EXPLORING RESEARCH AND INNOVATIONS

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Optimization of Solar Power by varying Tilt Angle/Slope

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Abstract— **In this Paper the optimization of PV power generating system with the help of Homer software which is design for it by varying the tilt angle/slope, azimuth and an incidence angle. The irradiance will vary with slope angle, azimuth, and an incidence angle so the output of PV model highly influence by the variable. The objective of this work is to find out the optimization of PV system.**

Keywords— **Solar collector, optimum tilt angle, clearness index, solar radiation, HOMER Software (For optimization and Simulation).**

I. INTRODUCTION

The amount of solar energy incident on a solar collector in various time scales is a complex function of many factors including the local radiation climatology, the orientation and tilt of the exposed collector surface and the ground reflection properties. The performance of a solar collector is highly influenced by its orientation and its angle of tilt with the horizon. This is due to the fact that both the orientation and tilt angle change the solar radiation reaching the surface of the collector.our main aim is to maximize the solar power by varying the tilt angle and slope in Chhatisgarh area.

SSCET Bhilai, Chhattisgarh has installed a solar photo voltaic power generating system of 100kw, 240V DC in his premises (latitude °N 21.217 and longitude °E 83.433).

HOMER will simulate system configurations; create a list of feasible system designs, and sort the list by cost-effectiveness. In the final step, we will use HOMER to perform a sensitivity analysis.

HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 hours (365x24) in a year. Over the last few years, many authors have presented models to Predict solar radiation on inclined surfaces. Some of these models apply to specific cases; some require special measurements and some are limited in their scope. These models use the same method of calculating beam and ground reflected radiation on a tilted surface. The only difference exists in the treatment of the diffuse radiation. The approximation commonly used for converting the diffuse component value for a horizontal surface to that for a tilted one is that sky radiation is isotropically distributed at all times [1–3].

However, theoretical as well as experimental results have shown that this simplifying assumption is generally far from reality [4]. Thus, it appears that sky radiance should be treated as anisotropic, particularly because of the strong forward scattering effect of aerosols [5–8]. Reviews on transforming data recorded by horizontal pyranometers to data that would have been received by tilted surfaces are given by many researches [9–14]. The best way to collect maximum daily energy is to use tracking systems. A tracker is a mechanical device that follows the direction of the sun on its daily sweep across the sky. The trackers are expensive, need energy for their operation and are not always applicable. Therefore, it is often practicable to orient the solar collector at an optimum tilt angle, and to correct the tilt from time to time. Several interesting articles have been devoted to this problem. Most of these articles treat the problem qualitatively and quantitatively [15–17], while others articles give an analytical treatment [18–21]. It is reported in the literature that in the northern hemisphere, the optimum orientation is south facing and the optimum tilt angle depends only on the latitude. No definite value is given by researchers for the optimum tilt angle. Further review of literature shows that there is a wide range of optimum tilt angle as recommended by different authors, and they are mostly for specific locations.

A simple mathematical procedure for the estimation of the optimal tilt angle of a collector is presented based on the monthly horizontal radiation [15]. As specified by the authors, this method gives a good estimation of the optimal tilt angle, except for places with a considerably lower clearness index. The results show that the angle the tracked panel has to rotate by is 0_ at solar noon, and increases towards dawn or dusk.

II. LITERATURE REVIEW

There are various devices for absorbing the solar radiation. The Sun rays are to be always focused onto the absorber plate. The collector has to be rotated by tracking system, but the tracking system is very costly so we cannot use this for every system economically. Due to this reason the solar collector is fixed either monthly, seasonally or yearly pattern, based on our requirements.

