Solar Tracking System

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1. Introduction:

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]

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.

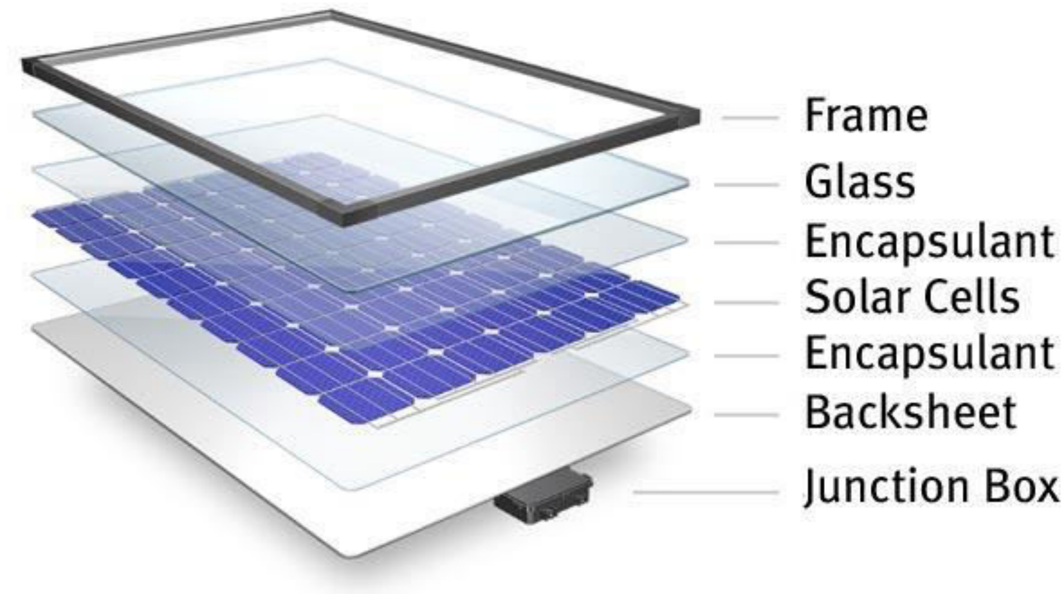


Figure 1**:** Layers of solar PV module

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]

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

2. Objectives of the work:

Specific Objectives:

iTo design and fabricate a four axis PV system that tracks the sun path.

General Objectives:

iTo study different solar parameters and methods of harvesting solar energy.

ii To understand the working mechanism of PV module and tracking system.

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.

3. Methodology:

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.

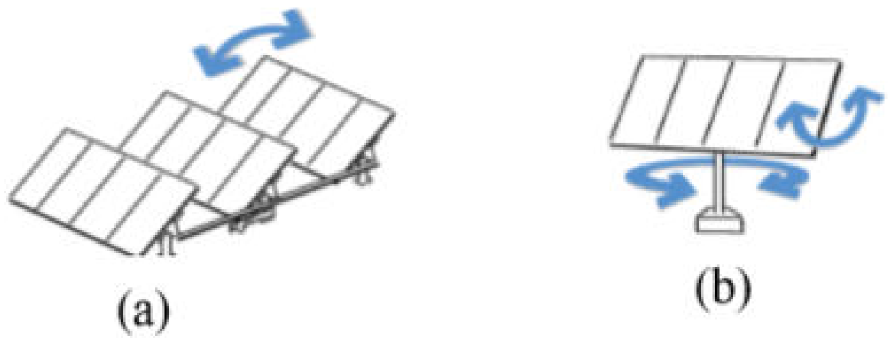


Figure : (a) Schematic diagram of single-axis solar tracker (b) Schematic diagram of double-axis solar tracker

Single-axis trackers have only one axis of movement as shown in Fig , 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 , 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. This optimizes maximum power from the PV system over a day than non-tracking system.

