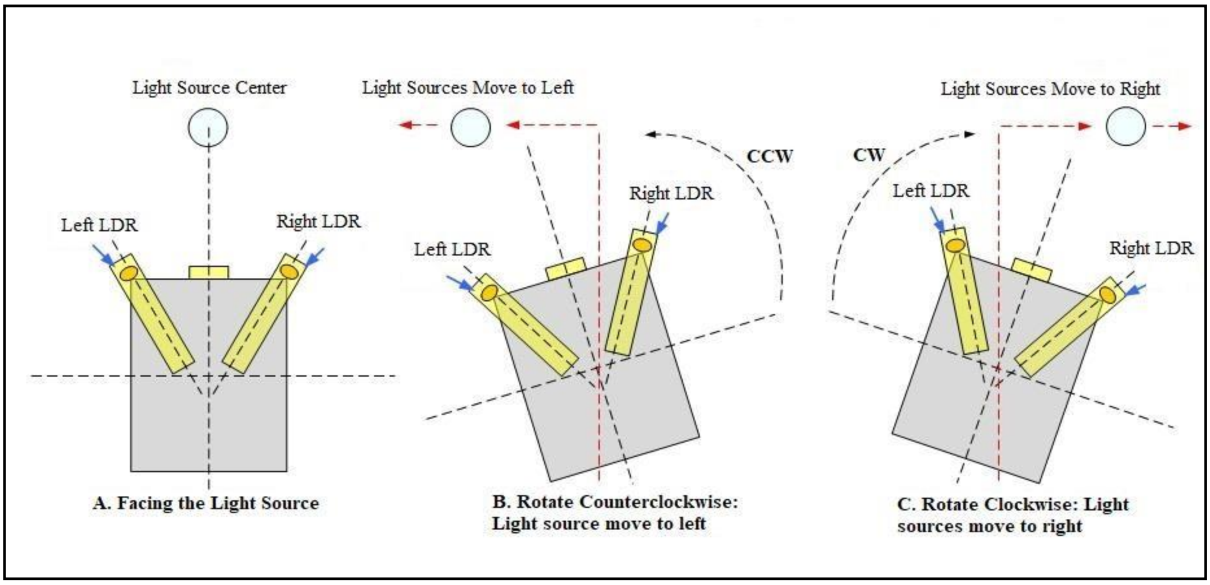
The LDR senses the analog input in voltages between 0 to 5 volts and provides a digital number at the output which generally ranges from 0 to 1023. Now this will give feedback to the microcontroller using the Arduino software(IDE). The servo motor position can be controlled by this mechanism. The tracker finally adjusts its position sensing the maximum intensity of light falling perpendicular to it and stays there till it notices any further change. The sensitivity of the LDR depends on point source of light. It hardly shows any effect on diffuse lighting condition.

Basic circuit diagram and flow chart of a dual axis solar tracker




Begin
Compare light intensity of LDR$_E$ and LDR$_W$
$V_E - V_W > V_{Th1}$
Yes
No
Move the motor toward east
$V_E - V_W < V_{Th2}$
Yes
No
Move the motor toward west
Stop motor
Compare light intensity of LDR$_N$ and LDR$_S$
$V_N - V_S > V_{Th1}$
Yes
No
Move the motor toward north
$V_N - V_S < V_{Th2}$
Yes
No
Move the motor toward south
Stop motor
End

