Project S

By

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STEPS INVOLVED FOR CONVERTING YOUR IDEA TO A WORKING PROTOTYPE

1. Designing and development of the reflector frame and attachment of aluminium mesh.
2. Ordering of the Solar panel.
3. Procuring material for the linear movement of the reflector (DC motors, threaded shaft with nut, ball bearing with housing and guideways).
4. Developing and constructing the reflector support and its movement system (Electromagnetic braking motor).
5. Assembly of the different subcomponents of the prototype.
6. Algorithm and coding of the Arduino Uno R3 microcontroller.
7. Measuring values for the efficiency, voltage, wattage, and energy density over the duration of 10 days (per hour time steps).
8. Plotting the graph for the efficiency, voltage, wattage, and energy density with respect to time (in hours) for the measured period.

OBJECTIVE

The projects' aim is to create a unique design that would facilitate *increased incident radiation by the use of a novel auxiliary reflector design thereby, increasing the efficiency* of the solar plant system.

INTRODUCTION

WHY SOLAR?

Global warming and the drive to minimise greenhouse gas emissions has put the focus on how to make the most of natural energy sources. The sun and the wind are freely available almost everywhere in the world and electric actuators can help improve the utilisation and efficiency of these sustainable sources of energy.

Solar tracking is an obvious way to improve the efficiency of solar power plants. As the sun moves across the sky an electric actuator system makes sure that the solar panels automatically follow and maintain the optimum angle in order to make the most of the sunbeams. But its shiny metal is not free from rust.

WHAT ARE THE TYPES OF SOLAR POWER TECHNOLOGIES?

There are three main Solar Power Technologies:

- Photovoltaic (PV)
- Concentrated Photovoltaic (CPV)
- Concentrated Solar Power (CSP)

WHAT IS A TRACKER AND WHY DO WE NEED IT?

A solar tracker is a device that orients a payload toward the sun. Payloads can be solar panels, parabolic troughs, Fresnel reflectors, mirrors or lenses.

For flat-panel photovoltaic systems, trackers are used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel. This increases the amount of energy produced from a fixed amount of installed power generating capacity.

WHAT ARE THE TYPES OF SOLAR TRACKING SYSTEMS?

Fixed

In this type the panel are fixed and not moving.

1. Horizontal without tilt

2. Horizontal with tilt

Single axis trackers

Single axis trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of single axis trackers is typically aligned along a true North meridian. It is possible to align them in any cardinal direction with advanced tracking algorithms. There are several common implementations of single axis trackers. These include:-

1. Horizontal single axis tracker (HSAT)
2. Horizontal Single Axis tracker with Tilted Modules(HTSAT)
3. Vertical single axis tracker (VSAT)
4. Tilted single axis tracker (TSAT)
5. Polar aligned single axis trackers (PASAT)

Dual axis trackers

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 and perpendicular to it, can be considered as a secondary axis. Dual axis trackers allow for optimum solar energy levels due to their ability to follow the sun about its vertical and horizontal axes. No matter where the sun is in the sky, dual axis trackers are able to angle themselves to be in direct alignment with the sun. There are several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. These include:-

1. Tip–tilt dual axis tracker (TTDAT)
2. Azimuth–altitude dual axis tracker (AADAT)

WHAT IS CRITERIA FOR SELECTION OF A TRACKER?

The selection of tracker type is dependent on many factors including installation size, electric rates, government incentives, land constraints, latitude, and local weather.

Horizontal single axis trackers are typically used for large distributed generation projects and utility scale projects. The combination of energy improvement and lower product cost and lower installation complexity results in compelling economics in large deployments. In addition the strong afternoon performance is particularly desirable for large grid-tied photovoltaic systems so that production will match the peak demand time. Horizontal single axis trackers also add a substantial amount of productivity during the spring and summer seasons when the sun is high in the sky. The inherent robustness of their supporting structure and the simplicity of the mechanism also result in high reliability which keeps maintenance costs low. Since the panels are horizontal, they can be compactly placed on the axle tube without danger of self-shading and are also readily accessible for cleaning.

A vertical axis tracker pivots only about a vertical axle, with the panels either vertical, at a fixed, adjustable, or tracked elevation angle. Such trackers with fixed or (seasonally) adjustable angles are suitable for high latitudes, where the apparent solar path is not especially high, but which leads to long days in summer, with the sun travelling through a long arc.

Dual axis trackers are typically used in smaller residential installations and locations with very high government feed in tariffs.

WHAT ARE THE VARIOUS ANGLES TO BE CONSIDERED DURING THE MATHEMATICAL MODELING OF PV PANELS?

