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Solar tracker

Mithilesh Rai
mithileshrai.mithi@gmail.com
ABES Engineering College, Ghaziabad, Uttar Pradesh

ABSTRACT

The renewable energy source is a non-depleting energy source, which is abundantly present in our climate. At present, the existing research areas are focused on renewable energy sources. This source of energy is clean and pollution-free. The only significant problem associated with this is its performance and profitability. We come across several solar panels every day. Those panels are fixed. We took this further on with tracking devices to solar panels. These solar tracking devices come in fixed structures with a single axis and dual axis. The Dual-axis tracking mechanism is quite effective as it is capable of capturing more irradiance than the other. These are capable of shifting the system in various co-ordinates of latitudes and longitudes according to the position of the sun. Fixed axis devices are capable of capturing the maximum intensity of the sun for one particular moment throughout the day when the sun is at zenith. These trackers are powered by small solar cells that provide motion to the panel according to the location of the sun. Also, it is not recommended to use solar trackers with small PV arrays because of the energy consumption of the driving systems, which vary from 2% to 3% of the energy increase delivered by the solar trackers. This paper intended to review different solar tracking system that increases the solar power output. A solar tracking system, using a photovoltaic device to monitor the changing solar position, is disclosed. The photovoltaic device is automatically overridden when the sun ceases to be the brightest point in the sky, for instance during times of partial cloud cover, and the machine attempts to attain the brightest spot in preference to the sun. The override system is clock-driven and moves the tracking system to approximate the solar position so that when the sun re-energizes as the brightest object in the sky, the photo-voltaic device can immediately reacquire the sun.

Keywords: *Solar Device, Tracker, Renewable Energy Harvesting*

1. INTRODUCTION

Nowadays, the world researchers are always finding sources of energy that are clean, renewable, pollution free and have no effect on global warming. Solar energy is among the sources of energy that contains all the above qualities. Moreover, solar energy is abundantly available almost worldwide, so far the efficiency of generating electric energy from solar radiation is low, because solar beam used to change direction with respect to time a day and also based on the season. Thus, increasing the efficiency of generating electric energy from the solar radiation becomes very important issue.

The power from the sun intercepted by the earth is approximately 1.8*1011MW, which is many thousands of times larger than the present consumption rate on the earth from all other in-use commercial energy sources. The main problem with the solar energy is its dilute nature. Even in the hottest regions on the earth, the solar radiation flux available rarely exceeds 1 KW/M, which is insufficient for technological utilization. This problem can be rectified by a device solar tracker which ensures maximum intensity of sun rays hitting the surface of the panel from sun-rise to sunset.

The Earth's orbit about the Sun is almost circular at an average distance of 149.6 million km. The Earth's axis of rotation is tilted by an angle 23.441° with respect to the normal to the plane of the Earth's orbit . The plane of the Earth's orbit is named as the plane of the ecliptic. The plane passing through the Earth's equator is inclined perpendicularly to the plane of the ecliptic, at an angle Ɛ (angle of obliquity). Based on conservation of angular momentum, the Earth's axis of rotation points as a fixed direction in space which means for the same location on Earth, at a fixed time (for midday as determined by solar time), the altitude of the Sun (the angular height above the horizon) will vary throughout the year.

The daily rotation of the earth is described by the rotation of the celestial sphere about the polar axis, and the instantaneous position of the sun is given by the hour angle ω, the angle between the meridian passing through the sun and the meridian of the site. The celestial sphere is imagined to rotate about the fixed Earth to depict the daily, apparent motion of the Sun and other celestial bodies.

