OPTIMIZATION OF GLOBAL SOLAR RADIATION OF TILT ANGLE FOR SOLAR PANELS, LOCATION: OUARGLA, ALGERIA

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Abstract *– The solar photovoltaic energy is a new and an appropriate alternative source, but the low conversion efficiency of the PV arrays and the large area necessitate their optimum use. In this paper, we analyze this problem and we show the importance of the inclination of the solar panels to maximize the efficiency of the system. Four optimization methods (monthly based, seasonal based, bi-annual based and annual based) are implemented. We have computed the maximal energy that can receive a solar panels, by choosing the monthly optimal angle of inclination and have demonstrated that for the considered geographical site this energy remains practically maximal by changing the tilt angle of the panels four times (seasonally) or two times(bi-annual) in a year only.*

Keywords*: Solar Panels, optimum tilt angle, global solar radiation photovoltaic, energy.*

I. Introduction

Solar energy occupies one of the most important places among the various possible alternative energy sources. Ouargla is geographically well situated with respect to a solar energy potential that is about 3900 hours per year. Average daily solar energy density is 5 kWh/m^2, environ 2263 kWh/m^2/year [1].

In any solar energy conversion system, the knowledge of global solar radiation is extremely important for the optimal design and the prediction of the system performance [2].

The most commonly used parameter for estimating global solar radiation in the publications is sunshine duration. Sunshine duration can be easily and reliably measured and data are widely available [3]. In most studies different mathematical models were used (isotropic and anisotropic models) in the calculation of total radiation on tilted surface for measurements based on a horizontal surface. In this paper, a simple model has been used is that of LIU and JORDAN.

The main objective of this study is to determine the optimum tilt angle for a solar panel and the total solar radiation on a tilted surface in Ouargla, Algeria. Total solar radiation on the solar panel surface with an optimum tilt angle is computed for specific periods (monthly, seasonal, bi-annual and yearly).

II. Place and Measurement

The insulation and sunshine duration data reported in this paper were supplied by the meteorological station at Ouargla, Algeria, a high rainfall station located at latitude 31 N, longitude 5°24′E with an altitude of 141 m and is as presented in Table 1 for the period 2000-2006[4,5].

TABLE I
Relevant meteorological data for Ouargla in Algeria.

Months	Insulation (h)	$\bar{S}$(h)	$\bar{S}_0$(h)
Jan	255	8.2	10.2
Feb	249	8.9	10.9
Mar	261	8.4	11.8
Apr	287	9.6	12.7
May	284	9.2	13.6
Jun	305	10.2	13.9
Jul	334	10.8	13.8
Aug	322	10.4	13.1
Sep	259	8.6	12.2
Oct	254	8.2	11.2
Nov	240	8	10.4
Dec	195	6.3	10

III. Methods of computation

III.1. Models for calculation of solar radiation on a horizontal surface

The total daily radiation on a horizontal plane, H, is the combination of two components: the direct (beam) radiation and the diffuse radiation from the sky. The Solar radiation data are commonly available in two forms, the monthly average daily global solar radiation on a horizontal surface (H) and the hourly total radiation on a horizontal surface, in this case all the calculations are related to the monthly average daily global solar radiation[6].
According to the formula of black, the clarity index is obtained by [7]:

$$k_T = \frac{H}{H_0} = a + b\,\sigma \qquad (1)$$

σ : The sunshine duration

$$\sigma = \frac{S}{S_0} \qquad (2)$$

Where H is daily global solar radiation on a horizontal surface, H_0 is the daily value of the extraterrestrial radiation, S is sunshine duration, S_0 is the maximum possible sunshine duration, can be obtained as:

$$S_0 = (2/15)\cos^{-1}(-\tan\psi\tan\delta) \qquad (3)$$

Where ψ is the latitude of the site, δ the solar declination,

$$\delta = 23{,}45.\,sin\left(2\pi\frac{284+n}{365}\right) \qquad (4)$$

Where n is the number of day of year starting from first of January.

The values of empirical constants a and b are given by Beeckman for the Sahara region in Algeria [7]:

$a = 0.3$
$b = 0.43$

The monthly average daily extraterrestrial radiation on a horizontal surface may be computed from the following equations [8, 9]:

$$H_0 = \frac{24}{\pi} G(n)(cos\,\psi\,cos\,\delta\,sin\,\omega_s + \omega_s\,sin\,\psi\,sin\,\delta) \qquad (5)$$

$$G(n) = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \qquad (6)$$

Where G_{sc} is the solar constant, ψ is the latitude of the site, δ the solar declination, ω_s and the sunrise hour is calculated as:

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \qquad (7)$$

Using equations (1) to (7), Table (2) shows the monthly average daily global solar radiation $\overline{H}$ and the monthly average extra-terrestrial daily radiation $\overline{H_0}$ on a horizontal surface in the city of Ouargla in Algeria.

Where n : the number typical of day of the month proposed by Klein [7].

TABLE II
Monthly average daily extraterrestrial and global solar radiation on horizontal surfaces.

Month	N° Day	$\overline{H_0}$[Wh /m^2. day]	$\overline{H}$[Wh /m^2. day]
Jan	17	5750	3706
Feb.	47	7081	4601
Mar	75	8680	5259
Apr	105	10187	6350
May	135	11119	6576
Jun	162	11447	7025
Jul.	198	11242	7157
Aug	228	10494	6729
Sep	258	9179	5541
Oct	288	7516	4616
Nov.	318	6044	3809
Déc.	344	5363	3058
Annual radiation [kWh/m^2]		**3166.43**	**1954**

III.2. Models for calculation of solar radiation on a tilted surface

The total solar radiation on a tilted surface H_T is made up of the direct or beam solar radiation H_b , diffuse radiation H_d, and ground reflected radiation H_r, assuming isotropic reflection. As a consequence, the monthly-average daily solar radiation on a tilted surface $\overline{H_T}$ may be expressed as follows (Liu and Jordan, 1960) [10]:

$$\overline{H}_T = \overline{H}_b.\overline{R}_b + \overline{H}_d\left(\frac{1+\cos\beta}{2}\right) + \overline{H}.\rho.\left(\frac{1-\cos\beta}{2}\right) \quad (8)$$

Where β is the tilt of the surface from horizontal, and ρ the reflectance on the ground. R_b is the ratio of the average beam radiation on the tilted surface, H_d diffuse radiation can be respectively calculated as[11]:

$$\overline{R}_b = \frac{\cos(\psi-\beta).\cos\delta.\sin\omega_s' + \omega_s'.\sin(\psi-\beta)\sin\delta}{\cos\psi.\cos\delta.\sin\omega_s + \omega_s.\sin\psi\sin\delta} \quad (9)$$

$$\frac{\overline{H}_d}{\overline{H}} = K_d = c + d.K_T \quad (10)$$

The values of constants c and d are given by Beeckman for the Sahara region in Algeria [7]:

$$\begin{cases} c = 0.91 \\ d = -0.98 \end{cases}$$

$\overline{H}_b$: The direct or beam solar radiation given by:

$$\overline{H}_b = \overline{H} - \overline{H}_d \quad (11)$$

ω_s : The sunrise hour angle.

ω_s' : The hourly angle of the sunset on the inclined plane

Where is the sunset hour angle for the tilted surface given as:

$$\omega_s' = \text{Min}[\omega_s, \cos^{-1}(-\tan(\psi-\beta)\tan\delta)] \quad (12)$$

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \quad (13)$$

The study made use of a computer program written in MATLAB programming language. The program computes the global solar irradiance on the tilted PV array using the data discussed above.

III.2.1. Tilt angle by latitude

The tilt angle has a major impact on the solar radiation incident on a surface. For a fixed tilt angle, the maximum power over the course of a year is obtained when the tilt Angle is equal to the latitude of the location.

Table 3 shows the tilt angle for each month of the year when the solar panel is tilted at the latitude Angle [12].

TABLE III

Monthly average daily global radiation and annual radiation at latitude angle.

Months	β_L	$\overline{H}_T[Wh/m^2.day]$
Jan	31	5613
Feb.	31	6158
Mar	31	6043
Apr	31	6394
May	31	6010
Jun	31	6137
Jul.	31	6359
Aug	31	6491
Sep	31	6027
Oct	31	5820
Nov.	31	5538
Dec.	31	4618
Annual radiation [kWh/m^2]		**2166**

III.2.2. Monthly optimum tilt angle

An isotropic model was developed using the above formula to calculate the monthly average daily total radiation on a south-facing surface. Table 4. show the average daily total solar radiation on a south-facing surface when the angle of the tilt varied from -10° to 90° in steps of 1°.

Optimum tilt angle and the monthly-average daily total solar radiation on an optimum tilted surface are given in Table 4. It is found that the optimum tilt angle was changing between -8° in June and the total monthly solar radiation falling on the panel surface at this tilt is 7073 Wh/m^2. day. The optimum tilt angle then increases during the winter months and reaches a maximum of 61° in December which collects 5167 Wh/m^2. day of solar energy monthly[13,11].

TABLE IV
Monthly average daily global radiation and annual radiation at optimum tilt angle.

Months	β_{opt}	$\overline{H}_T[Wh/m^2.day]$
Jan	60	6252
Feb	51	6459
Mar	35	6056
Apr	17	6531
May	-1	6576
Jun	-8	7073
Jul	-5	7176
Aug	10	6791
Sep	28	6032
Oct	46	5970
Nov	58	6049
Dec	61	5167
Annual radiation $[\mathbf{kWh/m^2}]$		**2315.7**

Figure 1 show the tilt angle for each month of the year when the solar panel is tilted at the optimum angle and the latitude Angle.

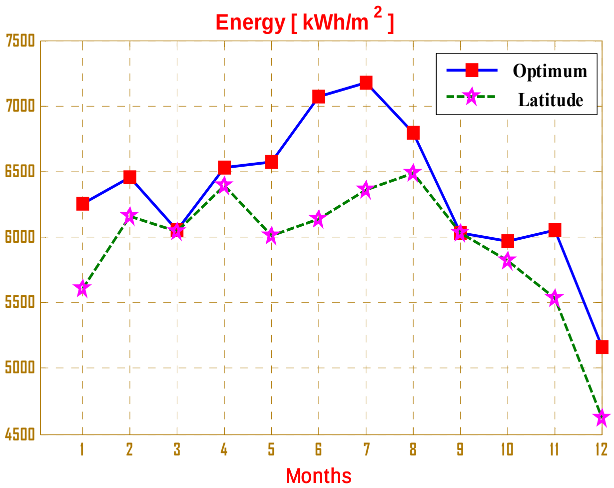

Fig.1. Comparison of mean monthly daily global radiation values for optimum tilt Angle and latitude Angle.

III.2.3. Seasonal tilt angle

The seasonal average was calculated by finding the average value of the tilt angle for each season, and the implementation of this requires that the collector tilt be changed four times in a year. In winter (December, January, and February) the tilt should be 57°, in spring (March, April, and May) 17°, in summer (June, July, and August) -1°, and in autumn (September, October, and November) 45°. Seasonal tilt angle and the monthly-average daily total solar radiation on at this tilted surface are given in Table 5[14].

TABLE V
Monthly average daily global radiation and annual radiation at Seasonal tilt angle.

Period	Months	Seasonal tilt angle	$\mathbf{\overline{H}_T[Wh/m^2.day]}$
Winter	Dec	57	5157
	Jan		6245
	Feb		6431
Spring	Mar	17	5835
	Apr		6531
	May		6398
Summer	Jun	-1	7037
	Jul		7164
	Aug		6717
Autumn	Sep	45	5851
	Oct		5969
	Nov		5931
ANNUAL RADIATION $[\mathbf{kWh/m^2}]$			**2289.4**

Figure 2 shows the tilt angle for each month of the year when the solar panel is tilted at the seasonal angle and the latitude Angle.

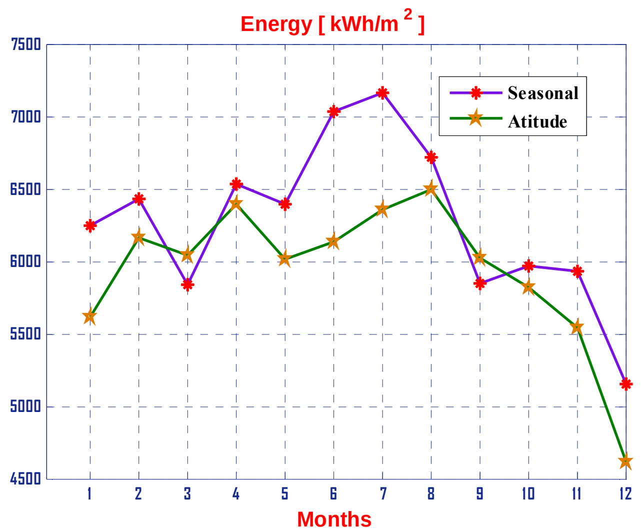

Fig.2. Comparison of mean monthly daily global radiation values for seasonal tilt Angle and latitude Angle.

III.2.4. *Bi-annual tilt angle*

Bi-annual tacking is a method of tracking the movement of the sun twice in a year. The tilt angle of the PV panels is changed two times in a year to maximize the solar energy received by them. During the summer months (Apr, May, Jun, Jul, Aug, Sep) the tilt angle is kept at angle β_1 and in winter months(Oct, Nov, Dec, Jan, Feb, Mar) it is kept at angle β_2. The advantage of this method is that it is simple and involves change in the tilt angle only two times in a year. Moreover, it does not need any complex control mechanism, or motorized and maintenance intensive system for tracking the sun [15].
The tilt angle β_1 is expressed as:

$$\beta_1 = \sum_{i=4}^{9} \frac{(\beta_{i-opt})}{6} \quad (14)$$

Where tilt angle β_2 and expressed as:

$$\beta_2 = \sum_{i=1}^{3} \frac{(\beta_{i-opt})}{3} + \sum_{i=10}^{12} \frac{(\beta_{i-opt})}{3} \quad (15)$$

Bi-annual tilt angle and the monthly-average daily total solar radiation on a bi-annual tilted surface are given in Table VI.

TABLE VI
Monthly average daily global radiation and annual radiation at Bi-annual tilt angle.

Months	**Bi-annual tilt angle**	$\overline{H}_T$ [Wh/m^2.day]
Jan	$\beta_2 = 52$	6200
Feb		6459
Mar		5880
Apr	$\beta_1 = 7$	6468
May		6544
Jun		6920
Jul		7079
Aug		6786
Sep		5749
Oct	$\beta_2 = 52$	5946
Nov		6025
Dec		5115
ANNUAL RADIATION [kWh/m^2]		**2286.5**

The data shown in figure 3 are the radiation values for a PV panel surface fixed at a tilt angle equal to the latitude of the location (Ouargla) 31° and for two other tilt angles, angle $\beta_1 = 7^0$ and $\beta_2 = 52^0$.

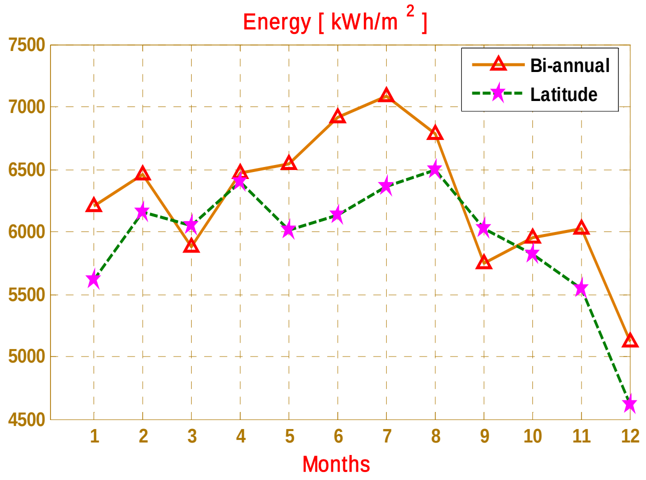

Fig.3. Comparison of mean monthly daily global radiation values for bi-annual tilt Angle and latitude Angle.

IV. Results and discussions

The results shown in Table: VII are the Annual radiation values for a PV panel surface at different tilt angle.
It is clear from Table: VII, the annual average of the solar radiation obtained through optimum tilt tracking is higher compared to the fixed tilt angle method. Comparing the fixed tilt and optimum tilt tracking configuration, the percentage increase in the solar energy obtained is (2315.7-2166)/ 2166= 6.9 %. Compared with fixed tilt angle method placed PV modules, the Seasonal tilt can generate (2289.4-2166)/ 2166= 5.7 % more power.
Similarly, the annual average of solar radiation obtained from bi-annual sun tracking equal 2286.5 kWh/m2. Is higher compared to the fixed tilt angle method. The percentage increase in the solar energy obtained is (2286.5 -2166)/ 2166= 5.56%.

TABLE VII
Annual solar radiation at different tilt angle

Angle	$\beta = 0$	$\beta = \psi$	$\beta = \beta_{opt}$	$\beta = \beta_{sea}$	$\beta = \beta_{bi}$
Energy [kWh/m^2]	**1954**	**2166**	**2315.7**	**2289.4**	**2286.5**

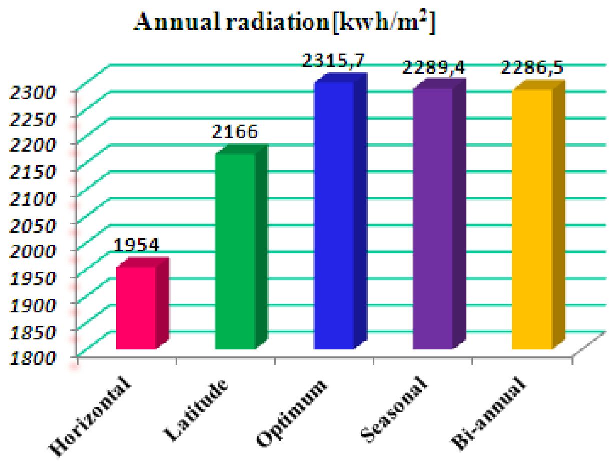

Fig.4. Comparison of Annual solar radiation values for horizontal, latitude, optimum, seasonal and bi-annual tilt angle configuration of a panel.

V. Conclusion

In this study, the effects of orientation for a solar panel and the optimum tilt angles for harvesting solar electricity in Ouargla city in Algeria is presented. On the basis of the obtained results (shows figure 4), the following conclusions can be drawn:

The maximum energy can be captured by positioning the PV panels at the monthly optimum tilt angle, the energy produced **is** (2315.7kWh/m^2) Even more, practical and more interesting, the energy remains maximal by changing the slope of the panels seasonal or bi-annual in a year. The solar energy computed from the bi-annual tracking method (2286.5kWh/m2) did not differ practically from those computed from seasonal method (2289.4kWh/m2). But the bi-annual tracking is very simple and economic. Is necessitates the change in the tilt angle of the panel two times in a year.

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