Hardware Model



Concept of using Two LDR

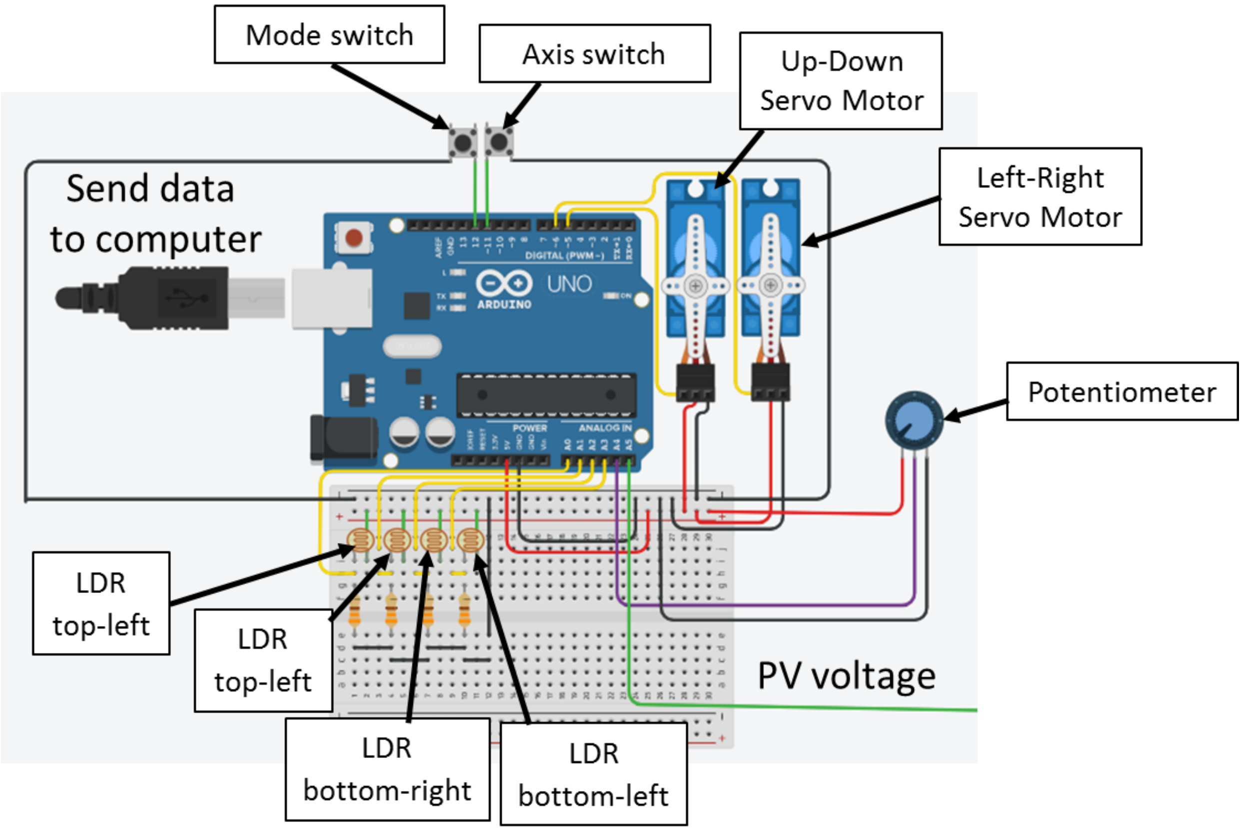
The figure depicts the notion for the instalment of the light dependent resistors (LDR). A secure state is attained when the light intensities of the two LDR become the same. The principal source of light energy, the Sun, moves from east to west. This movement of the Sun causes the variation in the level of light intensities falling on the two LDRs. The designed algorithm compares the variation in the light intensities the values are compared with each other by considering a particular LDR value as reference inside the microcontroller and the motor then is operated to rotate the solar panel, so it moves aligned with the trail of the light source.

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.

System components

1. **Arduino Uno**

The Arduino Uno is a microcontroller board based on the ATmega328. Arduino is an opensource, prototyping platform and its simplicity makes it ideal for hobbyists to use as well as professionals. The Arduino Uno has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-toDC adapter or battery to get started. The Arduino Uno differs from all preceding boards in that it does not use the FTDI USB-toserial driver chip. Instead, it features the Atmega8U2 microcontroller chip programmed as a USB-to-serial converter. "Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Arduino Uno and version 1.0 will be the reference versions of Arduno, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform.

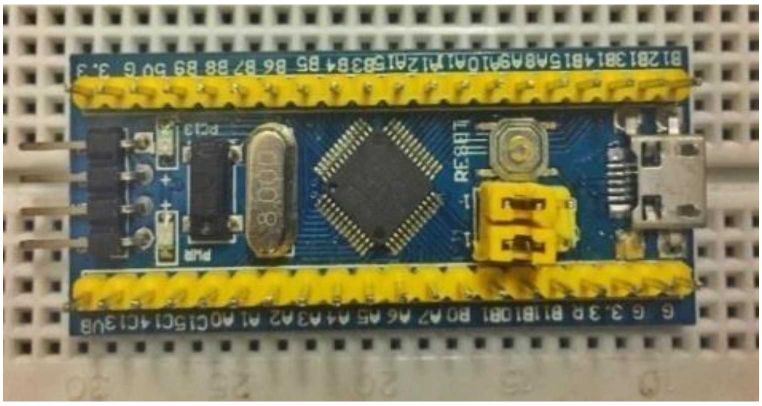


2. 32 – BIT ARM MICROCONTROLLER

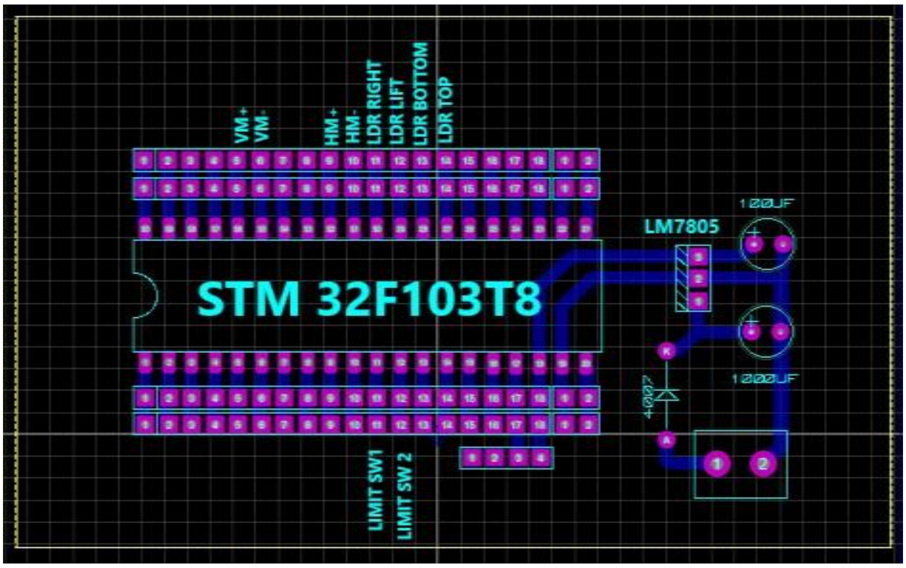
The operation of a dual axis solar tracking system is based on the Azimuth- Altitude principle which helps to move the solar panel in both horizontal and vertical directions. The proposed system uses a **32 -bit ARM microcontroller**. The microcontroller is interfaced with the light dependent resistor sensor module and a DC worm gear motor to rotate the system.