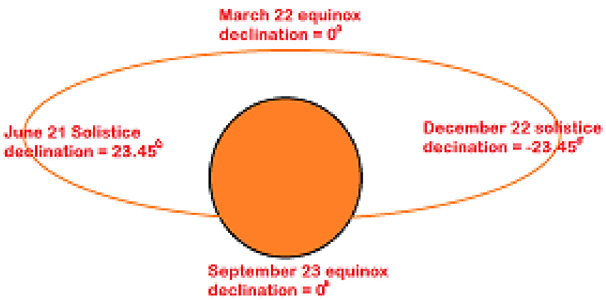
Our solar tracking system is based on NASA's sun-skimming Parker Solar Probe which uses sensors at the rear of the probe to maneuver the craft to keep sunlight from peeking around the sides of the shield. This design simplifies that scheme even more, by using solar cells as the four sensors. Mounted behind a solar shade, the cells are connected directly to small gear motors which control azimuth and elevation. When a cell sees the light, the motor that pushes the panel is driven the correct way to re-occlude the light, thus cutting power to the motor. You might see the obvious problem of what happens when the sun rises, and the array points the entire opposite direction after the previous sunset, but we're still not sure that his solution will work – a larger array of tracking cells mounted further apart. Also, we 're not sure how it will scale up to larger arrays that need bigger motors. Of course we've seen such arrays handled with more complicated trackers, but we hope this design's simplicity can be made practical for real-world use.

Nasa Solar Probe With Solar Trackking Device

2. THE NOMENCLATURE

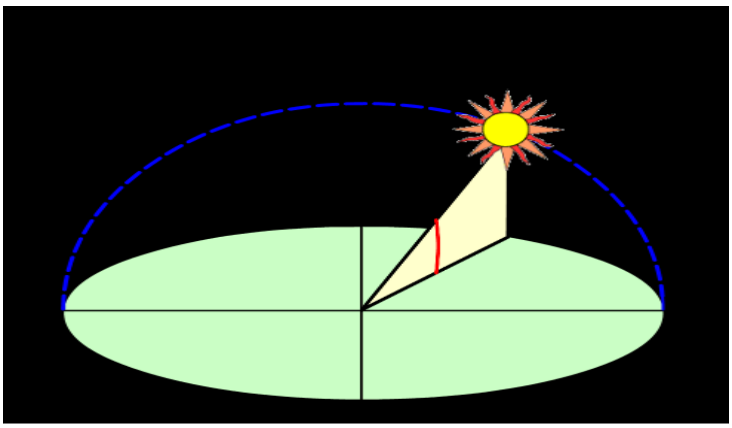
2.1 Declination angle (δ)

It is the angular distance of the sun's position in north or south of the earth's equator . The earth's axis is tilted 23.34° from the plane of the earth's orbit around the sun and the earth is in its annual path around the sun causes the declination angle to vary from 23.45° north on December 21st (Winter Solstice) to 23.45° south on June 21st (Summer Solstice). The angle of declination varies seasonally due to the Earth 's tilt on its rotation axis, and the Earth's rotation around the sun. If the Earth were not rotated to its rotational axis, the fall will still be 0 °. The Earth is however tilted by 23.45 ° and the angle of decline varies plus or minus that amount. Also at the equinoxes of spring and fall is the angle of declination equal to 0 °. The Earth's rotation around the sun and the difference in the angle of declination are seen in the illustration below.



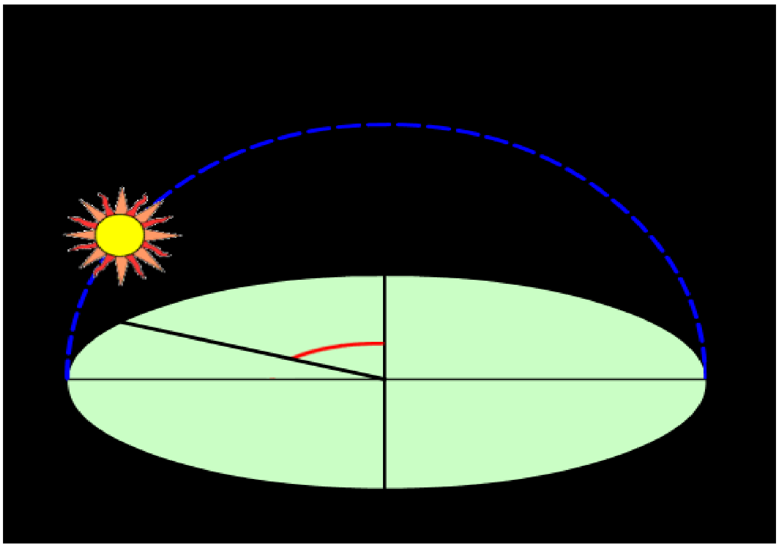
2.2 Elevation angle (α)

