www.ijramr.com

ISSN: 2350-0743

International Journal of Recent Advances in Multidisciplinary Research

Vol. 08, Issue 05, pp. 6840-6844, May, 2021

RESEARCH ARTICLE

ESTIMATION OF THE OPTIMAL TILT ANGLE FOR SOLAR PHOTOVOLTAIC MODULES IN ILARO TOWN SOUTHWESTERN NIGERIA

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ARTICLE INFO

Article History:
Received 20th February, 2021
Received in revised form
15th March, 2021
Accepted 18th April, 2021
Published online 30th May, 2021

Keywords:

Tilt Angle, Extraterrestrial, Photovoltaic, Solar Collector, Ilaro.

ABSTRACT

Solar energy is the radiative energy that comes from the sun. Solar radiation is electromagnetic in nature and its spectrum cover the ultraviolet (UV) through the visible (VIS) to the infrared (IR) part of the electromagnetic spectrum. The data used in this study was a 12 years average solar radiation data between year 2009 and 2021. Monthly mean daily data of the extraterrestrial solar radiation ($\overline{H}_0$), global solar insolation on horizontal surface ($\overline{H}$) and averaged surface albedo (ρ_g) data were obtained from the National Aeronautic and Space Authority (NASA) Surface Meteorology Solar Energy (NASA surface meteorology Solar Energy, 2021). The model used to compute the total radiation on tilted surfaces is the Liu & Jordan Model. The optimal tilt angle for maximum collection of the solar insolation for Ilaro town is 12^0 for fixed module. However, the result of higher annual insolation than that at a fixed 12^0 can be obtained using a seasonal tilt.

INTRODUCTION

The solar panel (the first component of an electric solar power system), is a collection of individual silicon cells that generate electricity from sunlight. The photons (light particles) produce an electric current as they strike the surface of the thin silicon wafers (Asowata *et al*., 2012). The performance of a solar collector is highly influenced by its orientation and its angle of tilt with the horizontal. This is due to the fact that both the orientation and tilt angle change the solar radiation reaching the surface of the collector. Therefore, in the design, simulation and operation of solar collectors, it is very essential to know the optimal tilt angle. Optimal tilt angle is applied to a variety of systems, such as flat or parabolic collectors, photovoltaic (PV)-systems, solar houses and solar greenhouses installed in a fixed position (Waziri *et al.*, 2014). Nigeria with a total installed electricity generation capacity of about 125,22MW, and actual generation of between 3,500MW and 5000MW, is currently faced with acute electricity problems, which is hindering its development despite the availability of vast natural resources in the country. An analysis of the power generation capacity required to support the vision 2027 economic vision, carried out by the National Technical Working Group (NTWG), shows that by 2027 Nigeria will need to generate electricity in the range of between 25,000MW to 40,000MW. This is based on the assumption that the country will take a less energy intensive growth path (energy intensity of less than 0.4) with lower electricity consumption, KWh per unit of GDP, unlike china which has an energy intensity of 0.91. Benghanem, (2010).In order to achieve this growth aspiration, it is necessary that alternative energy resources-hydro, solar, wind, biomass, coal and nuclear- are harnessed to reduce the country’s reliance on gas fired power plants. Also, intensive manpower development initiatives will be required including equipping the newly created National Power Training Institute, in Studies relevant to the availability of the solar energy resource in Nigeria have fully indicated its viability for practical use. Although solar radiation intensity appears rather dilute when compared with the volumetric concentration of energy in fossil fuels, it has been confirmed that Nigeria receives 5.08 x 10^{12} KWh of energy per day from the sun and if solar energy appliances with just 5% efficiency are used to cover only 1% of the country's surface area then 2.54 x 10^{6}MWh of electrical energy can be obtained from solar energy. This amount of electrical energy is equivalent to 4.66 million barrels of oil per day. Calabrò, 2013asserted that Nigeria is endowed with an annual average daily sunshine of 6.25 hrs, ranging from 3.5 hrs at the coastal areas to 9 hrs at the far collaboration with tertiary institutions, (NTWG, 2009). Similarly it has an annual daily radiation of about 5.25 KWm^{-2} at the coastal area and 7.0 KWm^{-2} at the northern boundary. Nigeria is also characterized by some cool and dusty atmosphere during the harmattan in the northern part for a period of about four months (i.e. November –February). It has been confirmed that the dust has an attenuating effect on the solar radiation intensity (Chandrakar & Tiwari, 2013). Nigeria has average solar insulation greater than the world average.