Ahmad M. Jamil and Tiwari G.N. [2] analyzed the theoretical aspects of choosing a tilt angle for the solar flat-plate collectors used at ten different stations in the world and makes recommendations on how the collected energy can be increased by varying the tilt angle. For Indian stations, the calculations are based upon the measured values of monthly mean daily global and diffuse solar radiation on a horizontal surface. As explained in Bekker et al [3]. The orientation and tilt of the panels directly relates to the annual energy yield of the panels Mehleri E.D. et. al. [4] determined optimum tilt angle and orientation for solar photovoltaic arrays in order to maximize incident solar irradiance exposed on the array, for a specific period of time. The ratio of monthly average hourly diffuse radiation to monthly average hourly global radiation was correlated by Ulgen Koray and Hepbasli Arif [5] with the monthly average hourly clearness index in the form of the polynomial relationships for the city of Izmir in the western part of Turkey. The values of the monthly average daily clearness index ranged from 0.41 to 0.66, averaged for the same period.

KorayUlgen [5] found that the optimum tilt angle changes between 0◦ (June) and 61◦ (December) throughout the year. In winter (December, January, and February) the tilt should be 55.7◦, in spring (March, April, and May) 18.3◦, in summer (June, July, and August) 4.3◦, and in autumn (September, October, and November) 43◦. Sakonidou E.P. et. al. [6] developed a mathematical model. The model starts by calculating the hourly solar irradiation components (direct, diffuse, ground-reflected) absorbed by the solar chimney of varying tilt and height for a given time (day of the year, hour) and place (latitude). Moghadam Hamid et. al. [7] estimated solar global radiation on a horizontal surface using a mathematical model and the results were compared. Ibrahim D. [8] examined for selection of optimum tilt angle of Cyprus. For maximum radiation the results were calculated by varying tilt angle form 0° to 90° with the increment of 10°. Tang R. and Tong W. [9] presented a mathematical procedure to compare the optimum tilt angles of collectors through monthly diffused radiation and actual monthly diffused radiations. The best orientation for solar collectors in Izmir was south facing.

III. PROBLEM IDENTIFICATION

Based on the literature survey it is seen that the incident solar radiations on a collector surface are greatest for an optimal tilt angle of the collector at a particular region which is also not constant throughout the year.

To obtain maximum power output from the solar collector system it is desirable to tilt the collector to that tilt angle at which the incident solar radiations are maximum. If not monthly, the tilt angles of the collector surfaces can be changed four times in a year to their seasonal optimum tilt angles at which slightly less power is obtained than monthly optimal angles but large compared to yearly optimal tilt angle.

IV. OBJECTIVE OF THE STUDY

The following objectives are covered under this study:

i. Daily and monthly Optimum slope angles.
ii. Seasonal Optimum tilt angles.
iii. Yearly optimum tilt angle.
iv. To compare the different model.

TABLE I
TECHNICAL DATA OF SOLAR PV MODULE IS GIVEN BELOW

1.	Solar module type	Mono crystalline silicon cell module
2..	Single module rated power(nominal)	175 Wp @ standard test conditions.
3.	Single module voltage (nominal)	24 V DC
4.	Single module current @ maximum power(lmp)	4.94 A DC
5.	Number of solar modules in series / string*	10 Nos.
6.	Number of such strings in parallel array**	58 Nos.
7.	Total number of solar module .system	500 Nos.

In this paper we can describe the orientation of the PV array using two parameters, a slope and an azimuth. The slope is the angle formed between the surface of the panel and the horizontal, so a slope of zero indicates a horizontal orientation, whereas a 90° slope indicates a vertical orientation. The azimuth is the direction towards which the surface faces. HOMER uses the convention whereby zero azimuth corresponds to due south, and positive values refer to west-facing orientations.

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So an azimuth of -45° corresponds to a southeast-facing orientation, and an azimuth of 90° corresponds to a west-facing orientation.