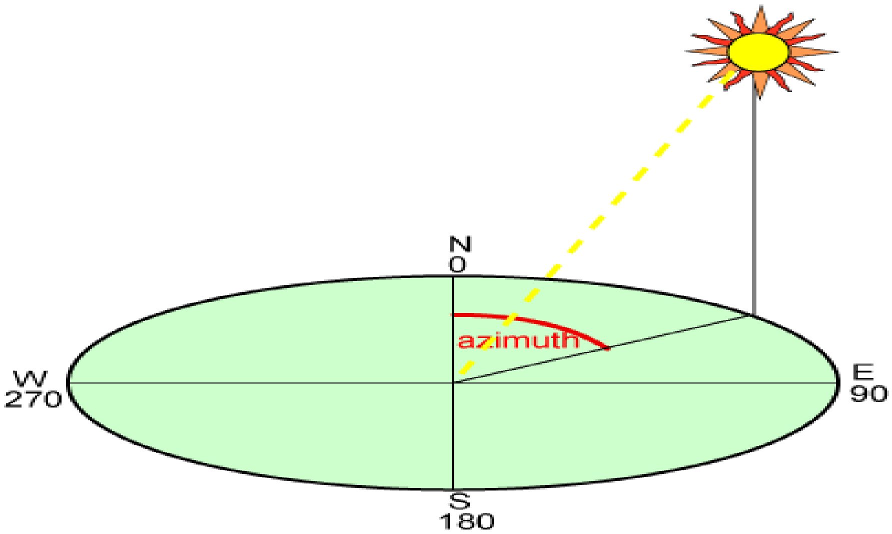
It shows how high the sun appears in the sky. The angle is measured between an imaginary line between the observer and the sun and the horizontal plane the observer is standing on. The altitude angle is negative when the sun drops below the horizon. The angle of elevation (used interchangeably with angle of altitude) is the angular height of the earth, estimated from the horizontal in the sky. Confusingly, they also use both altitude and elevation to describe the height in meters above sea level. The elevation is 0 ° at sunrise and 90 ° when the sun is directly overhead (which happens at the equator on the equinoxes of spring and fall, for example). The elevation angle varies throughout the day. It also depends on the latitude of a particular location and the day of the year. The maximum elevation angle occurs at solar noon.



2.3 Solar azimuth angle (ϒs)

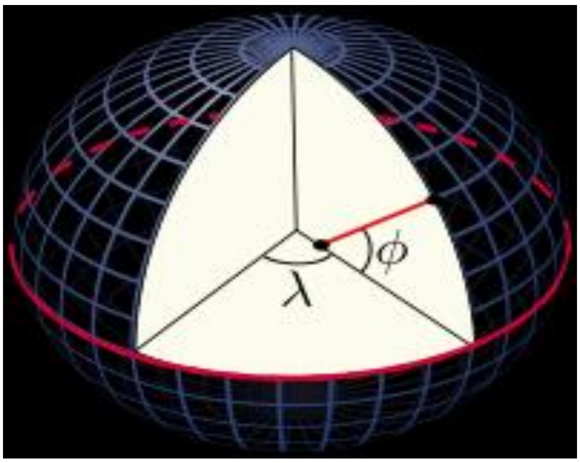
It is the angular distance between South and the projection of the line of sight to the sun on the ground. A positive solar azimuth angle indicates a position East of South, and a negative azimuth angle indicates West of South. The angle of azimuth is the direction of compass from which the sunlight is coming. At solar noon, the sun in the northern hemisphere is always directly south, and in the southern hemisphere is directly north. The angle of azimuth varies over the day, as seen in the illustration below. The sun rises directly east at the equinoxes and sets directly west irrespective of the latitude, rendering the azimuth angles 90 ° at sunrise, and 270 ° at sunset. Nevertheless, in general the angle of azimuth varies with the latitude and time of year.





2.4 The latitude (w)

It is a point or location is the angle made by the radial line joining the location to the center of the earth with the projection of the line on the equatorial plane. The earth's axis of rotation intersects the earth's surface at 90o latitude (North Pole) and -90o latitude (South Pole). Any location on the surface of the earth then can be defined by the intersection of a longitude angle and a latitude angle.



