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Research Article

DUAL-AXIS SOLAR TRACKER

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ABSTRACT

Non renewable energy sources like fossil fuels are soon being depleted and in near future we will be faced with its extinction. Alternative energy sources which are renewable and are available in abundant quantity are required. Sun's insulation fits both the criteria. Hence there are emerging technologies focused on harvesting solar energy. Be it photovoltaic panels or concentrating panels, they aren't most efficient if they are installed in a fixed position. Due to earth's spin we see sun in different positions throughout the day, hence light tracker is used along with mechanisms which orient a solar panel or a concentrating panel throughout the day. Designing and fabricating a Dual-axis solar tracker one needs to have a proper grasp of Basic electronics, control systems and mechanical mechanisms.

INTRODUCTION

The daily average solar energy incident over India varies from 4 to 7 kWh/m2 with about 1500–2000 sunshine hours per year (depending upon location), which is far more than current total energy consumption. For example, assuming the efficiency of PV modules were as low as 10%, this would still be a thousand times greater than the domestic electricity demand projected for 2015. Fig 1 shows the average solar radiations receiver by different regions in India. Gujarat government has signed a MOU with Clinton Foundation to build the world's largest solar-power plant in the region. The 3,000-megawatt plant near the border between India and Pakistan would be one of four planned by the initiative, a William J. Clinton Foundation program to promote renewable energy. The other proposed sites are in California, South Africa, and Australia.

However the problem with solar power is that it is directly dependent on light intensity. To produce the maximum amount of energy, a solar panel must be perpendicular to the light source. Because the sun moves both throughout the day as well as throughout the year, a solar panel must be able to follow the sun's movement to produce the maximum possible power. The solution is to use a tracking system that maintains the panel's orthogonal position with the light source. There are many tracking system designs available including passive and active systems with one or two axes of freedom.

The goal of our project was to design an active, dual axis, solar tracker that will have a minimum allowable error of 10° and also be economically feasible to market towards underprivileged countries. We started by examining the prior work done in solar tracking methods to determine our course of action. From there we designed and tested several mechanical and electrical options and chose the ones with the most desirable characteristics. Finally, we built our final tracking system, tested and compared it to ensure that we met our original goal.

Concepts on Solar Radiation

The sun, at an estimated temperature of 5800 K, emits high amounts of energy in the form of radiation, which reaches the planets of the solar system. Sunlight has two components, the direct beam and diffuse beam. Direct radiation (also called beam radiation) is the solar radiation of the sun that has not been scattered (causes shadow). Direct beam carries about 90% of the solar energy, and the "diffuse sunlight" that carries the remainder. The diffuse portion is the blue sky on a clear day and increases as a proportion on cloudy days. The diffuse radiation is the sun radiation that has been scattered (complete radiation on cloudy days). Reflected radiation is the incident radiation (beam and diffuse) that has been reflected by the

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earth. The sum of beams, diffuse and reflected radiation is considered as the global radiation on a surface. As the majority of the energy is in the direct beam, maximizing collection requires the sun to be visible to the panels as long as possible.

Insolation

Insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time. It is also called solar irradiation and expressed as hourly irradiation if recorded during an hour, daily irradiation if recorded during a day, for example. The unit recommended by the World Meteorological Organization is MJ/m2 (mega joules per square meter) or J/cm2 (joules per square centimeter).Practitioners in the business of solar energy may use the unit Wh/m2 (watt-hours per square meter). If this energy is divided by the recording time in hours, it is then a density of power called irradiance, expressed in W/m2 (watts per square meter). Over the course of a year the average solar radiation arriving at the top of the Earth's atmosphere at any point in time is roughly 1366 watts per square meter. The Sun's rays are attenuated as they pass through the atmosphere, thus reducing the irradiance at the Earth's surface to approximately 1000 W m 2 for a surface perpendicular to the Sun's rays at sea level on a clear day. The insolation of the sun can also be expressed in Suns, where one Sun equals 1000 W/m2

Projection Effect

The insolation into a surface is largest when the surface directly faces the Sun. As the angle increases between the direction at a right angle to the surface and the direction of the rays of sunlight, the insolation is reduced in proportion to cosine of the angle; see effect of sun angle on climate.

This 'projection effect' is the main reason why the Polar Regions are much colder than equatorial regions on Earth. On an annual average the poles receive less insolation than does the equator, because at the poles the Earth's surface are angled away from the Sun.

