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CREATING THE OPTIMUM PANEL INCLINATION ANGLES OF THE SOUTHERN AEGEAN REGION

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Abstract - Values that are used in solar energy applications are usually calculated by data for radiation reaching a horizontal plane. In order to achieve maximum efficiency in solar energy, panels must be at a suitable angle and position. This study determined monthly optimum panel angles for the Southern Aegean Region (Muğla) in Turkey and created three different correlations. In an annual course (January-December), panel angles varied in the order of 59^0, 49^0, 38^0, 20^0, 5^0, 0^0, 0^0, 15^0, 32^0, 49^0, 59^0 and 61^0. The average annual panel inclination angle was 32.25^0, and in the case of changing the angles monthly, the annual efficiency increased by 17.03% in comparison to horizontal position and reached the average annual radiation value of 5949 W/m^2-year. The best estimation model developed for the region was in the form of $\boldsymbol{\beta_{OPT.} = 0,0002(\delta)^3 - 0,0092(\delta)^2 - 1,4379(\delta) + 34,72}$. The statistical analysis values were R^2 (0.9973), MBE (0.0031), RMSE (1.22) and t-sat (0.0085), while they successfully corresponded to the panel inclination values.

Index Terms - PV, Tilt Angle, South Aegean, Correlations

I. INTRODUCTION

Studies on solar energy show that this type of energy is a highly strong alternative for the future. Nevertheless, despite several applications and studies, work on this issue is still in its infancy and it is not able to take the place it deserves among other types of energy as a strong option. In order to overcome this issue and achieve maximum utility, it is a must to place panels at a correct angle and position.

Khorasanizadeh et al. [1] conducted research for Tabass, Iran and found that panel inclination angles varied between 0^0 (June) and 64^0 (December), and there was an increase in efficiency by 23.15% when the angles were adjusted monthly. Benghanem [2] used panel angles for Medina, Saudi Arabia as 17^0 (Spring), 12^0 (Summer), 28^0 (Fall), 37^0 (Winter) and 23.5^0 (annual) and reported an increase of 8% in total annual efficiency at monthly optimum angles. Baringer et al.[3], in their experimental study for Hannover, Germany on Pv panels, found that angles were efficient between $0^0$and 30^0 in summer and 50^0 and 70^0 in winter, and there was a 6% difference in efficiency between the angles of $0^0$and 70^0. For Hong Kong, the study by Yang and Lu [4] found panel angels as $41^0$for winter months and 0^0 for summer months. They determined the average annual constant angle as 20^0. Ozbay et al. [5] conducted as study forBilecik, Turkey and found these angles as $10^0$for spring-summer, $20^0$for fall, and $40^0$for winter, while they found the annual constant angle in the range of 20^0-40^0. Kallioğlu et al. [6], in their study for Gaziantep, Turkey, found panel angles as $52^0$for winter, 19^0 for spring, $5^0$for summer and $44^0$for fall, while they found the annual angle as 30^0. The optimum angle value provided a 14% increase. There are several studies on solar panel inclination angles in the literature. The purpose of these studies is to obtain maximum radiation levels by optimum angle values in a regional location. Monthly, seasonal and annual optimum panel inclination angles about solar energy implementations have been determined or region-specific correlation formulae have been developed. Such implementations generally include photovoltaic systems, solar collectors, building-integrated photovoltaic and solar water heaters.

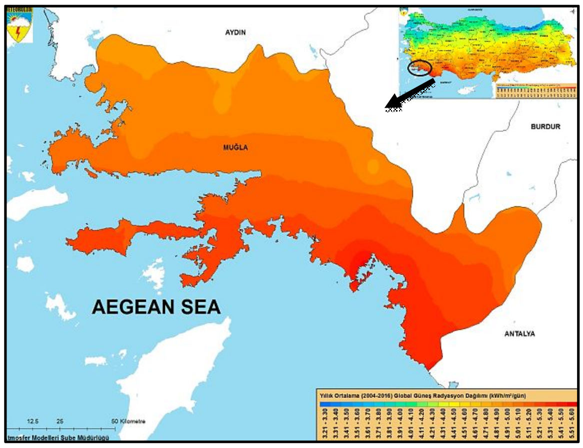

Figure 1. Location on the Map of the Study Area

The location of calculations was the province of Muğla located in the Southern Aegean Region of Turkey. The location has an altitude of 670 m, and it is located on the 37.20^0 northern parallel and 28.37^0 eastern meridian. A Warm-Mediterranean (Csa) climate is dominant in the region.

