Multidimensional Sun Tracking Models for Maximum Power Generation

Snehal Patil[1], Rajendra Patil[2]

[1]Department of Electronics and Telecommunication, VIT Wadala, Mumbai, M.S India

[2]Department of Physics, S. H. Jondhale Polytechnic, Dombivli, Thane, M.S India

Abstract: *This paper discusses the solar tracker, its types, solar power technologies. In addition, this paper provides survey of design, programming and results of a device that achieved low power consumption. The system has dual-axes tracking controlled by a Programmable Logic Controller (PLC) using a astronomical calculations which are precalculated using the altitude and azimuth of the sun. On a clear and sunny day, the power generated from the tracker is significantly higher than the non-tracking surface unit.*

Keywords: PV Panels, Single axis, Dual axes, Solar Tracker, CSP

1. Introduction

The great thing about solar energy systems is that they offer people the chance to be self sufficient. A one of investment in solar technology means that the can utilize the energy that is produced by the sun; forever! The great thing is that for they can instantly convert the energy from the sun and use the electricity that has been created to provide free power for their home.

Solar energy is the future when it comes to energy requirement of humans. About 47 per cent of the energy that the sun releases to the earth actually reaches the ground. About a third is reflected directly back into space by the atmosphere. The time in which solar energy is available, is also the time we least need it least - daytime. Because the sun's energy cannot be stored for use another time, we need to convert the suns energy into an energy that can be stored. The solar panels generate low grade heat, that is, they generate low temperatures for the amount of heat needed in a day. However this energy is highly inefficient in terms of the energy density (power/area). Therefore we need a method to ensure that the energy being cultivated is harnessed efficiently. The Sun is a star, around which Earth keeps rotating and revolving. Due to its rotation, relatively the Sun moves 360 degrees around the earth with respect to Earth. Therefore there comes the requirement of facing the Solar Energy harnessing equipment continuously to the Sun. Thus multidimensional tracker came into the picture using which we can generate large amount of energy.

With the tracker we always get many benefits but one major drawback also come along with it and i.e. energy consumed by motors. Thus to get the solution over it we focus on "a high power generation, low consumption solar tracker".

2. Solar Radiation

The rate in which the solar energy reaches a unit area on earth is called solar irradiance and is measured in Wm^{-2}. Solar radiation, on the other hand, is the quantity of solar energy that falls on a collector over a period of time, often described in Whm^{-2} or Jm^{-2}.

Before reaching the earth's atmosphere, the solar irradiance is 1367 Wm^{-2} and as it reaches the earth's surface, it is divided into 3 main components due to the reflection agents such as air quality, rain and clouds. Basically, the global irradiance is made up of combinations of direct, diffused and reflected irradiance as shown in Fig 1.

On a clear and sunny day, 90% of irradiance is accounted as direct irradiance and the maximum direct solar irradiance striking a PV surface is received when the sun's ray is perpendicular to the solar collector surface or when the solar incidence angle is 0º [6].
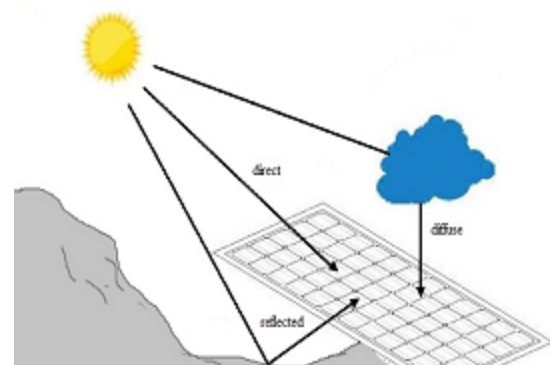

Figure 1: Solar Radiation

3. Solar Collector

A solar collector is a device used to capture the heat energy of the sun and convert it into a form more readily usable by humans.
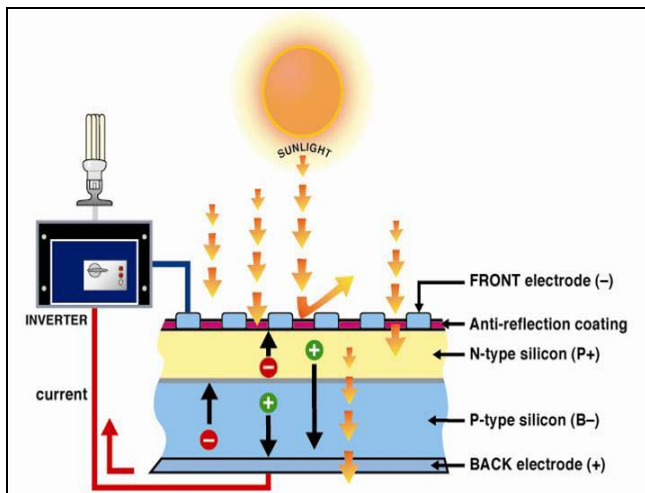
3.1 Working of PV panels

