SOLAR POWER OUTPUT WITH OPTIMUM TILT ANGLE USING MATLAB

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Abstract: The Tilt angle in a solar energy system is one of the important parameters for capturing maximum solar radiation falling on the solar panels. This angle is site specific as it depends on the daily, monthly and yearly path of the sun. An accurate determination of optimum tilt angle for the location of interest is essential for maximum energy extraction from the system. A numerous methods are being used for determining the tilt angle at different locations worldwide. Keeping in view the relevance of the optimum tilt angle in energy production and reducing the cost of solar energy systems, the present study has been undertaken. The study shows that for maximum energy gain, the optimum tilt angle for solar system must be determined accurately for each location. This review will be useful for designers and researchers to select suitable methodology for determining optimum tilt angle for solar systems at any site.

Keywords: Solar radiation, Tilt angle, solar geometry.

1. INTRODUCTION

The most significant feature of renewable energy is its plentiful supply. It is infinite. Renewable energy sources are hygienic sources of energy that have a much lesser negative environmental impact than conventional fossil energy technologies. Most renewable energy investments are spent on materials and personnel to build and maintain the facilities, rather than on costly energy imports. With technological advancements in mass communication, people have now become aware of the demerits of burning fossil fuels. Renewable energy is the need of the hour. Its clean and sustainable nature has compelled the human beings to think seriously about it. Scientists and Engineers, around the world, are continuously working and researching in this domain. They are finding new ways to use these sources of energy effectively. Global warming is a huge hazard which is being caused by burning of coal, oil and natural gas. It is very harmful for the planet and the living beings on it. Moreover, fossil fuels are a cause of many unfortunate mishaps in the past as described before. To put an end to this apocalypse; we must resort to renewable sources.

This is because they are cleaner and do not produce poisonous harmful gases. Moreover, fossil fuels are finite. They will certainly end one day. Therefore, before the crucial stage comes up, experts of energy sectors must maintain a positive attitude in this regard and should try their level best to replace fossils fuels with renewable energy sources as the main sources of generating electricity.

2. SOLAR RADIATION ON THE EARTH’S SURFACE

As the solar radiation reaches the atmosphere of the earth, it is scattered, reflected and absorbed by atmospheric particles. As a result, only a portion of the solar radiation outside the earth’s atmosphere, i.e., the extra-terrestrial radiation, actually reaches the surface of the earth. This portion, the terrestrial radiation, consists of three components, discussed.

2.1 EXTRA-TERRESTRIAL RADIATION

The extra-terrestrial radiation is defined as the radiation that passes perpendicularly through an imaginary surface just outside the earth’s atmosphere. It varies from day to day, depending on the distance between the sun and the earth. The extra-terrestrial radiation, I(0) (W/m2), on each day of the year is given.

\[ I_0 = SC \left[ 1 + 0.0334 \cos \frac{2\pi n}{365} \right] \]

Where SC is the solar constant and n is the day number (starting from the 1st of January). The solar constant is an estimate of the average annual extra-terrestrial radiation, having a generally accepted numerical value of 1377 W/m2.
2.2 TERRESTRIAL RADIATION

There are two types of radiations:

1) Beam radiation.
2) Diffuse radiation.

**Beam or direct radiation**
Solar radiation received at earth surface without changes of direction i.e. in the line with the sun.

**Diffuse radiation**
The radiation received by the earth, from all parts of the sky hemisphere (after being subjected to the scattering in the atmosphere)

2.3 SOLAR GEOMETRY

![Geometrical view](image)

- **Declination angle (δ):**
  It is the angle made by the line joining the centre of the sun and the earth with the projection of this line on the equatorial plane.
  \[ \delta = 23.45 \times \sin \left(360\times\left(284 + n\right)/365\right) \]

- **Hour Angle (ωs):**
  It is the angular measure of time and it is equivalent to 15 degrees per hour. It also varies from -180° to +180°
  \[ \omega_s = \cos^{-1}\left(-\tan \phi \tan \delta\right) \]

- **Slope (β):**
  It is the angle made by the plane surface with the horizontal. It can vary from 0 to 180°

- **Angle of incidence (θ):**
  It is the angle between an incident beam of flux and the normal to a plane surface.