II. MATERIAL AND METHOD

The amount of radiation utilized in solar energy calculations vary mainly based on the geographical location of the residential area where the plane is found in, the number of sunny days per year and the time period during the day. This study aimed to achieve maximum utility by determining monthly, seasonal and annual optimum panel angles for a solar panel on an inclined surface.

Different models that are used in isotropic and anisotropic diffusion conditions are utilized in calculations of diffused radiation that arrive at an inclined surface. It is assumed in isotropic models that the diffusion in the atmosphere is equal in all directions. The diffusion in this condition corresponds only to the diffusion in clean atmospheric conditions that is created only by air molecules. Anisotropic diffusion is where the magnitude of diffusion is not equal, and it is chosen for an atmosphere where there are aerosols and clouds. This diffusion is closer to real atmospheric diffusion.

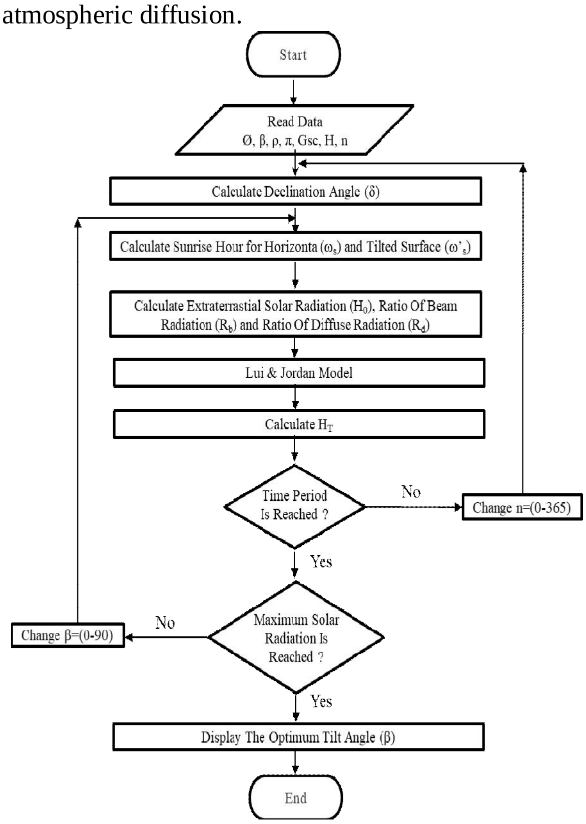

Figure 2.Flow chart for calculating optimal tiltangle.

Figure 2 shows the algorithm that was followed in general by the developed software. Among the variables, the number of days n was calculated between 1 and 365, while the panel inclination angle was calculated in the interval of $\beta = 0^0$-90^0 by 1^0 increments.

Solar radiation measurements consist of data that are broadly obtained on a horizontal surface. This study made calculations of the amount of radiation that falls onto an inclined surface by taking the azimuth in the northern hemisphere as zero ($\gamma = 0^0$). The daily average global radiation value per month on the inclined surface (H_T) is given in equation 1. This equation consists of the sum of the values of direct solar radiation (H_B), reflected radiation (H_R) and diffuse radiation (H_S) [7-8].

$$H_T = H_B + H_R + H_S \tag{1}$$

The direct solar radiation on the inclined surface (H_B) is given in equation 2. This value is calculated by using the monthly total radiation (H) and diffuse radiation (H_d) values on the inclined surface.

$$H_B = (H - H_d)R_b \tag{2}$$

The value R_b in equation 2 is the ratio of the direct radiation on the inclined surface to the amount of radiation on the horizontal surface. According to Lui and Jordan (1960), this is valid in cases where the azimuth in the northern hemisphere is equal to zero, and it is calculated by equation 3. This value is calculated as a function of latitude (Ø), solar deviation angle (δ), average angle of sunrise (ω_s) and angle of sunrise on the inclined surface [8].

$$R_b = \frac{\cos(Ø - \beta)\cos(\delta)\sin(\omega_s') + \omega_s'(\pi/180)\sin(\emptyset - \beta)\sin(\delta)}{\cos(Ø)\cos(\delta)\sin(\omega_S) + \omega_S(\pi/180)\sin(Ø)\sin(\delta)} \tag{3}$$

The daily amount of radiation that is reflected from the ground and onto the inclined surface is calculated by equation 4. The ρ value in this equation is the reflection coefficient of the ground, and it is dependent on the vegetation in the region, its altitude, topography and seasons. This study assumed the value 0.2 which is used in humid and warm climate zones [9]. The β value in the equation is the angle of inclination between the panel and the horizontal plane.

$$H_R = H\rho(1 - \cos\beta)/2 \tag{4}$$

The amount of diffuse radiation on the inclined surface is calculated by equation 5.