2.5 ZENITH Angle

The angle of zenith is the angle between the sun and the vertical dimension. The angle of the zenith is similar to the angle of elevation but is measured from the vertical rather than the horizontal angle.

3. IDEOLOGY FOR THE TOPIC

Sunlight has two elements, the direct ray carrying around 85% of the solar energy, and the diffused ray carrying the rest.

The blue sky is a dispersed part on a clear day, And a bigger share of the total on rainy days. A tracking system has the function of watching the Sun as it moves through the sky and harness the energy it generates. A great deal of work is aimed at improving surface materials to direct maximum energy into the cell and mitigate reflective losses

4. CALCULATION OF THE ANGLES

Elevation angle = E
Latitude of location = L
Declination angle = D
ZENITH Angle= Z

$$E = 90 + L - D$$

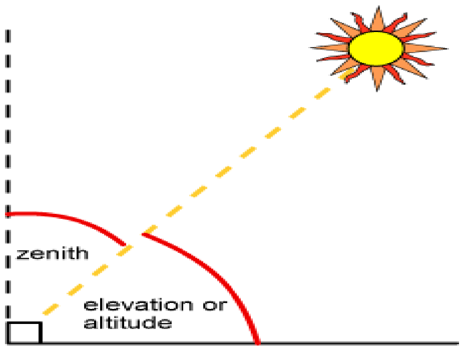
In above equation if the angle comes greater than 90 degree then subtract the angle by 180 and resultant will come. It means the sun at solar noon is coming from the south as is typical the northern hemisphere. On the summer solstice at the Tropic of Cancer the sun is directly overhead and the angle of elevation is 90 °. During summer, the elevation angle at the solar noon at latitudes between the equator and the Tropic of Cancer is greater than 90 °, meaning that the sunlight is coming from the north rather than from the south, as in most of the northern hemisphere. Likewise, at latitudes between the equator and the Capricorn Tropic, sunlight is incident from the south, rather than from the north, for certain times of the year.

Elevation angle can also be found by using the formula

$$E = \sin^{-1}\{ \sin(D) \sin(L) + \cos(D) \cos(L) \cos(HRA) \}$$

HRA is hour angle

$$Z = 90 - E$$



Azimuth angle can be calculated as

$$AZIMUTH = \cos^{-1} [\{ \sin(D) \cos(L) - \cos(D) \sin(L) \cos(HRA)\}/\cos(E)]$$

The above equation only gives the correct azimuth in the solar morning so that:

Azimuth = Azi, for LST <12 or HRA < 0

Azimuth = 360° - Azi, for LST > 12 or HRA >0

5. CALCULATION FOR SUNRISE AND SUNSET

$$SR = 12 - \frac{1}{15^\circ} \cos^{-1}\left(\frac{-\sin L \sin D}{\cos L \cos D} \right) - \frac{TC}{60}$$

$$SS = 12 + \frac{1}{15^\circ} \cos^{-1}\left(\frac{-\sin L \sin D}{\cos L \cos D} \right) - \frac{TC}{60}$$

TC → TIME CORRECTION

6. SOLAR POWER IN INDIA

***case study*:**

6.1 Adani Group of Green Energy, India

Two and a half million solar modules swimming in more than 2500 acres of land with 8,500 pairs of hands at work during the peak of the project, putting up an ambitious display of the finest in solar technology.

The robotic system does not use any sort of water or electricity; while racing towards a tight deadline managing the engineering procurement, project management and site construction in such a short span a huge challenge.

6.2 Initial Planning & Idea

Earlier this project, largest solar power plant at a single location was in California in the U.S. , that was completed in around three years

Planning was made for taking precautions during a partial solar eclipse. Aiming to make one of the world's largest solar power plants in a single location in an unassuming part of southern India , 648 megawatts of clean green electricity is generated and exported to the South Indian state of Tamil Nadu from March 31st 2016 and putting this massive solar power plant together on time is a team of dedicated and energetic engineers contractors and personnel at Adani one of India's leading infrastructure conglomerates An inside look at a mega structure that is India's solar power house :

Sun has always been radiating light in beauty but never before has its power been harnessed the way it has been in the 21st century and now more than ever with depleting fossil fuels worldwide the Sun takes centre stage. Since India is one of the fastest growing economy and energy is a crucial part for economic development thus huge demand for energy has led to vast utilization of nature of the subject to meet the surging demand.