Latitude Angle (ϕ)

The latitude angle 'ϕ' is the angle between a line drawn from a point on the earth's surface to the centre of the earth, and the earth's equatorial plane. The intersection of the equatorial plane with the surface of the earth forms the equator and is designated as 0 degrees latitude. The earth's axis of rotation intersects the earth's surface at 90 degrees latitude (North Pole) and -90 degrees 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.

Declination Angle (δ)

The plane that includes the earth's equator is called the equatorial plane. If a line is drawn between the centre of the earth and the sun, the angle between this line and the earth's equatorial plane is called the declination angle 'δ'.

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$$

Hour Angle (ω)

To describe the earth's rotation about its polar axis, we use the concept of the hour angle. The hour angle 'ω' is the angular distance between the meridian of the observer and the meridian whose plane contains the sun. The hour angle is zero at solar noon (when the sun reaches its highest point in the sky). At this time the sun is said to be 'due south' (or 'due north', in the Southern Hemisphere) since the meridian plane of the observer contains the sun. The hour angle increases by 15 degrees every hour.

$$\omega = -[15(12 - X)]$$

Solar altitude angle (α) and solar zenith angle (θ_Z)

The solar altitude angle 'α' is defined as the angle between the central ray from the sun, and a horizontal plane containing the observer. As an alternative, the sun's altitude may be described in terms of the solar zenith angle 'θ_Z' which is simply the complement of the solar altitude angle.

$$\theta z = \cos^{-1}(\cos\phi \, . \cos\delta \, . \cos\omega + \sin\phi \, . \sin\delta)$$

Solar Azimuth angle (A)

The other angle defining the position of the sun is the solar azimuth angle (A). It is the angle, measured clockwise on the horizontal plane, from the north-pointing coordinate axis to the projection of the sun's central ray. There are other conventions for the solar azimuth angle in use in the solar literature. One of the more common conventions is to measure the azimuth angle from the south-pointing coordinate rather than from the north-pointing coordinate. Another is to consider the counterclockwise direction positive rather than clockwise. The formula for calculation is:-

$$A' = \sin^{-1}\left(\frac{-\cos\delta \sin\omega}{\cos\alpha}\right) \qquad (\text{degrees})$$

$$\text{where if:} \quad \cos\omega \geq \left(\frac{\tan\delta}{\tan\phi}\right), \quad \text{then} \quad A = 180^\circ - A'$$

$$\text{otherwise:} \quad \cos\omega < \left(\frac{\tan\delta}{\tan\phi}\right), \quad \text{and} \quad A = 360^\circ + A'$$

Another way to calculate is:-

$$A'' = \cos^{-1}\left(\frac{\sin\delta \cos\phi - \cos\delta \cos\omega \sin\phi}{\cos\alpha}\right) \qquad (\text{degrees})$$

$$\text{where if:} \quad \sin\omega > 0 \quad \text{then} \quad A = 360^\circ - A''$$