$$H_S = H_d R_d \tag{5}$$

H_d is the amount of diffuse radiation on the horizontal surface and calculated by the isotropic equation 6. The isotropic sky diffuse model assumes that the diffuse radiation from the sky dome is uniform across the sky. [10].

$$H_d = H(1 - 1{,}13\, H/H_0\,) \tag{6}$$

H_0 in equation 6 is the extraterrestrial solar radiation on the horizontal surface, and it is calculated monthly by equation 7 as a function of the solar constant (G_{sc}), earth orbit eccentricity correction factor (k), solar deviation (δ), latitude of the location (∅) and average sunset angle (ω_s) [11]

$$H_o = \left(\frac{24}{\pi}\right) Gsc\; k \left[\cos\emptyset\cos\delta\sin\omega_s + \left(\frac{\pi}{180}\right)\sin\emptyset\sin\delta\omega_s\right] \tag{7}$$

The solar constant is generally accepted as 1367 W/m^2. Earth orbit eccentricity correction factor is found in relation to the radiation that reaches the earth's surface and the radiation that reaches the outer atmosphere. This correction factor (k) varies daily and is calculated by equation 8 where n is the number of days in the year (1-365).

$$k = 1 + 0{,}033\, cos(\, 360\, n/360) \qquad (8)$$

Solar deviation (δ) is calculated by equation 9. In this formula, n represents the number of days from 1 January up to the day for which the declination angle will be calculated. Monthly average declination angles are calculated by the average number of days determined for a month instead of all t he days found in a month [12].

$$\delta = 23{,}45^{\circ} sin\, (360\, (n + 284)/365\ ) \qquad (9)$$

The angles for the sun to rise based on horizontal (ω_s) and inclined (ω'_s) surfaces are calculated respectively by equations 5 and 6. These equations vary based on the inclined surface, latitude and solar deviation.

$$\omega_s = cos^{-1}(-\,tan\, \emptyset . \tan\delta) \qquad (10)$$

$$\omega_s^{'} = \min \begin{bmatrix} \omega = \cos^{-1}\,(-\tan\emptyset \tan\delta) \\ \cos^{-1}(-\tan(\emptyset - \beta)\tan\delta \end{bmatrix} \qquad (11)$$

R_d in equation 5 is calibration coefficient between daily average inclined and horizontal surfaces, and it is calculated by equation 7 [13].

$$R_d = (1 + \cos\beta)\,/2 \qquad (12)$$

RESULTS

This study utilized the meteorological data for regions in Turkey by the Directorate of Electrical Power Resources (EİE 2004-2017), the General Directorate of Meteorological Affairs. Using equations 1-12 subsequently, the monthly optimum panel angles were calculated by solar radiation values at different angles of the solar panel (0^0-90^0). The calculations utilized the isotropic Lui and Jordan method.

Months	H_0	H	H_d	K_T	$\beta_{OPT}(^0)$	H_T
Jan.	5311	2610	1161	0,49	59	4323
Feb.	6634	3370	1436	0,51	49	4571
Mar.	8292	4770	1669	0,58	38	5691
Apr.	9970	5940	1941	0,60	20	6222
May	11122	7110	1974	0,64	5	7127
Jun.	11578	7780	1873	0,67	0	7780
Jul.	11327	7560	1858	0,67	0	7560
Aug.	10387	6780	1779	0,65	15	6949
Sep.	8873	5550	1627	0,63	32	6300
Oct.	7101	4160	1406	0,59	49	5824
Nov.	5611	3040	1179	0,54	59	5010
Dec.	4938	2340	1087	0,47	61	4040

Table 1. Analysis Of Ho, H, H_D, KT, β_{OPT}, H_TValues for Muğla-Turkey

Table 1 shows the monthly average amount of radiation on the horizontal surface H (W/m2-day), and the monthly average amount of radiation reaching the outer atmosphere H_0 (W/m2-day). As a result of the calculations, the monthly average diffuse radiation on the horizontal surface Hd, the monthly average diffuse radiation on the inclined surface (W/m2-day), the optimum angle values $\beta_{OPT}(^0)$ and the radiation values on the panel that correspond to these angle values HT (W/m2-day) are shown monthly.

Figure 3.Monthly Optimum Angle Change

Looking at the results in general, the optimum angle values varied between $0^0$and 61^0. The highest values for angles were in the months December and January, while the lowest values were in the months June and July. The values of angles decreased in the period from December to June and increased in the period from June to December. The main reason for this is that solar rays arrive on the earth's surface with the steepest angle on 21 June, and with the narrowest angle on 21 December.

