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OPTIMUM TILT FOR SOLAR COLLECTORS IN RAJSHAHI, BANGLADESH

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Abstract: Incident solar irradiation of photovoltaic collector is affected by tilt and azimuth angles. This study measures the optimum tilt and azimuth angles for Photovoltaic Applications at Rajshahi in Bangladesh on yearly and seasonal bases. The result shows optimum tilt angles for PV applications. This study finds that optimum tilt angle is as the local latitude at Rajshahi for grid connected PV system to obtain maximum yearly energy generation where energy increment rate is 8.1% than horizontal radiation. Seasonal optimum tilt is found as 50 degree for months November-February and 10 degree for months April-September, 30 degree for March & October. Energy produced is 4.4% more than that of annual optimum tilts.

Keywords: Energy policy, tilted radiation, optimum tilt, surface orientation, annual tilt, seasonal tilt, increment rate.

INTRODUCTION:

The techniques for estimating typical solar radiation on tilted surfaces of various directions can be used to show the special effects of slope and azimuth angle on total energy received on a surface on a monthly, seasonal or annual basis. The surface direction leading to highest output of a solar energy structure may be fairly different from the orientation leading to maximum incident energy. For solar energy purposes, the most favorable orientation is usually recommended to be south facing in the northern hemisphere and the

optimum tilt depends simply on the local latitude, $\beta_{opt} = f(\varphi)$. Duffie and Beckman [1] recommended that optimum tilt is within the range $(\varphi \pm 15\ deg) \pm 15de$where φ is the local latitude.

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Christensen and Barker [4] found that surface tilt angles and azimuth angles can be varied over a significant range without considerably dropping the amount of yearly incident irradiation.

Prior to this work, a study was done to find the optimum orientation of solar collectors at Dhaka, Bangladesh and has been found 30 degree for optimum tilt at that location [11]. Then this study aims to check any difference in optimum tilt at Rajshahi where solar radiation intensity is maximum than any other locations of Bangladesh [12].

RATIO OF BEAM RADIATION ON INCLINED TO THAT ON HORIZONTAL SURFACE:

The geometric factor, R_b, the ratio of beam radiation on the tilted surface to that on a horizontal surface at any time, can be calculated exactly from the following equation. Figure 1 indicates the angle of incidence of beam radiation on the horizontal and tilted surfaces [1].

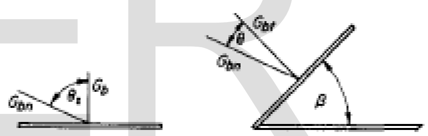

Figure 1: beam radiation on horizontal and tilted surfaces [1].

The ratio is given by

$$R_b = \frac{G_{b,T}}{G_b} = \frac{G_{b,n}\, cos\theta}{G_{b,n}\, cos\theta_z} = \frac{cos\theta}{cos\theta_z} \qquad (1)$$

where,

$$cos\theta = sin\delta\, sin\varphi\, cos\beta - sin\delta\, cos\varphi\, sin\beta\, cos\gamma + cos\delta\, cos\varphi\, cos\beta\, cos\omega + cos\delta\, sin\varphi\, sin\beta\, cos\gamma\, cos\omega + cos\delta\, sin\beta\, sin\gamma\, sin\omega$$

and $cos\theta_z = cos\varphi\, cos\delta\, cos\omega + sin\varphi\, sin\delta$

The best azimuth angle for solar collectors is usually 0^0 in the northern hemisphere. Thus, upon simplification equation (1) reduces to

$$R_b = \frac{\cos(\varphi - \beta)\ cos\delta\, cos\omega + \sin(\varphi - \beta)\ sin\delta}{cos\varphi\, cos\delta\, cos\omega + sin\varphi\, sin\delta} \qquad (2)$$

But according to Liu and Jordan [10] $\overline{R_b}$ is calculated from

$$\overline{R_b} = \frac{cos(\varphi - \beta) cos\delta sin\omega_s + \left(\pi/_{180}\right)\omega_s sin(\varphi - \beta) sin\delta}{cos\varphi cos\delta sin\omega_s + \left(\pi/_{180}\right)\omega_s sin\varphi sin\delta} \qquad (3)$$