Working of photovoltaics

Photovoltaics are the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

A solar cell (also called photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. Crystalline silicon PV cells are the most common photovoltaic cells in use today.A number of solar cells electrically connected to each other and mounted in a support structure or frame are called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module. Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity will be produced. Photovoltaic modules and arrays produce direct-current (DC) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

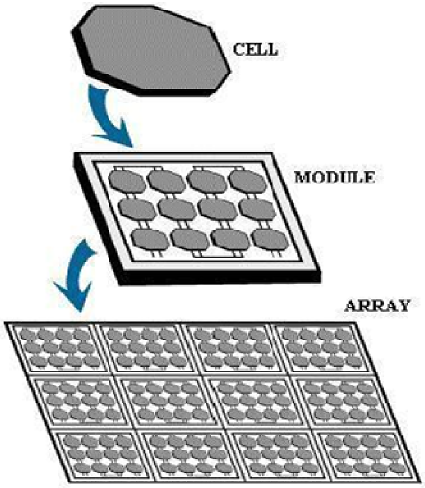

Figure 1 Photovoltaic panel or array

Solar Tracker

The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the panel. The table no. 1 shows the Direct power lost (%) due to misalignment (angle i).

Table no1 Direct power lost (%) due to misalignment (angle i)

Misalignment (angle i)	Direct power lost (%)=1-cos(i)
00	0
10	.015
30	.14
80	1
23.40	8.3
300	13.4
450	30
750	>75

The sun travels through 360 degrees east-west a day, but from the perspective of any fixed location the visible portion is 180 degrees during a 1/2 day period. Local horizon effects reduce this somewhat, making the effective motion about 150 degrees. A solar panel in a fixed orientation between the dawn and sunset extremes will see a motion of 75 degrees on either side, and thus, according to the table above, will lose 75% of the energy in the morning and evening. Rotating the panels to the east and west can help recapture these losses. A tracker rotating in the east-west direction is known as a single-axis tracker. The sun also moves through 46 degrees north-south over the period of a year. The same set of panels set at the midpoint between the two local extremes will thus see the sun move 23 degrees on either side, causing losses of 8.3% A tracker that accounts for both the daily and seasonal motions is known as a dual-axis tracker.

Passive Tracking Systems

The passive tracking system realizes the movement of the system by utilizing a low boiling point liquid. This liquid is vaporized by the added heat of the sun and the center of mass is shifted leading to that the system finds the new equilibrium position.

Active Tracking Systems

The two basic types of active solar tracker are single-axis and double-axis.

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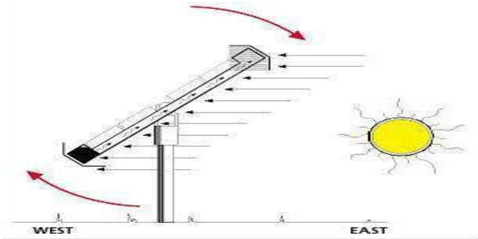


Fig 2 Active tracking system

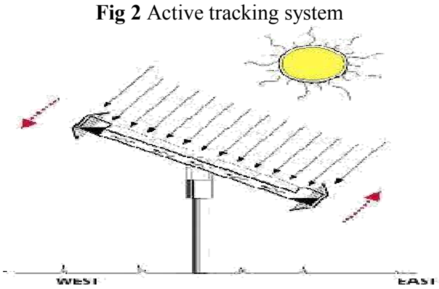


Figure 3 Passive tracking system

Single Axis Trackers

The single axis tracking systems realizes the movement of either elevation or azimuth for a solar power system. Which one of these movements is desired, depends on the technology used on the tracker as well as the space that it is mounted on. For example the parabolic through systems utilize the azimuthally tracking whereas the many rooftop PV-systems utilize elevation tracking because of the lack of space. A single-axis tracker can only pivot in one plane – either horizontally or vertically. This makes it less complicated and generally cheaper than a two-axis tracker, but also less effective at harvesting the total solar energy available at a site. Trackers use motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction. Since the motors consume energy, one wants to use them only as necessary.

Single axis trackers have one degree of freedom that acts as an axis of rotation. There are several common implementations of single axis trackers. These include horizontal single axis trackers (HSAT) and vertical single axis trackers (VSAT). A horizontal-axis tracker consists of a long horizontal tube to which solar modules are attached. The tube is aligned in a north-south direction, is supported on bearings mounted o n pylons or frames, and rotates slowly on its axis to follow the sun's motion across the sky. This kind of tracker is most effective at equatorial latitudes where the sun is more or less overhead at noon. In general, it is effective wherever the solar path is high in the sky for substantial parts of the year, but for this very reason, does not perform well at higher latitudes. For higher latitude, a vertical-axis tracker is better suited. This works well wherever the sun is typically lower in the sky and, at least in the summer months, the days are long.

Dual Axis Trackers

Dual axis trackers as shown in the figure 4 have two degrees of freedom that act as axes of rotation. Double-axis solar trackers, as the same suggest, can rotate simultaneously in horizontal and vertical directions, and s o are able to point exactly at the sun at all times in any location. Dual axis tracking systems realize movement both along the elevation- and azimuthally axes. These tracking systems naturally provide the best performance, given that the components have high enough accuracy as well.

Fig 4 Dual axis solar tracker

Design of Solar Tracker

Two separate prototypes were built and modified. One part of the frame follows the day time motion of the sun precisely and shifts in the vertical axis accordingly. Whereas the other part follows the seasonal displacement of the sun and moves the entire mechanism in the horizontal plane or in a lateral motion such that the orientation of the solar panel is always kept in a straight axis to the sun so that it complements the vertical actions of the tracker appropriately.

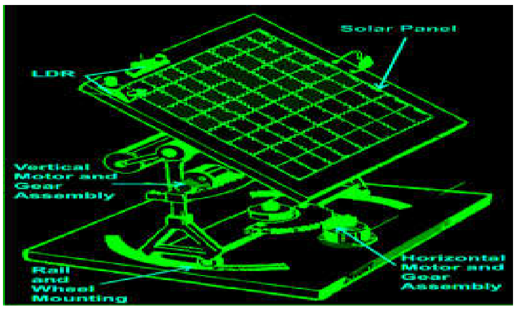
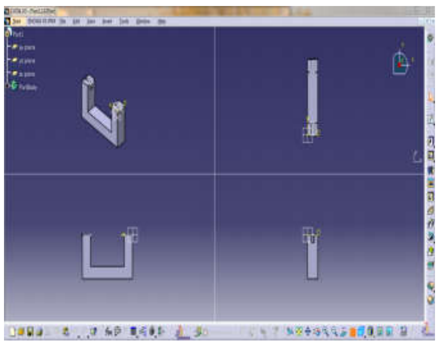


Fig 5 Structure of Tracker

For the tracker frame thrust bearing and radial bearings are welded by arc welding method.