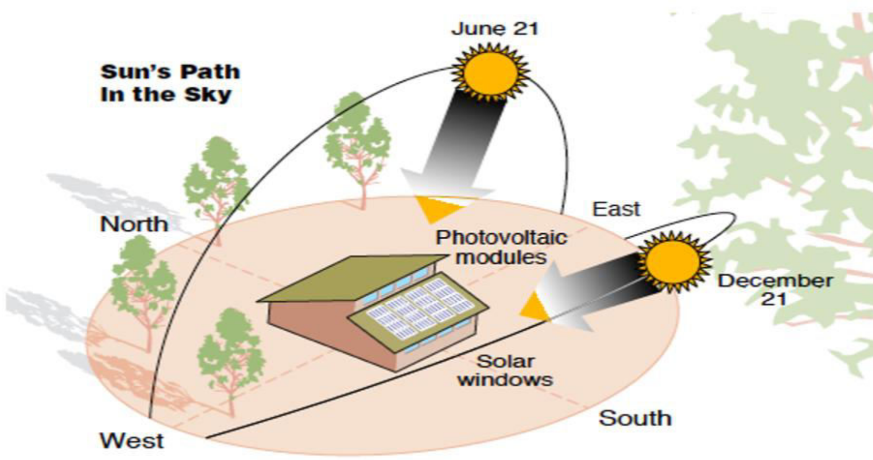


Figure :Variation in trajectory of sun from winter to summer

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

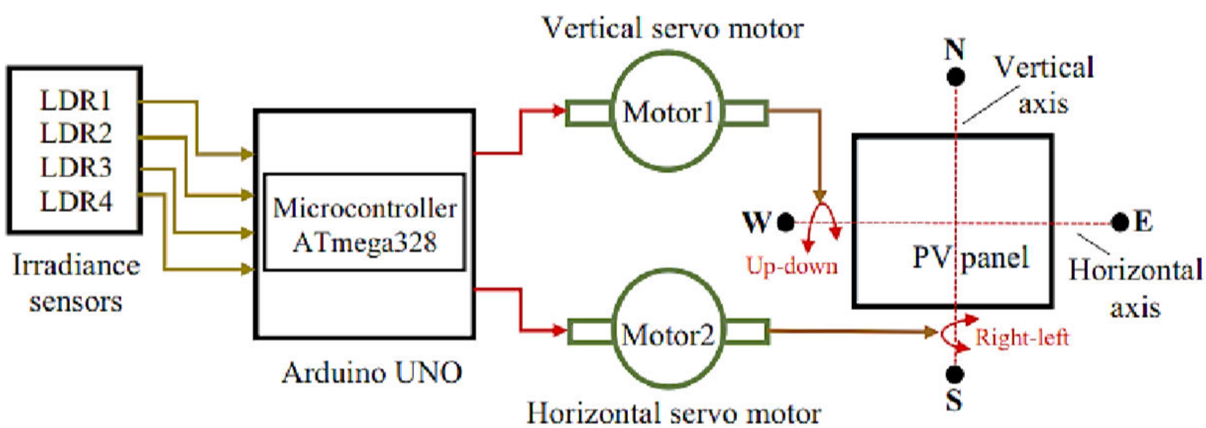


Figure: Simple flow chart of tracking system with components

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 90º.

Solar Altitude Angle, αs

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, γS

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.

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).

4. Literature Review:

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:

4.1 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.

• Thermo syphon 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.

4.2 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.

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 in the form of a p-n junction.

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.

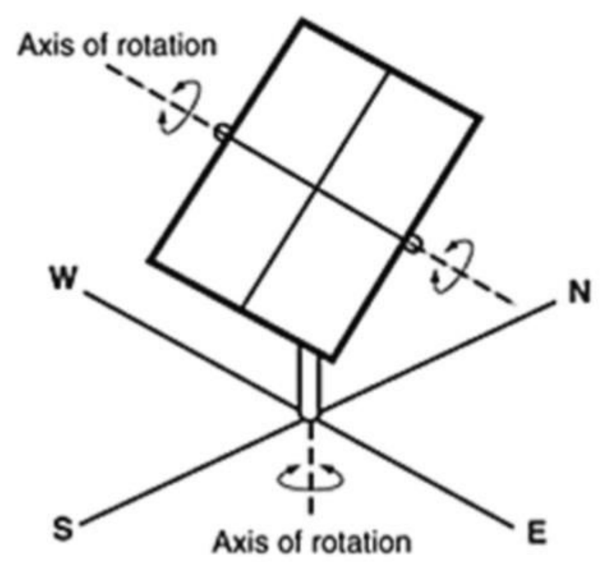
4.3 A Module Circuit Design

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.