Where, ω_s denotes the sunset hour angle and is taken to the smaller value from

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$$\omega_s = cos^{-1}(-tan\varphi tan\delta)$$
$$\omega_s = cos^{-1}(-tan(\varphi - \beta)tan\delta) \qquad (4)$$

METHODOLOGY FOR THE OPTIMUM TILT:

We now calculate the tilted radiation when the total horizontal radiation is known. For this we require the directions from which the beam and diffuse parts arrive at the surface. The direction from which diffuse radiation is received, i.e., its circulation over the sky dome, is a function of conditions of cloudiness and atmospheric clarity, which are mostly unpredictable.

The tilted radiation is the sum of a set of radiation streams including beam radiation, the three parts of diffuse flux from the sky, and radiation reflected from the different surfaces seen by the tilted surface. The total radiation on this surface can be written as

$$\overline{H_T} = \bar{H}\left(1 - \frac{\overline{H_d}}{\bar{H}}\right)\overline{R_b} + \overline{H_d}\left(\frac{1 + cos\beta}{2}\right) + \bar{H}\rho_g\left(\frac{1 - cos\beta}{2}\right) \qquad (5)$$

Where, $\overline{H_d}$ is the monthly average daily diffuse radiation, $\overline{R_b}$ is the monthly average daily geometric factor for beam radiation, β is the slope of the surface and ρ_g is the diffuse reflectance for the total solar radiation of the location.The surface view factor to the sky is $\left(\frac{1+cos\beta}{2}\right)$ and the surface view factor to the ground $\left(\frac{1-cos\beta}{2}\right)$

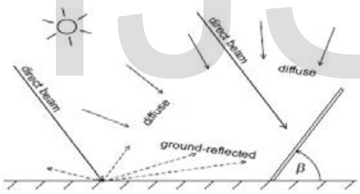

Figure 2: Beam, diffuse and reflected solar radiation on tilted surface [1]

The first step to calculate the average monthly tilted solar radiation is to calculate R_b using equation (3) and the relationship H_d/H from the measured data or using any of the correlation models. Equations considered in this study for these correlations are as follows [9]:

For $\omega_s \leq 81.4^0$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^{\,2} - 2.137\bar{K}_T^{\,3} \qquad (6)$$

And for $\omega_s > 81.4^0$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^{\,2} - 1.821\bar{K}_T^{\,3} \qquad (7)$$

For known R_b and H_d/H ratio, monthly average daily radiation on tilted surface was calculated.

For a fixed orientation, the optimum tilt angle can be found by solving the following equation for β

$$\frac{d}{d\beta}(\overline{H_T}) = 0 \qquad (8)$$

Now, since diffuse and ground reflected parts are negligible, the above equation turns into

$$\frac{d}{d\beta}(\overline{R_b}) = 0 \qquad (9)$$

$$\Rightarrow \frac{sin(\varphi - \beta)cos\delta sin\omega_s - \left(\pi/_{180}\right)\omega_s\, cos(\varphi - \beta)sin\delta}{cos\varphi cos\delta sin\omega_s + \left(\pi/_{180}\right)\omega_s sin\varphi sin\delta} = 0$$

$$\Rightarrow \beta = \varphi - tan^{-1}\left(\frac{(\pi/180)\omega_s\, sin\delta}{cos\delta\, sin\omega_s}\right) \qquad (10)$$

For fixed values of φ, ω_s and δ for a particular month at a specific location, the optimum tilt angle is easily determined.

RESULTS AND DISCUSSION

TOTAL ENERGY RECEIVED ON ANNUAL BASIS:

Finding the local annual optimum tilt angle is significant in determining the optimum orientation. The maximum energy obtained at south facing azimuth angle with latitude oriented slope as shown in figure 4. Compared with horizontally placed PV collectors, the modules with optimum slope can generate 8.1% more power. Upon determined the tilt factors by using equation (3), figure 3 presents graphically for the months for different orientations.

