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Estimation of Average Solar Radiation on Horizontal and Tilted Surfaces for Vijayawada Location

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Abstract: *Energy is required for a wide range of applications such as transportation, industrial, residential, agricultural and office applications. The energy requirement of the world is ever increasing. The increasing energy demands pose a lot of demand on the conventional energy sources like oil, gas, and coal. But the energy sources are limited in quantity and cause environmental pollution. Therefore, there is a need for alternative energy sources which can supply us energy in a sustainable manner. Electrical energy is the most convenient form of energy which can be converted to all other forms of energy. So, the obvious choice of a clean energy source, which is abundant, is the sun's energy. This paper describes a detailed evaluation of the solar radiation received at a particular location on monthly basis.*
Keywords: *Solar radiation(global , beam and diffuse radiation), horizontal and tilted surface ,monthly average.*

I. Introduction

Energy is in different forms like heat energy, mechanical energy, chemical energy, light energy nuclear energy, electrical energy and so on. Among all these, Electrical energy is virtually convenient form of energy which can be converted to all other forms of energy. It is one of the most changeable forms of energy, from the point of view of transmission, distribution and control.

The world energy demand is ever growing, particularly since the last few centuries. It is expected to grow further in the future. The availability and accessibility of sufficient amount of energy accelerate individual's and nation's growth. Afterward the use of energy has become an integral part of our life, its supply should be ensure and sustainable. Simultaneously it should be sparing, environmentally favorable and socially acceptable.

The main drivers for increase in the energy demand are: (a) increase in the world's population and (b) the techno-economic development of the countries, especially growing countries. As both of these grow, the energy demand grows proportionally. In order to fulfill the energy requirement of increased population, the scientists developed substitute sources known as renewable sources of energy which should be inexhaustible and provide a pollution free environment. Solar energy is a primary source of energy and is non-polluting and inexhaustible. There are three methods to harness solar energy: [1]

(i) Converting solar energy straightaway into electrical energy in solar power stations using photo cells or photovoltaic cells. (ii) Using photosynthetic and biological process for energy trapping. In the process of photosynthesis, green plants take up solar energy and convert it into chemical energy, stored in the form of carbohydrate. (iii) Converting solar energy in to thermal energy by suitable devices which may be subsequently converted into mechanical, chemical or electrical energy. [2]

Since solar energy is non-ending and its conversion to some other energy form is nonpolluting, attention should be paid for the maximum utilization of solar energy.In PV system design it is essential to know the amount of sunlight available at a particular location at a given time. The two common methods which characterize solar radiation are the solar radiance (or radiation) and solar insolation. The solar radiance is an instantaneous power density in units of kW/m^2. The solar radiance varies throughout the day from 0 kW/m^2 at night to a maximum of about 1 kW/m^2. The solar radiance is strongly dependant on location and local weather. Solar radiance measurements consist of global and/or direct radiation measurements taken periodically throughout the day. The measurements are taken using either a pyranometer (measuring global radiation) and/or a pyrheliometer (measuring direct radiation). In well established locations, this data has been collected for more than twenty years.

An alternative method of measuring solar radiation, which is less accurate but also less expensive, is using a sunshine recorder. These sunshine recorders (also known as Campbell-Stokes recorders), measure the number of hours in the day during which the sunshine is above a certain level (typically 200 mW/cm^2). Data collected in this way can be used to determine the solar insolation by comparing the measured number of sunshine hours to those based on calculations and including several correction factors. [3]

II. Methodology

A final method to estimate solar insolation is cloud cover data taken from existing satellite images. While solar irradiance is most commonly measured, a more common form of radiation data used in system design is the solar insolation. The solar insolation is the total amount of solar energy received at a particular location during a specified time period, often in units of kWh/ (m^2 day). While the units of solar insolation and solar irradiance are both a power density (for solar insolation the "hours" in the numerator are a time measurement as is the "day" in the denominator), solar insolation is quite different than the solar irradiance as the solar insolation is the instantaneous solar irradiance averaged over a given time period. Solar insolation data is commonly used for simple PV system design while solar radiance is used in more complicated PV system performance which calculates the system performance at each point in the day. Solar insolation can also be expressed in units of MJ/m^2 per year and other units and conversions are given in the unit's page. [4]

Solar radiation for a particular location can be given in several ways including:

- Typical mean year data for a particular location
- Average daily, monthly or yearly solar insolation for a given location
- Global isoflux contours either for a full year, a quarter year or a particular month
- Sunshine hours data
- Solar Insolation Based on Satellite Cloud-Cover Data
- Calculations of Solar Radiation

Solar constant variation with time over the year S_t is [4]

$$S_t = S[1 + 0.033\, COS\, \frac{360n}{365}] \quad (1)$$

Where

n = nth day of the year with 1st January being n = 1

S = Solar constant.