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.

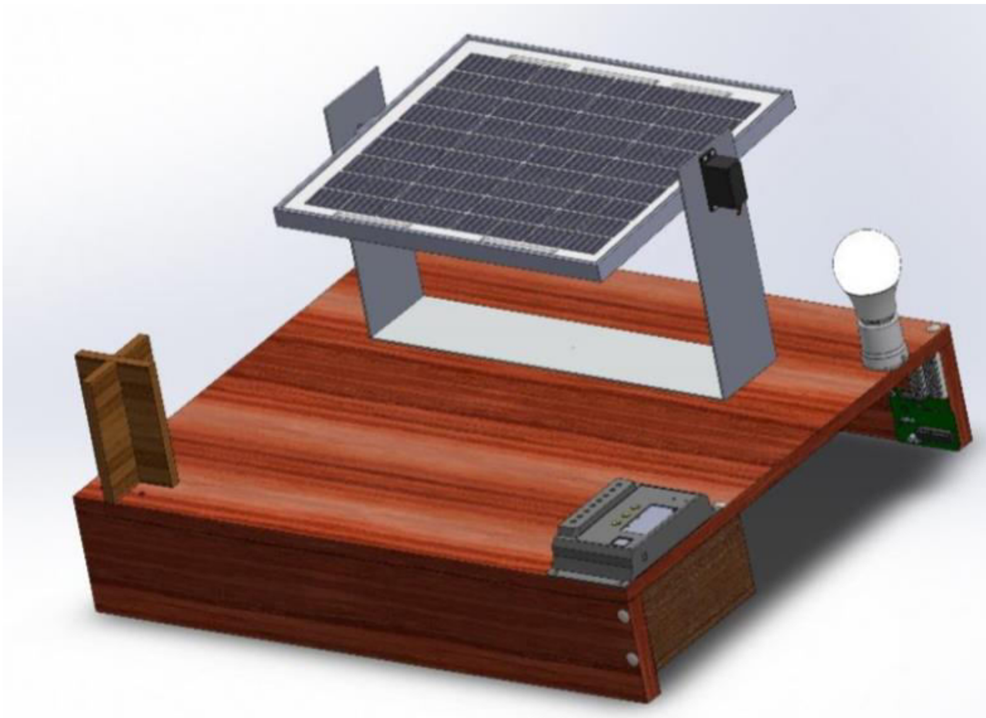
5. Construction and Working:

- ➢ The dual axis solar tracker is device which senses the light and positions towards the maximum intensity of light. It is made in such a way to track the light coming from any direction.
- ➢ To simulate the general scenario of the Sun's movement, the total coverage of the movement of the tracker is considered as 120˚ in both the directions.
- ➢ The initial position of both the servo motors are chosen at 90˚i.e, for east-west servo motor as well as for north-south servo motor.
- ➢ The position of the tracker ascends or descends only when the threshold value is above the tolerance limit.



Two-axis tracking system

6. 3D Proposed Project Model:



7. Action Plane:

1. Literature Review
2. Design of Solar Tracking mechanism.
3. Design of Electrical & Electronic system.
4. Manufacturing All Supporting Device & Programme.
5. Assembly the all mfg. parts.
6. Actual Testing and Report Writing.

Plan of Proposed Work

Sr. No	Activity/ Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April
1	Literature Review								
2	Design of Solar Tracking mechanism								
3	Design of Electrical & Electronic system								
4	Mfg All Supporting Device & Programme								
5	Assembly the all mfg. parts								
6	Actual Testing and Report Writing								

8. Calculation:

8.1 Solar Calculations:

Specification of Panel

Solar Panel, Model: SW010P

Specification	Symbol	Value
Max power	Pmax	10W
Voltage at maximum power	Vmpp	18.1V
Current at maximum power	Impp	0.55A
Open Circuit Voltage	Voc	21.8V
Short Circuit Current	Isc	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.

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) = $2\pi NT/60$ =2π×50×2.83 / 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) = $2\pi NT$ 60 =2π×20×1.16 60

= 2.43 $watt$

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