Table 1: Tilt factor and monthly average tilted radiation for latitude oriented and optimum oriented for annual optimum power output

Month	Tilt factor R_b	Monthly average Tilted	Tilt factor R_b $(\beta = \varphi)$	Monthly average Tilted radiation	Tilt factor R_b $(\beta = 30^0)$	Monthly average Tilted radiation(MJ/m^2)

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	$(\beta = 20^0)$	radiation (MJ/m^2)		(MJ/m^2)		
Jan	1.39	15.71	1.46	16.2399	1.52	16.6726
Feb	1.26	22.35	1.3	22.8417	1.33	23.1659
Mar	1.12	21.55	1.13	21.6374	1.13	21.5650
Apr	1	21.89	0.98	21.5354	0.95	20.9974
May	0.91	19.39	0.89	19.0882	0.84	18.3830
Jun	0.88	19.27	0.84	18.7113	0.79	17.9821
Jul	0.89	16.59	0.86	16.2478	0.81	15.6744
Aug	0.96	15.44	0.94	15.2117	0.91	14.8611
Sep	1.07	17.55	1.07	17.4888	1.06	17.2905
Oct	1.21	19.38	1.24	19.6551	1.27	19.8903
Nov	1.35	19.90	1.41	20.5721	1.47	21.2275
Dec	1.43	14.72	1.5	15.2269	1.58	15.7844
Annual total		6791.72		6811.32		6781.34

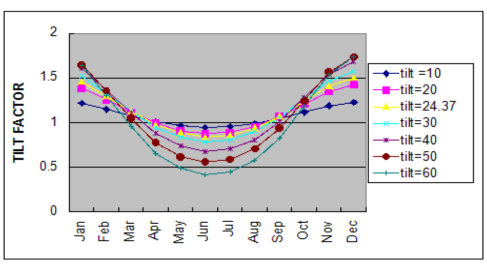

Figure 3: Tilt factor vs months of year for fixed slope

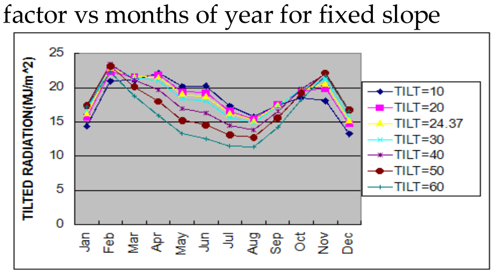

Figure 4: solar radiation (MJ/m^2) vs months for fixed orientation throughout the year

The yearly collected solar radiation reduces sharply when the slopes exceed 40 deg. Figure 5 shows bar charts of annual total tilted radiation for different tilts, where it has been found that for tilt equal to local latitude, the annual total solar radiation is highest.

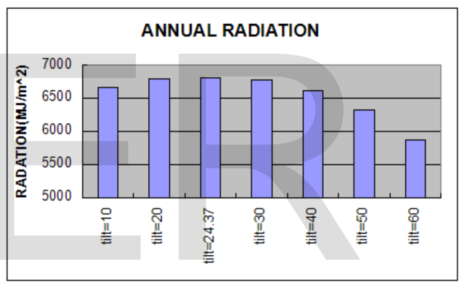

Figure 5: Annual total solar radiation (MJ/m^2) vs tilt

Total energy received on seasonal basis:

If we divide the whole year into two different categories on the basis of high and low tilt factor then we get an optimum tilt angle as 50 degree for the months November-February, 10 degree for the months April-September and 30 degree for the months March & October. Energy obtained in this case is 4.4% more than the energy obtained for annual optimum tilt.