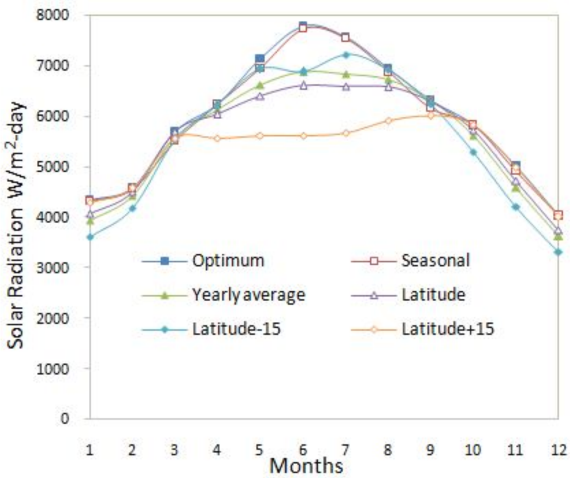

Figure 4.Optimum Solar Radiation Angle And Monthly Change

Figure 4shows that the relationship between the changes in panel angles and the amounts of radiation varied in different periods. While this change in the period of March-October was more noticeable, it was more ambiguous in the period of October-March. The main reason for this situation may be explained as the high magnitude of radiation and steeper angle of sunrays from when the Spring Equinox starts on 21 March to when the Fall Equinox starts on 23 September. Considering all regions in general for the period of March-October, the highest amount of radiation is obtained at the optimum value of inclination angle. In terms of their effects, this value was followed by seasonal angle, latitude - 15, latitude angle, latitude + 15. In the period of October-March, this order is as optimum angle, latitude + 15, latitude angle, average annual angles and latitude -15.

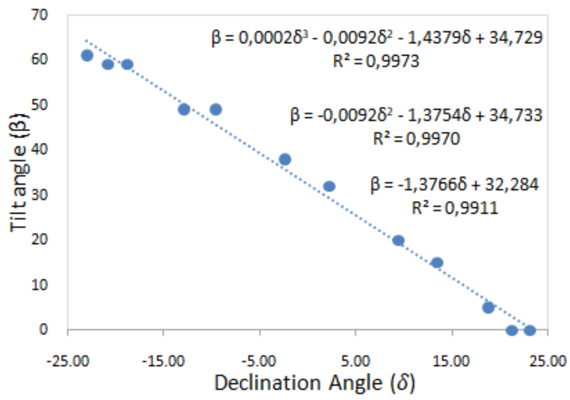

Figure 5.Correlation giving optimum tilt angles

By taking the declination angle (δ) values genuine to the study location as a basis, the linear equation 13, the second-degree polynomial equation 14 and the third-degree polynomial equation 15 were developed. The monthly panel inclination angle could be estimated by these equations.

$$\beta_{OPT.} = -1{,}3766(\delta) + 32{,}284 \quad (13)$$

$$\beta_{OPT.} = -0{,}0092(\delta)^{2} - 1{,}3754(\delta) + 34{,}733 \quad (14)$$

$$\beta_{OPT.} = 0{,}0002(\delta)^{3} - 0{,}0092(\delta)^{2} - 1{,}4379(\delta) + 34{,}729 \quad (15)$$

There are several different methods in the literature to verify the statistical accuracy equations. The most frequently used methods are mean bias error (MBE), root mean square error (RMSE) and the t-statistic [14,15,16]

Months	Eq.13	Bias.13	Eq.14	Bias.14	Eq.15	Bias.15
Jan.	61	2	59	0	59	0
Feb.	50	1	51	2	51	2
Mar.	36	-2	38	0	38	0
Apr.	19	-1	21	1	21	1
May	6	1	6	1	6	1
Jun.	1	1	-2	-2	-1	-1
Jul.	3	3	1	1	2	2
Aug.	14	-1	15	0	14	-1
Sep.	29	-3	32	0	31	-1
Oct.	45	-4	47	-2	48	-1
Nov.	58	-1	57	-2	57	-2
Dec.	64	3	62	1	61	0

Table 2. Relative Error Of Developed Equations

Table 2 shows the deviations in the monthly panel angles estimated in the models developed for Muğla and the calculated values. The highest and lowest deviation values for the equations were 4^0-1^0, 2^0-1^0 and 2^0-$1^0$for equations 13, 14 and 15 respectively. Deviation values were very close to the calculated values and within acceptable limits