- **Latitude (ϕ):**
  The latitude is the angle made by the radial line joining the location to the centre of the earth with the projection of the line on the equatorial plane.

- **Solar azimuth angle (ys):**
  It is the angle made in the horizontal plane between the horizontal line due south and the projection of the line of sight of the sun on the horizontal plane.

- **Surface azimuth angle (y):**
  It is the angle made in the horizontal plane between the horizontal line due south and the projection of the normal to the surface on the horizontal plane.

- **Zenith angle (θz):**
  It is the angle made by the sun's rays with the normal to a horizontal surface.

- **Solar altitude angle (αa):**
  It is the complement of the zenith angle

2.4 TILT FACTOR

Tilt factor is defined as the angle made by the ground surface to the surface of the solar photo voltaic plate called tilt angle.

For the case of tilted surface facing south is

\[ \cos \theta = \sin \delta \sin (\theta - \beta) + \cos \delta \cos \omega \cos (\phi - \beta) \]

While for the horizontal surface

\[ \cos \theta_z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega \]

Hence tilt factor for beam radiation is

\[ T_b = \frac{\cos \theta}{\cos \theta_z} = \frac{\sin \delta \sin (\theta - \beta) + \cos \delta \cos \omega \cos (\phi - \beta)}{\sin \theta \sin \delta + \cos \theta \cos \delta \cos \omega} \]

Similarly, expressions for RB can be derived for other situations in which the tilted surface is oriented in a different direction.

The tilt factor RD for diffuse radiation is the ratio of the diffuse radiation falling on the tilted surface to that falling on a horizontal surface. The value of this tilt factor depends upon the distribution of diffuse radiation over the sky and on the portion of the sky dome seen by the tilted surface.

Assuming that the sky is an isotropic source of diffuse radiation, we have for a tilted surface with a slope β,

\[ RD = (1 + \cos \beta / 2) \]

Total radiation for the horizontal surface is:

\[ HT = HB + HD \]

Now total radiation for tilted surface is:

\[ HT = HB \times RB + HD \times RD \]
The tilted surface also sees ground or other surroundings and if those surrounding have a diffuse reflectance of $\rho$ for solar radiation, the reflected radiation from the surrounding on the surface from total solar radiation.

$\rho = 0.2$ when there is no snow, $\rho = 0.7$ when there is a snow cover.

<table>
<thead>
<tr>
<th>Month</th>
<th>Declination angle $\delta$ (°)</th>
<th>Optimum tilt angle $\beta$ (degrees)</th>
<th>Total Irradiation tilted collector surface (Wh/m$^2$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>-20.9</td>
<td>34.9</td>
<td>7047</td>
</tr>
<tr>
<td>February</td>
<td>-13</td>
<td>27.02</td>
<td>7457</td>
</tr>
<tr>
<td>March</td>
<td>-2.4</td>
<td>16.48</td>
<td>7453</td>
</tr>
<tr>
<td>April</td>
<td>9.4</td>
<td>4.65</td>
<td>7075</td>
</tr>
<tr>
<td>May</td>
<td>18.8</td>
<td>-4.72</td>
<td>6783</td>
</tr>
<tr>
<td>June</td>
<td>23.1</td>
<td>-9.02</td>
<td>6082</td>
</tr>
<tr>
<td>July</td>
<td>21.2</td>
<td>-7.11</td>
<td>5438</td>
</tr>
<tr>
<td>August</td>
<td>13.5</td>
<td>0.61</td>
<td>5625</td>
</tr>
<tr>
<td>September</td>
<td>2.2</td>
<td>1.185</td>
<td>5743</td>
</tr>
<tr>
<td>October</td>
<td>-9.6</td>
<td>23.6</td>
<td>5433</td>
</tr>
<tr>
<td>November</td>
<td>-18.9</td>
<td>32.98</td>
<td>5703</td>
</tr>
<tr>
<td>December</td>
<td>-23</td>
<td>37.11</td>
<td>6191</td>
</tr>
</tbody>
</table>