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A number of studies have been carried out by various investigators in order to optimize the tilt angle and orientation of solar collectors around the world, while studies related to Nigeria are few in number and utilization efficiency of most solar energy appliances in Nigeria is very low. (Waziri *et al.*, 2014).The slope or tilt angle (β) is defined as the angle between the plane of the solar collector and the horizontal. When β is positive, the orientation of the surface is towards the equator, and when β is negative, it is towards toward the pole (Chang, 2008). On the basis of literature survey, a thumb rule for Indian conditions has been made. According to this rule, the optimum inclination of the surface receiving maximum radiation is given as $\beta = \emptyset \pm 15^0$, (Chandrakar & Tiwari, 2013). Where positive sign refers to winter condition and negative sign refers to summer conditions. Chang (2008) suggested the use of different slope angles for different seasonal applications. They suggested adjusting the slope angle at least twice a year; once in summer and once in winter. It could be concluded that a stationary solar collector cannot receive maximum solar energy on a year round basis because of the wide separation of optimum slope angles and orientation. Certain applications like crop or fruit drying, salt distillation and others, need to use the solar collector for certain period of the year.

MATERIALS AND METHODS

The data used in this study was a 12 years averaged solar radiation data between 2009 and 2021 which were monthly mean daily data of the extraterrestrial solar radiation ($\overline{H}_0$), global solar insolation on horizontal surface ($\overline{H}$) and averaged surface albedo (ρ_g) was obtained from the National Aeronautic and Space Authority (NASA) Surface Meteorology Solar Energy (NASA surface meteorology Solar Energy, 2021).

Model Used for the study: The model used to compute the total radiation on tilted surfaces is the (Liu & Jordan 2012) Model given by equation:

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

Where

H_T Mean Daily Solar Installation in the Tilted surface
R_b Function of Transmittance
H_d Diffuse Radiation Horizontal surface
H_b Beam Radiation Horizontal Surface
$H\rho_g$Average Surface Albedo Horizontal Surface

To apply Liu & Jordan Model, this work follows an approach used by Jakhrani *et al.*, (2012) in the estimation of the optimal tilt angle for solar photovoltaic modules in Ilarotown and consists of the following steps:

Determination of Declination Angle (δ)

The declination angle (δ) was determined using the day selected from each month and the number of days for each month as proposed by Cooper (2009). The formula used in the determination of the declination angle (δ) is:

$$\delta = 23.45 \sin\left(360\left(\frac{2\quad +n}{3}\right)\right) \quad (2)$$

Determination of Sunset Hour Angle (ω_s)

The formula used in the determination of the Sunset hour angle on horizontal surface (ω_s) is:$\omega_s = \cos^{-1}(-\tan\Box\tan\delta)$

Determination of the Mean Clearness Index ($\overline{K}_T$)

The ratio of solar radiation at the surface of the earth to the extraterrestrial radiation is termed as clearness index ($\overline{K}_T$) which is expressed as:

$$\overline{K}_T = \frac{\overline{H}}{(\overline{H}_0)} \quad (3)$$

Where$\overline{H}$ is the monthly mean daily global solar radiation on the horizontal surface (J/m^2).

Determination of Diffuse Radiation on Horizontal Surfaces ($\overline{H}_d$)

Monthly mean daily diffuse radiation ($\overline{H}_d$) was determined from monthly mean daily global solar radiation ($\overline{H}$) by considering the value of the clearness index $\overline{K}_T$ and the sunset hour angle (ω_s) based on the value of clearness index ($\overline{K}_T$). Based on the conditions cited by Erbs*et al*. (2003). When the sunset hour angle (ω_s) for mean day of the month is $\leq 81.4^0$ and $0.3 \leq \overline{K}_T \leq 0.8$, and then $\overline{H}_d$ can be calculated from:

$$\frac{H}{H} = 1.311 - 3.022K_{T^2} - 1.82K_{T^3} \quad (4)$$

If the sunset hour angle (ω_s) is >81.4^0 and $0.3 \leq \bar{K}_T \leq 0.8$ then $\bar{H}_d$ can be obtained from:

$$\frac{H}{H} = 1.311 - 3.022K_{T^3} + 3.427K_{T^3} - 1.821K_{T^3} \quad (5)$$

Determination of the Beam Radiation on the Horizontal surfaces ($\bar{H}_b$)