Figure 2: Working of PV panels

Essentially, when light strikes the cell, a certain bit of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. Solar PV cells also all have one or more electric fields that act to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current and by placing metal contacts on the top and bottom of the SPV cell, we can draw that current off to utilize remotely. The cells voltage defines the power that the solar cell can produce. The process of converting light into electricity is called the solar photovoltaic (SPV) effect. An array of solar panels converts solar energy into DC electricity. The DC electricity then enters an inverter. The inverter turns DC electricity into 120-volt AC electricity needed by home appliances.

4. Types of Solar Collector

Fixed mount: Domestic and small-scale commercial photovoltaic and hot-water panels are usually fixed, often flush-mounted on an appropriately facing pitched roof.

Floating ground mount: Solar trackers can be built using a "floating" foundation, which sits on top of the ground without the need for invasive concrete foundations. Instead of placing the tracker on concrete foundations, the tracker is placed on a gravel pan that can be filled with a variety of materials, such as sand or gravel, to secure the tracker to the ground..

Solar Tracker: A solar tracker is a device that tracks the sun as it moves on its path through the sky during the day, exposing your PV cells to an increased amount of sunlight and hence producing more electricity [6].

5. Types of Solar Tracker

Passive tracker: The passive trackers use a boiling point from a compressed fluid that is driven to one side to other by the solar heat which creates a gas pressure that may cause the tracker movement [3]. As this process presents a bad quality of precision orientation, it turns out to be unsuitable

for certain types of photovoltaic collectors. We call also passive tracker the photovoltaic panels that include a hologram behind stripes of photovoltaic cells. In this way, sunlight reflects on the hologram which allows the cell heat from behind, thereby increasing the module's efficiency. Moreover, the plant does not have to move while the hologram still reflects sunlight from the needed angle toward the photovoltaic cells.

Active Tracker: The active trackers use two motors and gear trains to drive the tracker, photovoltaic plant, or else, as controlled by a controller matched to the solar direction. In fact, two axis trackers are used to orient movable mirrors of heliostats that reflect the sunlight toward the absorber of a power station central. As each movable mirror has an individual orientation, these plants are controlled through a central computer system which also allows the system, when necessary, to be shut down. Types of Active tracker are single axis and dual axis.

Single Axis Solar Tracker: Single-axis solar trackers follow the sun from sunrise to sunset as it moves in the sky through the day from east to west. They are called a single-axis tracker as the mechanism only rotates in one plane around a single axis.

5.1 Types of Single axis Solar Tracker

Horizontal Single axis tracker (HSAT): The axis of rotation for horizontal single axis tracker is horizontal with respect to the ground. The posts at either end of the axis of rotation of a horizontal single axis tracker can be shared between trackers to lower the installation cost.

Vertical single axis tracker (VSAT): The axis of rotation for vertical single axis trackers is vertical with respect to the ground. These trackers rotate from East to West over the course of the day. Such trackers are more effective at high latitudes than are horizontal axis trackers.

Tilted single axis tracker (TSAT): All trackers with axes of rotation between horizontal and vertical are considered tilted single axis trackers. Tracker tilt angles are often limited to reduce the wind profile and decrease the elevated end height.

Polar aligned single axis trackers (PASAT): This method is scientifically well known as the standard method of mounting a telescope support structure. The tilted single axis is aligned to the polar star. It is therefore called a polar aligned single axis tracker (PASAT).

Dual Axes Sun Tracker: Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered a primary axis. The axis that is referenced to the primary axis can be considered a secondary axis. They are classified by the orientation of their primary axes with respect to the ground. Two common implementations are tip-tilt dual axis trackers (TTDAT) and azimuth-altitude dual axis trackers (AADAT).

Paper ID: SUB14216

81

5.2 Types of Dual Axes Sun Tracker

Tip–tilt dual axis tracker (TTDAT): A tip–tilt dual axis tracker is so-named because the panel array is mounted on the top of a pole. Normally the east-west movement is driven by rotating the array around the top of the pole. On top of the rotating bearing is a T- or H-shaped mechanism that provides vertical rotation of the panels and provides the main mounting points for the array. The posts at either end of the primary axis of rotation of a tip–tilt dual axis tracker can be shared between trackers to lower installation costs.