Table 1: Monthly Total Irradiance Analysis

<table>
<thead>
<tr>
<th>Month</th>
<th>Season</th>
<th>Optimum tilt angle $\beta$ (degrees)</th>
<th>Total Irradiation tilted collector surface (Wh/m$^2$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>Spring</td>
<td>5.4</td>
<td>7168</td>
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<tr>
<td>April</td>
<td></td>
<td>4.187</td>
<td>7076</td>
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<tr>
<td>May</td>
<td></td>
<td>6.680</td>
<td>6082</td>
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<tr>
<td>June</td>
<td>Summer</td>
<td>-5.1</td>
<td>5410</td>
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<td>July</td>
<td></td>
<td>5.996</td>
<td>5688</td>
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<tr>
<td>August</td>
<td></td>
<td>5.688</td>
<td>6046</td>
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<tr>
<td>September</td>
<td></td>
<td>22.8</td>
<td>5367</td>
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<tr>
<td>October</td>
<td>Autumn</td>
<td>33</td>
<td>5160</td>
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<tr>
<td>November</td>
<td></td>
<td>5818</td>
<td>5818</td>
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<tr>
<td>December</td>
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<td>6817</td>
<td>7788</td>
</tr>
</tbody>
</table>

Table 2: Seasonal Total Irradiance Analysis

<table>
<thead>
<tr>
<th>Month</th>
<th>Optimum tilt angle $\beta$ (degrees)</th>
<th>Total Irradiation tilted collector surface (Wh/m$^2$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>14</td>
<td>6369</td>
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<tr>
<td>February</td>
<td></td>
<td>7140</td>
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<tr>
<td>March</td>
<td></td>
<td>7437</td>
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<td>April</td>
<td></td>
<td>6909</td>
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<td>May</td>
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<td>6220</td>
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<td>June</td>
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<td>5433</td>
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<td>July</td>
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<td>5027</td>
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<td>August</td>
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<td>5421</td>
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<tr>
<td>September</td>
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<td>5729</td>
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<tr>
<td>October</td>
<td></td>
<td>5321</td>
</tr>
<tr>
<td>November</td>
<td></td>
<td>5329</td>
</tr>
<tr>
<td>December</td>
<td></td>
<td>5542</td>
</tr>
</tbody>
</table>

Table 3: Yearly Total Irradiance Analysis

3. OPTIMUM TILT ANGLE OF SOLAR PANEL

To get the most from solar panels, you need to point them in the direction that captures the most sun. But there are a number of variables in figuring out the best direction. This page is designed to help find the best placement of solar panels in any situation. This advice applies to any type of panel that gets energy from the sun: photovoltaic, solar hot water, etc. We assume that the panel is fixed, or has a tilt that can be adjusted seasonally. Panels that track the movement of the sun throughout the day can receive 10% (in winter) to 40% (in summer) more energy than fixed panels.

Solar panels should always face true south if you are in the northern hemisphere, or true north if you are in the southern hemisphere. True north is not the same as magnetic north. If compass is used to orient the panels, “magnetic declination” should be used to correct the difference, which varies from place to place.

The next question is, at what angle from horizontal should the panels be tilted? Books and articles on solar energy often give the advice that the tilt should be equal to your latitude, plus 15 degrees in winter or minus 15 degrees in summer. It turns out that you can do better than this about 4% better.

3.1 FIXED OR ADJUSTABLE

The mounts of solar panels nowadays are provided with greater flexibility i.e. one can keep them fixed to latitude angle or can tilt them to adjust until optimum angle as per sun’s intensity based on seasons. For instance, when the tilt are adjusted to and fro seasonally at 40° latitude for a panel, the conversion gains are quite desirable as depicted in the below table and the graph is shown for different adjustability; annually.