The declination angle in degrees can be given by [4]

$$\delta = 23.34 \sin \frac{360}{365}(284 + n) \quad (2)$$

The relation between the incidence angle and other angles is given by [4]

$$Cos\theta = \sin\Phi\,(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) + \cos\Phi\,(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\gamma\sin\omega\sin\beta \quad (3)$$

Situation 1: when the collector surface is lying flat on the ground, its angle with horizontal plane will be zero, i.e., $\beta=0°$. Thus, for the horizontal surface, Eq. (3) can be written as: [4]

$$Cos\theta = \sin\Phi\sin\delta + \cos\Phi\cos\delta\cos\omega = \cos\theta \quad (4)$$

Situation 2: When the collector surface is facing due south, the surface azimuth angle becomes zero, i.e., $\gamma=0°$. In the situation, Eq. (3) can be written as: [4]

$$Cos\theta = \sin\delta\sin(\Phi-\beta) + \cos\delta\cos\omega\cos(\Phi-\beta) \quad (5)$$

Equations (3), (4) and (5) can be used to find out the incident angle on solar collector under certain conditions, which then can be used to estimate the solar radiation falling on the collector.

The sunrise and sunset hour angle will be the angle for which the incidence angle of sunrays is 0^o or zenith angle is 90°. Substituting $\Theta = 0°$ in Eq. (3), we get

$$Cos\ \omega_s = -\tan\Phi\tan\delta \quad (6)$$

Or $\omega_s = \cos^{-1}(-\tan\Phi\tan\delta)$

Equation (6) will give a positive and a negative value of the hour angle. The positive value of $\boldsymbol{\omega_s}$ will represent the sunrise hour angle and the negative value represents sunset hour angle. The sunrise and sunset hour angles can be converted into hours, by using 1h=15°.

If the collector surface is inclined and south facing, the sunrise and sunset hour angles will be obtained from Eq. (5). Using $\theta=90^o$, we get:

$$\omega_{st} = \cos^{-1}(-\tan(\Phi-\beta)\tan\delta) \quad (7)$$

For the inclined surface the sunrise and sunset hour angles will be smaller, which means the day length for inclined collector surfaces will be smaller than the horizontal surface. The day length is the duration from the sunrise hour angle to the sunset hour angle. Due to symmetry both angles are same for the horizontal collector. Thus, the day length will be equal to 2 $\boldsymbol{\omega_s}$. In terms of the number of hours, the day length S_{max} (day length or maximum number of sunshine hours) will be given as [4]:

$S_{max} = \frac{2}{15}\cos^{-1}(-\tan\Phi\tan\delta)$ (8)

2.1 Estimation of Total Solar Radiation

To estimate the amount of solar radiation falling on a solar collector at a given time and location, the direct or beam radiation and diffuse radiation should be either measured or estimated using empirical equations. The monthly average daily global radiation on a horizontal surface H_{ga} is [5]

$$\frac{H_{ga}}{H_{oa}} = a + b\left[\frac{S_a}{S_{maxa}}\right] \quad (9)$$

Where
Hoa = monthly average extra-terrestrial solar radiation at horizontal surface
S_a = monthly average daily sunshine hours
S_{maxa} = maximum possible daily sunshine hours at a given location.
a and b are constants.

In Eq. (9), one needs to have a value of H_{oa} which can be estimated from the instantaneous value of extra-terrestrial solar radiation. Integration of extra-terrestrial radiation over a day will give the daily value of extra-terrestrial solar radiation, Ho (= H_{oa} if it is estimated for a given day of a month), which can be written as [4]:

$$H_a = S_t \int \cos\theta \; dt \quad (10)$$

$$= S\left[1 + 0.033\cos\frac{360n}{365}\right]\int_{sunrise}^{sunset}(sin\emptyset sin\delta + cos\emptyset cos\delta cos\omega)dt$$

Here t is time in hours. It can be converted to time in angles ω (radians) as:

$$dt = \frac{180}{15\pi}\, d\omega \quad (11)$$

$$H_o = \frac{12}{\pi} S\left[1 + 0.033\cos\frac{360n}{365}\right]\int_{-\omega_s}^{\omega_s}(sin\emptyset sin\delta + cos\emptyset cos\delta cos\omega)d\omega \quad (12)$$