Catia Designs of Dual Axis Solar Tracker



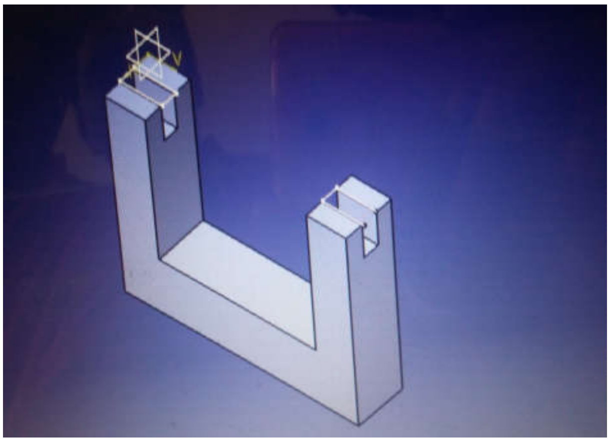


Fig 6 Catia designs of pivoting frame

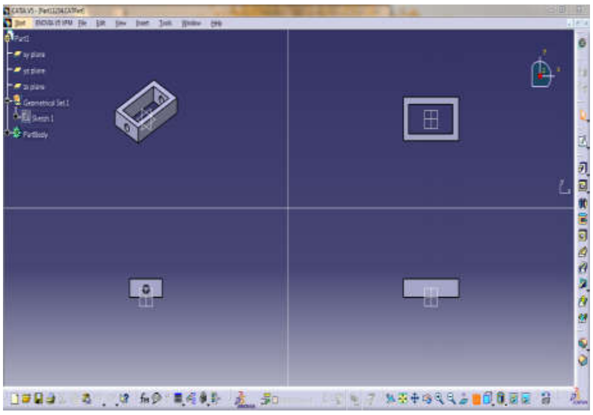


Fig 7 Catia designs of pivoting frame

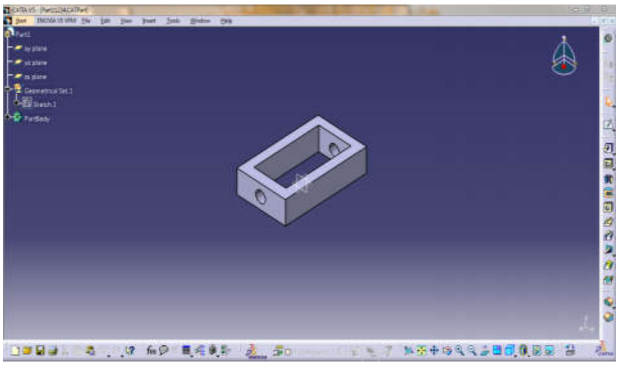


Fig 8 Catia deigns of panel pivoting frame

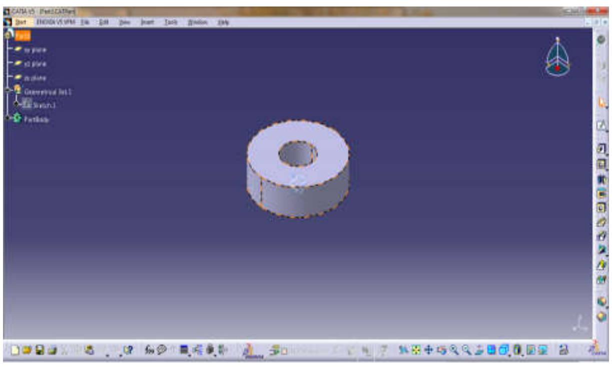


Fig 9 Design of bearing

Fig 10 design of pivoting rod

Final Tracker Frame

Fig 11 Tracker frame

Tracking System (Circuit)

The device is able to track day time motion of the sun precisely and shift in the vertical axis accordingly. The device also effectively tracks the seasonal displacement of the sun and moves the entire mechanism in the horizontal plane or in a lateral motion such that the orientation of the solar panel is always kept in a straight axis to the sun so that it complements the vertical actions of the tracker appropriately.

The position of the LDRs are critical here and the set of LDR which corresponds to this vertical plane movement is so positioned that it senses the sun light accurately and tries to keep the panel perpendicular to the sun rays by moving the motor in the appropriate direction through a definite number of stepped rotations.
The LDR sensing is actually accurately received and interpreted by an electronic circuit which commands the motor

for the above explained actions. Another mechanism which is quite similar to the above vertical setting, but moves the panel through a lateral motion or rather it moves the whole solar panel mount in circular motion over the horizontal plane.

This motion takes place in response to the position of the sun during the seasonal changes, therefore in contrast to the vertical movements; this operation is very gradual and cannot be experienced on a daily basis. Again the above motion is in response to the command given to the motor by the electronic circuit which operates in response to the sensing done by the LDRs.For the above procedure a different set of LDRs are used and are mounted horizontally over the panel, at a specific position as shown in the diagram.

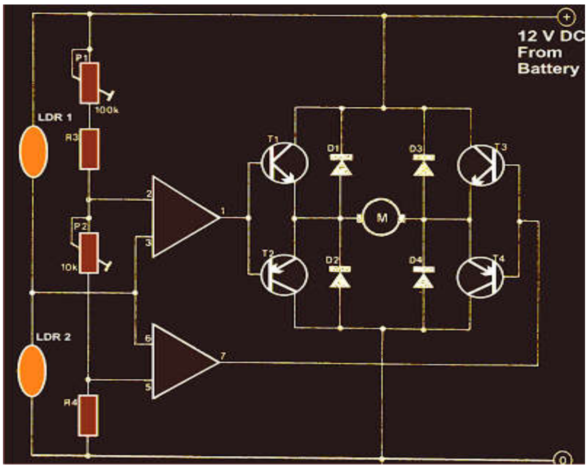


Fig. 12 Dual-axis Solar Tracker of Circuit

Components List

Resistors

R3 = 15K,
R4 = 39K,
Variable Resistors:
P1 = 100K,
P2 = 22K,

LDR = Normal type with a resistance of around 10 K to 40K in daylight under shade and infinite resistance in complete darkness.

Op-amps are from IC 324 or separately two 741 ICs may also be incorporated.

Transistors

T1, T3 = TIP31C,
T2,T4 = TIP32C,

Diodes

All diodes are 1N4007
Motor = As per the load and size of the solar panel

Working of the Circuit

The op amps are primarily wired to form a kind of window comparator, responsible for activating their outputs whenever their inputs waver or drift out of the predetermined window, set by the relevant pots. Two LDRs are connected to the inputs of the opamps for sensing the light levels. As long as as the lights over the two LDRs are uniform, the outputs of the opamp remain deactivated. However the moment one of the LDRs senses a different magnitude of light over it (which may happen due to the changing position of the sun) the balance over the input of the opamp shift toward one direction, immediately making the relevant opamps output go high.

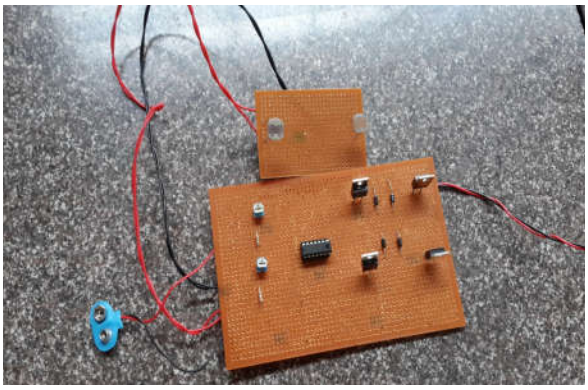


Fig 13 Soldered solar tracker circuit

This high output instantly activates the full bridge transistor network, which in turn rotates the connected motor in a set direction, such that the panel rotates and adjusts its alignment with the sun rays until uniform amount of light is restored over the relevant set of LDRs. Once the light level over the relevant LDR sets is restored, the opamps again become dormant and switch off their outputs and also the motor. The above sequence keeps on happening for the whole day, in steps, as the sun alters its position and the above mechanism keeps shifting in accordance to the suns position.

It should be noted that two sets of the above explained circuit assemblies will be required for controlling the dual actions or simply to make the above discussed dual tracker solar system mechanism.

CONCLUSION AND FURTHER CONSIDERATIONS

The Completion Of This Project Has Led To Several Conclusions To Be Made About This Solar Tracking System As Well As Solar Tracking Systems In General. Several Recommendations Were Also Outlined For Future Consideration In The Continuing Development Of Solar Tracking Systems.

Perhaps The Most Important Conclusion To Be Made From This Project Is The Total Cost For This Tracking System Is Very Low, Less Than $30 In Parts For Each Tracker In Mass Quantities. This Means That The System Can Be Built For A Very Low Cost And Most Importantly; This System Would Be Within The Financial Reach Of Many Developing Country Communities. Based On The Simulations, Test Results And Cost Analysis This Project Has Met Its Original Goals. To Improve The Efficiency Of This Tracking System, However, This Project Has Several Future Recommendations For Future Study In Solar Trackers.

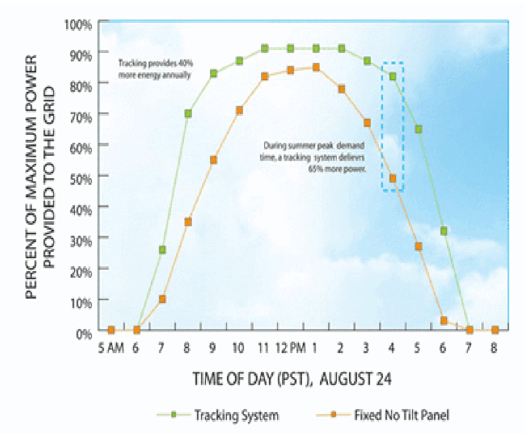


Fig 14 Comparison of dual tracking system against fixed panel

The Dual-Axis Solar tracker designed and built in this project show a clear benefit over both immobile and single-axis tracking systems. The tracker built has a maximum angular error to the sun of 1.5° in both axes of movement. This value corresponds to a 49% energy gain over an immobile solar panel setup assuming the solar panels mounted on the tracker and the immobile system are identical 20W panels. Furthermore, the single-axis trackers had gains over the immobile system for the entire range of latitudes but these gains were still lower than the dual-axis tracker for all latitudes.

Furthermore, testing showed that the power used by the tracking system built was much less than the power gained by tracking the sun accurately. This means that if the tracking system were to charge its own batteries, it would be entirely self-sufficient except for maintenance.

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