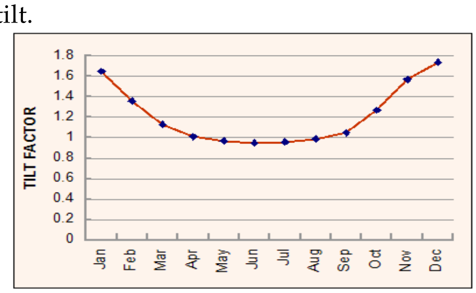

Figure 6: Tilt factor vs months of year for variable slope (Tilt for Apr-Sep is 10 degree and Nov-Feb is 50 degree and for March & October 30 degree)

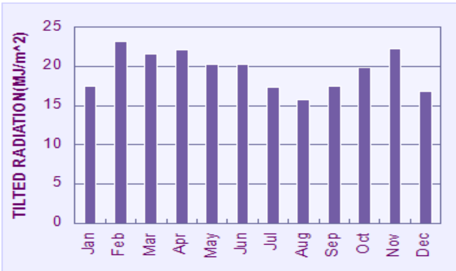

Figure 7: Tilted Solar radiation (MJ/m^2) vs months of year for variable slope (Tilt for Apr-Sep is 10 degree and Nov-Feb is 50 degree and for March & October 30 degree)

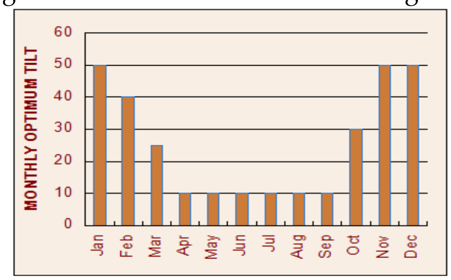

Figure 8: Optimum tilt for different months of the year

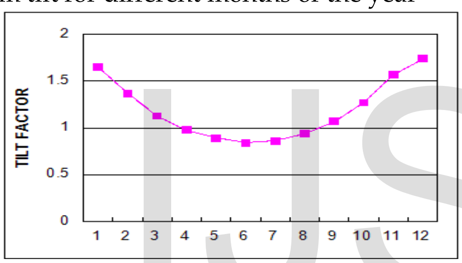

Figure 9: Tilt factors vs months for monthly optimum tilt

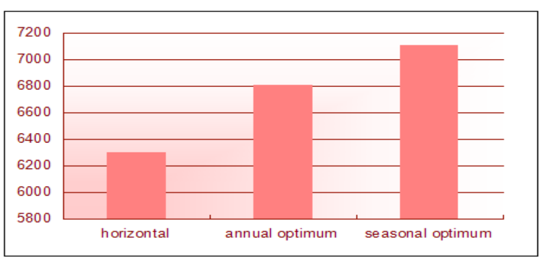

Figure 10: energy (MJ/m^2) output for three different orientations

It is seen from figure 10 that maximum power is generated for monthly optimum tilt. Seasonal tilt energy output is nearly equal to that of monthly output.

Table 3: Energy increment rate at different orientations

Surface orientation	Annual total Energy (MJ/m^2)	Increment rate than horizontal	Increment rate than annual oriented
Horizontal (tilt=0)	6301.21		
Annual optimum (tilt=24.37)	6811.33	8.1%	
Seasonal optimum	7111.12	12.85%	4.4%

Table 3 shows the increment rate of power produced over different types of surface orientations for annual fixed, seasonal fixed and monthly variations. Annual optimum ($\beta = 24.37^0$) energy is increased at a rate of 8.1% than horizontal orientation. Seasonal ($\beta = 10^0$ for Apr-Sep and 50^0 for Nov-Feb and 30^0 for March & October) optimum energy is increased 4.4% than annual optimum energy obtained.

CONCLUSION:

The efficiency and performance of solar collectors and Photovoltaic systems depend on the module's orientation. The Photovoltaic collectors should be tilted in an appropriate manner to obtain the utmost radiation. In this study it is found that optimum tilt angle in Rajshahi is equal to the local latitude of $\varphi = 24.37\ deg$ for both stand alone and grid connected PV system to obtain maximum yearly energy generation. Seasonal optimum tilt reaches to 50 degree for months (November-February) and 30^0 for March & October and 10 degree for months (April - September). If the slopes could be adjusted monthly, the power efficiency would likely be much better.

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