The beam radiation was a result obtained by subtracting the diffuse radiation ($\bar{H}_d$) from the monthly mean global radiation on horizontal surface ($\bar{H}$). The formula used in the determination of the beam radiation ($\bar{H}_b$) is as follow;

$$\bar{H}_b = \bar{H} - \bar{H}_d \quad (6)$$

Determination of the Function of Transmittance ($\bar{R}_b$)

The function of transmittance of atmosphere **($\bar{R}_b$)** was obtained as the ratio of the amount of the extraterrestrial radiation on the tilted surface to that on the horizontal surface which is expressed as:

$$\bar{R}_b = \frac{c \; (\square-\beta)c \qquad \dot{\omega}s+\left(\frac{\pi}{1}\right)\dot{\omega}s. \quad (\square-\beta)s}{c \; \square c \qquad +\left(\frac{\pi}{1}\right)\omega \quad \square s} \quad (7)$$

Determination of the Monthly Mean Daily Solar In solation on the Tilted Surfaces($\bar{H}_T$)

The total monthly mean solar In solation on the tilted surface (β) was determined by taking the tilt angles from 0^0, which is installing photovoltaic module on horizontal surface without tilting and changing the angle at intervals of 5^0 except within the interval of $10^0 \leq \beta \leq 15^0$ where a step of 1^0,was considered. $\bar{H}_T$ was also calculated for $\beta = \square = 10.246$ from then the interval was also changed to its initial state of 5^0 up to 75^0. The diffuse fraction of radiation on inclined surface is composed of isotropic, circumsolar and horizon brightening factors as;

$$\bar{H}_{T,d} = \bar{H}_{d,iso}F_{c-g} + \bar{H}_{d,ics}\bar{R}_b + \bar{H}_{d,}hzFc - hz \quad (8)$$

Determination of the Total Annual Solar Insolation on the Tilted Surface (H_T): The total annual solar Insolation on the tilted surface was determined by summing all the monthly mean solar Insolation of the year for each slope angle (β) of the photovoltaic module.

Selection of the optimal tilt angle: The optimal tilt angle for maximum collection of the solar Insolation for Ilarotown is 12^0 for fixed module. But, the result of higher annual insolation than that at a fixed 12^0 can be obtained using a seasonal tilt.

RESULTS AND DISCUSSION

The declination angle (δ) was determined using the day selected from each month and the number of days for each month as proposed by Karkee *et al*. (2017).Monthly mean daily diffuse radiation ($\bar{H}_d$) was determined from monthly mean daily global solar radiation ($\bar{H}$) by considering the value of the clearness index $\bar{K}_T$ and the sunset hour angle (ω_s) based on the value of clearness index ($\bar{K}_T$). Based on the conditions cited by Eke (2011) When the sunset hour angle (ω_s) for mean day of the month is ≤ 81.4^0 and $0.3 \leq \bar{K}_T \leq 0.8$.

Table1: Declination Angle (δ), Sunset Hour Angle on Horizontal Surface (ω_s), Clearness Index ($\bar{K}_T$), Diffuse Radiation ($\bar{H}_d$), Beam Radiation ($\bar{H}_b$)

MONTH	δ	ω_s	$\bar{K}_T$	$\bar{H}_d$	$\bar{H}_b$
JAN	20.91	86.03996	0.641808	1.713521	3.966479
FEB	12.94	87.61972	0.645464	1.847604	4.342396
MAR	-2.4	89.56592	0.632353	1.999037	4.450963
APR	9.43	91.72036	0.612381	2.104888	4.325112
MAY	18.81	93.52994	0.597115	2.115828	4.094172
JUN	23.09	94.41972	0.562136	2.152006	3.637994
JUL	21.17	94.01412	0.512621	2.202321	3.077679
AUG	13.43	92.4738	0.480769	2.239356	2.760644
SEP	2.19	90.39605	0.52549	2.171106	3.188894
OCT	-9.63	88.24245	0.587873	1.995343	3.724657
NOV	18.93	86.44579	0.633333	1.761716	3.938284
DEC	23.06	85.5867	0.635198	1.675581	3.774419