Solar energy is the best forms of energy. Energy from Sun is free nowadays it's sporting airports kitchens and planes and this is going to the future. The country is taking long and fast rides towards a national goal of becoming one of the world leaders and solar power generation by 2022 India.

Prime Minister Narendra Modi stated under the Paris Climate Agreement about India's commitment to the creation of 175 GW renewable energy capacity by 2022 :

"*AMBITIOUS TARGETS HAVE BEEN SET BY 2030. WE WILL REDUCE , EMISIONS FROM 33 TO 35% OF 2005 LEVELS AND PRODUCE 40% OF OUR POWER FROM NON-FOSSIL FUELS. IT REQUIRES A GLOBAL PEOPLE'S MOVEMENT TO BRING ABOUT SUCH CHANGE* "

That's a huge energy commitment especially as India is generating only around one-fifth of its goal right now with some 36 gigawatts of renewable power generation. Out of this only 4060 megawatts of the power generation comes from solar a number India wants to inflate to 100,000 megawatts by 2022 or powering nearly 60 million Indian homes.

6.3 Land Requirement & Availability

As a solar power producer land requirement is huge and land is a difficult task in a country like India which is highly populous. the solution lay near the South Indian city of Madurai and Tamil Nadu which is home to a unique structure that has captured the imagination of pilgrims and tourists alike. Some 90 kilometers away from Madurai in a little-known town called Kamuthi , arises a mega structure that has the potential to be monumental in its own way.

6.4 Land Selection

For such a mega-sized solar power plant , huge patch of land requirement is crucial for good solar radiations and the proximity with port for logistics purpose and all this was found at Kamuthi in Tamil Nadu and this was the beginning. ADANI group claimed to generate a maximum of 648 megawatts of power making it one of the world's largest single location solar power plants. India as a tremendous scope of generating solar energy and it is high tide to concentrate more on conservation of resources. Solar radiation is one of the most important factors in power generation. Solar irradiance is the measure of the amount of sun rays that falls on the surface. A happy problem of plenty in a country like India which basks in the Sun for around 300 days a year which is found in abundance in this District of Tamil Nadu.

At Kamuthi in July 2015 , the total land allocated for this project was 2500 acres. Over time the company had acquired the land needed for the project. Once the land was acquired it was all hands on deck with design and execution powering through simultaneously at Kamuthi.

6.5 Initial Setups

Initial planning included grasping all the infrastructure facility and to build a huge site office and the illumination facilities. One of the initial challenges in a remote agrarian non-industrial town like Kamuthi was sourcing manpower and equipment .Nearest town being Madurai, 90 kilometers away from site for providing machines and vehicles. The first load of containers arrived from China , with solar modules and module mounting structures with critical components like inverters that would need closed warehouses.

6.6 Conceptual Analysis and Automation

Solar energy works on a simple principle the sun rays fall on solar cells which convert sunlight into electricity. When sunlight hits the surface of a panel it excites electrons in the cells and they start to flow out as direct current. The direct current gets converted to alternating current using inverters and finally in most cases this clean and renewable form of energy gets exported to the grid on a large scale.

With a geographically spread installations managing the system manually could be difficult, thus needed an automation system which can provide information and allow controlling of operations for the spread out installations. For real time visualization and evaluation, the system utilized for such a widespread installation is called SCADA. In this particular supervisory control and data acquisition system or SCADA was installed for a particular feature. Internally called the control philosophy, this feature was allowed for limits to be set remotely on power generation depending on the grid requirement on an given day instead of field engineers being set on-site to turn down inverters according to the grids demand. For building a very huge solar plant of a scale of 640 megawatt power, the fluctuation in any solar plant will actually be affecting the grid operations, so in that case the grid operations are desired to maintain the power of the plant at a fixed output. Thus the need of SCADA is justified.

6.7 Constructional Analysis

Piles are structures made of steel that eventually support the all-important solar module. Almost 400,000 piles were laid on site with several contractors brought up to speed on standard operating procedures to make the perfect pile. It is important to ensure that the piles pass a pull-out test. A pressure of 1200 kilograms per square centimetre is applied to the pile and if it stays put in place it passes the test; an indication that the pile can survive high wind speeds and any other force of nature.

Eventually two and a half million modules were to be rested on tables of galvanized steel (around 30,000 metric tons), the panels alone occupying an area of 1270 acres. These module mounting structures or MMS were grouped into tables with a specific capacity. One table generated almost 50 kilowatts of peak electricity.

The entire 648 megawatt plant was made up of clusters of modules of 4 to 5 megawatts each and inverters are a link to the solar modules.

An inverter’s job is to convert direct current into alternating current and 144 pre-engineered buildings were made just to house the 576 inverters required for this plan. Project to gets completed within schedule and within the budget were the main parameters for measuring the success of the project.

The port at Tuticorin ,110 kilometers away from the site was a crucial part of the operations as this port received more than six thousand containers from all over the world including countries like China Japan Malaysia Taiwan Israel Italy Germany Turkey and Switzerland.

6.8 Cleaning and Maintainance

Typically in a power plant the output depends on the radiation level on a given day. this project was spread over an area of 2500 acres so many a times ,one small part of this area had a cloud cover, so generation in that part was affected momentarily. If not cloudy or rainy day, electricity generation could take a hit if modules were dusty .Luckily solar power plants are relatively easy to maintain.

An average photo voltaic cell may last 25 years or more if cleaned the module regularly. In Kamuthi what would otherwise have been a manual and water intensive job, was then been mechanized with state-of-the-art robotic technology from Israel. Robot was powered by a soft panel that charges during the day units on batteries; it would be cleaned every evening with waterless cleaning technology for semi-arid dry regions like Kamuthi where water is a scarce resource.
This robotic solar panel cleaning system uses soft microfiber on wheel that push dust off the modules. The robotic system was remotely monitored, managed and controlled.

6.9 Project Completion and Success
With renewable energy it's always a two-way street. A solar power plant operates on the principle of generation while the Sun shine, and at sun down solar power production stops.

Unlike an off-grid system that stores power and batteries and kicks in when there is no electricity ,a power plant like this is what is called a grid interactive stroller power plant. Finally the nation achieved the unachievable 648 megawatt solar power plant which is a big pride for all of us

As of 2013 around 1.2 billion people around the world have little or no access to electricity and more than 20% of that population lives in India. This solar power plant has lit up the lives of millions of people and is a baby step towards the company's next target setting up a solar park

In the year 2022 India will celebrate 75 years of independence .the present government has a vision to provide 24/7 affordable environment-friendly power for all by 2022. In plants like these are fast helping bridge the demand supply gap in the nation.

6.10 Errors
There are different types of errors that may result in the energy loss from the solar cell. These losses are:
a) **Reflective Losses:** The reflectivity of incoming light depends on the polarization of the incident light and it increases as the incident angle increases (Brewster's Law). These losses increases a lot when there is no tracking device. A panel can receive the direct beam of the area of 75 degrees from either side of the normal of the panel. In the morning and in the evening that is during the sunrise and the sunset time, approximately 65%-70% energy is lost.
b) **Temperature losses:** As the incident direct rays increases the intensity of incoming radiation, the heat generated also increases and thus this results in the increase in the loss due to temperature increase (approx. 0.4%/K).
c) **Seasonal losses:** As the season changes from summer to winter to rainy, the cloud keep son increase and this results in the increment of more diffuse light and less direct light which results in the decrement of heat generation and thus the solar panels are unable to generate enough energy.

6.11 Key Highlights
1) Trackers sum up machine costs and maintenance. When they add 30% to the cost and improve the efficiency by 30%, the same value can be accomplished by making the machine 30% bigger, removing additional maintenance.
2) Tracking can cause problems with shading, too.
3) As the panels shift over the course of the day, it is likely that they can shadow each other due to profile angle effects, if the panels are placed too close to each other.
4) Single axis tracking systems are still vulnerable to instability at relatively moderate wind speeds

6.12 Working of the Tracker and its Advantage Over Other Existing Trackers
Sun trace a complex path. It traverse east-west during daily basis where as north-south during seasonal yearly basis. This variation throughout the year gives rise to the difficulty in tracking algorithms which eventually require a micro-controller for calculating

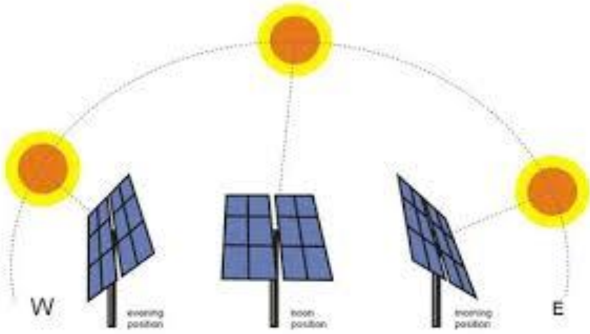
the formulae using the date/time and the geographical information. The total energy available that can be interpret by the panel. The overall intensity can be calculated by making the product of Area of panel with the cosine of incident angle. This is very similar to the Lambert's law. Thus the existing trackers that are horizontal dual axis trackers require Drives, Sensors, Sensors controlled, Motor and Motor controller, Micro-controller.

In our solar tracking device we have eliminated the microprocessor thus a major cost is reduced because these microprocessors require several algorithms for tracking sun thus they are very expensive. Our tracking device will be following the sun just by tracking the sunlight with the help of 4 small PV cells that will act as sunflower leafs. The working of tracking device is simplified and thus the cost is reduced. This tracker will be used in small scale panels because the motors will work with the help of the small PV cells and as those PV cells will give very small energy thus heavy power can not be generated.

6.13 Analysis

The amount of output mainly depends on the cosine angle of incidence (the angle between the rays of and the horizontal surface) gives the amount of output. To achieve max power output , minimum incidence has to be provided. During mid-noon , sun is normal to surface , providing maximum angle of incidence and thus maximum power output. Afterwards the angle tends to decrease , causing decrease in the power output. Thus the efficiency of the solar plate varies throughout the day.

The issue with efficiency can be resolved with the application of a solar tracker. The first mechanical solar tracker introduced by Finster in 1962. After this many inventions were sought to bring about the control of the movement of the plates.
Solar tracking system can be classed into two categories namely.