$$\text{otherwise} \quad \sin\omega \leq 0 \quad \text{and} \quad A = A''$$

RADIATION

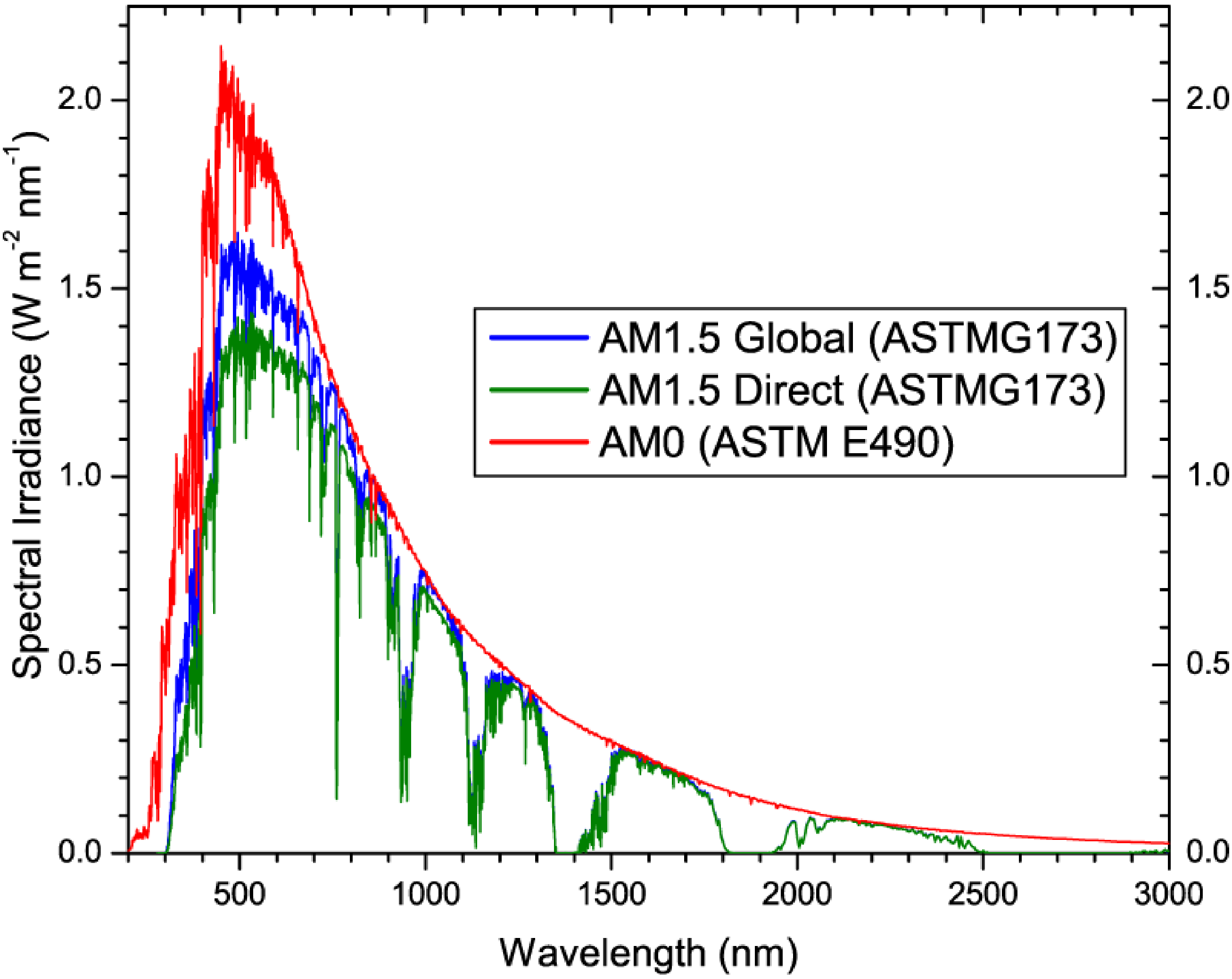
The solar spectrum changes throughout the day and with location. Standard reference spectra are defined to allow the performance comparison of photovoltaic devices from different manufacturers and research laboratories. The standard spectra were refined in the early 2000's to increase the resolution and to co-ordinate the standards internationally. The previous solar spectrum, ASTMG159, was withdrawn from use in 2005. In most cases, the difference between the spectrums has little effect on device performance and the newer spectra are easier to use.

ASTM E-490

The standard spectrum for space applications is referred to as AM0. It has an integrated power of 1366.1 W/m2

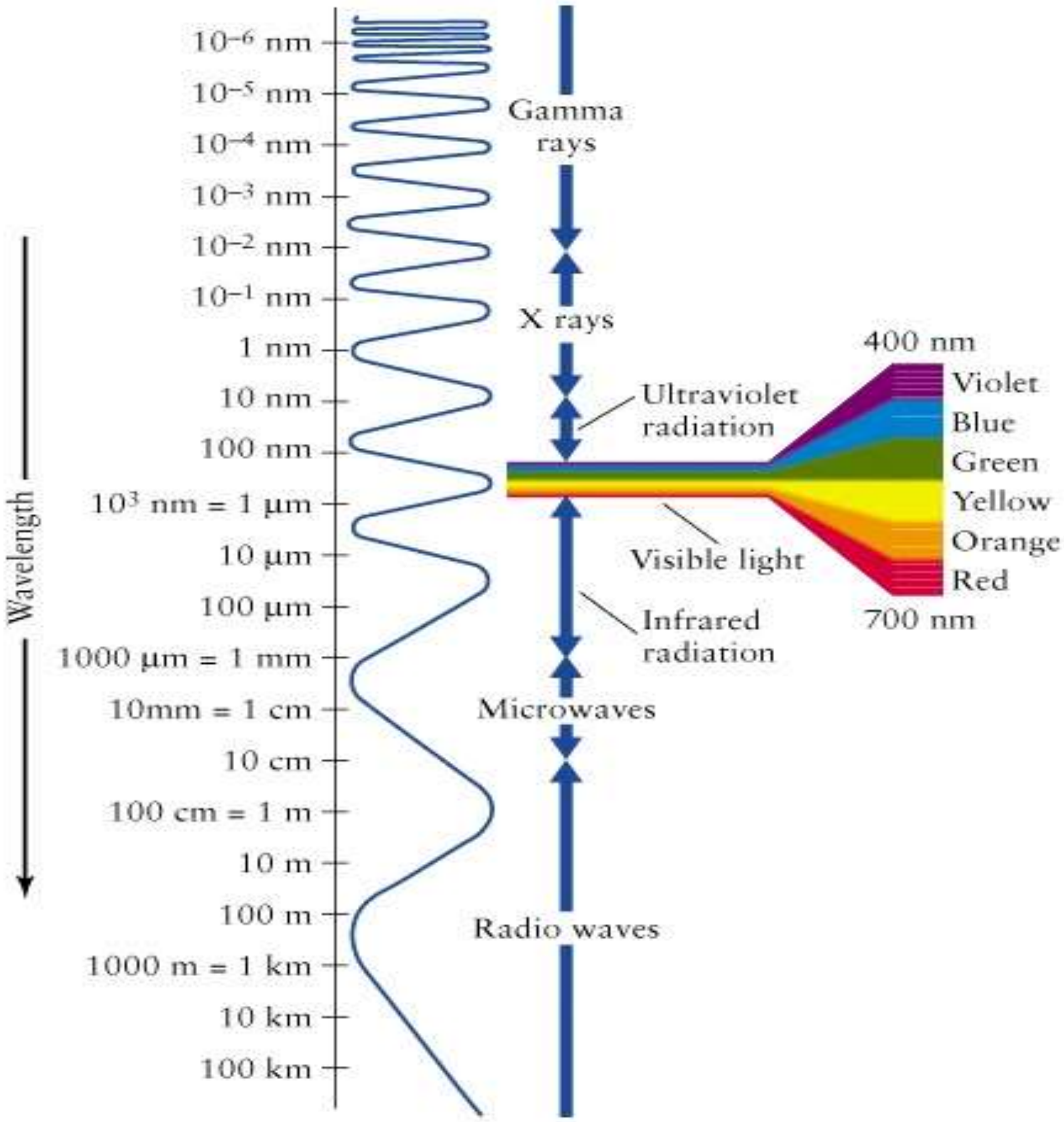
ASTM G-173-03 (INTERNATIONAL STANDARD ISO 9845-1, 1992)