Azimuth-altitude dual axes tracker (AADAT): An azimuth–altitude dual axis tracker has its primary axis vertical to the ground. The secondary axis is then typically normal to the primary axis. They are similar to tip-tilt systems in operation, but they differ in the way the array is rotated for daily tracking. Instead of rotating the array around the top of the pole, AADAT systems typically use a large ring mounted on the ground with the array mounted on a series of rollers. The main advantage of this arrangement is the weight of the array is distributed over a portion of the ring, as opposed to the single loading point of the pole in the TTDAT.

Solar Power Technologies: There are several kinds of solar techniques that are currently available. However, each of them is based on quite different concepts and science and each has its unique advantages. Analysis and comparison between different technologies will help us to adopt the most efficient and beneficial technology given a specific set of conditions.

There are main three solar power technologies and those are listed below:
1. Photovoltaic (PV)
2. Concentrated Photovoltaic (CPV)
3. Concentrated Solar Power (CSP)

Photovoltaic Solar panel: Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Photovoltaic solar panel is the most commonly used solar technology to generate electricity energy.

Concentrated Photovoltaic (CPV): Concentrated photovoltaic technology uses optics, such as lenses to concentrate a large amount of sunlight onto a small area of solar photovoltaic materials to generate electricity. CPV systems are categorized according to the amount of solar concentration, measured in *suns* (the square of the magnification).

Concentrated Solar Power (CSP): Concentrated solar power systems use mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electrical power is produced when the concentrated light is converted to heat which drives a heat engine (usually a steam turbine) connected to an electrical power generator.

Photovoltaic Solar Panels and Concentrated Solar Power Systems:

Table 1: compares the PV and CSP energy technologies

Characteristics	PV	CSP
Use	Direct & diffuse sunlight	Direct Sunlight
Size	From Watt to MW	10MW to a few hundred
Installation	700-2000 full load hours	2000-7000 full load hours
Reserve Capacity	External	Internal
Proofed life time	>20 years	>20 years

6. To generate maximum power using multidimensional sun tracking model with low power consumption.

Design Approach

Any sun tracking model get designed mainly using two approaches:
1. Using sensor devices known as "closed loop system" to keep track of the sun
2. Using astronomical position of the sun

Drawback of conventional sensor based system or closed loop system:
1. Power is wasted in driving motor forward & backward specially in mode searching during overcast skies.
2. Additional equipments are also required for motor movement thus it becomes complex.
3. These drawbacks are overcome by open loop system which provides following advantages.

Advantages of open loop system:
1. Predetermined mathematical calculation of the sun movement.
2. It is Independent of weather.
3. Power is saved in driving motor.
4. Hence less complex.

Solar Tracking
Consequently, the main objective of solar tracking is to minimize the incidence angle thus maximizing the solar irradiance received. For that reason, the solar tracker follows the sun accordingly to maintain the incidence angle to ideally 0°.

Solar Path
The sun's location in the sky corresponding to a location on the surface of the earth can be specified by two angles; the altitude angle and azimuth angle. The altitude angle is defined as the angle from the horizon of the observer to the sun, perpendicular to the horizontal plane. The value is 0° at sunrise and sunset while it is negative before sunrise and after the sunset. The maximum value of altitude angle is at noon, but is not necessarily 90°. The altitude angle at noon varies according to the given days in a year and given locations.
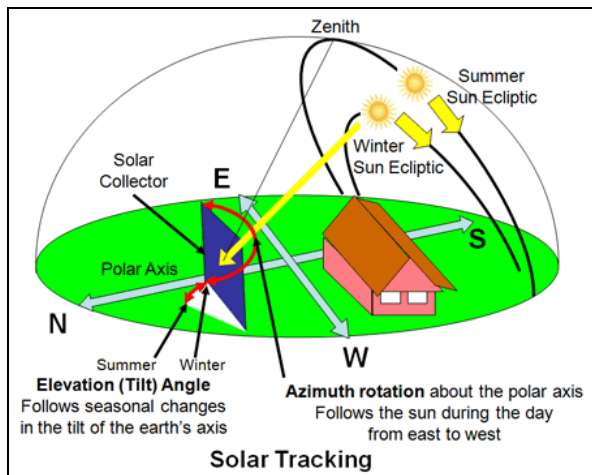
Paper ID: SUB14216

82

Figure 3: Solar Path

Solar Tracker

In order to reduce the power consumption of a solar tracking unit, the weight of the solar tracker structure needs to be minimized. Therefore, the solar tracker was designed from easily available hollow aluminium forms, not only to reduce the power consumed but also the overall cost of the whole system. The simplified design of the structure, the electromechanical wiring and programming are described as follows.