<table>
<thead>
<tr>
<th>Tilt Adjustment</th>
<th>Fixed</th>
<th>Adj.2 seasons</th>
<th>Adj.4 seasons</th>
<th>2-axis tracker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Gain of optimum energy</td>
<td>71.1%</td>
<td>75.2%</td>
<td>75.7%</td>
<td>100%</td>
</tr>
</tbody>
</table>
3.3 ADJUSTING THE TILT FOUR TIMES A YEAR

The following table gives the best dates on which to adjust the panel tilt four times a year. This is advantageous to Grid tied systems.

In winter, a panel fixed at the winter angle will be relatively efficient, capturing 81 to 88 percent of the energy compared to optimum tracking. In the spring, summer, and autumn, the efficiency is lower (74–75% in spring/autumn, and 68–74% in summer), because in these seasons the sun travels a larger area of the sky, and a fixed panel can't capture as much of it. These are the seasons in which tracking systems give the most benefit.

Note that the winter angle is about 5° steeper than what has been commonly recommended. The reason is that in the winter, most of the solar energy comes at midday, so the panel should be pointed almost directly at the sun at noon. The angle is fine-tuned to gather the most total energy throughout the day.

The summer angles are about 12 degrees flatter than is usually recommended. In fact, at 25° latitude in summer, the panel should actually be tilted slightly away from the equator.

Table 7: Best dates to adjust the Tilt four times a year.

4. MATLAB CODING

An optimal tilt angle essentially can be calculated by using MATLAB which provides quick and correct results. When the necessary inputs are provided to the matlab code, gives out the respective tilt to the relevant data at location of interest. This saves lot of time and complex math calculations which are to be done manually otherwise. Also this code provides greater flexibility in finding optimum tilt instantly for any number of sites by simply changing the inputs and executing the code. The code with comments given below is easy to
grasp MATLAB code to obtain optimal tilt of solar panel on any day of a year and at any location on the planet blue.

Clear all;
clc;
ch=menu('choose a type of tilt angle','monthly','seasonal','annual');
if(ch==1)
clc;
clearall;
day=input('n day=');
%insert the sequence of the day in the month, from 1 to 31
x=input('n mo=');%insert the corresponding number of the month, from 1 to 12
hour=input('n hour=');%insert the hour in the 24 hour system(e.g. 13 for 1 p.m)
min=input('minute=');%insert the minute, from 0 to 59
N=input('n number of days in given month=');
L=input('local latitude in deg=');%the values above is local and independent.
Az=input('surface azimuth angle in deg=');%the values above is local and independent.
Hg=input('monthly mean daily global radiation on horizontal surface=');
HD=input('monthly mean daily diffuse radiation on horizontal surface=');
Ro=0.2;%ground albedo
%%calculation of day sequence
m=[0 31 59 90 120 151 181 212 243 273 304 334];
N=m(x)+day;%this step evaluate the day sequence number in the year
fprintf('n day number:%d',n);
%%calculate of declination angle
dx1=(360/365)*(284+n);
d1=(23.45*sind(x1));%see equ(1)
fprintf('n declination for month1:%d',d1);
d2=(23.45*sind(x2));%see equ(2)
fprintf('n declination for month2:%d',d2);
d3=(23.45*sind(x3));%see equ(3)
fprintf('n declination for month3:%d',d3);
D=(d1+d2+d3)/3;
fprintf('n average seasonal declination angle:%d',D);

Bt=atan((sin(L)*cos(L)*cos(L)*cos(Az)*cos(h))- (cos(L)*sin(L)*cos(Az);cos(h))/cos(L));
fprintf('n day optimum tilt angle:%d,Bt);
%%calculation of direct beam radiation
Rb=(cos(L-Bt)*cos(L)*sin(Hs))+(hs1*sin(L-Bt)*sin(Hs))/((cos(L)*cos(L)*sin(L)+hs1*sin(L)*

io=(1.033*cosd(360*n)/365.25);
Ho=((N/pi)*(86400*i*sin(L)*cos(L)*sin(Hs)-

Rd=((HB/Ho)*Rb)+(1-(HB/Ho))*((1+cosd(bt))*2)+(1+sqrt(HB/Hg)*sind(bt/2^3));
fprintf('n n rb:%d',Rb);