Two standards are defined for terrestrial use. The ***AM1.5 Global spectrum*** is designed for flat plate modules and has an integrated power of 1000 W/m2 (100 mW/cm2). The AM1.5 Direct (+circumsolar) spectrum is defined for solar concentrator work. It includes the the direct beam from the sun plus the circumsolar component in a disk 2.5 degrees around the sun. The direct plus circumsolar spectrum has an integrated power density of 900 W/m2. The SMARTS (Simple Model of the Atmospheric Radiative Transfer of Sunshine) program is used to generate the standard spectra and can also be used to generate other spectra as required.



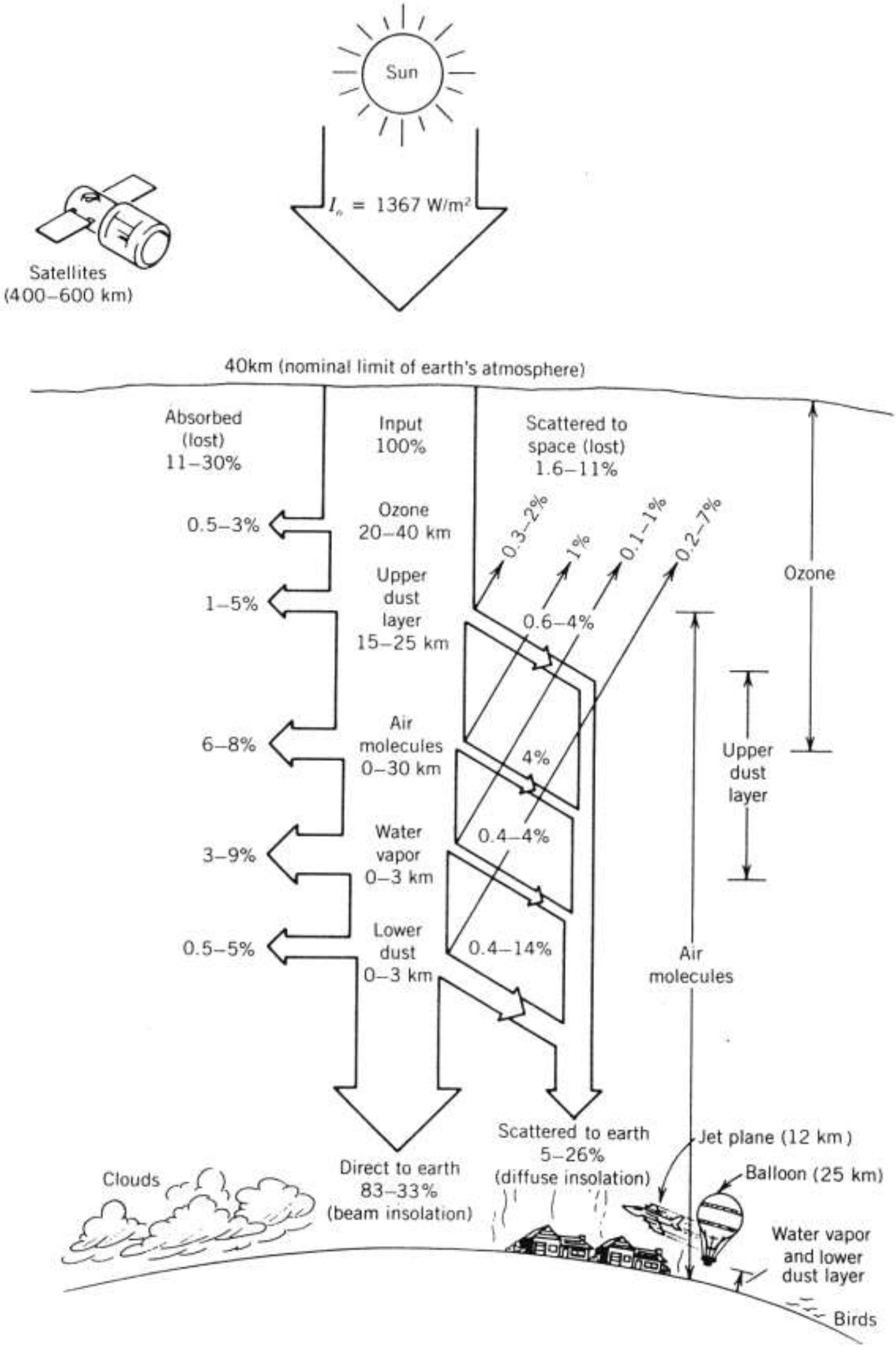
Standard Solar Spectra for space and terrestrial use.

The wavelength of light primarily used by solar PV cells lies between 350nm to about 1100nm. This wavelength range spans from the edge of the ultraviolet part of the spectrum, the edge closer to visible light, to a small portion of the infrared part of the spectrum. The visible spectrum of light has a wavelength spectrum of 400nm to 700nm. This means that a majority of the light and the most effective part of the spectrum range lie in the visible spectra. This also implies that the reflective material used can be the same as that used in greenhouses, such as metallized films.



The international measurement laboratories are in the processes of ratifying the new standards. In the meantime, concentrator cells are measured using a low aerosol depth spectrum (Lo-AOD) that is appropriate for typical concentrator locations such as the southwest of USA. It is essentially the same as the ASTM G-173-03 direct data given on this page.

SOLAR RADIATION



On the surface of the earth, we perceive a *beam* or d*irect* solar irradiance that comes directly from the disc of the sun and a *diffuse* or *scattered* solar irradiance that appear to come from all directions over the entire sky. In this text we will use the term *direct* to signify solar irradiance coming directly from the sun's disc, and the term *diffuse* to indicate solar irradiance coming from all other directions. We use the traditional subscript *b* to represent the direct component of solar irradiance and the subscript *d* to indicate the diffuse component. The sum of direct and diffuse solar irradiance is called the *global or total* solar irradiance and is identified by the traditional subscript *t*. In this book we will use the term *global* to indicate this sum.

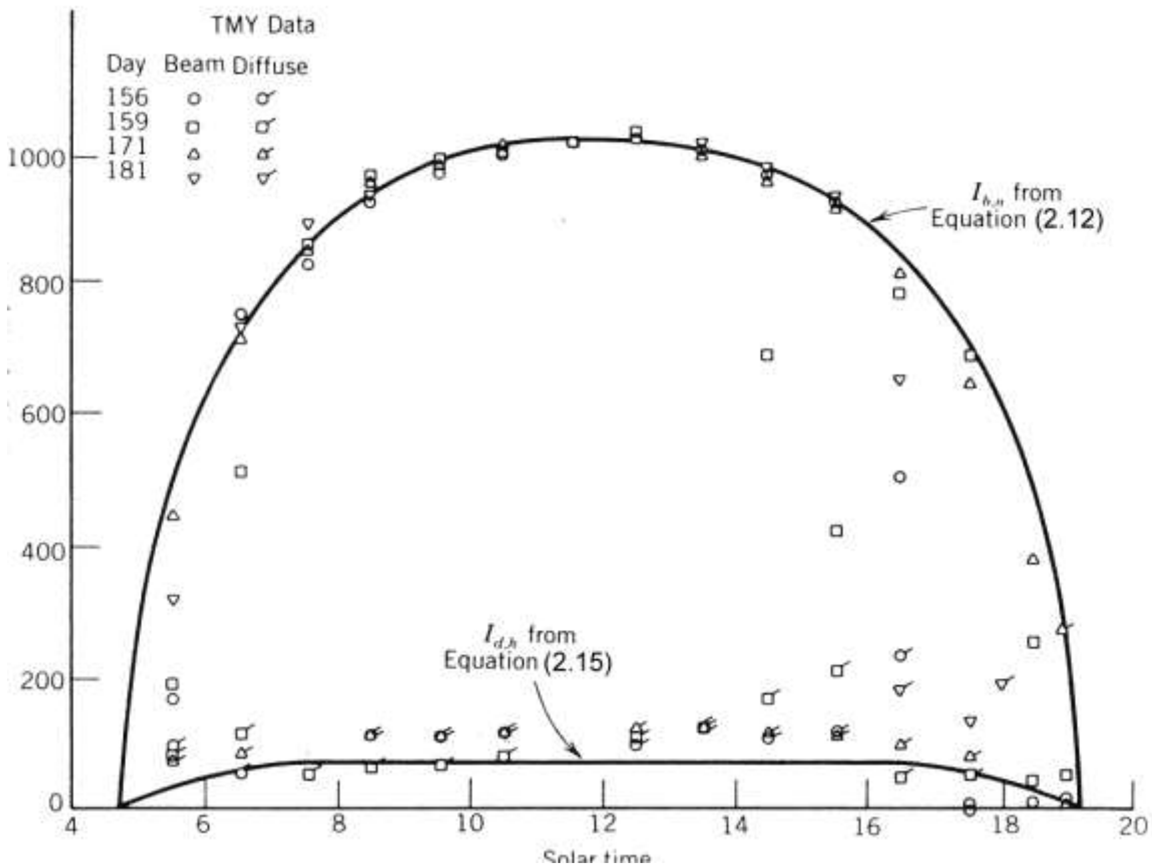
On a clear day, direct solar irradiance represents about 80 or 90 percent of the total amount of solar energy reaching the surface of the earth. Local blockage of the direct component of solar irradiance produces shadows. On a cloudy or foggy day when "you can't see the sun," the direct component of solar irradiance is essentially zero and there are no shadows. The direct component of solar irradiance is of the greatest interest to designers of high-temperature solar energy systems because it can be concentrated on small areas using mirrors or lenses, whereas the diffuse component cannot.

The diffuse or scattered component of solar irradiance is what permits us to see in the shade. If there was no diffuse component of solar irradiance, the sky would appear black as at night and stars would be visible throughout the day. The first astronauts vividly described this phenomenon to us from the moon where there is no atmosphere to scatter the solar radiation.

As depicted in the above Figure, diffuse radiation is the result of downward scattering of solar irradiance by nitrogen, oxygen, and water molecules, water droplets, and dust particles in the atmosphere. The amount of this scattering depends on the amount of water and dust in the atmosphere and the altitude of the observer above sea level.

Since diffuse solar irradiance cannot be concentrated, only flat-plate (non-concentrating) solar collectors and some low-temperature types of concentrators (having wide acceptance angles) can collect diffuse solar irradiance. Few of the collectors used in industrial applications can utilize the diffuse component of solar radiation.

The variation of these factors, especially that of water droplets (i.e. clouds) as they attenuate the direct component and change the diffuse component, is the major unknown parameter in the design of systems to collect solar energy. Consequently, a considerable amount of effort has been and is being spent in measuring, cataloguing, and developing analytical models to predict these effects.



Comparison of Albuquerque TMY data with solar irradiance values predicted by clear-day direct and diffuse models for the same latitude and elevation on day 156

DISADVANTAGE OF TRADITIONAL SYSTEMS

TRACKERS ARE EXPENSIVE.