The other factors relevant to the geometry of the situation are the latitude, the time of year, and the time of day. The time of year affects the solar declination, which is the latitude at which the sun's rays are perpendicular to the earth's surface at solar noon. HOMER uses the following equation to calculate the solar declination:

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

Where:

n is a the day of the year [a number 1 through 365]

IV- How to Calculate the PV Array Power Output

The following equation to calculate the output of the PV array

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}}\right) [1 + \alpha_p (T_c - T_{c,STC})]$$

Where:

Y_{pv} is the rated capacity of the PV array, meaning its power output under standard test conditions [KW]

f_{pv} is the PV derating factor [%]

$\overline{G}_T$ is the solar radiation incident on the PV array in the current time step[KW/m²]

$\overline{G}_{T,STC}$ is the incident radiation at standard test conditions [1KW/m²]

α_p is the temperature certification of power [%/°C]

T_c is the PV cell temperature in the current time step[°C]

$T_{c,STC}$ is the PV cell temperature under standard test conditions[25 °C]

PV Efficiency at Standard Test Conditions

Type: Input Variable

Units: %

Symbol: $\eta_{mp,STC}$

The efficiency with which the PV array converts sunlight into electricity at its maximum power point under standard test conditions. The efficiency to calculate the PV cell temperature.

PV manufacturers rarely report this efficiency in their product brochures, but one can calculate it for any PV module using the following equation:

$$\eta_{mp,STC} = \frac{Y_{pv}}{A_{pv} G_{T,STC}}$$

Where:

$\eta_{mp,STC}$ is the efficiency of the PV Module under standard test conditions[%]

Y_{pv} is the rated power output of the PV module under standard test conditions[KW]

A_{pv} is the surface area of the PV Module[m²]

$G_{T,STC}$ is the radiation at standard test conditions [1 KW/m²]

V- CALCULATION OF GLOBAL SOLAR RADIATION

The time of day affects the location of the sun in the sky, which we can describe by an hour angle. HOMER uses the convention whereby the hour angle is zero at solar noon (the time of day at which the sun is at its highest point in the sky), negative before solar noon, and positive after solar noon. HOMER uses the following equation to calculate the hour angle:

$$\omega = (t_s - 12hr).15°/\text{hr}$$

where:

t_s is the solar time [hr]

The value of t_s is 12hr at solar noon, and 13.5hr ninety minutes later. The above equation follows from the fact that the sun moves across the sky at 15 degrees per hour.

HOMER assumes that all time-dependent data, such as solar radiation data and electric load data, are specified not in solar time, but in *civil time*, also called local standard time. HOMER calculates solar time from civil time using the following equation:

$$t_s = t_c + \frac{\lambda}{15°/hr} - Z_c + E$$

where:

t_c is the civil time in hours corresponding to the midpoint of the time step [hr]

Λ is the longitude [°]

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Z_c is the time zone in hours east of GMT [hr]

E is the equation of time [hr]

Note that west longitudes are negative, and time zones west of GMT are negative as well.

The equation of time accounts for the effects of obliquity (the tilt of the earth's axis of rotation relative to the plane of the ecliptic) and the eccentricity of the earth's orbit. HOMER calculates the equation of time as follows:

$$E=3.82\begin{pmatrix}0.000075+0.001868\cdot\cos B-0.032.77\cdot\sin B\\-0.014615\cdot\cos 2B—0.04089\cdot\sin 2B\end{pmatrix}$$

Where B is given by:

$$B=360°\frac{(n-1)}{365}$$

Where n is the day of the year, starting with 1 for January 1st.

Now, for a surface with any orientation, we can define the angle of incidence, meaning the angle between the sun's beam radiation and the normal to the surface, using the following equation:

$$\begin{aligned}\cos\theta = {} & \sin\delta\sin\emptyset\cos\beta \\ & -\sin\delta\cos\emptyset\sin\beta\cos\gamma \\ & +\cos\delta\cos\emptyset\cos\beta\cos\omega \\ & +\cos\delta\sin\emptyset\sin\beta\cos\gamma\cos\omega \\ & +\cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned}$$

Where

θ is the angle of incidence [°]
β is the slop of the surface [°]
γ is the azimuth of the surface [°]
$\emptyset$ is the latitude[°]
δ is the solar declination[°]
ω is the hour angle [°]