The STM32 development board called Blue Pill is an ARM CortexM3 microcontroller platform. It is similar to an Arduino mini. The board has a built-in radio control unit (RTC) that may be able to sleep, making it more feasible for battery-powered applications. The RTC is driven by two oscillators, one at 8MHz and the other at 32 kHz (real-time clock) . The Figure below shows the 32-bit ARM microcontroller (STM32F103C8T6) and its PCB design, respectively.

Pin Diagram:

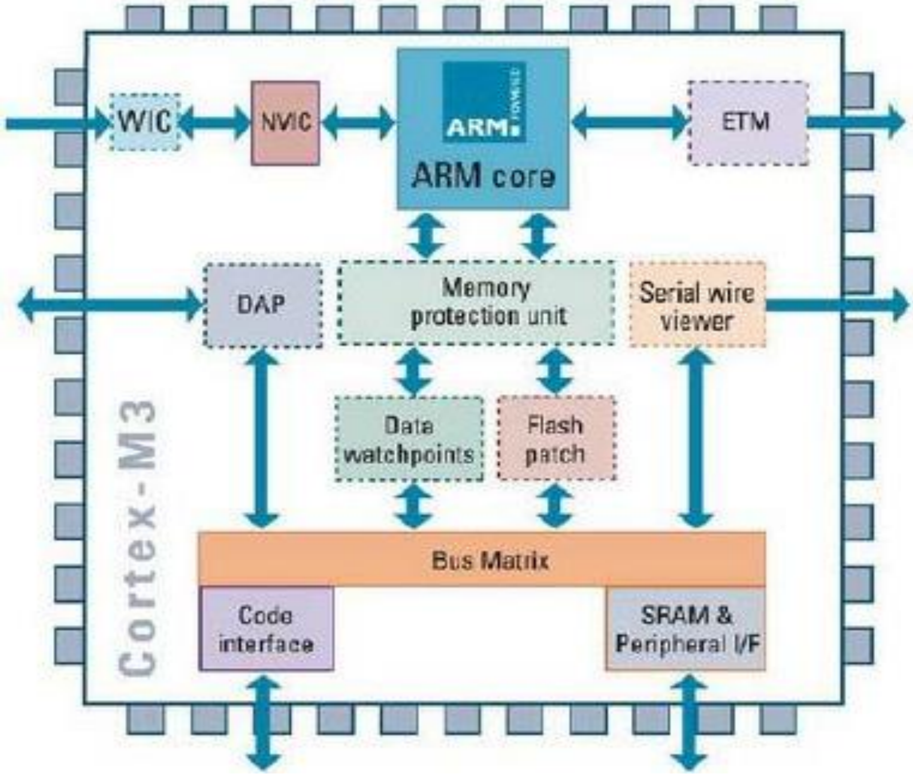


The pin layout is shown in the figure below



3. **STM32 - ARM CortexM3**

The main function of the **CortexM3** is to ensure correct program execution. The CPU must therefore be able to access memories, perform calculations, control peripherals, and handle interrupts. Flash, EEPROM, and SRAM are all integrated onto a single chip, removing the need for external memory in most applications. Some devices have a parallel external bus option to allow adding additional data memory or memory-mapped devices.



4. **CPU**

The CPU of the AVR microcontroller is same but so simple like the one in a computer. The main purpose of the CPU is to confirm correct program performance. Therefore, the CPU must be able to access perform calculations, memories, control peripherals & handle interrupts. The CPUs of Atmel's 8-bit and 32-bit AVR are based on an innovative "Harvard architecture" thus every IC has two buses namely one instruction bus and data bus. The CPU reads executable instructions in instruction bus, wherein the data bus, is to read or write the corresponding data. The CPU core of the AVR consists of the ALU, General Purpose Registers, Program Counter, Instruction Register, Instruction Decoder, Status Register and Stack Pointer.

5. **Flash Program Memory**

The program of the AVR microcontroller is stored in non-volatile programmable Flash program memory which is just similar to the flash storage in your SD Card or Mp3 Player. The Flash program memory is separated into two units. The first unit is the Application Flash section. It is where the program of the AVR is stored. The second section is named as the Boot Flash section and can be fixed to perform directly when the device is powered up. One significant fact to note is that the microcontrollers Flash program memory has a resolution of at least 10,000 writes/erase cycles,

6. **SRAM**

The SRAM (Static Random Access Memory) of the AVR microcontroller is just like computer RAM. While the registers are used to execute calculations, the SRAM is used to supply data through the runtime. This volatile memory is prearranged in 8-bit registers.

7. **EEPROM**

The term EEPROM stands for Electrically Erasable Read-Only Memory is like a non-volatile memory, but you can't run a program from it, but it is used as long-time storage. The EEPROM doesn't get removed when the IC loses power. It's a great place for storing data like device parameters and configuration of the system at runtime so that it can continue between resets of the application processor. One significant fact to note is that the EEPROM memory of the AVR has a limited lifetime of 100,000 writes / EEPROM page – reads are limitless. Keep this in mind in your application and try to keep writing to a minimum, so that you only write the small amount of info required for your application every time you update the EEPROM.

8. **Digital I/O Modules**

The digital I/O modules let digital communication or logic communication with the AVR microcontroller and the exterior world. Communication signals are that of TTL/CMOS logic.

9. **Analog I/O Modules**

Analog I/O modules are used to input or output analog information from or to the exterior world. These modules comprise analog comparators and analog-to-digital converters (ADC).

10. **Interrupt Unit**

Interrupts have enabled the microcontroller to monitor particular events in the background while performing and application program & respond to the occurrence if required pausing the unique program. This is all synchronized by the interrupt Unit.

11. **Timer**

Most AVR microcontrollers have at least one Timer or Counter module which is used to achieve timing or counting operations in the microcontroller. These comprise time stamping, counting events, measuring intervals, etc.

12. **Light Dependent Resistor (LDR)**

It is a photo-resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices. They are also called as photo conductors, photo conductive cells or simply photocells. They are made up of semiconductor materials having high resistance. LDR works on the principle of photo conductivity. Photo conductivity is an optical phenomenon in which the material's conductivity is increased when light is absorbed by the material. The most common type of LDR has a resistance that falls with an increase in the light intensity falling upon the device.

The resistance of an LDR may typically have the following resistances:

- Daylight = 5KΩ and Dark = 20MΩ

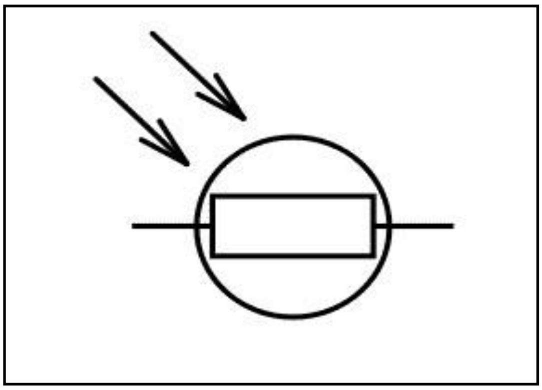
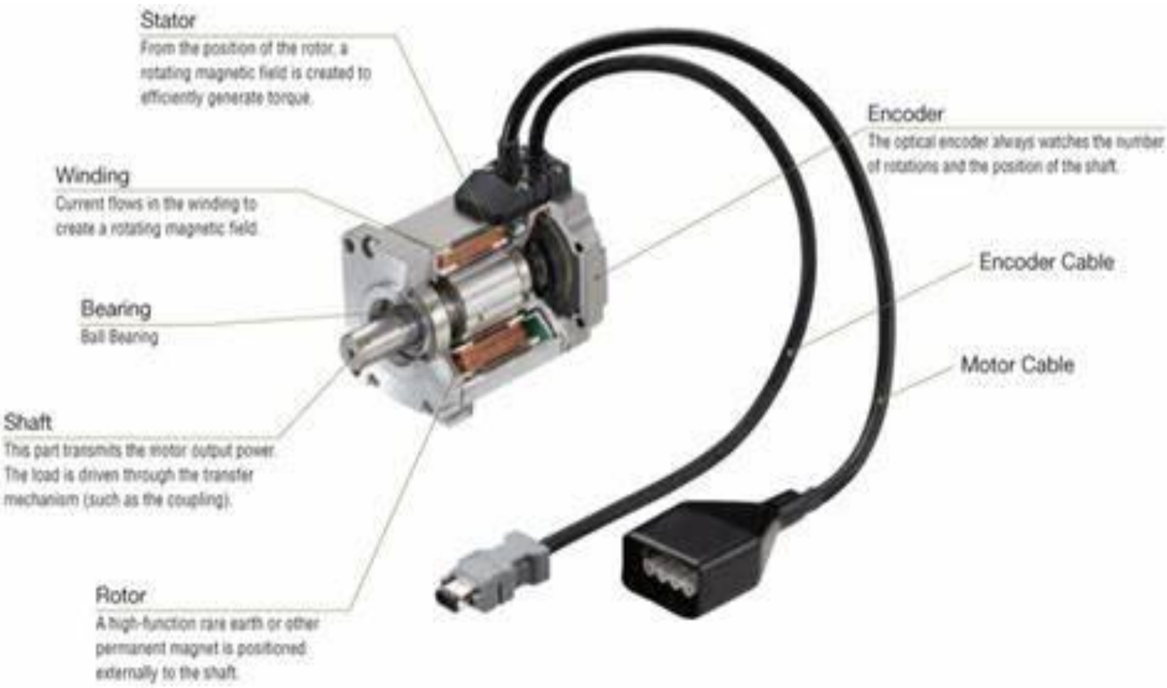


Figure 4. 2: Symbol of LDR

13. SERVO MOTOR

A DC servo motor consists of a small DC motor, feedback potentiometer, gearbox, motor drive electronic circuit and electronic feedback control loop. It is more or less similar to the normal DC motor. The stator of the motor consists of a cylindrical frame and the magnet is attached to the inside of the frame. A brush is built with an armature coil that supplies the current to the commutator. At the back of the shaft, a detector is built into the rotor in order to detect the rotation speed. With this construction, it is simple to design a controller using simple circuitry because the torque is proportional to the amount of current flow through the armature.



ADC concept in Arduino UNO

Arduino uno board has 6 ADC input ports. Among those any one or all of them can be used as inputs for analog voltage. The Arduino Uno ADC is of 10-bit resolution (so the integer values from (0-(2^10) 1023)). This means that it will map input voltages between 0 and 5 volts into integer values between 0 and 1023. So, for every (5/1024= 4.9mV) per unit.

The UNO ADC channels have a default reference value of 5V. This means we can give a maximum input voltage of 5V for ADC conversion at any input channel. Since some sensors provide voltages from 0-2.5V, with a 5V reference we get lesser accuracy, so we have a instruction that enables us to change this reference value. So for changing the reference value we have ("analogReference();").

As default we get the maximum board ADC resolution which is 10bits, this resolution can be changed by using instruction ("analogReadResolution(bits);").

Software Design

The embedded software is the piece that will be embedded in the hardware (Arduino Uno) to control and monitor the solar tracker test bench. The embedded software is designed to cover the following requirements:

1. The test bench has two modes: manual and automatic. A pushbutton is connected to pin 12 to switch between the two modes.
2. If the manual mode is active, the potentiometer can control servomotors either from east to west for left-right motor or from south to north for the up-down motor. A push-button is connected to pin 11 to switch the potentiometer between the two motors, either it controls the left-right servomotor or up-down servo motor.
3. If the automatic mode is active, the algorithm presented in Fig. 4 will be executed. The latter uses the analog values returned by LDR sensors. For instance, considering azimuth or vertical axis, the average values from two right LDRs and two left LDRs are compared and if the left set of LDRs receives more light, the solar tracker will move in that direction through the left-right servomotor. The latter will continue to rotate until the difference result is in the range [−10, 10]. This range is used to stabilize the controller and once the solar tracker is perpendicular to the sun, no further control is made. On the other hand, if the right set of LDRs receive more light, the solar tracker moves in that direction through the left-right servomotor and will continue to rotate until the difference result is in the range [−10, 10]. The same way is used for the elevation axis. Moreover, we also determined the average radiation between the four LDR sensors and if this value is less than a little value (8: a value which has been adjusted and tested practically and is returned when the irradiation is null). That is to say, the night has come. In this case, the solar tracker must return to the sun's rising position. For example, if the sun's rising position can be reached by setting 0 degrees in the left-right servomotor, and 30 degrees in the up-down servomotor. This can easily be done through the C function "servox. write(angle)" provided by Arduino IDE.
4. The PV voltage acquired through the analog pin A5 must be treated and used to compute the PV current and power. Then all these data and the actual mode must be sent through a USB cable to the computer and then present them in MS Excel.

```
//Servo motor library
#include <Servo.h>
//Initialize variables
int  mode = 0;
int axe = 0;
int buttonState1 = 0;
int buttonState2  = 0;
int prevButtonState1 = 0;
int prevButtonState2 = 0;

int ldrtopr=  0;                // top-right LDR
int ldrtopl = 1;               // top-left LDR
int ldrbotr = 2;               //  bottom-right LDR
int ldrbotl = 3;               // bottom-left  LDR
int topl = 0;
int topr = 0;
int botl = 0;
int  botr = 0;

//Declare two servos
Servo servo_updown;
Servo servo_rightleft;

int  threshold_value=10;           //measurement sensitivity

void setup()
{
  Serial.begin(9600);                                  //serial
connection setup  //opens  serial port, sets data rate to 9600 bps
  Serial.println("CLEARDATA");                         //clear  all
data thatâ€™s been place in already
  Serial.println("LABEL,t,voltage,current,power,Mode");   //define
the column headings (PLX-DAQ command)

  pinMode(12, INPUT);              //Mode  switch Button
  pinMode(11, INPUT);              //Axis switch
  pinMode(A4,  INPUT);              //Potentiometer for right-left
movement and for up-down movement

  servo_updown.attach(5);             //Servo motor up-down movement
  servo_rightleft.attach(6);          //Servo motor right-left
movement
}

void loop()
{
//  pv_power();
char  Mode;
    float volt = analogRead(A5)*5.0/1023;
    float voltage = 2*volt;                //
Volt=(R1/R1+R2)*Voltage / R1=R2=10Ohms  => voltage=2*volt)
    float current = voltage/20;            //  I=voltage/(R1+R2)
    float power  = voltage*current;
```

```
    Serial.print("DATA,TIME,"); // PLX-DAQ command
    Serial.print(voltage);    //send the voltage to serial port
    Serial.print(",");
    Serial.print(current);    //send the current to serial port
    Serial.print(",");
    Serial.print(power);  //send the power to serial port
    Serial.print(",");

//    Serial.println(Mode);
  buttonState1 = digitalRead(12);
  if (buttonState1 != prevButtonState1)  {
    if (buttonState1 == HIGH) {
      //Change mode and ligh up the correct  indicator
      if (mode == 1) {
        mode = 0;
      } else {
        mode = 1;
      }
    }
  }
  prevButtonState1 = buttonState1;
  delay(50); // Wait for 50 millisecond(s)

  if (mode == 0) {
    Mode='M';
    Serial.println(Mode);   //send Mode "Manual" to serial port
    manualsolartracker();
  } else { // mode automatic
    Mode = 'A';
    Serial.println(Mode);
    automaticsolartracker(); //send Mode "Automatic" to serial port
    }
}

void  automaticsolartracker(){

     //capturing analog values of each LDR
     topr= analogRead(ldrtopr);         //capturing analog value of
top right LDR
     topl= analogRead(ldrtopl);         //capturing analog value of
top left LDR
     botr= analogRead(ldrbotr);         //capturing analog value of
bot right LDR
     botl= analogRead(ldrbotl);         //capturing analog value of
bot left LDR

    // calculating average
     int avgtop = (topr + topl) / 2;     //average  of top LDRs
     int avgbot = (botr + botl) / 2;     //average of bottom LDRs
     int avgleft = (topl + botl) / 2;    //average of left LDRs
     int avgright  = (topr + botr) / 2;   //average of right LDRs

    //Get the different
     int diffelev = avgtop - avgbot;      //Get the different
average betwen  LDRs top and LDRs bot
```

```
     int diffazi = avgright - avgleft;    //Get the different
average betwen LDRs right and LDRs left

    //left-right movement of  solar tracker

      if (abs(diffazi) >= threshold_value){        //Change
position only if light difference is bigger then the threshold_value
       if  (diffazi > 0) {
        if (servo_rightleft.read() < 180) {
          servo_rightleft.write((servo_updown.read()  + 2));
        }
      }
      if (diffazi <  0) {
        if (servo_rightleft.read()  > 0) {
          servo_rightleft.write((servo_updown.read() - 2));
        }
      }
    }

      //up-down movement of solar tracker

      if (abs(diffelev) >= threshold_value){    //Change position
only if light  difference is bigger then thethreshold_value
       if (diffelev > 0) {
        if  (servo_updown.read() < 180) {
          servo_updown.write((servo_rightleft.read()  - 2));
        }
      }
      if (diffelev <  0) {
        if (servo_updown.read()  > 0) {
          servo_updown.write((servo_rightleft.read() + 2));
        }
      }
    }
 }

void manualsolartracker(){
  buttonState2  = digitalRead(13);
  if (buttonState2 != prevButtonState2) {
    if (buttonState2  == HIGH) {
      //Change mode and ligh up the correct indicator
      if  (axe == 1) {
        axe = 0;
      } else {
        axe = 1;
      }
    }
  }
  prevButtonState2 = buttonState2;
  delay(50); // Wait for 50  millisecond(s)
  if (axe == 0) {     //control right-left movement
    servo_rightleft.write(map(analogRead(A4),  0, 1023, 0, 180));
  } else { // //control up-down movement
    servo_updown.write(map(analogRead(A4),  0, 1023, 0, 180));
  }
```

Solar Module's Performance and connected load

Solar panel is placed at the top and connected to a load directly. The load may a led or a voltmeter which could be connected to get the exact voltage which depends on the intensity of light falling on the panel and the position of the tracker.

Concentrated solar photovoltaics' and have optics that directly accept sunlight, so solar trackers must be angled correctly to collect energy. All concentrated solar systems have trackers because the systems do not produce energy unless directed correctly toward the sun.

The solar panel is just a mere device to accept the light radiation which is purely controlled by LDR sensors and the load connected depends upon the rating of the panel used.

CHAPTER 4

EXPERIMENT TEST, RESULTS AND ANALYSIS

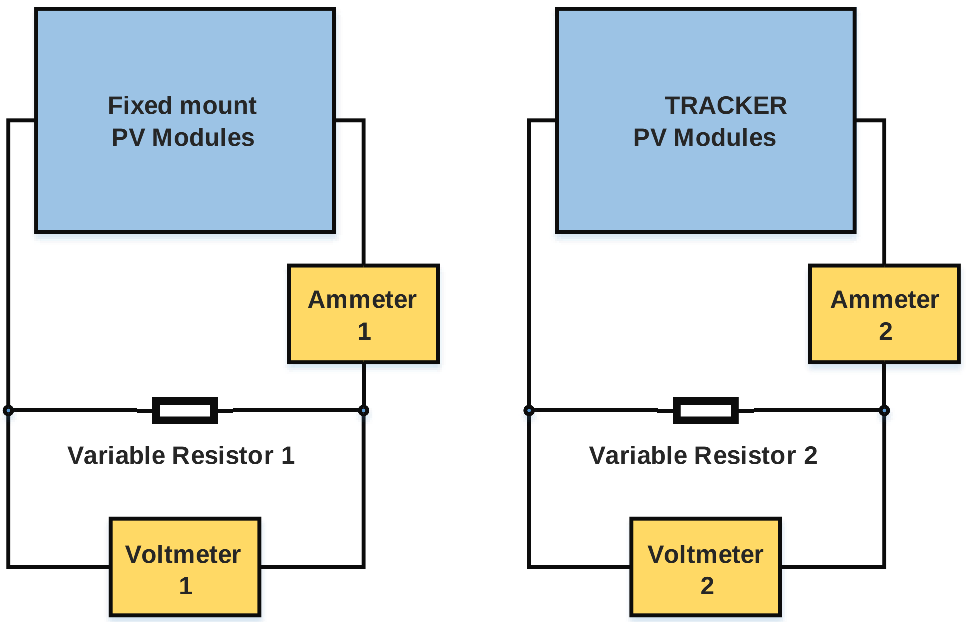
Testing of Device Functionality

Because LDR photo sensor can work with any kind of visible light, testing process for the initial prototype was completed indoor using table lamp as source of light. In the first test, the device was able to detect the movement of light source and rotate to align with it. Light detection had some small delay, due to the characteristic of LDR photo sensor, but that is acceptable for solar PV applications, because the sun moves slowly and gradually during device's operation.

Unfortunately, the first version of the system did not have enough stability. The weight of all the components mounted on top of secondary stepper motor put a strain on it, which cause improper and incorrect rotation from time to time. Also, in practical, the stepper motors only worked properly with 12 steps per rotation, which resulted in imperfect alignment of photo sensors, causing repetitive realignments. Under the scope of this project, it was hard to circumvent these drawbacks without replacing stepper motors with better ones.

Evaluation of the system in Improving PV Panel's Efficiency

The main purpose of this stage was to perform a quantitative evaluation of how much the designed tracker system improves over normal fixed mount PV systems. In order to do that, an identical solar PV panel was used on a fixed mount at equal height with the panel with the tracker system. PV panel of in fixed mount configuration was placed horizontally. The two systems were placed outside, under the same weather condition, with the same setup of measuring equipment, which are shown in figure below.



In each system, the solar PV panel consisted of two PV modules in series connection. Each module had rated power output of 0.6 W at voltage 6 V, giving the total rated output of 1.2 W at voltage 12 V. With the way of set up measuring equipment as in figure 22, the variable resistor provided a more detailed result of performance of two systems with different loads. The evaluation had been carried out on a summer day in May 2016, with the following goals:

- Measurements are done in multiple sessions during different time of the day.
- In each session, it is important that two systems are measured simultaneously, under the same solar radiation.
- Measurements include open-circuit voltage, short-circuit current, output voltage and current at different loads in the range 10 Ω to 10 KΩ.

With the provided goals, six sessions were carried out, where voltage and current values for ten different load value were recorded. After the sessions, all output power values of two systems were calculated using data collected from the measurements. From those data, we can observe how well the tracker system improves the output of PV modules, comapared to fixed mount system. Measured data of open-circuit voltages and short-circuit current of two systems are display in the table below

The below table shows the performance of the solar panel without tracker

Time (Hrs)	**Voltage (V)**	**Current(A)**	**Power (W)**
9am	5.5	0.11	0.605
10am	9	0.19	1.71
11am	10.5	0.2	2.1
12 pm	12.5	0.28	3.5
1 pm	14	0.32	4.49
2 pm	13.5	0.3	4.05
3 pm	11	0.26	2.86
4 pm	8	0.16	1.28
5 pm	6	0.12	0.72

Solar panel without tracking system.

The table given below shows the efficiency and performance of the solar panel with tracking.

Time (Hrs)	Voltage (V)	Current(A)	Power (W)
9am	12.2	0.23	2.8
10am	13.5	0.25	3.4
11am	14	0.28	3.92
12 pm	14	0.3	4.2
1 pm	15	0.3	4.5
2 pm	14	0.3	4.2
3 pm	13	0.26	3.38
4 pm	10	0.25	2.5
5 pm	7	0.2	1.4

Analysis

From the tables, it can be seen that the maximum sunlight occurs at around midday, with maximum values obtained between 1200 hours and 1400 hours. In the morning and late evening, intensity of sunlight diminishes and the values obtained are less that those obtained during the day. After sunset, the tracking system is switched off to save energy. It is switched back on in the morning. The tracking system is most efficient when it is sunny. It will be able to harness most of the solar power which will be converted into energy. In terms of the power output of the solar panels for tracking and fixed systems, it is evident that the tracking system will have increased power output. This is because the power generated by solar panels is dependent on the intensity of light. The more the light intensity the more the power that will be generated by the solar panel.

2.134 Watts is the average power obtained from solar panel without tracking and **3.18 Watts** power is obtained from solar panel with tracking.

41.64% is the improved efficiency neglecting the power consumption of motor. So, the proposed automatic solar tracking system presents efficient system to connect solar energy which ensures that consumption of energy is more than the fixed solar panel. In this project the hardware of solar tracking solar panel design and the implementation of the design has been proposed. The result shows that the solar tracking system increases the efficiency of the solar panel. Solar tracking solar panel is completely automatic and it ensures the minimum low cost. So, it is a dual axis system which maximizes the efficiency and can be obtained over a period of time. Normally a solar panel converts only 30 to 40 per cent of the incident solar radiation in to electrical energy. An automated system is required to get a constant output, which should be capable to constantly rotate the solar panel. The sun tracking system is made as a prototype to solve the problem. It will be automatic and keeps the panel in forward facing of sun until that is visible.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Conclusion

The goal of the project was to design and implement a small-scale prototype of an automatic solar tracker with basic tracking functions. Designing and implementing processes have been accordingly completed for the work of the project. The final result was a complete design of such a system, with functionality that met the design requirements.

While the project has succeeded in creating a device with basic required features, there are still considerable drawbacks and limitations with the performance of the device, as discussed in the implementation work of the project. It is possible to overcome these limitations and to improve the performance of the device in future development. It is a useful reference for those who needs to develop similar systems. The knowledge and information from this project can also become the starting point for future development of a various of applications. This project was implemented with minimal resources. The circuitry was kept simple, understandable and user friendly.

Recommendations

The goals of this project were outlined keeping in mind the timeline and resources that were attainable. However, this initial design can be subjected to many improvements. Initially this design represents a miniature scale model which can be modified into a much larger scale. Easy to bend cables can be used which do not apply any force on the motor when it is rotating the solar panel. To get a better tracking precision, a photo transistor with and amplification circuit can be used. Furthermore, accuracy can also be increased by utilizing dual axis design versus single axis design. Future projects can make use of microcontroller. This microcontroller can serve as standalone unit in the fabricated circuit.

CHAPTER 6

REFERENCES

1. Ying-Tung Hsiao, China-Hong Chen, “Maximum Power Tracking for Photovoltaic Power System,” Conference Record of the 2002 IEEE Industry Applications Conference. 37th IAS Annual Meeting, ISBN-0-7803-7420-7, 13-18 Oct, 2002, pp 1035-1039.
2. Kamrul Islam Chowdhury, Md.Iftekhar-ul-Alam, Promit Shams Bakshi, “Performance Comparison Between Fixed Panel, Single-axis and Dual-axis Sun Tracking Solar Panel System,” BRAC University, Department of Electrical and Electronic Engineering, 2017.
3. Mayank Kumar Lokhande, “Automatic Solar Tracking System,” International Journel of Core Engineering & Management, October, 2014.
4. Akhil,K. (March 25, 2016). Solar Tracking System. Retrieved on October 3rd, 2019 from: https://www.slideshare.net/Reejasunil/solar-tracking-system-60035017
5. Gajadharane, M. R., Gijare, N.A., & Joshi, M. H. (June, 2016). Design and development of mechanical Solar Tracking System. Retrieved on October 7, 2019 from https://www.academia.edu/26526209/Design_and_Development_of_Mechanical_Solar_Tracking_System
6. Mishra, J., Thakur, R. & Deep, A. (May, 2017). Arduino based dual axis smart solar tracker. Retrieved on September 29, 2019 from https://media.neliti.com/media/publications/239849-arduino-based-dual-axis-smartsolar-trac-8ab31d
7. Dhanabal.R., Bharathi.V., Ranjitha.R., Ponni.A., Deepthi.S., and Mageshkannan.P. 2013. “Comparison of efficiencies of solar tracker systems with static panel single axis tracking system and dual axis tracking system with fixed mount.” International Journal of Engineering and Technology (IJET) 5:1925-1933.
8. Bione.J., Vilela.OC., and Fraidenraich.N. 2004. “Comparison of the performance of PV water pumping systems driven by fixed, tracking and V-trough generators.” Solar energy 76:703-11.