Table 2: Function of transmittance of atmosphere ($\bar{R}_b$) for all β Angles

			MONTH									
B	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
β = 0	1	1	1	1	1	1	1	1	1	1	1	1
β = 5	1.069716	1.045749	1.017916	0.989212	0.966819	0.956341	0.961075	0.979706	1.006583	1.036647	1.063436	1.076834
β = 10	1.13129	1.083539	1.028086	0.971102	0.927109	0.906674	0.915895	0.952375	1.005516	1.065404	1.118778	1.145472
β = □	1.134101	1.085188	1.028385	0.970024	0.924992	0.904081	0.913516	0.950852	1.005266	1.066611	1.121284	1.148628
β = 11	1.142586	1.090116	1.029182	0.966612	0.918408	0.89605	0.906136	0.946081	1.004385	1.070189	1.128837	1.15817
β = 12	1.153533	1.096361	1.029965	0.961836	0.90946	0.885203	0.896143	0.939516	1.002948	1.074647	1.138552	1.170514
β = 13	1.16413	1.102271	1.030434	0.956775	0.900268	0.874137	0.885919	0.93268	1.001205	1.078778	1.14792	1.182502
β = 14	1.174371	1.107846	1.03059	0.951431	0.890834	0.862854	0.875466	0.925577	0.999159	1.08258	1.156939	1.194129
β = 15	1.184255	1.113083	1.030431	0.945805	0.881162	0.85136	0.864789	0.918209	0.996808	1.086053	1.165605	1.205393
β = 20	1.228207	1.134156	1.024934	0.913517	0.829336	0.790833	0.808158	0.877473	0.980525	1.098437	1.203562	1.25614
β = 25	1.262811	1.146597	1.011637	0.874489	0.772055	0.7256	0.746471	0.830491	0.956792	1.10246	1.232359	1.297327
β = 30	1.287805	1.150312	0.99064	0.829032	0.709807	0.656241	0.680264	0.777647	0.925789	1.098093	1.251776	1.328641
β = 35	1.302998	1.145272	0.962104	0.777511	0.643147	0.58341	0.610148	0.719383	0.887753	1.08537	1.261668	1.349843

Table 3: Monthly Mean Daily Solar Insolation on the Tilt Angles ($\bar{H}_T$)

β	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
β = 0	5.68	6.19	6.45	6.43	6.21	5.79	5.28	5	5.36	5.72	5.7	5.45
β = 5	5.955859	6.38809	6.52901	6.382394	6.073198	5.629829	5.158524	4.941999	5.379206	5.855204	5.94897	5.739304
β = 10	6.198099	6.550482	6.572073	6.301235	5.907765	5.445129	5.01445	4.86063	5.370463	5.958445	6.164357	5.996282
β =	6.209116	6.557527	6.573257	6.296385	5.898907	5.435431	5.006796	4.856033	5.369312	5.962684	6.174057	6.008055
β = 11	6.242346	6.578563	6.576339	6.281025	5.871345	5.405358	4.983012	4.841601	5.365362	5.975184	6.203255	6.043622
β = 12	6.285159	6.605157	6.579151	6.259503	5.833838	5.364672	4.950721	4.821668	5.359147	5.990607	6.240732	6.089575
β = 13	6.326527	6.630256	6.580509	6.236675	5.795256	5.323082	4.917588	4.800835	5.351819	6.00471	6.276776	6.134128
β = 14	6.366437	6.653853	6.580413	6.212547	5.755612	5.280602	4.883621	4.779109	5.343381	6.017488	6.311376	6.177266
β = 15	6.404875	6.67594	6.578862	6.187129	5.714917	5.237244	4.848833	4.756497	5.333836	6.028937	6.344522	6.218978
β = 20	6.574614	6.763509	6.549325	6.040953	5.496158	5.007808	4.662968	4.630407	5.269604	6.066145	6.488094	6.405697
β = 25	6.706024	6.812524	6.483686	5.863852	5.253272	4.758733	4.458385	4.483357	5.178257	6.069786	6.59398	6.555019
β = 30	6.798106	6.822611	6.382446	5.657227	4.988323	4.492215	4.236852	4.31654	5.060493	6.03983	6.661375	6.665806

Table 4. Results of the total annual solar insolation on the tilted surface (H_T)

Angle	
0	69.26
5	69.9816
10	70.3394
10.246	70.3476
11	70.367
12	70.3799
13	70.3782
14	70.3617
15	70.3306
20	69.9553
25	69.2169
30	68.1218
35	66.6798
40	64.9036