HD=Rs*HD;
fprintf('n sky diffuse radiation:%d',HD);
%%calculation of total radiation on tilted surface
HT=HB+HR+HD;
fprintf('n n total radiation tilt surface:%d',HT);
elseif(ch==2)
clc;
clearall;
di=input('n day sequence from month1=');

D2=input('n day sequence from month2=');

D3=input('n day sequence from month3=');

D2=di+input('n day sequence from month2=');

D3=di+input('n day sequence from month3=');

inmonth,from 1to31
D2=di+input('n day sequence from month2=');

D3=di+input('n day sequence from month3=');

inmonth,from 32to60
D3=di+input('n day sequence from month3=');

inmonth,from 33to365
L=input('local latitude in deg=');
Az=input('surface azimuth angle in deg=');
%the values above is local and independent.

D1=23.45*sin(284+D1)*(360/365);
D2=23.45*sin(284+D2)*(360/365);
D3=23.45*sin(284+D3)*(360/365);
D1=23.45*sin(284+D1)*360/365;
D2=23.45*sin(284+D2)*360/365;
D3=23.45*sin(284+D3)*360/365;
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D1=23.45*sin(284+D1)*360/365;
D2=23.45*sin(284+D2)*360/365;
D3=23.45*sin(284+D3)*360/365;

day=input('
 day=');
%insert the sequence of the day in the month,from 1 to 31
x=input('
 month=');
%insert the corresponding number of the month, from 1 to 12
hour=input('
 hour=');
%insert the hour in the 24 hour system (e.g. 13 for 1 p.m.)
min=input('
 minute=');
%insert the minute, from 0 to 59
Hg=input('monthly mean daily global radiation on horizontal surface=');
HD=input('monthly mean daily diffuse radiation on horizontal surface=');
Ro=0.2;

Ro=0.2;

HT=HB+HR+HD;
fprintf(' n total radiation tilt surface: %d',HT);
else if(ch==3)
clearall;
cle


%insert the sequence of the day in the month, from 1 to 31
x=input('
 Month=');
%insert the corresponding number of the month, from 1 to 12
hour=input('
 Hour=');
%insert the hour in the 24 hour system (e.g. 13 for 1 p.m.)
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Rb=abs(Rb);
fprintf('n Rb:%d',RB);
HB=(Hg-Hd)*Rb;%direct beam radiation
fprintf('n direct beam radiation:%d',HB);
%%calculation of ground reflection beam radiation
HR=Hg*Ro*(1-cosd(Bt))/2;
fprintf('n ground reflection beam radiation:%d',HR);
%%calculation of diffused beam radiation
Rd=(1+cosd(Bt))/2;
fprintf('n Rd:%d',Rd);
HD=Rd*HD;
fprintf('n sky diffuse radiation:%d',HD);
%%calculation of total radiation on tilted surface
HT=HB+HR+HD;
fprintf('n total radiation tilt surface:%d',HT);

Else if(ch==3)
clearall;
clc;
day=input('n Day=');%insert the sequence of the day in the month,from 1 to 31
x=input('n Month=');%insert the corresponding number of the month,from 1 to 12
hour=input('n Hour=');%insert the hour in the 24 hour system(e.g.13 for 1 p.m.)
min=input('Minute=');%insert the minute from 0 to 59
L=input('n local latitude in deg=');
Hg=input('monthly mean daily global radiation on horizontal surface=');
Hd=input('monthly mean daily diffuse radiation on horizontal surface=');
Ro=0.2;
%%calculation of day sequence
m=[0 31 59 90 120 151 181 212 243 273 304 334];
N=m(x)+day;%this step evaluate the day sequence number in the year
fprintf('n day number:%d',N);