The integration in Eq. (12) will give us the following: [6]

$$H_0 = \frac{24}{\pi} S\left[1 + 0.033\cos\frac{360n}{365}\right](\omega_S sin\emptyset sin\delta + cos\emptyset cos\delta sin\omega_S) \quad (13)$$

If S is in W/m², H_o will be in W-h/m². Multiplying term ω_s in Eq. (13) should be in radians. Equation (13) can be used to calculate the daily value of H_o. Here, the declination angle in the equation represents the day of the year. It has been shown by Klein (1977) that of Ho is calculated for a particular day of the month, its value will be equal to its average value over the month (i.e., Hoa). The dates at which H_o is equal to Hoa are: January 17, February 16, March 16, April 15, May 15, June 11, July 17, August 16, September 15, October 15, November 14 and December 10.[4]

2.2 Solar Radiation on Tilted Surface

In practice, the solar collectors are installed tilted for better energy collection. The radiation falling on tilted surface will be the sum of direct radiation, diffuse radiation and reflected radiation. These can be estimated as follows:

2.3 Direct Radiation

The ratio of the direct solar radiation falling on tilted surface to that falling on a horizontal surface is called the tilt factor r_b for the beam or direct radiation. The r_b for the collector surface facing south (γ=0˚) will be given as [4]:

$$r_b = \frac{\cos\theta}{\cos\theta_Z} = \frac{\sin\delta\sin(\emptyset-\beta) + \cos\delta\cos(\emptyset-\beta)\cos\omega}{\sin\delta\sin\emptyset + \cos\delta\cos\emptyset\cos\omega} \quad (14)$$

Similarly, the r_b can be written for a situation where the collection is not facing the south direction, i.e., γ ≠0˚. The beam radiation falling on a tilted surface will be given by $I_b \times r_b$, where I_b is the instantaneous value of beam radiation.

2.4 Diffuse Radiation

The diffuse part of solar radiation is one of the elements necessary for the design and evaluation of energy production of a solar system [5]. Similar to the tilt factor for the direct radiation, tilt factor for the diffuse radiation rd is defined as the ratio of the radiation flux falling on the tilted surface to the diffuse radiation falling on the horizontal surface. If the sky is considered as isotropic source of diffuse radiation (it may not be true in all conditions), the r_d can be written as [6]:

$$r_d = \frac{1 + \cos\beta}{2} \qquad (15)$$

The diffuse radiation falling on a tilted surface will be given by Idrd, where Id is the instantaneous value of diffuse radiation.

2.5 Reflected Radiation

The reflected radiation from the ground and surrounding area can also reach the collector with tilted surface. The tilt factor for the reflected radiation r_r is given by the following equation [6]:

$$r_r = \rho\, \frac{1 - \cos\beta}{2} \qquad (16)$$

Where ρ is the reflectivity of the surrounding in which the collector is located. Normally, a value of about 0.2 is taken for the reflectivity of grass or concrete.

2.6 Total Radiation On Tilted Surface

The total radiation on a tilted surface of the collector will be the sum of direct, diffuse and reflected radiations. It will be given by [4]

$$I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r \qquad (17)$$

Where I_b, I_d and I_r are the instantaneous values of beam, diffuse and reflected radiations, respectively. And r_b, r_d and r_r are the tilt factor for the beam, diffuse and reflected radiations, respectively. On dividing Eq. (16) by the instantaneous global horizontal radiation I_g, we get the ratio of the radiation flux falling on a tilted surface to that of a horizontal surface:

$$\frac{I_T}{I_g} = \left(1 - \frac{I_d}{I_g}\right) r_b + \frac{I_d}{I_g} r_d + r_r \qquad (18)$$

Equation (18) is obtained by considering that $I_b+I_d=I_g$. Equation (18) can also be used to calculate the total hourly radiation falling on tilted if the value of the hour angle ω is taken at the midpoint of the hour.

III. Results And Discussion

Example:
Calculation of all parameters for a particular day in March for Vijayawada location:
Latitude: 16.5 N
Longitude: 80.64 E
Assume values for a= 0.28, b= 0.47
Solution: Case 1: On Horizontal Surface
Assume Sunshine hours per day is 11.9051
For March 20,
Day number n=31+28+20= 79
$\delta = 23.34 \sin((360/365) \times (284+79)) = -2.406^\circ$

The sunshine hour angle is:

$\omega_s = \cos^{-1}(-\tan \phi \tan \delta)$
$= \cos^{-1}(-\tan(16.5) \tan(-2.406))$
$= 89.288^\circ$