Design

The design of the solar tracker incorporated several distinctive features: easy to assemble and dismantle, lightweight and manually portable. A small DC motor was placed at the edge of circumference to only rotate the base but not to carry the whole load. The simplified structure of the solar tracker is shown in Figure 3, where the cylindrical base is able to rotate 360º, clockwise and counter clockwise for azimuth tracking, and the upper part holding the solar panel is able to rotate up and down within a 90º arc.
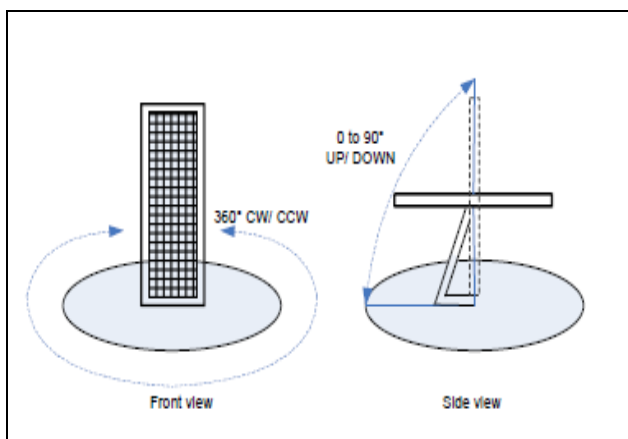

Figure 4: Simplified Structure

Electromechanical Component

In this proposed system, a Programmable Logic Controller (PLC) was used in the programming of the actuators' movements. The input and output points of the PLC are connected electromechanically and the simplified system structure is shown in Fig 5. Since the input points of the motor shares the same point for forward and backward movement of the motors, the program is made to interlock; consequently, the motor moves in only one restricted direction at one time, for security reason. The program controlling the power supply of the motors was written based on a precalculated altitude and azimuth angle from a year's analysis. The power supply of the motor was adjusted using a speed controller circuit to a rate where the solar panel unit followed the sun by moving only one degree at one-minute intervals, on its axis. Simultaneously, the cylindrical base motor's speed was also timed to move the base in tandem with the panel unit. Thus, the entire device is able to achieve the axis, altitude and azimuth tracking of the sun [1].
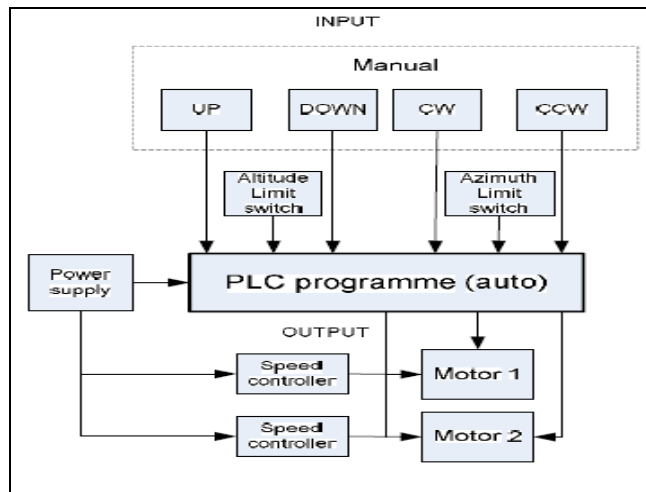

Figure 5: Proposed System

Programming

The programming of the tracker was made to follow closely the movement of the sun. For different times in a day, the solar tracker moves at varying intervals for several seconds, depending on the pre-calculated angular movement of the sun. The time gap between one movement and the next varies, where during the morning and afternoon, the gap is bigger, whilst the gap is narrower during noon. The programming uses a counter for repeated time-gaps. The same programming approach applies to the axis, altitude and azimuth controlling motors. The rotation of clockwise and counter clockwise motor also differs based on the time of day and the day in a year. For the altitude controlling motor, the motor moves the panel up during morning from sunrise up till noon, and moves it back down to the original position for sunset. At the same time, the bases rotates clockwise or counter clockwise for azimuth tracking. The simplified program flowchart is demonstrated in Fig 6 .
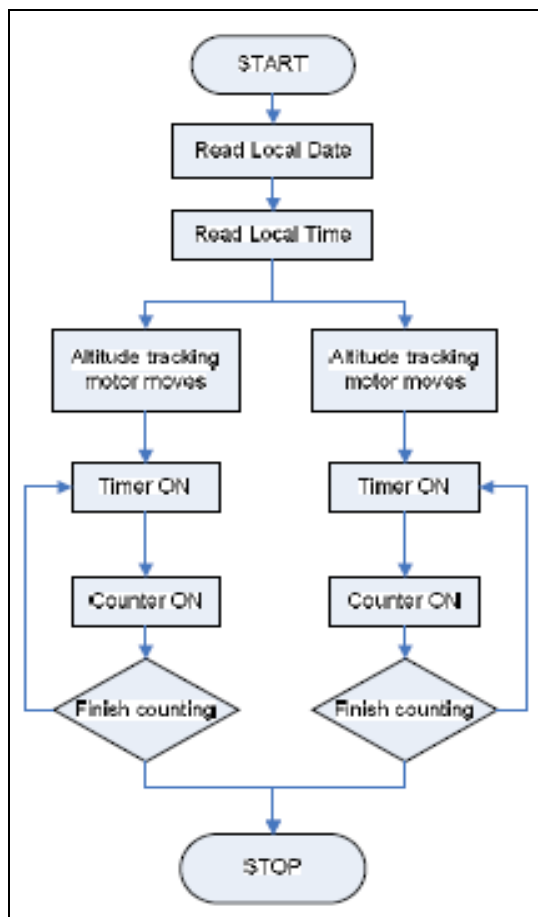
Figure 6: Programming Flowchart

7. Power Consumption Of Tracker

As this is an open-loop tracking system, the power consumption of the tracker can be easily calculated since the movements of the actuator is dependent on the program and not on the weather. The calculated total energy consumed in a day is calculated based on following equation.

Energy (E) = Voltage (V) × Current (A) × time(s)

Altogether, the power consumption of the actuators was very low; small differences in the amount of movements daily did not affect the total daily power consumption of the whole tracking system. Based on calculations, the power consumed for altitude tracking and azimuth tracking for one day is when added, the power consumption of the tracking motors is only 0.05% of the power generated from a clear and sunny day. However, the power consumption of the controller is high with a 5.84% of the power generated on a sunny and clear day. Overall, the total power consumed for the tracker is 5.89% of the power generated on a sunny and clear day. Further table is showing results of power feasibility for tracking and non-tracking [1].

Table 2: Power feasibility

	Power consumption (Wh)		Power generation (Wh)	
	tracking	Non-tracking	tracking	Non-tracking
Sunny and mostly clear day	8.72	-	147.90	61.49
Cloudy day	8.72	-	70.18	27.83
Severe overcast and rainy day	8.72	-	15.89	10.80

8. Conclusion

In conclusion, from the overall study, it can be seen that the power consumption of the driving systems for this tracking system is very low and constant in all weather conditions. Despite, the superior design that contributes to the low power consumption of the solar tracker, the system can be further improved if the tracker carries two PV modules at the same time and the controller is substituted with a lower powered controller. This will significantly enhance the power generation and reduce the total power consumption and also power technologies say that PV will remain dominant in the distribute market i.e At the distributed level, low operating and maintenance costs will likely be determinative. Unless CSP technologies can match those of PV, the distributed market will be tough for CSP technology to penetrate. And the PV industry's scale and ability to serve more markets than CSP

References

[1] Salsabila Ahmad, "A High Power generation, low power consumption solar tracker", pp 366-371,IEEE International conference on power & energy (PECon), December 2012.
[2] S. Ahmad, M. Z. A. A. Kadir, S. Shafie, "Current perspective of the renewable energy development in Malaysia", Renewable and Sustainable Energy Reviews, vol. 15, pp. 897-904, 2011.
[3] Ahmed Rhif, "A Position Control Review for a Photovoltaic System: Dual Axis Sun Tracker", pp 479-485, IETE Technical Review, Vol 28, Issue 6 , Nov-Dec 2011
[4] C. Sungur, "Multi-axes sun-tracking system with PLC control for photovoltaic panels in Turkey," Renewable Energy, vol. 34, pp. 1119-1125, 2009.
[5] N.A. Kelly, T.L. Gibson, "Improved photovoltaic energy output for cloudy conditions with a solar tracking system," *Solar Energy*, vol. 83, pp. 2092- 2102, 2009.
[6] http://en.wikipedia.org/wiki/Solar_tracker
[7]] http://www.greentechmedia.com/

Author Profile

Snehal Patil is a PG Student, VIT, Wadala. B.E, Mumbai University, Maharashtra, India

Rajendra Patil is serving as Sr.Lecturer, S.H.J.P. MSc (Physics with Electronics), Pune University, Maharashtra, India