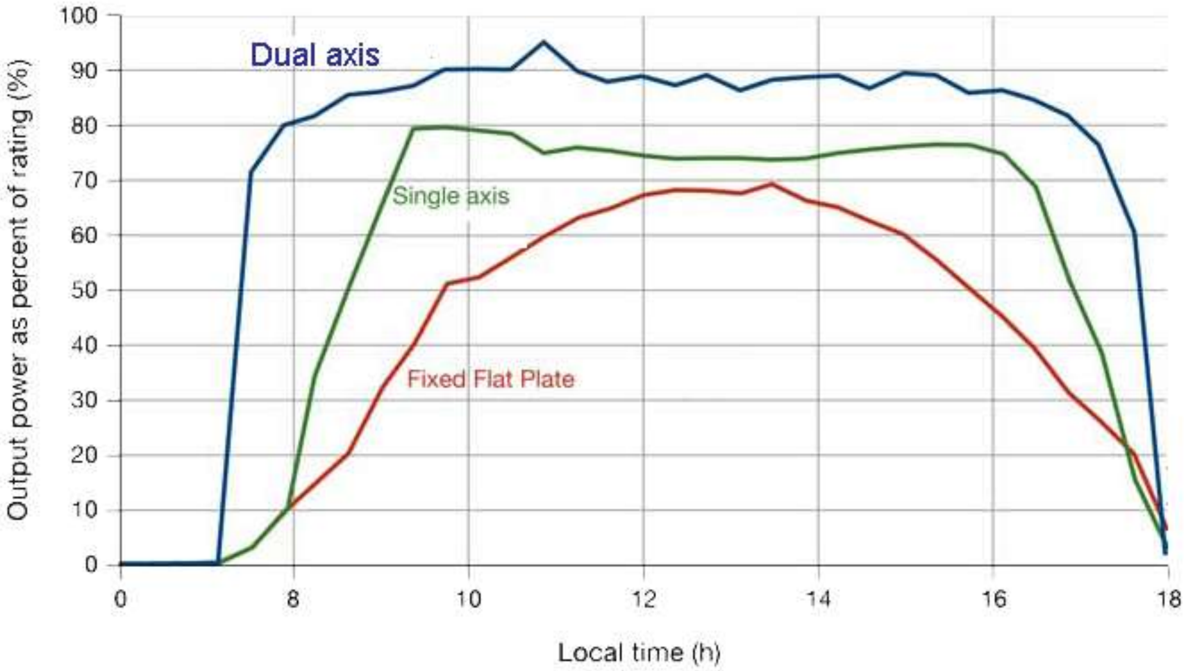
Traditional trackers orient the solar panel along the suns' path. This involves providing heavy weight bearing motors and support structures, which exponentially increases the cost of the system

MOTORS REQUIRED FOR MOVING HEAVY PANELS ARE COSTLY.

A 175.5 kg-cm stepper motor costs ₹32,650/- (From bholanath.in with model no. BH86SH156-6204AKS-IP65 bipolar) whereas a motor with high torque requirements would cost much higher which not only is difficult to manufacture but very costly too. For e.g. a 250W panel on average weighs 20kg and has a width of 100cm and length of 160cm therefore, the torque required to rotate the panel about its axes would be 1000kg-cm and 1600kg-cm respectively (From Emmvee photovoltaic power private limited).

FIXED PANELS

They produce peak wattage at solar noon, thus becoming quite inefficient.



DUAL AXIS TRACKING

Although dual axis tracking gives 25% efficiency improvement it adds immensely to the installation and maintenance cost.

SINGLE AXIS TRACKING

Although single axis tracking gives 13% efficiency improvement it suffers from the same drawbacks that plague dual axis tracking. It however is cheaper than dual axis racking but is less efficient.

TRACKING IS ALSO NOT SUITABLE FOR TYPICAL RESIDENTIAL ROOFTOP PHOTOVOLTAIC INSTALLATIONS.

Trackers have very high demand for area, this makes them unsuitable for use on residential rooftops. Most of the time, the cost of investment is much higher than financial returns in the case of residential installations.

SHADING PROBLEMS

Tracking face shading problems. Despite the myths that state that trackers are the ultimate in solar generation they are not free from parasites like shading; they too have shading problems.

THE IDEA

INCREASING THE INCIDENT RADIATION BY NOVEL AUXILIARY REFLECTOR DESIGN THEREBY, INCREASING THE EFFICIENCY

Global warming and the drive to minimize greenhouse gas emissions have put the focus on how to make the most of natural energy sources. The sun is freely available almost everywhere in the world and electric actuators can help improve the exploitation and efficiency of this sustainable energy source.

Solar tracking is an obvious way to improve the efficiency of solar power plants. As the sun moves across the sky an electric actuator system makes sure that the solar panels automatically follow and maintain the optimum angle in order to increase the direct beam radiation over the panel. This however, has the downside of being irrationally expensive. Solar panels are large and heavy, so to rotate the panels along even a single axis requires a very large capacity motor. Instead of rotating the panel, a reflector, of very low weight, can be rotated. The auxiliary reflector system consists of a guide way to allow the reflector's movement from the east to the west, and vice-versa. This is accomplished with the help of a linear actuator stepper motor.

The technical description of the working of the system is as follows:

The solar panel is a tilted module, at an angle beta (the Greek alphabet), facing the south in the north-south axis and is mounted on a structure. There is a provision on the mounting structure for the rotation of the panel about the east-west axis. There exist 'c channel' guideways to the north and south of the solar panel for the movement of the reflector from east to west, and vice versa. The reflector is oriented along north-south axis to the west of the panel to face the east till noon, and then it is moved towards east and rotated to face the west. The reflector can rotate about the east west axis via manual operation. Additionally it can rotate along the north-south axis via a stepper motor (allows for precise rotation in clockwise and anticlockwise directions). A linear actuator motor is used to move the reflector setup back and forth along the guideway.