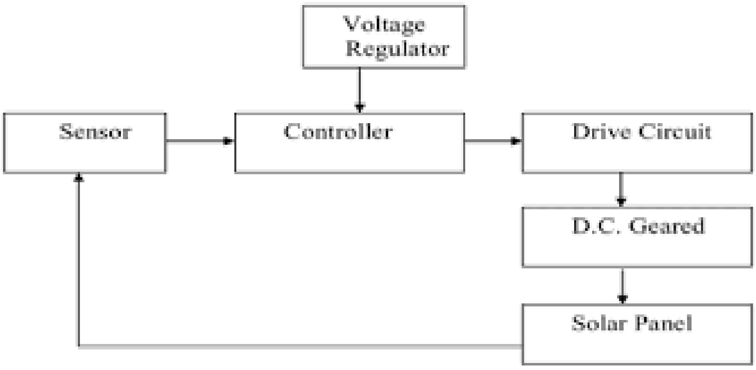


7. CLASSIFICATION BASED ON NATURE OF MOTION

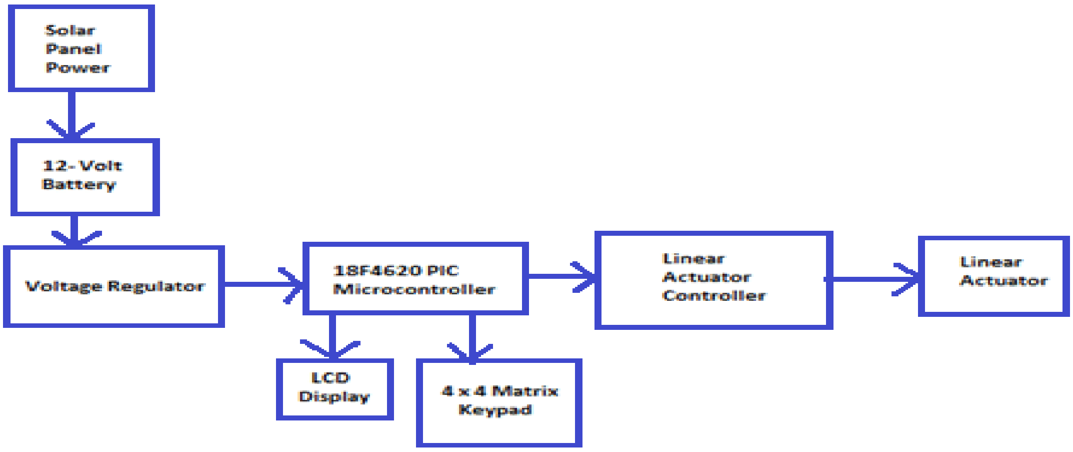
- **Passive (Mechanical/Chemical) Solar Tracking System**: This system uses the idea of thermal expansion of materials or a low boiling point compressed gas fluid driven to one side or the other as a method for tracking. When the panel is perpendicular with the sun, the two sides are at equilibrium. Once the sun moves, one side is heated and causes one side to expand and the other to contract, causing the solar panel to rotate.
- **Active (Electrical) Solar Tracking System**: These systems make use of motors and gear trains for direction of the tracker as commanded by the controller responding to the solar direction. The position of the sun is monitored throughout the day. When the tracker is subjected to darkness, it either sleeps or stops depending on the design. This is done using sensors that are sensitive to light such as LDRs. Their voltage output is put into a micro-controller that then drives actuators to adjust the position of the solar panel.

8. CLASSIFICATION BASED ON FREEDOM OF MOTION

1. **Single Axis Tracking System**: These trackers have one degree of freedom that act as the axis of rotation. The axis of rotation of single axis trackers is aligned along the meridian of the true North. With advanced tracking algorithms, it is possible to align them in any cardinal direction.



2. **Dual Axis Tracking System**: These systems have two degrees of freedom that act as axes of rotation. These axes are typically normal to each other. The primary axis is the one that is fixed with respect to the ground. The secondary axis is the one referenced to the primary axis.



Bases on the dual axis tracking device , the solar tracker is made as it follows the sky , like a sunflower. Instead of using light sensors , tiny solar panels could be used to run small electric motors directly. Any tiny solar panel that receives the sunlight, generates enough electricity to power up the attached geared motors attached to each tiny panel . These geared motors rotates to the swiveling amount until the tiny solar panels are back into shade (behind the main solar panel) , causing the motors to turn off. There will be two geared motors , one for side-to-side movement of the device and other for up-down movement of the panel. Each motor is connected to two solar panels wired in opposite configuration so that motors spin in one particular direction when any one of the smaller panel is exposed, i.e. the smaller panels are wired to the motor with opposite polarity.

Complete setup is fixed such that the main solar panel can completely cover up the four tiny solar panels behind it . when the device is completely aligned with the sun, getting the maximum intensity.

As soon the sun moves a certain distance out of line, the shadow moves with it , tiny panel gets exposed, and tracker will adjust. As the day ends and sun sets in the WEST, the solar panel stays facing WEST throughout the night.

As the sun sets to rise again the next day , from the opposite direction(EAST) ,sun-rays would be falling at such an obtuse angle that tiny panels would not receive the rays , thus preventing the motors to adjust and incline the device towards sun.

This can be mitigated by making whole setup larger in diameter so that the tiny panels are further apart.

Thus sun-rays would not find it difficult to fall on any one of the panel. Due to this, this design works even better , the larger it is made.

Another issue would be sun-rays falling on all the panels at once , causing it difficult for adjustment. Solution is to put a vertical sun shade between opposite tiny panels thus allowing sun-rays to fall on any one side of panel at once.

9. CONCLUSION

Power developed by solar panels are less than that produced with the application of solar tracker. Solar systems which track the changes in the sun's trajectory over the course of the day collect a far greater amount of solar energy, and therefore generate a significantly higher output power. The use of solar tracking systems can boost the collected energy from the sun by 10% to 100% at different times of the year and under different geographical conditions . From the review work done in this paper, the solar tracking system can either be passive or active solar tracking system, among which active is made to track the sun trajectory in dual axes. The result revealed the solar system with tracking is more efficient compared to that fixed solar system. Furthermore, dual axis tracking system is also more efficient than single axis tracking system due to the fact that dual axis tracking system have ability to track the solar irradiate on both axes.

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