An incidence angle of particular importance, which we will need shortly, is the *zenith angle*, meaning the angle between a vertical line and the line to the sun. The zenith angle is zero when the sun is directly overhead and 90° when the sun is at the horizon. Because a horizontal surface has a slope of zero, we can find an equation for the zenith angle by setting β=o° in the above equation, which yields:

$$\cos\theta_z = \cos\emptyset\cos\delta\cos\omega + \sin\emptyset\sin\delta$$

Where:

θ_z is the zenith angle [°]

Now we turn to the issue of the amount of solar radiation arriving at the top of the atmosphere over a particular point on the earth's surface. HOMER assumes the output of the sun is constant in time. But the amount of sunlight striking the top of the earth's atmosphere varies over the year because the distance between the sun and the earth varies over the year due to the eccentricity of earth's orbit. To calculate the *extraterrestrial normal radiation*, defined as the amount of solar radiation striking a surface normal (perpendicular) to the sun's rays at the top of the earth's atmosphere, HOMER uses the following equation:

$$G_{on}=G_{sc}\left(1+0.033\cdot cos\ \frac{360n}{365}\right)$$

Where:

G_{on} is the extraterrestrial normal radiation [kW/m^2]

G_{sc} is the solar constant [1.367 kW/m^2]

n is the day of the year [a number between 1 and 365]

To calculate the *extraterrestrial horizontal radiation*, defined as the amount of solar radiation striking a horizontal surface at the top of the atmosphere, HOMER uses the following equation

$$G_o=G_{on}\cos\theta_z$$

Where:

G_o is the extraterrestrial horizontal radiation [kW/m^2]
G_{on} is the extraterrestrial normal radiation [kW/m^2]
θ_z is the zenith angle [°]

Since HOMER simulates on a time step by time step basis, we integrate the above equation over one time step to find the average extraterrestrial horizontal radiation over the time step

$$\overline{G}_o=\frac{12}{\pi}G_{on}[\cos\emptyset\cos\delta\,(\sin\omega_2 - sin\ \omega_1)+\frac{\pi(\omega_2-\omega_1)}{180°}\sin\emptyset\sin\delta]$$

Where: $\overline{\mathbf{G}}_{\mathbf{o}}$ is the extraterrestrial horizontal radiation averaged over the time step [kW/m^2]

G_{on} is the extraterrestrial normal radiation [kW/m^2]

ω_1 is the hour angle at the beginning of the time step[°]

ω_2 is the hour angle at the end of the time step [°]The above equation gives the average amount of solar radiation striking a horizontal surface at the top of the atmosphere in any time step.

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The solar resource data give the average amount of solar radiation striking a horizontal surface at the bottom of the atmosphere (the surface of the earth) in every time step. The ratio of the surface radiation to the extraterrestrial radiation is called the clearness index. The following equation defines the clearness index: $K_T = \frac{\bar{G}}{\bar{G}_o}$

Where: $\bar{G}$ is the global horizontal radiation on the earth's surface averaged over the time step [kW/m^2]. $\bar{G}_o$ is the extraterrestrial horizontal radiation averaged over the time step [kW/m^2]

Table II
Solar radiation and clearness in Chhattisgarh (Durg Bhilai) throughout the year is given below in table

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.626	4.560
February	0.645	5.360
March	0.627	5.980
April	0.627	6.580
May	0.582	6.380
June	0.438	4.840
July	0.359	3.940
August	0.357	3.790
September	0.443	4.350
October	0.562	4.860
November	0.617	4.620
December	0.638	4.430

Now let us look more closely at the solar radiation on the earth's surface. Some of that radiation is *beam radiation*, defined as solar radiation that travels from the sun to the earth's surface without any scattering by the atmosphere. Beam radiation (sometimes called direct radiation) casts a shadow. The rest of the radiation is *diffuse radiation*, defined as solar radiation whose direction has been changed by the earth's atmosphere. Diffuse radiation comes from all parts of the sky and does not cast a shadow. The sum of beam and diffuse radiation is called global solar radiation, a relation expressed by the following equation:

$$\bar{G} = \bar{G}_b + \bar{G}_d$$

Where:

$\bar{G}_b$ is the beam radiation [kW/m^2]

$\bar{G}_d$ is the diffuse radiation [kW/m^2]

The distinction between beam and diffuse radiation is important when calculating the amount of radiation incident on an inclined surface. The orientation of the surface has a stronger effect on the beam radiation, which comes from only one part of the sky, than it does on the diffuse radiation, which comes from all parts of the sky.

V. Methodology And Results

In summer months, the beam component is more than diffuse component and thus the main contribution comes from the beam component. In monsoon season, the diffuse component is more than beam component.

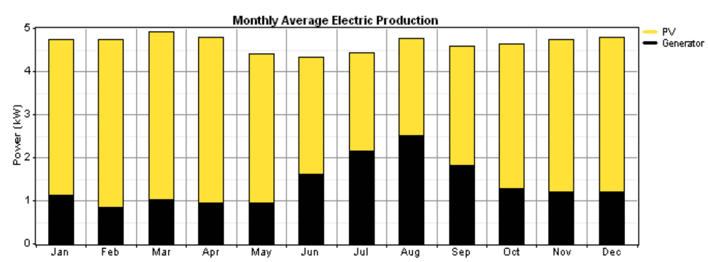

Fig 1 : monthly average electric production

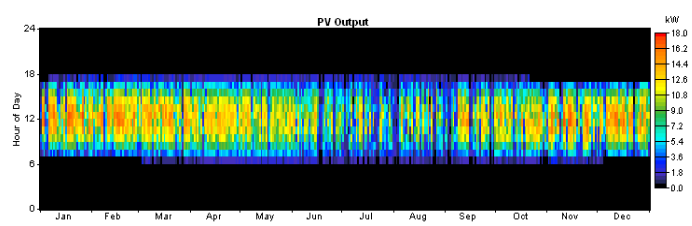

Fig 2 : PV O/P Vs day

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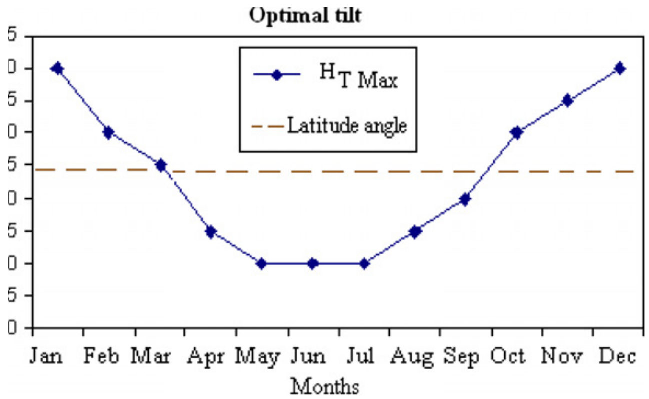

FIG. 3. OPTIMUM AVERAGE TILT ANGLE FOR EACH MONTH OF THE YEAR AT CHHATISGARH SITE.

37_o	17_o	12_o	28_o
Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug	Sep-Oct-Nov

FIG. 4. THE SEASONALLY ADJUSTED TILT ANGLES.

VI. CONCLUSION

The optimum tilt is different for each months of the year. The Collected solar energy will be greater if we choose the optimum panel tilt for each month. Also, we have found that the yearly average of optimum tilt is equal to the latitude of the site. The results show that the average optimum tilt angle at Chhattisgarh for the winter months is 37_ and for the summer months is 12_. So, the yearly average tilt panel is 23.5_ which nearly corresponding to the latitude of Chhattisgarh site (24.5_). This, in general, is in agreement with the results of many other researchers [15, 16].The loss of energy when using the yearly average fixed angle is around 8% compared with the optimum tilt for each month at Chhattisgarh. It can be concluded that a yearly average fixed tilt can be used in many general applications in order to keep the manufacturing and installation costs of collectors low. For higher efficiency, the collector should be designed such that the angle of tilt can easily be changed at least on a seasonal basis, if not monthly. Alternatively, solar tracking systems can be used in industrial installations where higher efficiency is required.

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