In the mornings the auxiliary reflector is positioned to the west of the solar panel; it is moved along the guideway via the linear actuator motor to the east of the panel during solar noon. In the evenings, after sunset the reflector is brought back to the west of the panel, from the east via the linear actuator motor. The reflector is held at the very top of and between two vertical poles. The reflector is tilted at an angle beta (the Greek alphabet) along its axis of rotation with respect to the ground. The movement of the reflector setup is done by attaching a screwed shaft, attached to the bottom of one of the vertical poles using a bolt. The movement of the shaft causes the whole setup of the reflector to move back and forth.

The reflector can rotate along its tilted axis of rotation to face the east-west direction, with the help of an electromagnetic braking stepper motor. The electromagnetic braking is required to provide a passive holding torque to hold the reflector in place, against the force of gravity, without the motor consuming power.

The entire operation is controlled through the use of an Arduino Uno R3 micro-controller board. The linear actuator stepper motor and the electromagnetic braking stepper motor receive power through motor shields.

ADVANTAGES OF OUR IDEA

- Economical.
  The investment cost is much cheaper compared to single axis tracking and dual axis tracking. It's approximately 50% cheaper compared to dual axis tracking.

- Lower capacity servo motor required.
  The average weight of a solar panel is 20kg approximately which demands higher torque rated servo motor/stepper motor with higher demand for energy but in case of our design, the weight of the reflector is 2kg approximately so lower torque rated motor and lower demand of energy.

- Auxiliary system is light weight.
  The auxiliary system is light weight so the transportation is easier.

- Efficiency improvement comparable to dual axis tracking.
  Our design produces an efficiency increase of 20% over horizontally fixed with tilt PV panel.

- Robust, simple construction.

- Wind movement taken into consideration.
  Our design takes into account the wind speed, and beyond a certain wind threshold it orients the reflector along the wind direction. This prevents damage to the reflector system and allows it to sustain incredibly high wind speeds.

COST ANALYSIS (ITEMIZED COST ESTIMATE FOR THIS PROJECT)

Sl. No	Item description	Estimate INR
1	Solar Panel (250 Wp, polycrystalline, 60 cell)	Rs. 9,000/-
2	Microcontroller (Arduino Uno R3)	Rs. 500/-

3	Aluminum mesh (48 sq. ft.)	Rs. 800/-
4	Reflective film	Rs. 420/- (Rs. 20/sq. ft.)
5	Electromagnetic braking stepper motor (3.6 kg-cm)	Rs. 5200/-
6	Linear actuator DC motors (12 kg-cm) (Quantity: 2)	Rs. 300/-
7	Motor shield (Quantity: 2)	Rs. 1000/-
8	Threaded shaft (diameter = 20mm) (2.7 m) (Quantity: 2)	Rs. 1500/-
9	Steel runners for base (20 ft.) (Quantity:2)	Rs. 800/-
10	Steel runners for vertical support structure (20 ft.) (Quantity:2)	Rs. 320/-
11	Bearing with housing (Quantity: 4)	Rs. 300/-
12	Wooden bidding (1 inch wide, 7mm thick, 6ft. long) (Quantity: 8)	Rs. 450/-
13	AC to DC converter (24 V DC output)	Rs. 50/-
14	proximity switches (Quantity: 2)	Rs. 400/-
15	4 wheel rollers (Quantity: 4)	Rs. 600/-
16	Jumper wires, normal wiring	Rs. 400/-
18	Aluminum rod (10ft)	Rs. 250/-
	TOTAL Estimated Cost of the Project	Rs. 22,290/-

TIME TABLE FOR PROJECT COMPLETION

Sl No	Activity to be completed/ Milestone to be reached	Date
1	Design and development of the reflector frame and attachment of aluminum mesh	13th October, 2015
2	Ordering the Solar panel	16th October, 2015
3	Procuring material for the linear movement of the reflector	17th October, 2015
4	Developing and constructing the reflector support and its movement system	20th October, 2015

5	Assembly of the subcomponents of the prototype	30th November, 2015
6	Algorithm and coding of the Arduino Uno R3 microcontroller	1st December, 2015
7	Measuring values for efficiency, voltage, wattage, and energy density over the duration of 10 days (per hour time steps)	2nd December, 2015
8	Plotting the graph for the efficiency, voltage, wattage, and energy density with respect to time (in hours) for the measured period	5th December, 2015
9	Making and uploading the video	15th December, 2015
	Completion Date	**Dec 15th, 2015**

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