Day length = $(2/15) \times \omega_s$
$= (2/15) \times (89.288) = 11.9$h

The extra-terrestrial solar radiation can be calculated as:

$$H_0 = \frac{24}{\pi} S \left[1 + 0.033 \cos\frac{360n}{365}\right] (\omega_S \sin\emptyset \sin\delta + \cos\emptyset \cos\delta \sin\omega_S)$$

$$H_0 = \frac{24}{\pi} 1.367\ X\ 3600 \left[1 + 0.033 \cos \frac{360X79}{365}\right] (1.5575 sin16.5 \sin(-2.406) + cos16.5 \cos(-2.406)\ sin89.283)$$

H_o=35560.06694 kJ/m^2 - day or 9.87 kWh/m^2

Now, the global solar radiation on the horizontal plane can be estimated using Eq. (9) as:

$$\frac{H_{ga}}{H_{oa}} = a + b\left(\frac{S_a}{S_{maxa}}\right)$$

$$\frac{H_{ga}}{35560.06694} = 0.28 + 0.47\left(\frac{11.9051}{11.9}\right)$$

H_{ga} = 26677.21302 kJ/m^2 or 7.410 kWh/m^2 – day

The monthly average daily diffuse radiation on the horizontal surface, H_{da} can be calculated by:

$\frac{H_{da}}{H_{ga}}$ = 1.311-3.022K_T+3.427 K^2_T-1.821K^3_T

K_t= (H_{ga}/H_{oa}) = (26677.21302/35560.06694)=0.75

H_{da}= (1.321-3.022(0.75) +3.427(0.75)2-1.821(0.75)3) × (26677.21302)

=5707.67kJ/m²

Table 1: Similarly Estimation of Total Global Solar Radiation For Some Particular Dates

Dates	St in Hours	S_{maxa} in hours	H_{oa} in kWh/m^2	H_{ga} in kWh/m^2
January-17	11.1398	11.13740941	8.011075996	6.009115179
February-16	11.4632	11.47979747	8.942268367	6.70062478
March-16	11.9028	11.90212543	9.898172127	7.423892764
April-15	12.3746	12.37024336	10.56896056	7.928469876
May-15	12.7662	12.76431373	10.78102337	8.086516328
June-11	12.9662	12.96022233	10.77083097	8.080458117
July-17	12.8722	12.87533271	10.73241464	8.048083658
August-16	12.537	12.54219895	10.59847257	7.946789601
September-15	12.0829	12.09144172	10.10845194	7.577982739
October-15	11.6122	11.62367661	9.202822717	6.897846437
November-14	11.224	11.23136023	8.220933542	6.163168073
December-10	11.039	11.04183456	7.718310177	5.787801387

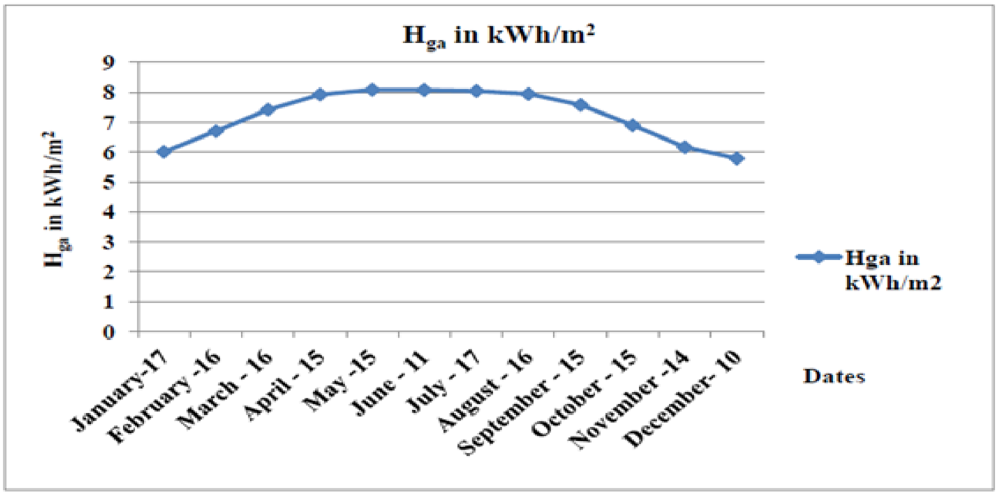

Figure 1: Total Global Solar Radiation for some particular Dates.