CONCLUSION

1. The highest and lowest values in the monthly calculations of the optimum panel angle values were 7780 W/m2-day (June) and 4040 (December) respectively.
2. The seasonal panel angles in Muğla were 56.33^0 for winter, 21^0 for spring, $5^0$for summer and $46.66^0$for fall. The average annual panel angle was 32.25^0.
3. When the monthly optimum panel inclination angles calculated for the regions were used, the annual percentage of increase in efficiency was 17.03%, and the total annual radiation value increased from 61010 to 71397 W/m2-year.
4. The MBE (mean bias error) values were respectively 0.0002, 0.0058 and 0.0031 for equations 13, 14 and 15.
5. The RMSE (root mean square error) values were respectively 2.13, 1.22 and 1.22 for equations 13, 14 and 15.
1. 6 The t-statistic values were respectively 0.0003, 0.0157 and 0.0085 for equations 13, 14 and 15.
6. While models developed specifically for a region are simple and practical, their statistical verification is strong. This way, they may be used in equations that are suitable for optimum panel angles independently of meteorological data when needed.
7. The highest yield from changing panel inclination angles was obtained in winter month, while the differences among the other months in terms of solar radiation were minimized. This way, the amount of fluctuation in the annual energy values may be reduced and constant energy production may be achieved. This allows opportunities of stable revenues for companies that invest in solar energy.
8. The optimum angle values and the mathematical equations that were created may be used in the Southern Mediterranean Regions which is on a similar latitude, as well as in other parts of the world. Significant ones among these regions include Washington DC and San Francisco in the USA, Lisbon and Faro in Portugal, Granada, Malaga and Seville in Spain, Palermo and Catania in Italy, Athens and Mykonos in Greece, Tabriz in Iran, Ashgabat in Turkmenistan and Seoul in South Korea.

Consequently, it was aimed to achieve maximum utility by calculating optimum panel inclination angles because the costs of sun-seeking system are high, especially for developing counties.

REFERENCES

[1] Khorasanizadeh, H., Mohammadi, K., & Mostafaeipour, A. (2014). Establishing a diffuse solar radiation model for determining the optimum tilt angle of solar surfaces in Tabass, Iran. Energy conversion and management, 78, 805-814.

[2] Benghanem, M. (2011). Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia. Applied Energy, 88(4), 1427-1433.

[3] Beringer, S., Schilke, H., Lohse, I., & Seckmeyer, G. (2011). Case study showing that the tilt angle of photovoltaic plants is nearly irrelevant. Solar energy, 85(3), 470-476.

[4] Yang, H., & Lu, L. (2007). The optimum tilt angles and orientations of PV claddings for building-integrated photovoltaic (BIPV) applications. Journal of Solar Energy Engineering, 129(2), 253-255.

[5] Ozbay, H., Karafil, A., Onal, Y., Kesler, M., & Parmaksiz, H. (2017). The Monitoring of Monthly, Seasonal and Yearly Optimum Tilt Angles by Raspberry Pi Card for Bilecik City, Turkey. Energy Procedia, 113, 311-318.

[6] Kallioğlu, M., Ercan U., Avcı S., Karakaya H., (2017) Optimization Of Tilt Angle For Solar Panel.2'nd International Energy & Engineering Conference (p180-186) Gaziantep, Turkey.

[7] Muneer, T., & Saluja, G. S. (1985). A brief review of models for computing solar radiation on inclined surfaces. Energy conversion and management, 25(4), 443-458.

[8] Liu, B. Y. H., & Jordan, R. C. (1960). The interrelationship and of direct diffuse and characteristic distribution total solar radiation. Solar Energy, 4(3), 1-19.

[9] Muneer, T. (2007). Solar radiation and daylight models. Routledge.

[10] Lewis, G. (1987). Optimum tilt of a solar collector. Solar & wind technology, 4(3), 407-410.

[11] Duffie, J. A., & Beckman, W. A. (2013). Solar engineering of thermal processes. John Wiley & Sons.

[12] Cooper, P. I. (1969). The absorption of radiation in solar stills. Solar energy, 12(3), 333-346.

[13] Liu, B., & Jordan, R. (1961). Daily insolation on surfaces tilted towards equator. ASHRAE J.;(United States), 10.

[14] Ma, C. C. Y., & Iqbal, M. (1983). Statistical comparison of models for estimating solar radiation on inclined surgaces. Solar Energy, 31(3), 313-317.

[15] Bakirci, K., & Kirtiloglu, Y. (2018). Prediction of diffuse solar radiation using satellite data. International Journal of Green Energy, 1-4.

[16] Akinoğlu, B. G., & Ecevit, A. (1990). A further comparison and discussion of sunshine-based models to estimate global solar radiation. Energy, 15(10), 865-872.

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