The function of transmittance of atmosphere ($\bar{R}_b$) was obtained as the ratio of the amount of the extraterrestrial radiation on the tilted surface to that on the horizontal surface. The total monthly mean solar Insolation on the tilted surface (β) was determined by taking the tilt angles from 0^0, which is installing photovoltaic module on horizontal surface without tilting and changing the angle at intervals of 5^0 except within the interval of $10^0 \leq \beta \leq 15^0$ where a step of $1^0$was considered. $\bar{H}_T$ was also calculated for β = □ = 10.246 from then the interval was also changed to its initial state of 5^0 up to 75^0. The diffuse fraction of radiation on inclined surface is composed of isotropic, circumsolar and horizon brightening. The total annual solar Insolation on the tilted surface was determined by summing all the monthly mean solar Insolation of the year for each slope angle (β) of the photovoltaic module. The optimal tilt angle for maximum collection of the solar Insolation for Ilarotown is 12^0 for module. But, the result of higher annual insolation than that at a fixed 12^0 can be obtained using a seasonal tilt.

CONCLUSION

This study applied an approach used by Jakhrani *et al.* (2012), in the estimation of the optimal tilt angle for solar photovoltaic modules in Ilaro town. The total monthly mean solar insolation on the tilted surface (β) was determined by taking the tilt angles from 0^0, which is installing photovoltaic module on horizontal surface without tilting and changing the angle at intervals of 5^0 except within the interval of $10^0 \leq \beta \leq 15^0$ where a step of $1^0$was considered. $\bar{H}_T$ was also calculated for β = □ = *10.246* from then the interval was also changed to its initial state of 5^0 up to 75^0. The total annual solar insolation on the tilted surface was determined by summing all the monthly mean solar insolation of the year for each slope angle (β) of the photovoltaic module.

The optimal tilt angle for maximum collection of the solar insolation for Ilarotown was 12^0 for fixed module. But, the result of higher annual insolation than that at a fixed 12^0 can be obtained using a seasonal tilt.

CONFLICT OF INTEREST: Author declares no conflict of interest.

REFERENCES

Asowata, O., Swart, J. & Pienaar, C. 2012. Optimum Tilt Angles for Photovoltaic Panels during Winter Months in the Vaal Triangle, South Africa. *Smart Grid and Renewable Energy*, 119-125

Benghanem, M. 2010. Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia. *Applied Energy* 88 (2011) 1427–1433.

Calabrò, E. 2013. The Disagreement between Anisotropic-Isotropic Diffuse Solar Radiation Models as a Function of Solar Declination: Computing the Optimum Tilt Angle of Solar Panels in the Area of Southern-Italy, Smart Grid and Renewable Energy, 253-259.

Chandrakar, A. & Tiwari, Y. 2013. Optimization of Solar Power by varying Tilt Angle/Slope in Chhattingarh.*International Journal of Emerging Technology and Advanced Engineering* 145-150.

Chang, T. (2008). Study on the Optimal Tilt Angle of Solar Collector According to Different Radiation Types in Taiwan. *International Journal of Applied Science and Engineering*, 151-161

Eke, A. B. 2011. Prediction of optimum angle of inclination for flat plate solar collector in Zaria, Nigeria. Agricultural Engineering International*: CIGR Journal*. Vol. 13, No.4, 2011.Manuscript No. 1840.

Jakhrani, A., Othman, A., Rigit, A. R. H., Samo, S. R. & Kamboh, A. (2012). Estimation of Incident Solar Radiation on Tilted Surface by Different Empirical Models. *International Journal of Scientific and Research Publications*, 2250-3153.

Karkee, R., Khadka, S., Luitel, G., Devkota, M., Khadka, B., Sapkota, S. & Bhetwal, P. 2017. Comparing and Optimizing of Solar Insolation on Yearly, Monthly and Seasonally Basis for Solar Devices Performance in Nepal. *International Journal of New Technology and Research (IJNTR)*,26-33.

Khasawneh, Q. A., Damra, Q. A. & Salman, O. 2015. Determining the Optimum Tilt Angle for Solar Applications in Northern Jordan. *Jordan Journal of Mechanical and Industrial Engineering*, 187-193.

Waziri, N. H., Usman A. M., Enaburekhan, J. S. & Babakano, A. 2014. Determination of Optimum Tilt Angle and Orientation of a Flat Plate Solar Collector for Different Periods in Kano. *Scientific Research Journal (SCIRJ)*, 2201-2796.

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