Global hourly radiation Ig from global daily radiation data on a horizontal surface can be obtained by:

$a=\sin(\omega_s-60)\times 0.5016+0.409$

$a=\sin(89.288-60)\times(0.5016)+(0.409)$

$a=0.654$

$b=\sin(\omega_s-60)\times 0.4767+0.660$

$b=\sin(89.288-60)\times(0.4767)+(0.660)$

$b=0.893$

Table2: Estimation Of Hourly Global Radiation For The Day 79 On The Horizontal surface

Cosω (in hours)	r_t	$I_g = r_t \times H_g$, in kWh/m²
7	0.029113	0.2157
8	0.0716	0.5305
9	0.119	0.8817
10	0.162	1.2
11	0.193	1.430
12	0.203	1.504
13	0.193	1.430
14	0.162	1.2
15	0.119	0.8817
16	0.0716	0.5305
17	0.029113	0.2157

Figure 2: Representing total global solar radiation for day 79.

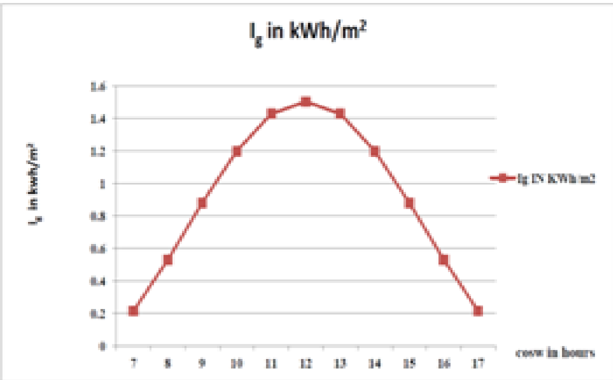

Table3: Diffuse hourly radiation Id from diffuse daily radiation data on a horizontal surface can be obtained by:

Cosω in hours	r_d	$I_d = r_d \times H_d$, in kWh/m²
7	0.0328	0.0519
8	0.065	0.1030
9	0.0927	0.1469
10	0.1139	0.1805
11	0.1272	0.2016
12	0.1318	0.2089
13	0.1272	0.2016
14	0.1139	0.1805
15	0.0927	0.1469
16	0.065	0.1030
17	0.0328	0.0519

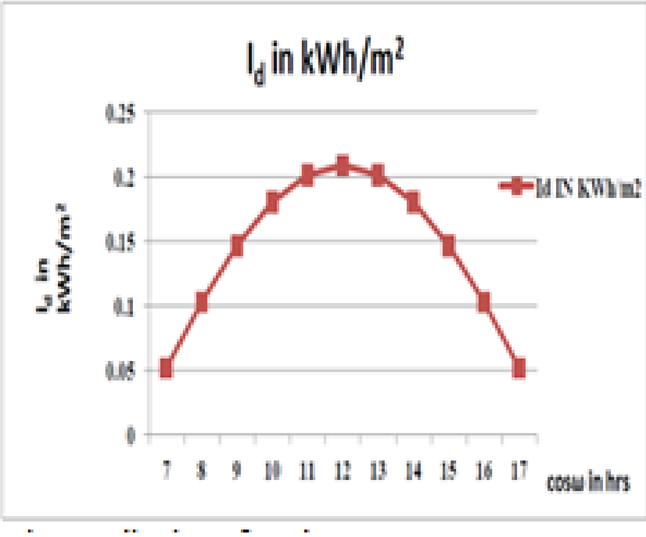

Figure 3: Representing total diffuse solar radiation for day79.

Case 2: On Vertical Surface (β= φ)

Assume Sunshine hours per day is 12.0428

From Case1: n=31+28+20= 79, δ = -2.406˚, ωs =89.288˚, Day length = 11.9h

Ho = 35560.06694 kJ/m²- day or 9.87kWh/m²

Hga =26677.21302 kJ/m² or 7.410kWh/m² - day

β=16.59-(-2.406) =18.997°

Calculation of tilt factors:

The tilt factors are calculated using the equations (14), (15), (16)

Table 4: Total solar radiation on inclined surfaces (β= φ)**:**

Cosω in Hours	I_b	r_b	I_d	r_d	r_r	$I_T=I_br_b+I_dr_d+(I_b+I_d)r_r$ in kWh/m^2
7	0.1638	1.0956	0.015	0.9727	0.00544	0.1950
8	0.4275	1.0695	0.1030	0.9727	0.00544	0.56028
9	0.7348	1.0616	0.1469	0.9727	0.00544	0.9277
10	1.0195	1.0581	0.1805	0.9727	0.00544	1.2608
11	1.2284	1.0565	0.2016	0.9727	0.00544	1.5016
12	1.2951	1.0560	0.2089	0.9727	0.00544	1.579
13	1.2284	1.0565	0.2016	0.9727	0.00544	1.5016
14	1.0195	1.0581	0.1805	0.9727	0.00544	1.2608
15	0.7348	1.0616	0.1469	0.9727	0.00544	0.9277
16	0.4275	1.0695	0.1030	0.9727	0.00544	0.56028
17	0.1638	1.0956	0.015	0.9727	0.00544	0.1950

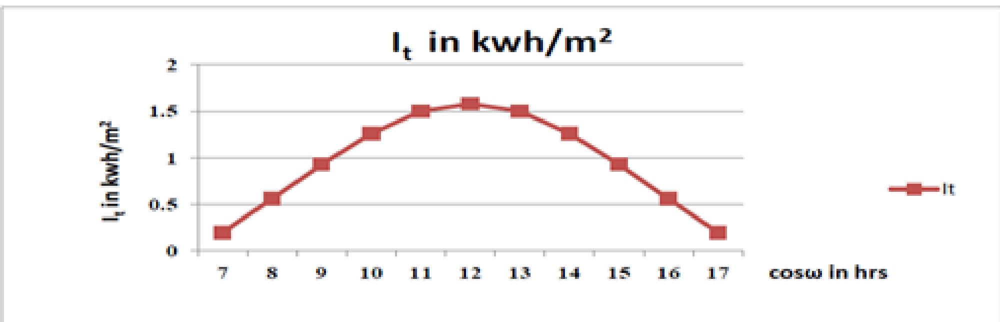

Figure 4: Representing Total Solar Radiation on Inclined Surface for day 79 at (β= φ)

Case 3: On inclined surface (β = φ+ 15˚)

Assume Sunshine hour angle = 12.53

From Case 1: n=31+28+20= 79, δ = -2.406˚, ωs =89.288˚, Day length = 11.9h

Ho = 35560.06694 kJ/m²- day or 9.87kWh/m²

Hga =26677.21302 kJ/m² or 7.410kWh/m² - day

Estimation of tilt factors

Table 5: Total Radiation on Inclined Surface (β = φ+ 15˚)

Hours	I_b	r_b	I_d	r_d	r_r	I_T
7	0.1638	1.1044	0.0519	0.9149	0.017	0.2320
8	0.4275	1.0564	0.1030	0.9149	0.017	0.5548
9	0.7348	1.0418	0.1469	0.9149	0.017	0.9149
10	1.0195	1.0354	0.1805	0.9149	0.017	1.2411
11	1.2284	1.0325	0.2016	0.9149	0.017	1.4780
12	1.2951	1.0316	0.2089	0.9149	0.017	1.5527
13	1.2284	1.0325	0.2016	0.9149	0.017	1.4780
14	1.0195	1.0354	0.1805	0.9149	0.017	1.2411
15	0.7348	1.0418	0.1469	0.9149	0.017	0.9149
16	0.4275	1.0564	0.1030	0.9149	0.017	0.5548
17	0.1638	1.1044	0.0519	0.9149	0.017	0.2320

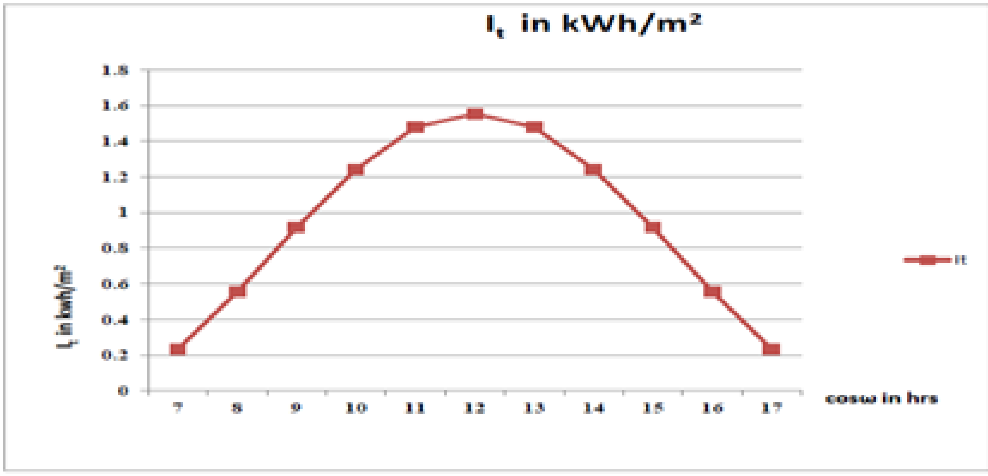

Figure 5: Representing total solar radiation on Inclined Surface for day 79 at (β = φ+ 15˚):

Case 4: On inclined surface (β= φ- 15˚)

Assume Sunshine hour angle = 12.038

From Case 1: n=31+28+20= 79

δ = -2.406˚ ω_s =89.288˚

Day length = 11.9h

Ho = 35560.06694 kJ/m²- day or 9.87kWh/m²

Hga =26677.21302 kJ/m² or 7.410kWh/m² - day

Table 6: Total radiation on inclined surface (β = φ - 15˚)

Hours	I_b	r_b	I_d	r_d	r_r	I_T (kWh/m^2)
7	0.1638	1.01233	0.0519	0.9988	0.0002322	0.2177
8	0.4275	1.0099	0.1039	0.9988	0.0002322	0.5737
9	0.7348	1.0092	0.1469	0.9988	0.0002322	0.8884
10	1.0195	1.0088	0.1805	0.9988	0.0002322	1.2090
11	1.2284	1.0087	0.2016	0.9988	0.0002322	1.4407
12	1.2951	1.0086	0.2089	0.9988	0.0002322	1.5152
13	1.2284	1.0087	0.2016	0.9988	0.0002322	1.4407
14	1.0195	1.0088	0.1805	0.9988	0.0002322	1.2090
15	0.7348	1.0092	0.1469	0.9988	0.0002322	0.8884
16	0.4275	1.0099	0.1039	0.9988	0.0002322	0.5737
17	0.1638	1.01233	0.0519	0.9988	0.0002322	0.2177

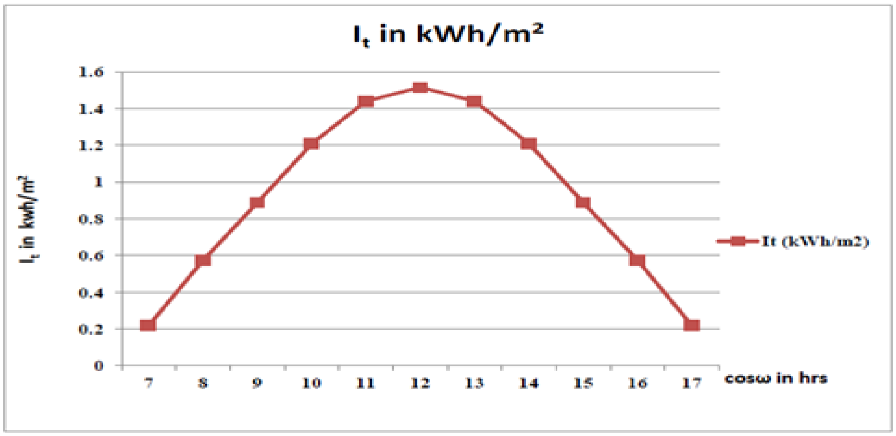

Figure 6: Representing Total Solar Radiation on Inclined Surface for day 79 at (β= φ-15)

Table 7:Summary of Total radiation on inclined surface for three different tilt angles on 79th day

Cosω in Hours	I_T β = φ	I_T β = φ+ 15˚	I_T β= φ- 15˚
7	0.195	0.232	0.2177
8	0.56028	0.5548	0.5737
9	0.9277	0.9149	0.8884
10	1.2608	1.2411	1.209
11	1.5016	1.478	1.4407
12	1.579	1.5527	1.5152
13	1.5016	1.478	1.4407
14	1.2608	1.2411	1.209
15	0.9277	0.9149	0.8884
16	0.56028	0.5548	0.5737
17	0.195	0.232	0.2177
Avg	0.951796	0.944936	0.924927

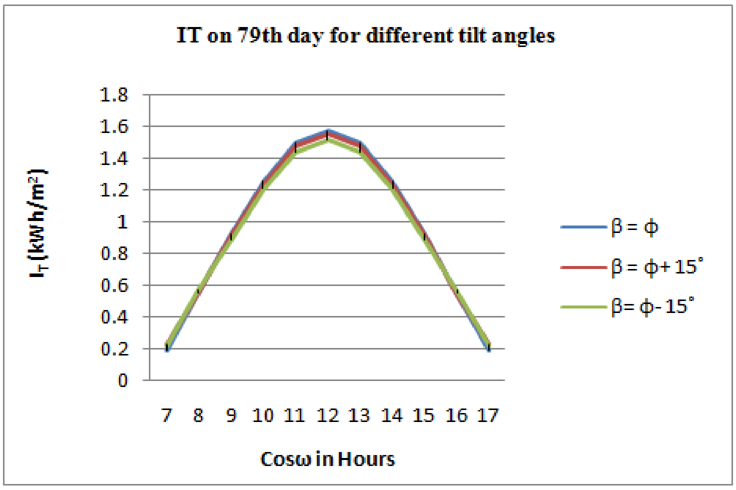

Figure 7: Summary representing Total Solar Radiation on Inclined Surface for day 79 at three different tilt angles

Table 8: daily average global radiation for different tilt angles is calculated and tabulated as follows.

Dates	Hg Horizontal	Hg β = φ	Hg β = φ+ 15˚	Hg β= φ- 15˚
17-Jan	6.00912	7.05912	7.60912	6.19912
16-Feb	6.70062	7.52062	7.81062	6.85062
16-Mar	7.42389	7.70389	7.58389	7.50389
15-Apr	7.92847	7.75847	7.25847	7.92847
15-May	8.08652	7.57652	6.81652	8.03652
11-Jun	8.08046	7.42046	7.62046	8.04046
17-Jul	8.04808	7.57808	7.67808	8.02808
16-Aug	7.94679	7.50679	7.64679	7.93679
15-Sep	7.57798	7.48798	7.50798	7.59798
15-Oct	6.89785	7.31785	7.36785	6.98785
14-Nov	6.16317	7.01317	7.38317	6.32317
10-Dec	5.78780	6.83780	7.36780	5.97780

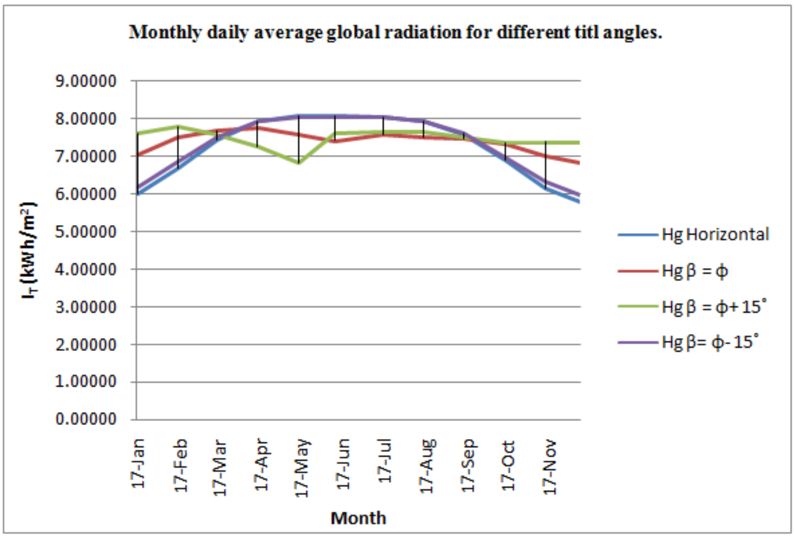

Figure 8: Monthly daily average global radiation for different tilt angles.

IV. Conclusion

From table 8 and Fig 8, it is observed that for Vijayawada location daily average global solar radiation on horizontal surface is 7.2208 kWh/m^2. Overall, January to June daily average global solar radiation is 7.3715 kWh/m^2. July to December daily average global solar radiation is 7.0702 kWh/m^2. The advantage of this method of calculation is, it gives the optimal inclination angle of the panel to be maintained. For example during May in Vijayawada location the optimal angle to be maintained is inclination angle equals to latitude of location. Limitation is, the calculations have not considered the shadow effects. If shadow falls on the panels then the available radiation will not fall on the panel so the output power will be less than the estimated.

From table 7 and Fig.7 For a particular day in March (79^{th} day in year) the average hourly global radiation is maximum of 0.951756 kWh/m^2 for inclination angle is equal to latitude of the location.

From Fig.8 the optimal inclination to trap maximum radiation from sun at Vijayawada location is as follows.

Month	**Inclination angle**
January	Φ + 15 = 31.5
February	Φ + 15 = 31.5
March	Φ = 16.5
April	Horizontal = 0
May	Horizontal = 0
June	Horizontal = 0
Month	**Inclination angle**
July	Horizontal = 0
August	Horizontal = 0
September	Φ - 15 = 1.5
October	Φ + 15 = 31.5
November	Φ + 15 = 31.5
December	Φ + 15 = 31.5

V. Future Scope

In Future work cost analysis can be made by calculating the power output from photovoltaic panel implementing dual axis tracking and changing the inclination angle with the above procedure manually on monthly basis.

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