%%calculate of declination angle
x1=(360/365)*(284+N);
D=(23.45*sin(x1));%see equ(1)
fprintf('n declination angle:%d,D);
%%calculation of hour angle
x2=hour+(min/60)-12;
h=x2*15;%see equ(2)
fprintf('n hour angle:%d,h);
%%calculation of altitude angle
a=asin(sin(L)*sind(D)+cosd(L)*cosd(D)*cosd(h));%see equ(3)
fprintf('n altitude angle:%d,a);

%%calculation of zenith angle
Zs=90-a;
%%calculation of seasonal tilt angle
Bt=L;
%%calculation of sun set hour angle
Hs=acosd(tand(L+Bt)*tand(D));
%%calculation of total radiation tilt surface
HT=HB+HR+HD;
fprintf('n total radiation tilt surface:%d',HT);

5. RESULTS AND DISCUSSION

Represented tilt angle for month, seasonal and year wise the seasonal average is calculated by taking average of tilt angle for each season and same is implemented 4times a year. In winter the angle of collector should be 33° during spacing tilt is 5.4° in summer tilt is 5°and during autumn tilt is 23° the yearly average tilt is calculation by taking average of all months or it also can be maintained at latitude angle which 14°.negative tilt angle incidences that the solar panel towards north during summer in order to capture maximum solar irradiation the orientation of solar collector also plays an important role as tilt angle of collector which gives a loss of 1.1% if fix panel toward role as tilt angle of increased /decreased loss according to location.
the power obtained is 986w/m. Number of kwh generated per month is 0.986kw/31days =213wh/month

By maintaining monthly and seasonal optimum tilt angle the solar setup achieve 5.6 and 4.6 percent more energy compared with the yearly field system.

<table>
<thead>
<tr>
<th>Month</th>
<th>Monthly optimum tilt average hourly irradiation (w/m²)</th>
<th>Power(w/h)</th>
<th>Number of kwh/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1026</td>
<td>996</td>
<td>213</td>
</tr>
<tr>
<td>February</td>
<td>1049</td>
<td>1048</td>
<td>205</td>
</tr>
<tr>
<td>March</td>
<td>1064</td>
<td>990</td>
<td>207</td>
</tr>
<tr>
<td>April</td>
<td>1010</td>
<td>951</td>
<td>206</td>
</tr>
<tr>
<td>May</td>
<td>868</td>
<td>850</td>
<td>178</td>
</tr>
<tr>
<td>June</td>
<td>776</td>
<td>761</td>
<td>165</td>
</tr>
<tr>
<td>July</td>
<td>805</td>
<td>787</td>
<td>170</td>
</tr>
<tr>
<td>August</td>
<td>820</td>
<td>802</td>
<td>168</td>
</tr>
<tr>
<td>September</td>
<td>713</td>
<td>698</td>
<td>150</td>
</tr>
<tr>
<td>October</td>
<td>814</td>
<td>797</td>
<td>169</td>
</tr>
<tr>
<td>November</td>
<td>824</td>
<td>861</td>
<td>180</td>
</tr>
</tbody>
</table>

Number of kwh generated by 1km solar system using optimum tilt angle. The number of kwh/month achieved using monthly, seasonal and fixed optimum tilt angles. For a 1kw system fixed/yearly optimum tilt we can achieve 213kwh/month at the same way by seasonal optimum tilt angle we can achieve 228 kw/month with optimum tilt.

6. Conclusion & Future Scope

Using relevant meteorological parameters and the methods described in this study, monthly averages of the beam irradiation, the diffused radiation and the global irradiation at different tilt angles was determined. The effects and contributions of each of the components (beam, diffuse) for the general case and at their optimum angles were highlighted. Result from the study shows that, using
the tilt angle that yields the optimum irradiation for each month can substantially increase PV energy production.

The average annual maximum irradiation could be obtained at a tilt angle of about 6° which is approximately equal to the latitude of the location. The results obtained could be used to estimate the KWh generation of a PV module at any site of interest.

Design and develop the plug and play solar rooftop power system. This work mainly focuses on three areas of optimization. Module spacing and tilt azimuth orientation, inverter and power optimizer with shade tolerance.

REFERENCES:


