KATHMANDU UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

PROJECT REPORT ON

DESIGN AND FABRICATION OF DUAL-AXIS SOLAR TRACKING SYSTEM

In Partial Fulfillment of the Requirements for

MEEG 215

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July 2019

AUTHORIZATION

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PROJECT EVALUATION

Design and fabrication of dual-axis solar tracking system

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ABSTRACT

Dual axis solar tracker can simultaneously track sun’s radiation in both horizontal and vertical axis. They use the same principle as the mountings of astronomical telescopes. In order to achieve maximum efficiency, the device tracks seasonal variations and daily tilt. The work focuses on the design and fabrication of automatic dual axis solar tracker prototype using Arduino code based on microcontroller along with fundamental of solar panel parameter and its use. The device is able to simulate the sun’s tracking of 12 months within few minutes thus, implementing automation mechanism in tracking system.

LIST OF ABBREVIATIONS

MPPT	Maximum Power Point Tracker
ICS	Improved Cooking Stove
FY	Fiscal Year
AEPC	Alternative Energy Production Centre
SHS	Solar Home System
NEA	Nepal Electricity Authority
DOD	Depth of Discharge
PWM	Pulse Width Modulation
PTs	Passive Trackers
ATs	Active Trackers
SAST	Single Axis Solar Tracker
DAST	Double Axis Solar Tracker
LDR	Light Dependent Resistor

CHAPTER 1 INTRODUCTION

1.1 Background

When it comes to the development of any nation, energy is the main driving factor. There is an enormous quantity of energy that gets extracted, distributed, converted and consumed every single day in the global society. The world population is increasing day by day and the demand for energy is increasing accordingly. Oil and coal are the main source of energy nowadays but there is a fact that the fossil fuels are limited and hand strong pollution. Even the price of petroleum has been increasing year by year and the previsions on the medium term there are not quite encouraging. Utilization of this resources increases the emission of carbon monoxide (CO), hydrogen chloride (HCL), Nitrogen Oxides, and Sulphur Oxides which are responsible for the global warming and greenhouse effect. This results the devastating effect in the environment.

With the view point of minimizing above mentioned problems, many researched have been carried since late 19th century by researchers and engineers. Renewable energy sources as an alternative to fossil fuel were the major found out. They are derived from natural processes that are replenished constantly. Renewable energies are inexhaustible and clean. The energy comes from natural resources such as sun, wind, tides, waves, and geothermal heat. Solar energy is quite simply the energy produced directly by the sun. The history of solar energy is as old as humankind. In general, solar energy is radiant light and heat from the sun harnessed using a range of technologies such as photovoltaic and concentrator. In the last two centuries, we started using Sun's energy directly to make electricity.

In 1839, Alexandre Edmond Becquerel discovered that certain materials produced small amounts of electric current when exposed to light. In 1876, When William Grylls Adams and his student, Richard Evans Day, discovered that an electrical current could be started in selenium solely by exposing it to light, they felt confident that they had discovered something completely new. [1] Werner von Siemens, a contemporary whose reputation in the field of electricity ranked him alongside Thomas Edison, called the discovery “scientifically of the most far-reaching importance.” This pioneering work portended quantum mechanics long before most chemists and physicist had accepted the reality of atoms. Although selenium solar cells failed to convert enough sunlight to power electrical equipment, they proved that a solid material could change light into electricity without heat or any moving parts. Later in 1905 Albert Einstein published the first theoretical work describing the photovoltaic effect titled "Concerning a Heuristic Point of View Toward the Emission and Transformation of Light." In the paper, he showed that light possesses an attribute that earlier scientists had not recognized. Light, Einstein discovered, contains packets of energy, which he called light quanta. Einstein's bold and novel description of light, combined with the [1898] discovery of the electron, gave scientists in the second decade of the twentieth century a better understanding of photo electricity. They saw that the more powerful photons carry enough energy to knock poorly linked electrons from their atomic orbits in materials like selenium. When wires are attached, the liberated electrons flow through them as electricity. By the 1920s, scientists referred to the phenomenon as the "photovoltaic effect." In 1953, Bell Laboratories (now AT&T labs) scientists Gerald Pearson, Daryl Chapin and Calvin Fuller developed the first silicon solar cell capable of generating a measurable electric current. The New York Times reported the discovery as "the beginning of a new era, leading eventually to the realization of harnessing the almost limitless energy of the sun for the uses of civilization [2]. After years of experiments to improve the efficiency and commercialization of solar power, solar energy gained support when the government used it to power space exploration equipment in 1958. The first solar-powered satellite, Vanguard 1, has traveled more than 197,000 revolutions around Earth in the 50 years. Consequently, in 1982 and 1985 first solar parks and retractable RV solar panels are created respectively. In 1994, the National Renewable Energy Laboratory developed a new solar cell from gallium indium phosphide and gallium arsenide that exceeded 30% conversion efficiency. By the end of the century, the laboratory created thin-film solar cells that converted 32% of the sunlight it collected into usable energy [3] Due to dedicated research worldwide, the efficiency of photovoltaics has continued to increase while production costs have also dropped substantially over the years.

A solar cell (also called a photovoltaic cell) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. A solar panel is a set of solar photovoltaic modules electrically connected and mounted on a supporting structure. The layer of solar module is shown in Figure 1 [4]

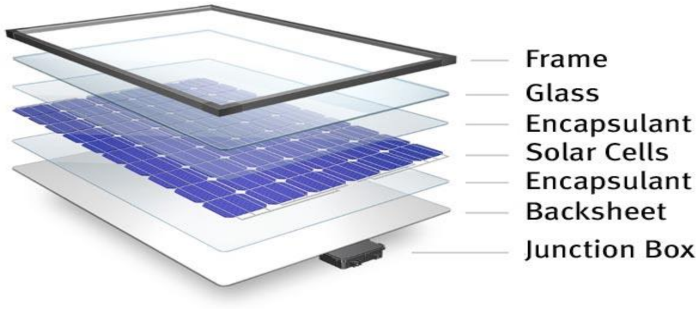


Figure 1**:** Layers of solar PV module

The majority of modules use wafer based crystalline silicon cells or thin-film cells based on cadmium telluride or silicon. The structural member of a module can either be the top layer or the back layer. Electrical connections are made in series to achieve a desired output voltage and in parallel to provide a desired current capability. Several types of solar cells are available. Monocrystalline Solar Cells, Polycrystalline Solar Cells, Amorphous Silicon (a-Si) Solar Cells, Cadmium Telluride (CdTe) Solar Cells. Their efficiency is 24.5% on the higher side [5]. Three ways of increasing the efficiency of the solar panels are through increase of cell efficiency, maximizing the power output and the use of a tracking system.

Maximum power point tracking (MPPT) is the process of maximizing the power output from the solar panel by keeping its operation on the knee point of P-V characteristics. MPPT technology will only offer maximum power which can be received from stationary arrays of solar panels at any given time [6]. Automatic solar tracker increases the efficiency of the solar panel by keeping the solar panel aligned with the rotating sun. Solar tracking is a mechanized system to track the sun’s position that increases power output of solar panel 30% to 60% than the stationary system. [7]

S. Shanmugam et al. had given the tracking of the sun for solar paraboloid dish concentrators in 2005. Rong-Jong Wai et al. had given grid connected photovoltaic (PV) generation system with an adaptive step-perturbation (ASP) method and an active sun tracking scheme in 2006. Cemil Sungur had given the electromechanical control system of a photovoltaic (PV) panel tracking the sun on the axis it moved along according to its azimuth angle in 2007. The elevation angle of the sun be in the same place almost invariant in a month and varies little (latitude ± 10°) in a year. Therefore, a single axis position control scheme may be enough for the collection of solar energy in some applications (Konar and Mandal, 1991. Yeong-Chau, et al., 2001. Wilamowski and Xiangli, 2002). The change in sun's position is monitored, and the system always keeps that the plane of the panel is normal to the direction of the sun. A few design methodologies of solar tracking system have been proposed in recent days. [8]

1.2 Solar energy distribution in global context

The global solar energy market has enjoyed growth at an exceptional rate over the recent years, facilitated by the rising solar power output from world's top solar energy producing countries**.** With the growing demand for alternative and eco-friendly energy that significantly reduces carbon emissions around the world, many major countries have been rapidly increasing the capacity of their solar power facilities and other renewable energy installations over the past few years. While the global solar energy market continues to surge, the world's top solar energy producing countries, including China, Japan, Germany and the USA are expected to maintain their leadership in global solar energy capacity in the future.

Within global renewable energy installations, solar power plants have enjoyed the fastest growth in volume over the past few years. Thanks to the vast availability and certainty of sunlight, solar power projects have outperformed other forms of renewable energy sources such as wind and geothermal. Moreover, with the advancements in technologies, including concentrated solar power generation techniques, and a decline in prices of PV modules, solar energy has become the most cost-effective source of renewable energy. [9]

According to the report from BP, total solar PV power generating capacity reached 301 GW by the end of 2016, representing a 33.2% increase from 2015. A total 75 GW of new installations were added to the global solar energy capacity in 2016. The largest increments in 2016 were recorded in China (34.5 GW) and the US (14.7 GW), together accounting for two-thirds of the growth in global solar capacity. Japan provided the third largest addition (8.6 GW). China also leads in terms of cumulative installed capacity (78.1 GW), with more than a quarter of the global total. Japan (42.8 GW) moved past Germany (41.3 GW) to take second place, with the US (40.3 GW) now close behind Germany. [10]

Table 1: Solar energy production by country

Rank	Country	Total Capacity GW, 2016
1	China	78.07
2	Japan	42.75
3	Germany	41.22
4	United States	40.3
5	Italy	19.28
6	United Kingdom	11.63
7	India	9.01
8	France	7.13
9	Australia	5.9
10	Spain	5.49

1.3 Solar energy in the context of Nepal

In the context of Nepal, energy sources have been categorized under three broad types (i) traditional, (ii) commercial and (iii) alternative energy sources. Alternative energy is synonymous with new, renewable and non-conventional forms of energy. Traditional source of energy includes biomass fuels particularly fuel wood, agricultural residues and animal dung used in the traditional way, which is direct combustion. Commercial sources of energy are fossil fuels and electricity. Alternative source which can generate power by exploiting the locally available energy resources, are: hydropower (micro & pico-hydro, small hydro, large hydro), biomass related biogas, briquettes, gasifier, liquid bio-fuel, Improved Cooking Stove (ICS) , solar photovoltaic, solar thermal and wind powered plants. [11] Statically, in Fiscal Year(FY) 2016/17, the proportion of traditional, commercial and renewable energy consumption in the total energy consumption was 74.5 %, 22.0 % and 3.5 %. While in the first eight months of the current FY 2017/18, this proportion is 68.9 %, 27.9 % and 3.2 % respectively as shown in Figure 1. [12] So we can say that Nepal's energy mix is characterized by the dominance of traditional sources, followed by commercial and renewable.

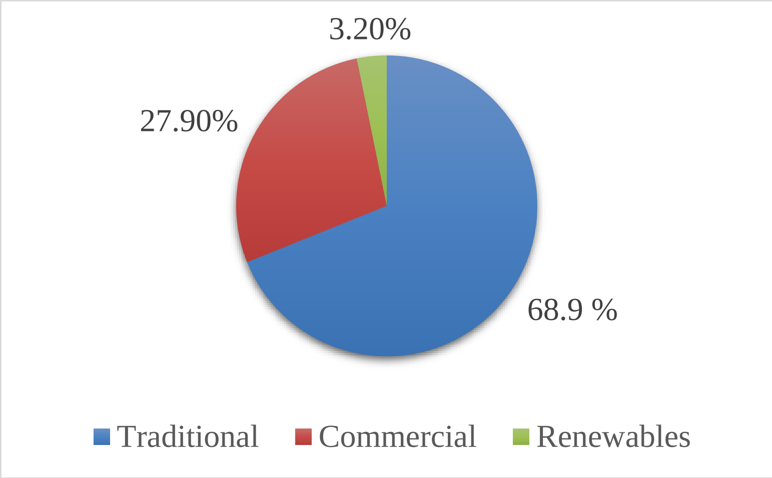


Figure 2**:** Percentage composition of energy in Nepal

Among above mentioned technologies, micro-hydro (below 100 kW), biogas, ICS, solar photovoltaic home systems, and solar water heaters are becoming popular and are at varying stages of commercialization.

When it comes to solar energy, Nepal, being located in favorable latitude, receives ample solar radiation. It's hard to say from when use of solar energy started for specific purpose but traditionally used for drying such things as crops, clothes, fuel wood, and crop residues and still in use. Today there are basically two major applications of solar energy: thermal and electrical.

Solar water heaters and solar dryers are the two main types of solar thermal devices used under thermal application. Of these, solar water heaters are popular in Hilly and Terai region. While nationwide survey revealed that three types of solar drying systems were in common use: cabinet type for domestic use, racks type for commercial, and tunnel type for industrial purposes [13]. The other uses of solar energy are for water pumping for drip irrigation and drinking, which appears to be technically and economically feasible. On the other hand, the solar cooking is not effective because of the trends, and traditional eating and cooking habits using food cooked with kerosene and biomass products. [14]

Nepal's theoretical hydropower potential has been estimated at about 83,000 MW and its technically and economically feasible potential of about 42,000 MW. [15] Nepal started hydropower in back 1911, but today in 2018, we are able to generate only 1044.6 MW. While the energy demand is 1508.2 MW. So, by the first eight months of the current FY 2017/18, 1,834 GW hours of electricity is imported from India in order to reduce the load shedding. [12] In the real practice the energy sources are limited in one hand and on the other hand 1.35 % of population growth rate in Nepal creates further pressure on extra energy demand. So solar PV should be developed as an alternative to hydropower. As on average, Nepal has 6.8 sunshine hours per day with the intensity of solar radiation ranging from $3.9 - 5.1\ kWh/\ m^2 day$, and the sun shines for about 300 days a year. Using PV module of 12% efficiency, total energy generated will be $0.12\ \times 5.5\ kWh/day \times 147{,}181 \times 10^6 m^2$ =$97{,}139 GWh/day$ (assuming peak sun to be 5.5 hours). This energy generated is more than energy required for fulfilling the whole energy demand of the world. The total estimated world energy demand at present is about 13TW. If we use just 0.01% of the total area of Nepal, we can generate solar electricity of 9.7 GWh/day that is 3540.5 GWh/year (which is more than the energy generated by NEA in the FY 2013/2014 amounting 2283 GWh/year). [16]

Progress of renewable energy started when Alternative Energy Promotion Centre (AEPC) is established on November 3, 1996 under the Ministry of Science and Technology with the objective of developing and promoting alternative energy technologies in Nepal as governmental institution. Currently, it is under the Ministry of Energy, Water Resources and Irrigation. The mission of AEPC is to make renewable energy mainstream resource through increased access, knowledge and adaptability contributing to the improved living conditions of people in Nepal. [17] While measurements and quality control of renewable energy products, components and systems are done by Renewable Energy Test Station (RETS), an autonomous body governed by "renewable energy test station rules 2063" framed under clause 31 of Nepal Academy of Science and Technology (NAST) Act 2048. It was formally established in July 2001 with mutual collaboration of Nepal Academy of Science and Technology (NAST), AEPC, Energy Sector Assistance Program (ESAP), Nepal Bureau of Standards and Metrology (NBSM) and Solar Electric Manufacturers Association of Nepal (SEMAN). [18] In more specific, Nepal Photovoltaic Quality Assurance (NEPQA) specifies the documents and technical requirements of the components used in PV applications. Based on this document, the RETS will test and certify the quality of the PV systems and components used in PV applications. [19]

While commercially it is handled by SEMAN, an umbrella organization of Nepalese Solar Photovoltaic System Manufacturing Companies.
In Nepal, solar PV systems can be categorized into four types based on their application areas: solar home systems (SHS), solar lantern, community solar PV systems and institutional solar PV system. Currently over 600,000 household solar home systems with capacity of 10–40 Wp. Majority of SHS are installed in Mid-Western Region. Solar lantern popularly known as Solar Tuki or Tukimara has module size between 2.5 and 10 Wp. A popular version of Solar Tuki, which is commonly used in rural areas for lighting purpose consist of 3 Wp and two WLED lamps of 0.4 Wp. Over 100,000 solar lanterns have been installed by AEPC so far. Even individual solar PV panel between from 130 Wp and 40 kWp are used for solar PV powered water pumping system, especially for drinking water and irrigation purposes for community in Nepal. Also, about 500 solar PV systems have been installed of capacity between 34 Wp and 6.5 kWp in schools, health centers, religious buildings, government buildings, communication, etc. The majority of these systems were installed in the mid and far-western regions. Installment of PV in different area has been increasing at the rate of 20 percent every year. With the advancement of technology, per watt cost of solar energy has come down to US$ 2 from $8. [20] Stating that the solar energy is getting cheaper the NEA is gearing up to revise the power purchase rates for new solar projects. Even NEA is aiming for an energy mix of 85:15, in which 85 per cent of the energy is generated through hydropower and 15 per cent through solar projects. [21] Recently, the government had laid the foundation stone for the construction of 25MW solar plant at Devighat Hydropower Station in Nuwakot-which till date was Nepal’s largest solar power plant at a single location. The government has targeted to complete the project within a year and build solar plants with a total installed capacity of 500 MW within the next five years. [22] So, the thing is many countries in the world have done very well in developing alternative energy sources, and Nepal can learn from them. A combination of political will, investments in renewable technologies and solid legal framework, however, is a must.

1.4 Statement of Problems

The main goal is to keep solar PV panel perpendicular to the sun throughout the day in order to increase the energy generation. Dual axis solar tracking system can be an effective way to increase the efficiency of solar cells. The devastating problem on both biotic and abiotic components of our home (i.e. pollution) can be reduced by using solar energy as the major source for power generation. The natural gift like fossil fuels, woods, etc. which are limited in amount can be saved from crisis and extinction. For people, due to its more efficiency and less harmful impacts dual axis solar tracking system might be good decision for the intermediate future. So, this project can practically demonstrate effect of this variation to people.

1.5 Objectives

1.5.1 Specific Objectives

i. To design and fabricate a dual axis PV system that tracks the sun path.

1.5.2 General Objectives

i. To study different solar parameters and methods of harvesting solar energy.
ii. To understand the working mechanism of PV module and tracking system.

1.6 Significances

- Solar tracking systems continually orient photovoltaic panels towards the sun and can help maximize your investment in PV system.
- One-time investment which provides higher efficiency and flexibility on dependency.
- Energy production is an optimum and energy output is increased year around.

1.7 Limitations

- The reading taken will be compromised by the weather.
- The readings and tracking system are as good as the calibration of low-cost materials to be used in the system.

CHAPTER 2 METHODOLOGY

2.1 Theoretical Framework

Solar panel is mainly made from semiconductor materials. Si used as the major component of solar panels, which is maximum 24.5% efficient. Unless highly efficient solar panels are invented, the only way to enhance the performance of a solar panel is to increase the intensity of light falling on it. Three ways of increasing the efficiency of the solar panels are through increase of cell efficiency, maximizing the power output and the use of a tracking system. MPPT technology will only offer maximum power which can be received from stationary arrays of solar panels at any given time. The technology cannot however increase generation of power when the sun is not aligned with the system. Because the position of the sun changes during the course of the day and season over the year. So, the implementation of a solar tracker is the best solution to increase energy production. Solar tracking is a system that is mechanized to track the position of the sun and align perpendicular to increase power output by between 30% and 60% than systems that are stationary. [7] It is a more cost-effective solution than the purchase of solar panels. Some researchers have conducted various studies to establish the optimal degree of tilt of a solar panel to increase the output power. Currently, there are two main types of solar trackers: the one axis and two axes.

(a) (b)

Figure 3: (a) Schematic diagram of single-axis solar tracker (b) Schematic diagram of double-axis solar tracker

Single-axis trackers have only one axis of movement as shown in Fig 3 [23], usually aligned with North and South. This allows the panels to arc from east to west, tracking the sun as it rises, travels across the sky, and sets. Dual-axis trackers have two degrees of freedom as shown in Fig 4 [23], that act as axes of rotation, aligned with North-South and with East-West, giving them a wide range of position options. When seasons changes, the sun's path goes from low in the sky in winter too high in the sky in summer as shown in figure 5 [24] . So, in order to accurately follow the sun, the two-axis tracking is required as solar azimuth angle as well as solar altitude angle of sun varies (in two axis) all the time [23]. This optimizes maximum power from the PV system over a day than non-tracking system.

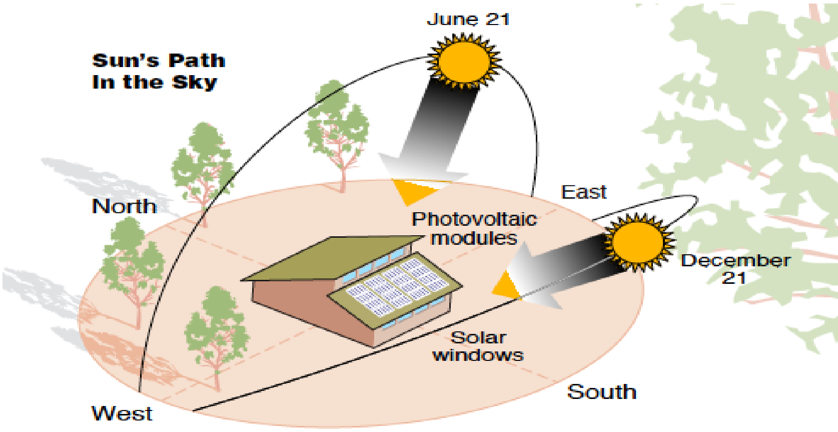


Figure 4 :Variation in trajectory of sun from winter to summer

The dual axis tracking system is uniquely designed on sensor-based technology avoiding the need for manual programming time to time. The major components of the system are:

1. PV module
2. Servo motors
3. Light sensors
4. Arduino UNO
5. Battery
6. Inverter
7. AC or DC loads
8. Halogen light

System consists of two portion mechanical and electrical system. In mechanical system, a solar panel is fitted in support, motor and shaft. While the electrical system consists of Sensors, microcontroller and battery. Four sensors detect the intensity of light, which are further connected to the microcontroller circuit (Arduino). Then microcontroller sends the signal to the servo motors for the direction of sun. Then the combined mechanism of motors and shaft rotates the PV panel in the direction of the sun. Here the microcontroller and motors are operated through the external battery. The flow chart of the whole system is shown in Fig 5. [25]

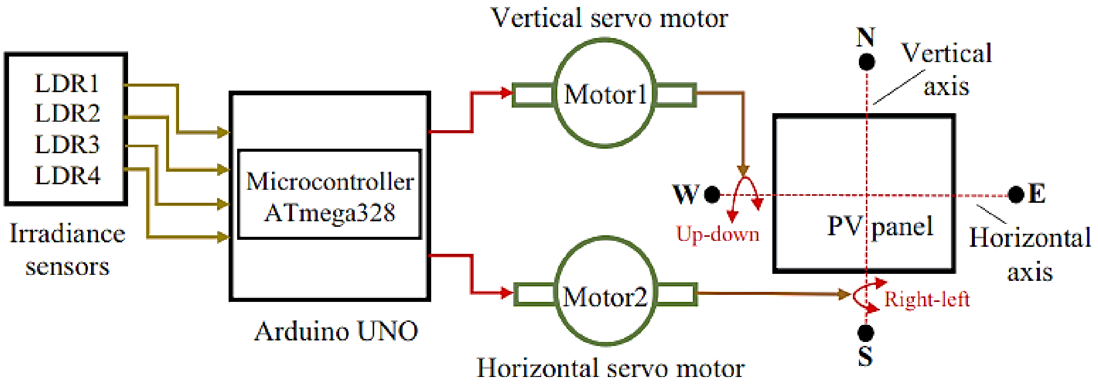


Figure 5: Simple flow chart of tracking system with components

2.1 Study Design

The project is designed and fabricated using following strategic approaches.

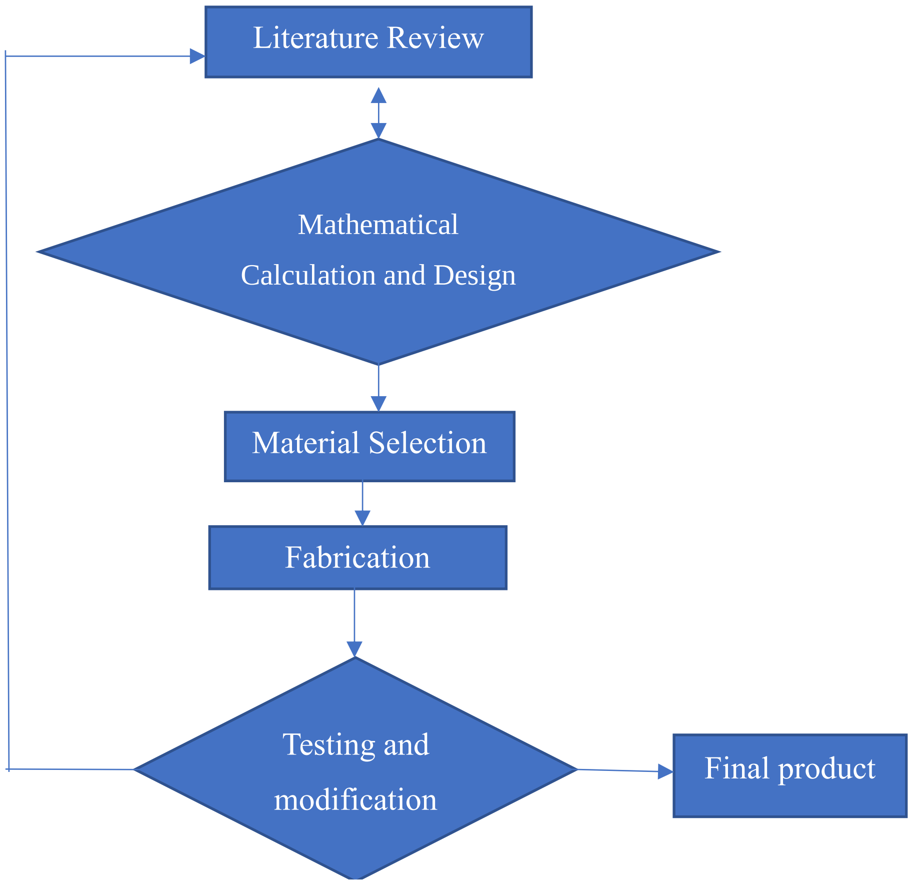


Figure 6: Study design Process

2.1.1 Literature Review

2.1.1.1 Thermal Application of Solar Energy

As we know that the sun produces both heat and light energy in the form of electromagnetic radiation. When it comes to thermal use, it is mainly used for water heating and heat sources to different types of concentrator for various heat application. This are discussed below:

1) WATER HEATER

Solar water heaters also called solar domestic hot water systems, can be a cost-effective way to generate hot water for your home. They can be used in any climate, and the fuel they use: sunshine, is free.

Working of solar water heating systems include storage tanks and solar collectors. There are two types of solar water heating systems: active, which have circulating pumps and controls, and passive, which don't.

i. Active solar water heating systems

Active systems use one or more pumps to circulate water and/or heating fluid in the system. Though slightly more expensive, active systems offer several advantages. There are two types of active solar water heating systems:

- **Direct circulation systems**

Pumps circulate household water through the collectors and into the home. They work well in climates where it rarely freezes.

- **Indirect circulation systems**

Pumps circulate a non-freezing, heat-transfer fluid through the collectors and a heat exchanger. This heats the water that then flows into the home. They are popular in climates prone to freezing temperatures.

ii. Passive solar water heating systems

Passive solar water heating systems are typically less expensive than active systems, but they're usually not as efficient. However, passive systems can be more reliable and may last longer. There are two basic types of passive systems:

- **Integral collector-storage passive systems**

These work best in areas where temperatures rarely fall below freezing. They also work well in households with significant daytime and evening hot-water needs.

- **Thermosyphon systems**

Water flows through the system when warm water rises as cooler water sinks. The collector must be installed below the storage tank so that warm water will rise into the tank. These systems are reliable, but contractors must pay careful attention to the roof design because of the heavy storage tank. They are usually more expensive than integral collector-storage passive systems. [26]

2) SOLAR CONCENTRATOR

As the maximum temperature of a normal place can vary from 20-40 ℃. But we may need higher temperature for different heating purpose. So, various types of concentrator are designed to generate a required amount of heat and temperature in a surface. Different types of concentrator with their temperature production and principle of operation are shown in table.

Table 2: Types of concentrator

Type of Collector	Temperature of working fluid	Principle of Collection
Flat plate	Low temperature around 150°C	Radiation received by the surface without focusing.
Parabolic trough type with line focus	Moderate temperature around 300°C	Parabolic through shaped mirrors reflect the beam radiation on axial pipe.
Paraboloid dish with point focus	High temperature around 500°C	Paraboloid dish shaped reflectors focus the reflected rays on the focus point.
Fresnel lens with center focus	High temperature around 500°C or higher	Lens focus the light at the central point.
Heliostats with central receiver focusing	High temperature 1200°C	Several nearly flat mirrors on ground reflect the beam radiation on a central receiver on a tall tower.

2.1.1.2 Electrical Application of Solar Energy

Today the measure concern about the solar energy is production of electricity from it with the help of PV cells or solar cells. Different types of solar cells are developed and developing to increase their efficiency. Different parameters regarding photovoltaic module are described below:

1) PV CELLS

A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials

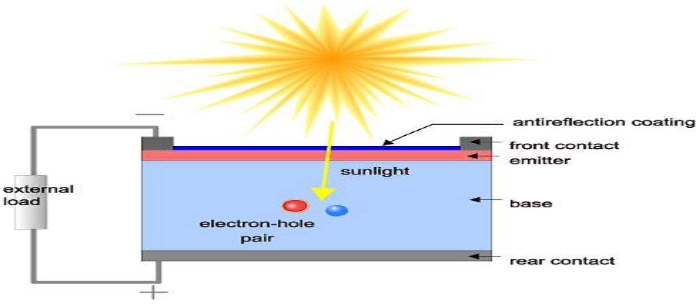


Figure 7: Photo electric effect in PV cell

in the form of a *p-n* junction. The basic working can be seen from the fig 7. [27]

The basic steps in the operation of a solar cell are:

- the generation of light-generated carriers;
- the collection of the light-generated carries to generate a current;
- the generation of a large voltage across the solar cell; and
- the dissipation of power in the load and in parasitic resistances.

The generation of current in a solar cell, known as the "light-generated current", involves two key processes. The first process is the absorption of incident photons to create electron-hole pairs. Electron-hole pairs will be generated in the solar cell provided that the incident photon has an energy greater than that of the band gap. However, electrons (in the p-type material), and holes (in the n-type material) are meta-stable and will only exist, on average, for a length of time equal to the minority carrier lifetime before they recombine. If the carrier recombines, then the light-generated electron-hole pair is lost and no current or power can be generated.

A second process, the collection of these carriers by the p-n junction, prevents this recombination by using a p-n junction to spatially separate the electron and the hole. The carriers are separated by the action of the electric field existing at the p-n junction. If the light-generated minority carrier reaches the p-n junction, it is swept across the junction by the electric field at the junction, where it is now a majority carrier. If the emitter and base of the solar cell are connected together (i.e., if the solar cell is short-circuited), the light-generated carriers flow through the external circuit. The ideal short circuit flow of electrons and holes at a *p-n* junction. Minority carriers cannot cross a semiconductor-metal boundary and to prevent recombination they must be collected by the junction if they are to contribute to current flow.

The collection of light-generated carriers does not by itself give rise to power generation. In order to generate power, a voltage must be generated as well as a current. Voltage is generated in a solar cell by a process known as the "photovoltaic effect". The collection of light-generated carriers by the *p-n* junction causes a movement of electrons to the *n*-type side and holes to the *p*-type side of the junction. Under short circuit conditions, there is no buildup of charge, as the carriers exit the device as light-generated current.

However, if the light-generated carriers are prevented from leaving the solar cell, then the collection of light-generated carriers causes an increase in the number of electrons on the *n*-type side of the *p-n* junction and a similar increase in holes in the *p*-type material. This separation of charge creates an electric field at the junction which is in opposition to that already existing at the junction, thereby reducing the net electric field. Since the electric field represents a barrier to the flow of the forward bias diffusion current, the reduction of the electric field increases the diffusion current. A new equilibrium is reached in which a voltage exists across the *p-n* junction. The current from the solar cell is the difference between I_L and the forward bias current. Under open circuit conditions, the forward bias of the junction increases to a point where the light-generated current is exactly balanced by the forward bias diffusion current, and the net current is zero. The voltage required to cause these two currents to balance is called the "open-circuit voltage".

2) I-V CURVE

The IV curve of a solar cell is the superposition of the IV curve of the solar cell diode in the dark with the light-generated current. The light has the effect of shifting the IV curve down into the fourth quadrant where power can be extracted from the diode. Illuminating a cell adds to the normal "dark" currents in the diode so that the diode law becomes:

$$I = I_0\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] - I_L$$

where I_L = light generated current.

Without the illumination, a solar cell has the same electrical characteristics as a large diode. When the light shines on the cell, the I-V curve shifts as the cell begins to generate power. Fig 8 shows the IV- curve of solar cell. [27]

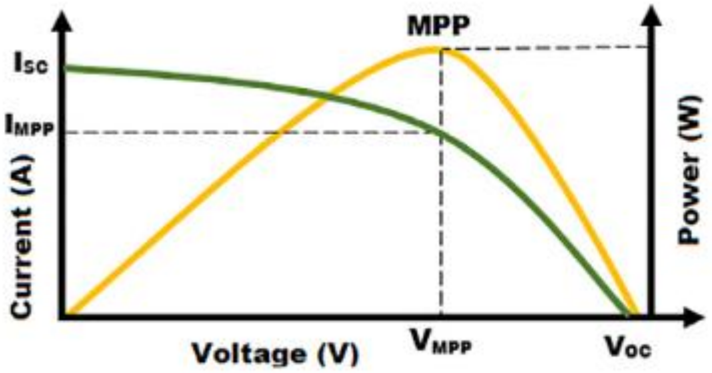


Figure 8: I-V curve of solar cells

Several important parameters which are used to characterize solar cells are discussed below:

i. **Short-circuit current**

The short-circuit current is the current through the solar cell when the voltage across the solar cell is zero (i.e., when the solar cell is short circuited). Usually written as I_{SC}, the short-circuit current. The short-circuit current is due to the generation and collection of light-generated carriers and it is the largest current which may be drawn from the solar cell.

ii. **Open-circuit voltage**

The open-circuit voltage, V_{oc}, is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current. V_{oc} depends on the saturation current of the solar cell and the light-generated current.

iii. Maximum power point (P_m)

It is the maximum power that a solar cell produces under STC. The higher the P_m, the better is the cell. It is measured in watts. A solar cell can operate at many current and voltage combinations, but a solar cell will produce maximum power only when operating at certain current and voltage.

$$P_m = I_m \times V_m$$

iv. Current at maximum power point (I_m)

This is the current which solar cell will produce when operating at maximum power point. The I_m is always lesser than $I_{SC.}$

v. Voltage at maximum power point (V_m)

This is the voltage which solar cell will produce when operating at maximum power point. The V_m is always less than $V_{OC.}$

vi. Fill Factor (FF)

The "fill factor", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}. Graphically, the FF is a measure of the "squareness" of the solar cell and is also the area of the largest rectangle which will fit in the IV curve. Mathematically,

$$FF = \frac{\mathrm{Im \times Vm}}{\mathrm{Isc \times Vsc}} = \frac{Pm}{Isc \times Voc}$$

vii. Solar cell efficiency

Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another. Terrestrial solar cells are measured under AM 1.5 conditions and at a temperature of 25°C. The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{max} = V_{OC} I_{SC} FF$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

Where:

V_{oc} is the open-circuit voltage

I_{sc} is the short-circuit current

FF is the fill factor and

η is the efficiency

3) A MODULE CIRCUIT DESIGN

A bulk silicon PV module consists of multiple individual solar cells connected, nearly always in series, to increase the power and voltage above that from a single solar cell. The voltage of a PV module is usually chosen to be compatible with a 12V battery. An individual silicon solar cell has a voltage of just under 0.6V under 25 °C and AM1.5 illuminations. Taking into account an expected reduction in PV module voltage due to temperature and the fact that a battery may require voltages of 15V or more to charge, most modules contain 36 solar cells in series. This gives an open-circuit voltage of about 21V under standard test conditions, and an operating voltage at maximum power and operating temperature of about 17 or 18V. The remaining excess voltage is included to account for voltage drops caused by other elements of the PV system, including operation away from maximum power point and reductions in light intensity. [27]

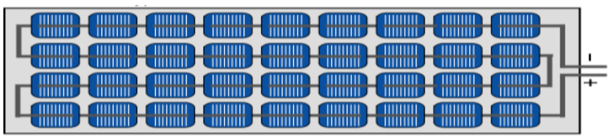


Figure 9: Pictorial view of PV panel

While the voltage from the PV module is determined by the number of solar cells, the current from the module depends primarily on the size of the solar cells and also on their efficiency. Also, we can connect cells in parallel for higher charging current.

Module are also being interconnected either in series or parallel to create what is refer to as an array. Array may consist of both series and parallel connection, which improves both the system voltage and charging current.

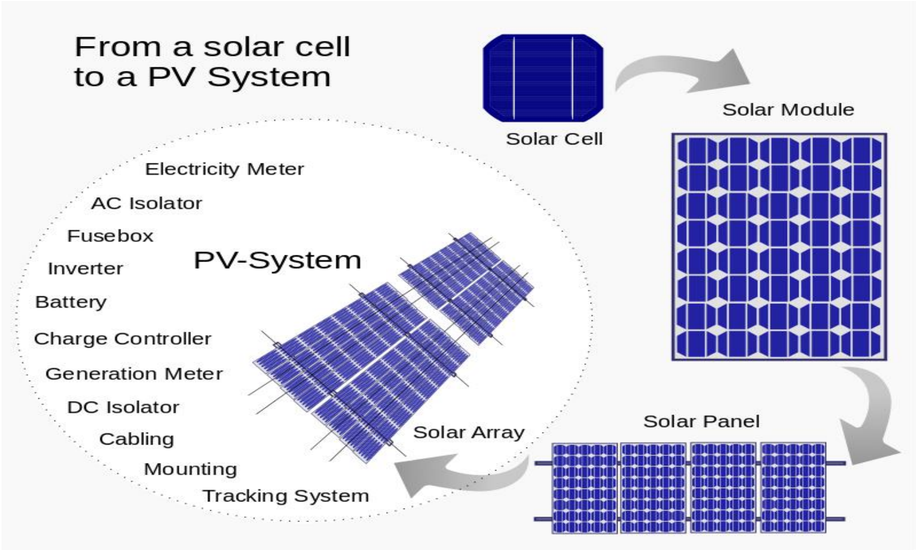


Figure 10: Pictorial representation from solar cell to solar array

2.1.1.3 Factors affecting the efficiency of solar cells

There are several factors which reduces the power from cell as follows:

a) Mismatch effect

Mismatch losses are caused by the interconnection of solar cells or modules which do not have identical properties or which experience different conditions from one another. Or when, electrical parameters of one solar cell are significantly altered from those of the remaining devices. This in turn can lead to highly localized power dissipation and the resultant local heating may cause irreversible damage to the module.

b) Effect of Temperature in PV module

An unwanted side-effect of the encapsulation of solar cells into a PV module is that the encapsulation alters the heat flow into and out of the PV module, thereby increasing the operating temperature of the PV module. These increases in temperature have a major impact on the PV module by reducing its voltage, thereby lowering the output power. In addition, increases in temperature are implicated in several failure or degradation modes of PV modules, as elevated temperatures increase stresses associated with thermal expansion and also increase degradation rates by a factor of about two for each 10°C increase in temperature. The operating temperature of a module is determined by the equilibrium between the heat produced by the PV module, the heat lost to the environment and the ambient operating temperature. The heat produced by the module depends on the operating point of the module, the optical properties of the module and solar cells, and the packing density of the solar cells in the PV module. While the heat is lost to surrounding by three main mechanisms of heat loss: conduction, convection and radiation.

2.1.1.4 Types of Solar PV modules

Solar PV modules or panels are generally classified according to the cell technology used to produce or manufacture them. On this basis there are three types of PV modules: [28]

a) Amorphous silicon (a-Si) PV module

The term amorphous literally means shapeless. The silicon used to make amorphous silicon cells is not structured or crystallized as in other types of PV modules. The solar cells are made up of one or several layers of photovoltaic material deposited onto a substrate. These panels are cheap and have an appealing look. However, they are bigger in size and therefore require a lot of space.

b) Monocrystalline silicon PV module

The solar cells used in this module are made from uniform silicon lattice cut out of a single crystal. They have high efficiency rates since they are made out of high-grade silicon. They are also smaller than amorphous silicon panels and therefore do not require a lot of space. However, they are the most expensive solar panels.

c) Polycrystalline silicon PV module

The solar cells used in this module are made from raw silicon, which is melted and poured into a square mould. Once cooled, it is cut into perfectly square wafers. This process makes these modules simpler and cheaper to produce than those in a monocrystalline module. However, polycrystalline modules have lower space efficiency. That is, you need to cover a wider surface to produce the same electrical power that you would with solar panels made of monocrystalline silicon.

Figure 11: Types of solar cells

d) Hybrid Cell

These types of cells are simply PV cells that use two different types of PV technology. For example, a hybrid cell could be composed of a monocrystalline PV cell covered by a layer of amorphous silicon. These cells generally perform well at high temperatures and have efficiencies exceeding 18%. However, these cells can be very expensive.

e) Other Types of Cells

The four types of cells listed above are the most commonly used solar cells, however there are many other types of cells that exist but are not used widely. There are many other kinds of thin film cells that are built using some material other than silicon. These cells include cadmium telluride (9-11% efficient), copper indium gallium selenide (sometimes known as CIGS, they are 10-12% efficient), and organic photovoltaic cells. However, the only cell that is as cost-efficient as silicon panels is currently the cadmium telluride cell. CIGS cells show the most promise in terms of efficiency in the future, and contain smaller amounts of toxic cadmium than other alternatives. Organic photovoltaics are simply photovoltaic cells that utilize inexpensive plastics and electronics that are made of conductive organic molecules. They are not widely used.

2.1.1.5 Components of PV system

a) Battery

A fundamental characteristic of a photovoltaic system is that power is produced only while sunlight is available. For systems in which the photovoltaics is the sole generation source, storage is typically needed. By far the most common type of storage is chemical storage, in the form of a battery, although in some cases other forms of storage can be used. Battery will store the energy produced by the PV array during the day and to supply it to electrical loads as needed (during the night and periods of cloudy weather). The measure of storing capacity or energy that can be stored in battery is called capacity of battery. It is measured in Ampere-hour (Ah). It is the number of hours that a battery can provide a current equal to the discharge rate at the nominal voltage of discharge rate at the nominal voltage of the battery (designed battery voltage). For example, 4000 mAh at 11.1V means the battery capacity is 4000 mAh x 11.1V = 44.4 Watt-hour (Wh). 4000 mAh at 14.8V means the battery capacity is 4000mAh x 14.8V = 59.2 Watt-hour (Wh). In any photovoltaic system that includes batteries, the batteries become a central component of the overall system which significantly affect the cost, maintenance requirements, reliability, and design of the photovoltaic system.

An ideal battery would be able to be charged and discharged indefinitely under arbitrary charging/discharging regimes, would have high efficiency, high energy density, low-self-discharge and be low cost. These are controlled not only by the initial choice of the battery but also by how it is used in the system, particularly how it is charged and discharged and its temperature. However, in practice, no battery can achieve the above set of requirements. During charging and discharging cycles, all battery parameter is affected. Battery state of charge (BSOC or SOC) gives the ratio of the amount of energy presently stored in the battery to the nominal rated capacity. For example, for a battery at 80% SOC and with a 500 Ah capacity, the energy stored in the battery is 400 Ah. A common way to measure the BSOC is to measure the voltage of the battery and compare this to the voltage of a fully charged battery. Also, in many types of batteries, the full energy stored in the battery cannot be withdrawn (in other words, the battery cannot be fully discharged) without causing serious, and often irreparable damage to the battery. The Depth of Discharge (DOD) of a battery determines the fraction of power that can be withdrawn from the battery. For example, a battery 500 Ah with a DOD of 20% can only provide 500Ah x .2 = 100 Ah.

There are basically two types of batteries: primary and secondary. Primary batteries are used only once and then disposed of since they are not rechargeable. For example: dry cells, wet cells, mercury cells, etc. While secondary batteries are electrically recharged after their use, in order to restore them to their original condition. Example: Lead acid battery, commonly used in motor vehicles and in solar home systems to provide light. They are of four types: the automotive type (starts the lights and ignition), industrial type (provides a continuous power supply), flooded type (need to top up the battery with distilled water) and the closed or sealed type (does not need any topping up). In most of battery, during discharging a chemical reaction between sulphuric acid and the load plates produces electricity to light the bulb. The acid decreases and the water increase. A finely divided amorphous form of lead sulphate ($PbSO_4$) is produced. While during charging, the acid increases and the water decreases. The lead sulphate deposits are converted back to lead, lead oxide and sulphuric acid, thus returning the battery to its former state.

b) Charge Controller

A charge controller is an essential part of nearly all power systems that charge batteries, whether the power source is PV cells, wind, hydro, fuel or utility grid. The charge controller connects the battery to the PV module for charging and also connects the load to the battery. Its main job is to protect and automate battery charging and discharging. It applies its high voltage disconnect switch (HVD) to stop over charging and low voltage disconnect (LVD) switch in case of over discharging. There are different types of charge controller available as below:

a) Shunt type charge controller
b) Series charge controller design
c) Pulse width modulation (PWM) charge controller
d) MPPT (Maximum Power Point Tracker) charge controller

c) Inverter

As we know that electricity generated from PV module is of DC type. So, in order to convert into AC, we need to connect an inverter. Inverter is an electrical device which converts DC current into AC current.

d) Loads

It includes any electrical appliances either AC or DC like bulb, TV, heaters, etc.

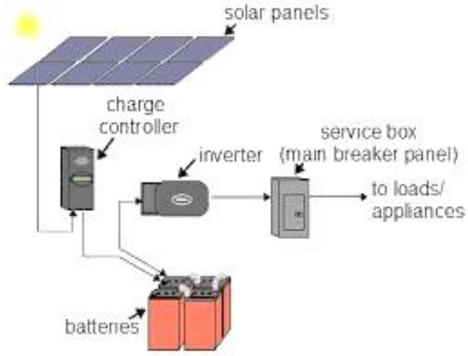


Figure 12: Solar design configuration

2.1.1.6 Rays Transmission from sun

Sun consists of about 73% of hydrogen, 25% of helium and about 2% of other elements (oxygen, carbon, nitrogen, etc.). The hydrogen in the sun is continuously going through the process of fusion reaction (four hydrogen atoms combine to give one heavy molecule of helium) releasing tremendous amount of energy, equivalent to the loss of mass in the process. The total power emitted by the sun is about $3.8 \times 10^{26}\ Watts$ which transmits in outer space in the form of electromagnetic waves. [27] As the radiation spreads out, becomes less intense when reaches just outside the earth's atmosphere. Because of large distance between them and by that time they are considered to be parallel. The calculated solar irradiance at the Earth's atmosphere is about $1.36\ kW/m^2$ also called solar constant. Although the Earth also receives electromagnetic energy from the other bodies in space, it's negligible, compared with solar energy. Now, when it enters through the earth's atmosphere it undergoes several interactions (absorption, reflection and scattering) with the gaseous molecules (CO_2, ozone and water vapours) and other particles in the atmosphere. From Fig 14, when radiation meets the atmosphere, 6% of the irradiation is reflected and 16% is absorbed. After passing through different gaseous molecules and other particles, its loss radiation and only about 51% reaches the earth's surface. Even, radiation is reflected towards the space from earth's surface, atmosphere and clouds by various means giving balance between incoming energy from the sun and the outgoing longwave (thermal) and reflected shortwave energy from the Earth. In this process, earth's plane receives following types of radiation:

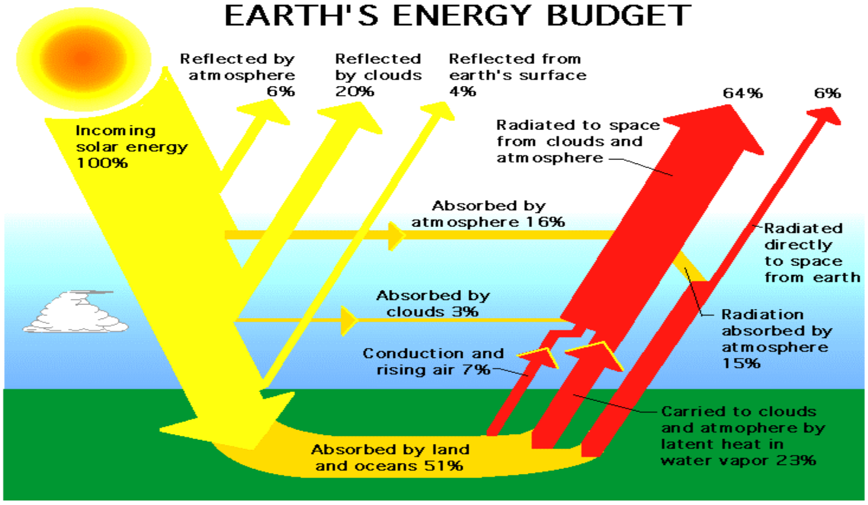


Figure 13: Earth's energy budget

- **Beam (or direct) radiation** – coming straight through the atmosphere to hit the plane (very directional);
- **Diffused radiation** – scattered in all direction in the atmosphere and then some arrives at the plane on the Earth's surface (not directional);
- **Reflected radiation** – beam and diffused radiation that hits the Earth's surface and is reflected onto the plane.

But, the radiation on a day will be affected by geographic location, time of day, season, local landscape and local weather.

2.1.1.7 Solar Angles

Zenith Angle, θz

This is the angle between the line that points to the sun and the vertical — basically, this is just where the sun is in the sky. At sunrise and sunset this angle is 90°.

Solar Altitude Angle, α_s

This is the angle between the line that points to the sun and the horizontal. It is the complement of the zenith angle. At sunrise and sunset this angle is 0º.

Solar Azimuth Angle, γ_s

This is the angle between the line that points to the sun and south. Angles to the east are negative. Angles to the west are positive. It is probably close to -90º at sunrise and 90º at sunset, depending on the season.

Angle of Incidence, θ

This is the angle between the line that points to the sun and the angle that points straight out of a PV panel (this is the line that is normal to the surface of the panel). This is the most important angle. Solar panels are the most efficient when pointing at the sun, so engineers want to minimize this angle at all times.

Hour Angle, ω

This is based on the sun's angular displacement, east or west, of the local meridian (the line the local time zone is based on).

Surface Azimuth Angle, γ

This is the angle between the line that points straight out of a PV panel and south. It is only measured in the horizontal plane. If a panel is pointed south, this angle would be 0º.

Declination, δ

This is the angle between the line that points to the sun from the equator and the line that points straight out from the equator (at solar noon). North is positive and south is negative. This angle varies from 23.45 to -23.45 throughout the year, which is related to why we have seasons.

Latitude, φ

This is the angle between a line that points from the center of the earth to a location on the earth's surface and a line that points from the center of the earth to the equator.

2.1.1.8 Solar Tracking System

Solar tracking systems are the best devices for maximizing the collected energy by the PV panel whose purpose is to keep the PV panel perpendicular to the incident solar radiation. The maximum power can be extracted from the PV panel when the tilt angle of the panel is synchronized with the daily and seasonal changes of the sun's motions. Many researchers have proven that solar trackers maximize the PV energy generation (10%- 50%).

Solar trackers can be classified, according to tracking mechanisms, into two main types: passive trackers (mechanical mechanism) and active trackers (electrical mechanism). Passive trackers (PTs) use compressed gas to move the panel. Depending on the difference in the falling sunlight on gas containers mounted on the eastern and western sides of the PV panel, a difference in gas pressure is created and then the tracker is moved until it reaches an equilibrium position. This tracking type is simple because it works without any electronic controls and motors. However, its accuracy is limited and it cannot operate at low temperature. On the other hand, active trackers (ATs) use electrical components to direct PV panels toward the sun. The advantage of these compared to PTs is that they have better tracking accuracy. ATs can be classified into two main categories according to their principle working: astronomical and sensor-based solar trackers. Astronomical solar trackers work based on approaches that calculate the sun's position from predefined geometric and astronomical equations. However, this tracking approach requires manual intervention to change the site's latitude, local date, and time zone. On the other side, sensor- based solar trackers widely use light sensors such as photo resistors (LDRs), photodiodes, solar cells, pyrometers to follow instantaneously sun's movement. The most commonly used sensors are LDRs in view of their simple circuit and very low price. These tracking systems use two or four LDR sensors, depending on the tracking structure (SAST or DAST). [25]

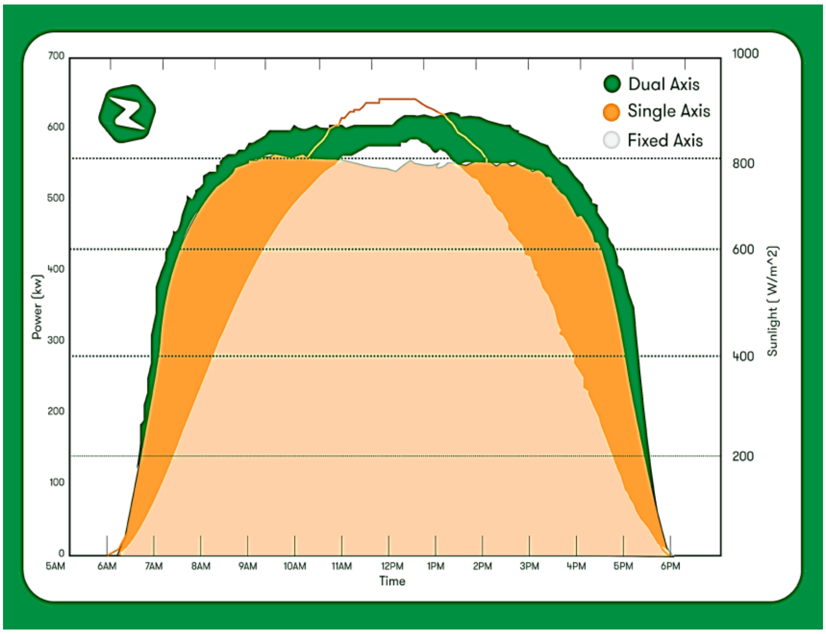


Figure 14: Power comparison of dual axis, single axis and fixed axis mode

In this project four LDRs are used as system is dual-axis tracking. They detect the sunbeam and provide return signals to a controller (microcontrollers, PLCs or others), which in turn aligns the panel via one or two motors perpendicularly with the high sunbeams. Since the LDR sensor circuit is designed as a voltage divider. Whenever the intensity of light on LDR changes, its resistance and hence the output voltage are changed; change in intensity is translated into a change in voltage. This system is mainly based on following a light source by orienting the PV panel, through two servo motors, optimally in the direction of sun's light rays. The motors are controlled based on the solar incidence measured by four LDRs, which were placed at the four PV panel's corners. Then the signal from LDRs is processed by microcontroller of the Arduino UNO board. Here, microcontroller converts the analogue value from LDRs to digital values and provides two output channels to control the rotation of PV panel through two servo motors. Then, the rotation movements occur in two axes: vertical and horizontal, from east to west (azimuth tracking) during the day and from south to north (elevation tracking) during the seasons. The variation in season can be analyzed with the help of given sun path's diagram in fig 15. [29]

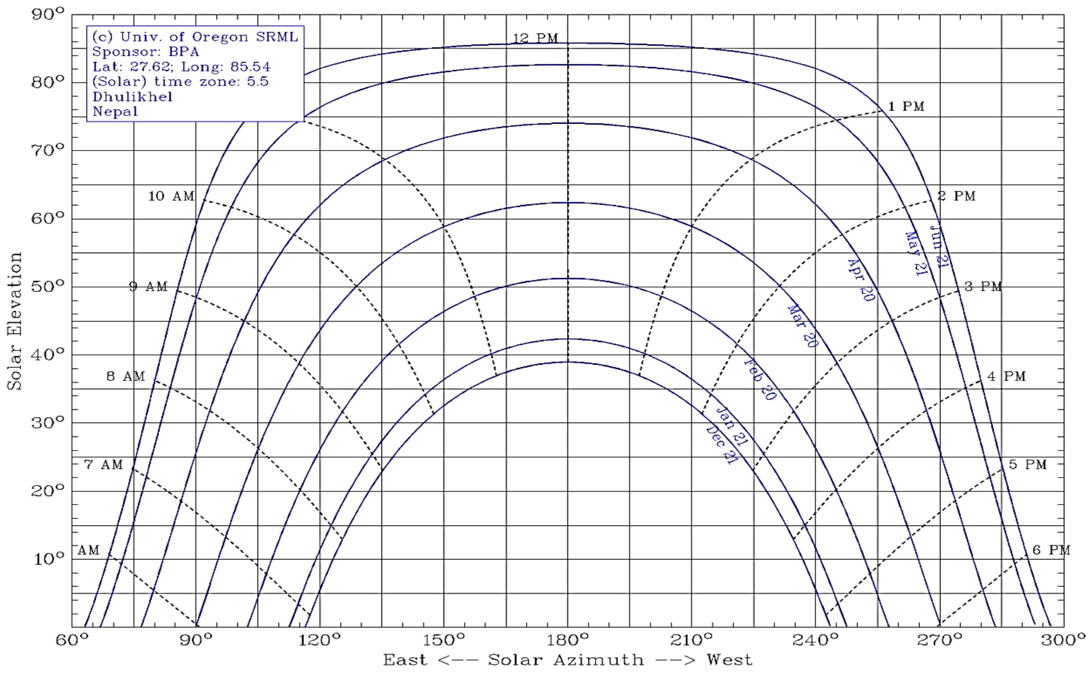


Figure 15: Sun path diagram for Dhulikhel

Here, we can see summer sun' path is largest for June 21 and shortest for Dec 21. Within a year seven different paths are traveled by sun. According to this path we can see the variation in sun rise time, sun set time and length of day. Also given figure clearly shows the variation in elevation of sun from winter solstice to summer solstice.

So, to demonstrate this variation a path will be created and source of light will be supplied with the help of halogen lamp. Tungsten halogen lamps are ideal light sources for spectrophotometers as they provide broadband spectral radiation ranging from the ultraviolet, through the visible and into the infrared out to five microns. In this project halogen lamp is used.

DC motors, stepper motors or servo motors are highly used in the solar tracking systems to motorize the PV panel. In this work, two 180° servo motors are used as shown in fig 15. A servo motor is able to wait for predetermined positions in the instructions given to it and then to maintain them, so it works in a closed loop. It consumes power when it turns to the desired position; otherwise, no energy is consumed. Whereas, stepper motors continue to consume energy to maintain the commanded position the advantage of the servo motor is that we can control its stop, run, the direction of rotation, and speed using a single low current wire connected directly to a PWM output of the microcontroller, there is no need of interface circuit. The used servo motors are controlled by the microcontroller of Arduino as shown in fig 16. [25]

Figure 16: MG996r servo motor

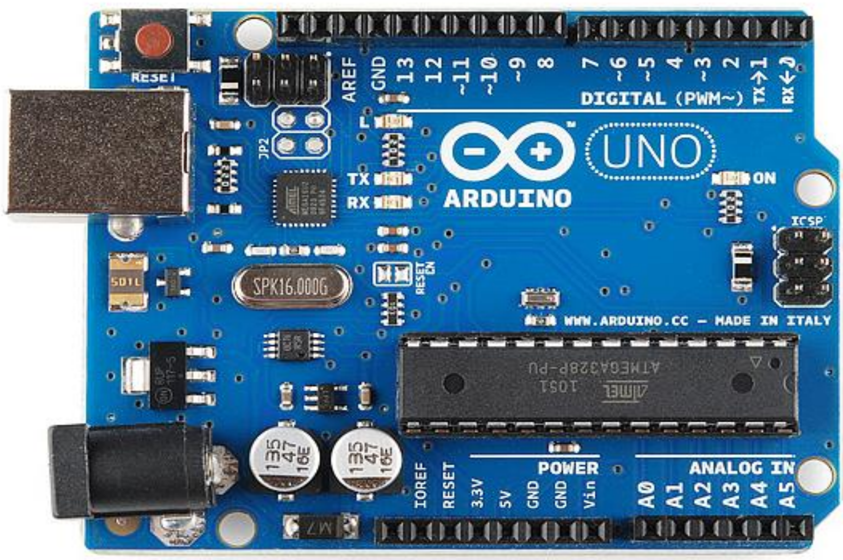


Figure 17: Arduino UNO

Under the following conditions, tracker decides the direction to be moved. [30]

- If light intensity on both LDRs is same, it means their resistance would be equal (R_E=R_W) and hence the same voltage to the controller; solar tracker will maintain its present position.

- If intensity on LDR_E is larger than intensity on LDR_W, the resistance of LDR_E will be lower than the resistance of LDR_W resulting in $V_E > V_W$; solar tracker will move toward the east.
- If intensity on LDR_W is larger than intensity on LDR_E, the resistance of LDR_W will be lower than the resistance of LDR_E resulting in $V_W > V_E$; solar tracker will move toward the west.

Based on the above-stated conditions, solar tracker flowchart is shown in Fig. The light intensity of east and west LDRs are com-pared and accordingly decision is made whether to move the panel in east or west direction. After proper orientation in the east–west direction, south-north orientation is checked and implemented. Each time the position of the sun is changed, the controller repeats the same flowchart algorithm and orients the panel in the sun's direction.

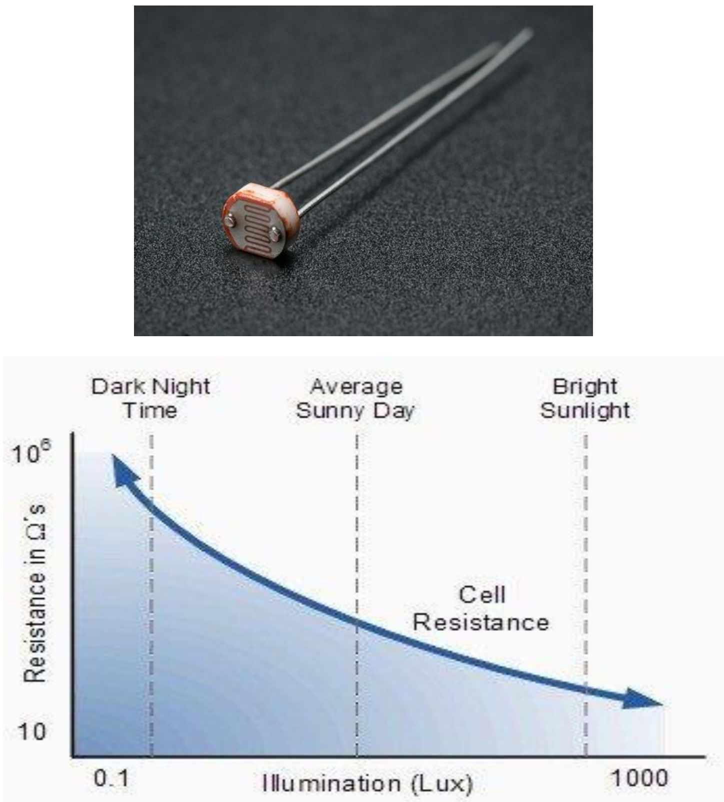


Figure 18: LDR and variation of resistance with light

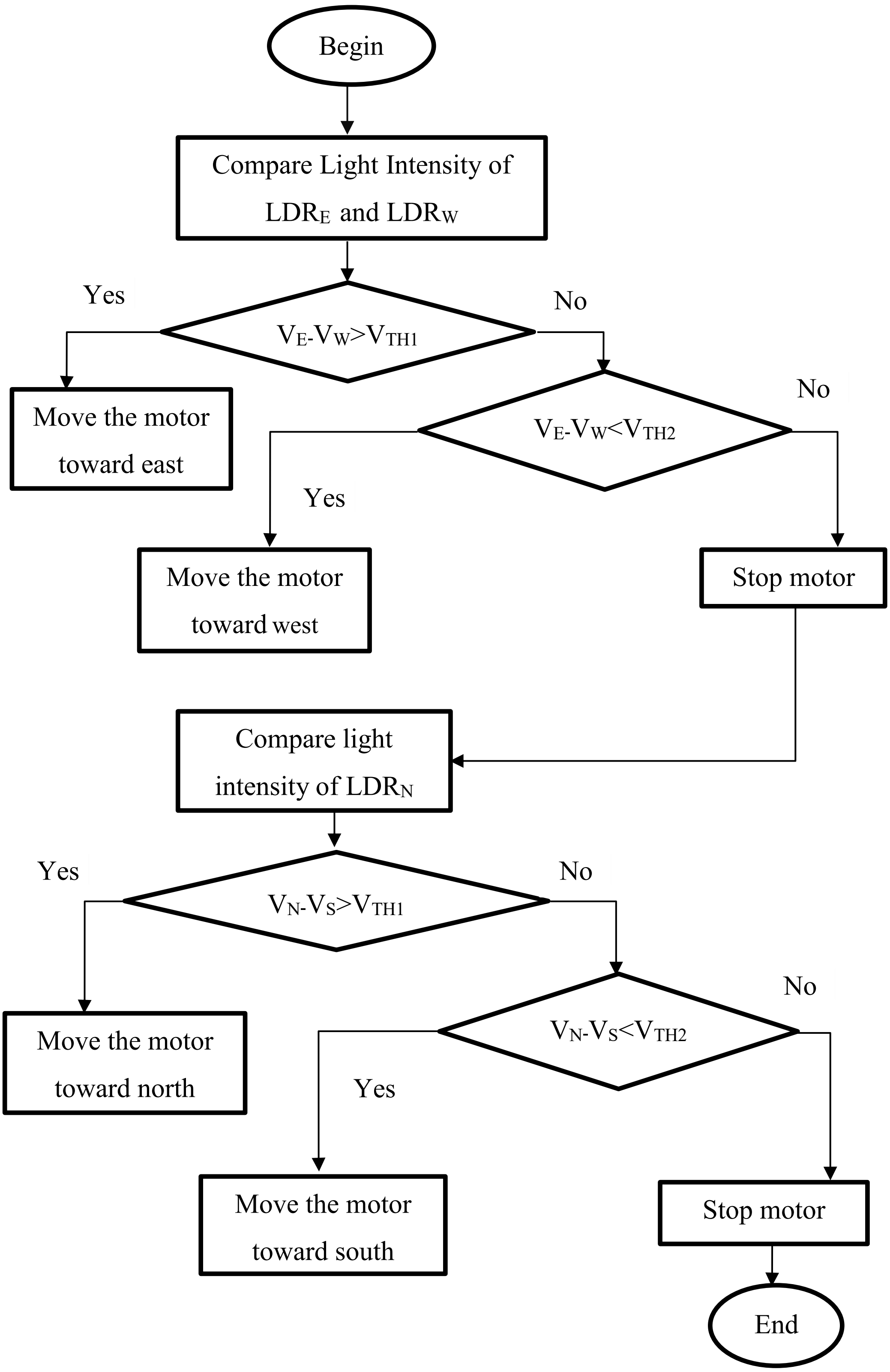


Figure 19: Algorithm for tracking

2.1.2 Mathematical Calculations

2.1.2.1 Solar Calculations

Specification of Panel

Solar Panel, **Model: SW010P**

Specification	**Symbol**	**Value**
Max power	P_{max}	10W
Voltage at maximum power	V_{mpp}	18.1V
Current at maximum power	I_{mpp}	0.55A
Open Circuit Voltage	V_{oc}	21.8V
Short Circuit Current	I_{sc}	0.60A
Dimension(mm)		345mm*240mm*30mm
Weight (KG)		0.988 kg
Panel Efficiency		11.30%

Average sunshine hour in Nepal per day = 5.5 hrs/day

Total power produced in 1 day by panel= (5.5 × 10) watt-hr/day= 55 W-h/day

Losses due to temperature, dust, atmospheric condition, etc. =10% of total power

=5.5 W-h/day

Corrected power produced by the PV in non-standard condition = 49.5 W-h/day

System voltage = 12V

Total power in Amp-hr/day by PV = 4.13 Amp-hr/day

Efficiency of charge controller = 99%

Power reaching to the battery = 4.08 Amp-hr/day = 49.01 W-h/day

So, battery of 12 V, 4.08 AH can be used. This will be charged in one day by chosen PV panel.

Battery Capacity = ~ 4.08Ah

Efficiency of battery (Loss in charging and discharging) = 90%

Expected power from battery = 3.68 Ah = 44.10 W-h

But battery can’t be fully discharged. So, considering DOD to be 80%

Corrected power that can be discharged from battery = 2.94 Ah =35.28 W-h

This power can be used by DC loads. But if we have to use AC loads, some power will be consumed by invertor.

If efficiency of invertor = 96%

Total output power from invertor = 33.87 Watt-hr

So, AC load of ~ 33 Watt can be operated by this system.

2.1.2.2 Torque Calculation

a) For daily movement of a tracker

Frame dimensions

Length: 41.5 cm

Breadth: 19.3 cm

Height: 0.6 cm

Total length or radius to be lifted by the motor = Length/2 = 41.5/2 = 20.75 cm

i.e. r = 220 mm

Weight of frame =0.343kg

Weight of motor = 0.051 kg

Weight of panel = 0.988 kg

Weight of remaining accessories = 0.01 kg

Hence, total weights to be considered, F= (0.343+0.051+0.988+0.01) x 9.8 = 13.641 N

Torque Required = F × r = 13.641 N x (20.75/100) m = 2.83 N m

Speed of motor (N) = 20 rpm

Power require to drive the system (P) = $\frac{2\pi NT}{60} = \frac{2\pi\times 50\times 2.83}{60} = 5.93\ watt$

b) For seasonal moment of the tracker

Panel dimensions

Length: 34.5 cm

Breadth: 24.0 cm

Height: 3 cm

Since the motor is aligned to the center

Total length or radius to be lifted by the motor = Breadth/2

= 24/2 = 12 cm = 0.12 m

i.e. r = 0.12 m

Weight of panel = 0.988 kg

Hence, total weight to consider, F = 9.68 N

Torque required = F × r = 9.68 N × (0.12) m = 1.16 Nm

Speed of motor (N) = 20 rpm

Power required to drive the system (P) = $\frac{2\pi NT}{60} = \frac{2\pi\times20\times1.16}{60} = 2.43\ watt$

2.1.3 Design

The design of the system is divided in to two parts as described below:

2.1.3.1 Mechanical Design

On the basis of availability of panel dimension, the U-shaped frame for the setup is designed using solid-works. Then with the help of above calculations and literature review, two MG996R servo motors are taken for two axis rotation. As the MG996R motor have a stall torque value of 9.4kg/cm (4.8v); 11kg/cm (6.0v).

As it will be difficult to have intensity difference of light in resistor due to small area. So, structure is made to create a shadow in certain LDRs with the position of light source as shown in fig 16.

Then another stand is made for the halogen lamp to give an ideology of sun.

Figure 20: Mechanical frames

2.1.3.2 Electrical Design

Under electrical portion, design includes the connection of LDRs, resistors, Arduino and servo motors together in the bread board. Beside this an additional connection of battery, invertor, charge controller and load are also made. The circuit diagram is shown in the figure 17. Here Arduino is powered through pc using cables. Then grounding (GND) and 5V is supplied to motors and LDRs by Arduino. After the completion of all the connection coding as per requirement is uploaded in board. So, the microprocessor will act as per the program.

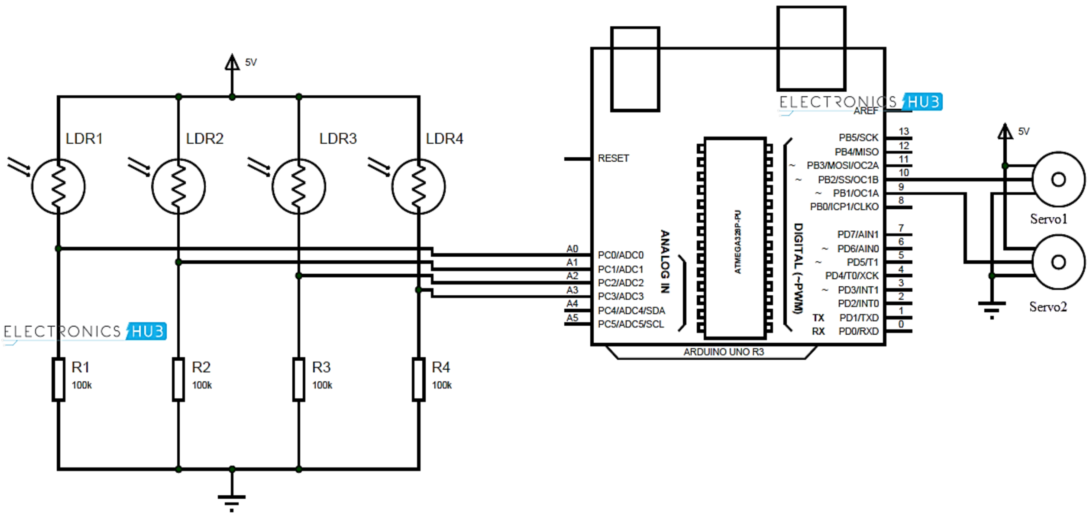


Figure 21: Circuit diagram

The complete design of the project is shown in fig below:

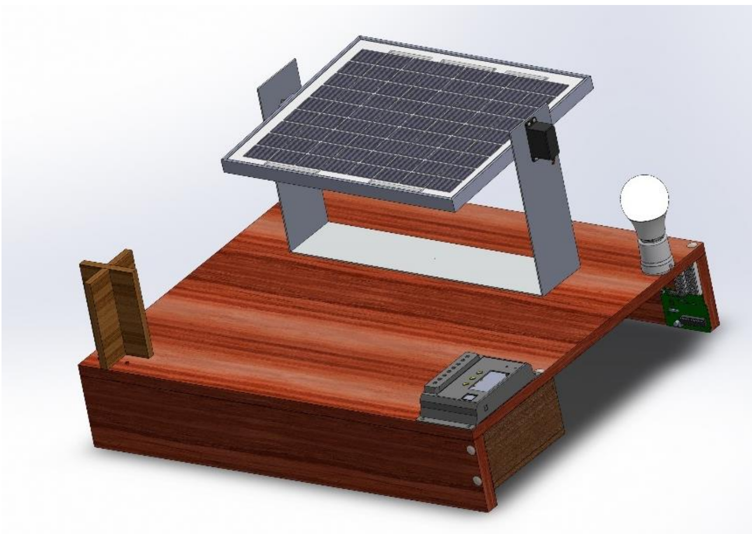


Figure 22: 3D model of dual axis solar tracker

2.1.4 Marketing and material selection

Marketing is done for the purchases of motors, bulb, Arduino, breadboard and wires. While for the frame initially aluminum is preferred but due to unavailability of required thickness and difficult in fabrication, wood was used as its successor.

2.1.5 Fabrication

Fabrication includes the frame for panel, fixing of motors, light barriers for the LDRs and stand for the halogen lamp. This were carried out as per the calculations, design and material selection.

2.1.6 Testing and modification

After the completion of fabrication, project was tested for different light sources. It was not that much sensitive to the scatter light so; we should use light source that gives beam radiation for better performance.

CHAPTER 3 GANTT CHART

Given table represents the activities that have been performed in respective week throughout the project.

Table 3: Gantt chart

Year	**2018-2019**										
Month	**09**	**10**	**11**	**12**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
Topic Selection											
Literature Review											
Proposal Defense											
Preliminary Design											
Mid report submission											
Market Survey and Material Selection											
Fabrication											
Testing and Modification											
Final Report Submission											

Index:

Work Completed	
Work Remaining	

CHAPTER 4 BUDGETS

Following table shows the total cost of the project.

Table 4: Total budget of the project

S.N.	Material	Rate (Rs) per piece	Qty.	VAT Amount (13%)	Cost (Rs)	Remarks
1.	MG996R Servo Motor	900	2	234	2034	13% VAT
2.	GS9025 Servo Motor	750	1	-	750	
3.	L293D Motor Driver	350	2	91	791	13% VAT
4.	Motor Driver	275	1	-	275	
5	7*9 Matrix Green	60	1	7.8	67.8	13% VAT
6.	Arduino UNO	750	1	-	750	
7.	Cable	50	1	-	50	
8	Jump Wires	5	20	-	100	
9.	Screw	5	10	-	50	
10.	Nut and Bolts	18	10	23.40	203.40	13% VAT
11	Resistors	1	4	-	4	
12	Halogen Bulb	350	1	-	350	
13	LDRs	20	4	-	80	
14	Charge Controller	1700	1	-	1700	Solar Lab
15	Invertor	2000	1	-	2000	Solar Lab
16	Battery	1100	1	-	1100	

17	Solar Panel	1000	1	-	1000	Solar Lab
18	Miscellaneous	-	-	-	515	
	Total				11,820.2	

Total project cost = Rs 11,820.2

Total academic cost = Rs 7,120.2

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The paper has presented a means of tracking the sun's position with the help of microcontroller and LDR sensors. Specially, it demonstrates a working software solution for maximizing solar cell output by positioning a solar panel at the point of maximum light intensity. Moreover, the tracker can initialize the starting position itself which reduce the need of any more photo resistors. The attractive feature of the designed solar tracker is simple mechanism to control the system.

As solar power production is used in large scale worldwide so, even an increment in efficiency by 1% than stationery plane will increases the net power production by large amount. Hence, no matter by how much tracker increases an efficiency it is always welcomed.

In a conclusion, this mechanism could be manifested in wide range of applications that require solar tracking such as parabolic trough collector, solar dish, lens and other PV systems to collect maximum radiation from sun.

5. 2 RECOMMENDATION

Though we have performed our work in much efficient way. There is still room for improvement for this system and it is hoped that further study can be carried out to further develop the system.

- Use higher motors with large torque value for larger panel size.
- It will be better to use geographical equation algorithm for the real timing tracking.
- Use diffused reflection phenomenon.

CHAPTER 6 REFERENCES

[1] "Go Solar California," [Online]. Available: http://www.gosolarcalifornia.ca.gov/about/gosolar/california.php. [Accessed 27 September 2018].

[2] J. Bartlett, "Arise Energy Solutions," Arise Energy Solutions, LLC, [Online]. Available: http://ariseenergy.com/training-education/history-of-pv-solar-energy. [Accessed 28 September 2018].

[3] A. Baker, 13 July 2013. [Online]. Available: https://www.solarpowerauthority.com/a-history-of-solar-cells/. [Accessed 28 September 2018].

[4] S. Wahid, 25 February 2015. [Online]. Available: https://www.greentechlead.com/solar/tsec-dupont-to-showcase-v-series-solar-panels-at-tokyo-expo-21927. [Accessed 26 September 2018].

[5] J Pradeep, "Development of Dual-Axis Solar Tracking using Arduino with Lab VIEW," International Journal of Engineering Trends and Technology (IJETT), vol. 17, p. 321, 2014.

[6] Md. Tanvir Arafat Khan, "Design and Construction of an Automatic Solar Tracking System," International Conference on Electrical and Computer Engineering, ICECE, pp. 326-27, December 2010.

[7] O. R. Otieno, "SOLAR TRACKER FOR SOLAR PANEL," University of Nairobi, 2009.

[8] "Utility Drive," 29 November 2016. [Online]. Available: https://www.utilitydive.com/news/following-the-sun-a-brief-history-of-solar-trackers/431189/. [Accessed 29 September 2018].

[9] "Coursera," [Online]. Available: https://www.coursera.org/lecture/photovoltaic-solar-energy/1-the-global-context-energetics-SQu3n. [Accessed 29 October 2018].

[10] [Online]. Available: https://www.finder.com/uk/nation-most-solar-power. [Accessed 28 October 2018].

[11] R. Bhandari, "Electrification using solar photovoltaic systems in Nepal," ELSEVIER, pp. 458-465, 2011.

[12] "Economic Survey 2017/18," GoN, Ministry of Finance, June 2018. [Online]. Available: http://mof.gov.np/en/archive-documents/economic-survey-21.html?lang. [Accessed 13 10 2018].

[13] C. Joshi, B. Pradhan and T. Pathak, "Application of Solar Drying Systems in Rural Nepal," in World Renewable Energy Congress VI, Brighton, UK, 2007, pp. 2237-2240.

[14] Suresh Baral, "Existing and Recommended Renewable Energy," SAP, vol. 4, pp. 16-28, 2014.

[15] W. community, "Energy Sector Synopsis Report Nepal," Water and Energy Commission Secretariat (WECS), Nepal, 2010.

[16] WECS, "National Energy Strategy of Nepal," Government of Nepal Water and Energy Commission Secretariat , Kathmandu, 2013.

[17] "Alternative Energy Promotion Centre," [Online]. Available: https://www.aepc.gov.np. [Accessed 13 10 2018].

[18] "Renewable Energy Test Station," [Online]. Available: http://www.retsnepal.org/site/pages/Profile. [Accessed 14 October 2018].

[19] "RETS," [Online]. Available: http://www.retsnepal.org/uploads/file/23NEPQA%202015%20rev1.pdf. [Accessed 12 October 2018].

[20] D. A. Gurung, A. Ghimeray and S. Hassan, "The prospects of renewable energy technologies for rural electrification: A review from Nepal," Energy Policy, 2011. [Online]. Available: doi:10.1016/j.enpol.2011.10.022. [Accessed 13 October 2018].

[21] "NEA to revise power purchase rates for solar projects," The Himalayan Times, 23 August 2018. [Online]. Available: thehimalayantimes.com. [Accessed 14 October 2018].

[22] R. Khanal, "170MW solar power plant gets $200m investment," the Kathmandupost, 13 August 2018. [Online]. Available: http://kathmandupost.ekantipur.com. [Accessed 14 October 2018].

[23] S. M. Shrivastava, "Dual Axis Solar Tracker," Gautam Budha Technical University, Lucknow, May 2013.

[24] K. L. Horiuchi. [Online]. Available: https://greenpassivesolar.com. [Accessed 30 September 2018].

[25] E. H. Aboubakre, M. Saad, E. G. Abdelaziz, C. Abdelilah and D. Aziz, "A simple and low-cost active dual-axis solar tracker," Energy Science and Engineering, 2018.

[26] "Energy.gov," [Online]. Available: https://www.energy.gov/energysaver/water-heating/solar-water-heaters. [Accessed 15 Nov 2018].

[27] H. Christiana and B. Stuart, "PVEDUCATION.ORG," [Online]. Available: https://pveducation.org/pvcdrom/pn-junctions/introduction-to-semiconductors. [Accessed 7 Nov 2018].

[28] M. B. Askari, M. A. Mirzaei and M. Mirhabibi, "Category of different types of panels," American Journal of Optics and photonics, vol. 3, no. 5, pp. 94-113, 2018.

[29] "Solar Radiation Monotoring Laboratory," [Online]. Available: http://solardat.uoregon.edu/SunChartProgram.html. [Accessed 20 Dec 2018].

[30] Kamran, Mudassar, F. Rayyan and A. Usman. [Online]. Available: https://www.researchgate.net/publication/325849636_Implementation_of_improved_Perturb_Observe_MPPT_technique_with_confined_search_space_for_standalone_photovoltaic_system. [Accessed 6 Jan 2019].

[31] A. K. Mishra, "Dual axis solar tracker," IOE, Lalitpur, 23 March, 2010.

APPENDIX

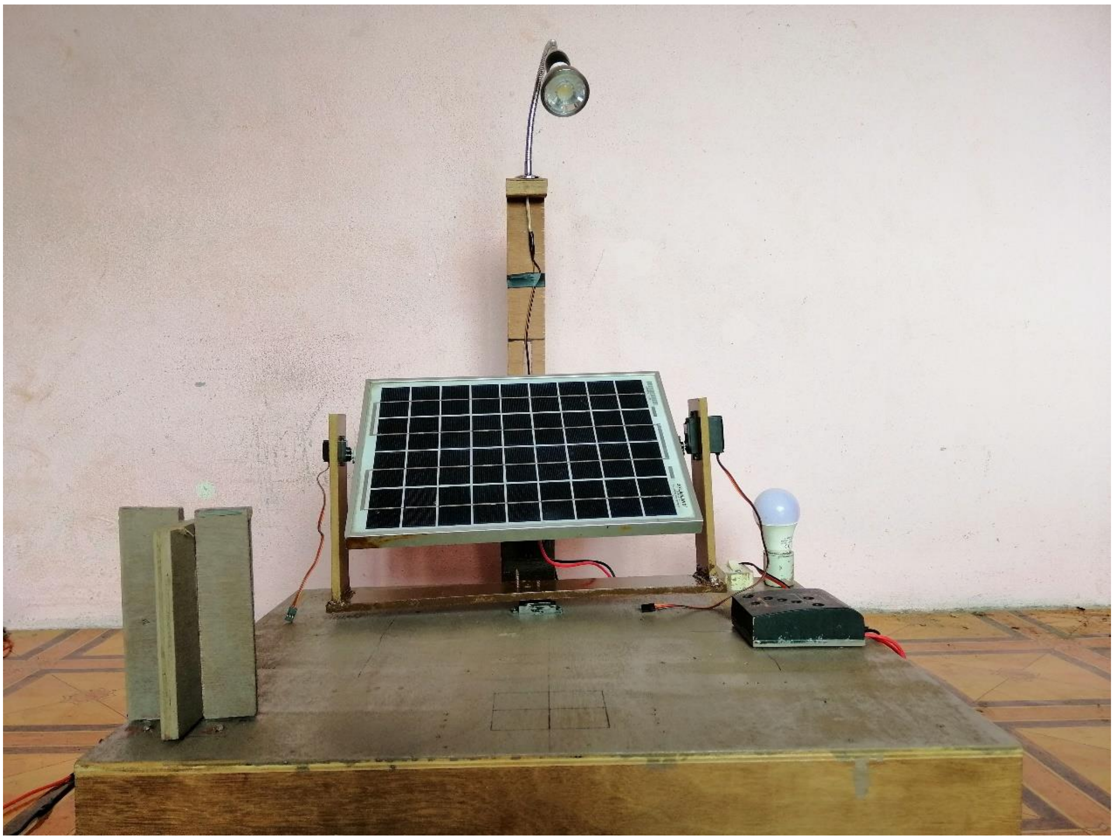
Arduino Code:

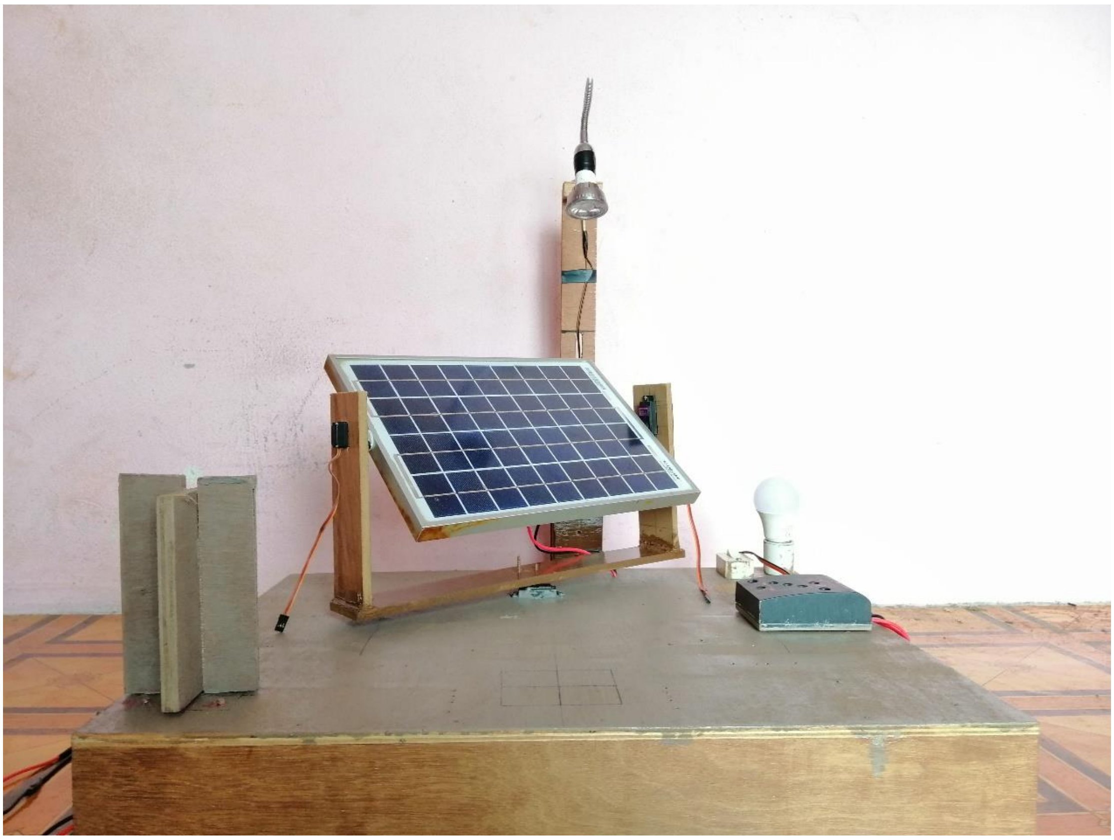
```
#include <Servo.h> // include Servo library

// 180 horizontal MAX
Servo horizontal; // horizontal servo
int servoh = 180;   // 90;     // stand horizontal servo

int servohLimitHigh = 180;
int servohLimitLow = 65;

// 65 degrees MAX
Servo vertical;   // vertical servo
int servov = 45;    //   90;     // stand vertical servo

int servovLimitHigh = 80;
int servovLimitLow = 15;



// LDR pin connections
//  name  = analogpin;
int ldrlt = 3; //LDR top left - BOTTOM LEFT    <--- BDG
int ldrrt = 1; //LDR top rigt - BOTTOM RIGHT
int ldrld = 2; //LDR down left - TOP LEFT
int ldrrd = 0; //ldr down rigt - TOP RIGHT

void setup()
{
  Serial.begin(9600);
// servo connections
// name.attacht(pin);
```

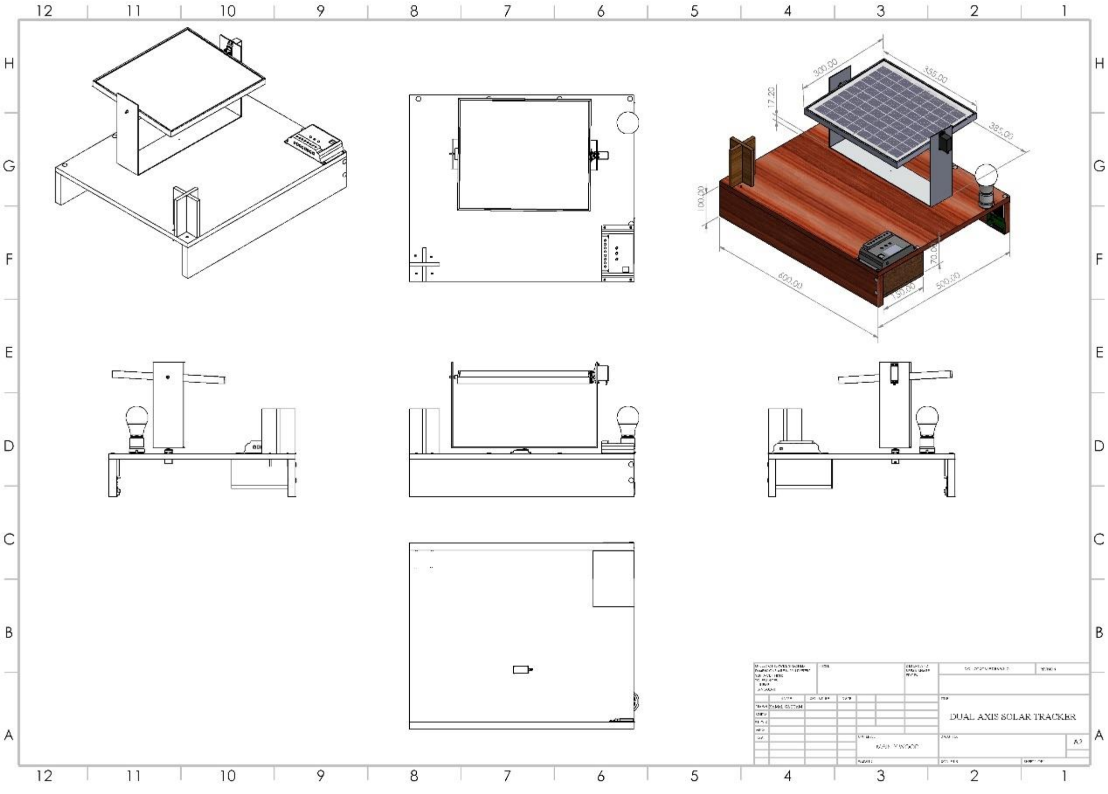
```
  horizontal.attach(9);
  vertical.attach(10);
  horizontal.write(180);
  vertical.write(45);
  delay(3000);
}

void loop()
{
  int lt = analogRead(ldrlt); // top left
  int rt = analogRead(ldrrt); // top right
  int ld = analogRead(ldrld); // down left
  int rd = analogRead(ldrrd); // down rigt

  // int dtime = analogRead(4)/20; // read potentiometers
  // int tol = analogRead(5)/4;
  int dtime = 10;
  int tol = 50;

  int avt = (lt + rt) / 2; // average value top
  int avd = (ld + rd) / 2; // average value down
  int avl = (lt + ld) / 2; // average value left
  int avr = (rt + rd) / 2; // average value right

  int dvert = avt - avd; // check the diffirence of up and down
  int dhoriz = avl - avr;// check the diffirence og left and rigt



  Serial.print(avt);
  Serial.print(" ");
  Serial.print(avd);
  Serial.print(" ");
  Serial.print(avl);
```

```
  Serial.print(" ");
  Serial.print(avr);
  Serial.print("   ");
  Serial.print(dtime);
  Serial.print("   ");
  Serial.print(tol);
  Serial.println(" ");


  if (-1*tol > dvert || dvert > tol) // check if the diffirence is in the tolerance else change vertical angle
  {
  if (avt > avd)
  {
    servov = ++servov;
     if (servov > servovLimitHigh)
     {
      servov = servovLimitHigh;
     }
  }
  else if (avt < avd)
  {
    servov= --servov;
    if (servov < servovLimitLow)
  {
    servov = servovLimitLow;
  }
  }
  vertical.write(servov);
  }

  if (-1*tol > dhoriz || dhoriz > tol) // check if the diffirence is in the tolerance else change horizontal angle
```

```
 {
 if (avl > avr)
 {
   servoh = --servoh;
   if (servoh < servohLimitLow)
    {
   servoh = servohLimitLow;
    }
 }
 else if (avl < avr)
 {
   servoh = ++servoh;
    if (servoh > servohLimitHigh)
     {
    servoh = servohLimitHigh;
     }
 }
 else if (avl = avr)
 {
   // nothing
 }
 horizontal.write(servoh);
 }
  delay(dtime);

}
```







DUAL AXIS SOLAR TRACKER