MATLAB Based Angle Optimization Study for Solar Panels in Bursa

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Abstract:- The use of solar energy provides significant opportunities for high levels of clean energy production, particularly in southern regions of our country, given the high energy potential and long periods of sunshine. In recent years, with the increasing focus on sustainability efforts, the utilization of solar energy in our country has been steadily increasing. This study aims to examine the most suitable solar panel angles for the city center of Bursa and Uludag region, with a focus on determining the optimum panel angles on a monthly, seasonal, and yearly basis. The calculation method involved mathematical simulations of panel angles for both regions using MATLAB. Angle values were determined for each degree in the 0-90 degree range for 365 days, based on maximum radiation. The effects of altitude and snowy surface reflection were considered in determining the optimum panel angles. According to the obtained results, the difference between the optimum panel angles for the two regions is 5 degrees annually, it increases to 12 degrees in February. The yearly optimum panel angle is for 34 degrees for the city center, and 39 degrees for Uludag. It was observed that the effect of altitude and snowy surface reflection in Uludag region results in higher panel efficiency and generated electrical energy compared to the city center. Angle values are higher in winter and lower in summer. Although the optimum angle values differ between the two regions during spring and autumn, the yearly total radiation values are the same due to seasonal gains. When considering the seasonal optimum angles for yearly use, the highest total radiation is achieved with the spring and autumn panel angles, while the lowest value is observed with the adjusted panel angle for the summer season. Considering the increase in efficiency based on monthly and yearly optimum angles, it is recommended to adjust the tilt angle periodically to improve the panel efficiency.

Keywords:- *Solar Energy, Solar Panel Tilt Angle, Optimization.*

I. INTRODUCTION

Despite the existence of multiple methods for generating electricity from solar energy, photovoltaic (PV) systems are predominantly utilized. Solar energy is converted into electrical energy using solar panels, representing a significant source of clean electricity production. However, challenges such as high costs and low efficiency hinder the full realization of solar energy's potential. To maximize the performance, there is a need for effective and flexible methods that can easily regulate factors like irradiation and temperature. The efficiency of PV systems is influenced by various factors, including panel material (e.g., amorphous, monocrystalline, and polycrystalline), contamination, panel tilt and orientation. These factors are considered critical indicators in determining the total energy yield from solar power.

Due to its geographical location, our country possesses a high solar energy potential. According to the Solar Energy Potential Atlas of Turkey [6], the average annual total sunshine duration is 2741 hours, and the average annual total irradiation value is 1527.46 kWh/m². As of the end of June 2022, our solar energy-based electricity installed capacity was 8.479 MW, it reached to 12.425 MW by February 2024 [6].

II. RELATED WORKS

This study aims to calculate monthly, seasonal, and annual optimal tilt angles for Bursa city center and Uludag region. The objectives include comparing the differences arising due to winter snowfall and the determined optimal angles. The study is completed by conducting a literature review and calculating the instant or seasonal optimal surface angles based on the solar irradiation incident on the surface using MATLAB, followed by the interpretation of the results. Akyürek et al. [1] conducted a study on the optimal tilt angle of solar panels for the Western Mediterranean region, specifically examining Antalya, Burdur, and Isparta. They found that the annual panel tilt angle ranged between 1-66°, with the lowest angle being 1° during June and July for all three cities.

Kaçıra et al. [7] investigated the optimal tilt angles and orientations of photovoltaic panels in Şanlıurfa. Their results indicated that the seasonal optimal tilt angle and the tilt angle equal to the latitude resulted in gains of 1.1% and 3.9%, respectively, in the annual solar irradiation received by the PV panel compared to the monthly optimal tilt angle. Additionally, a comparison between a panel fixed at a 14° tilt angle and a dual-axis solar tracking system on a specific day in July showed an average daily increase of 29.3% in solar irradiation.

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Koçer et al. [8] focused on optimizing the tilt angles for maximizing the performance of solar collectors and panels in Ankara and its districts. They determined that the most suitable angle was 34° ± 1. The study also found that changing the tilt angle twice a year resulted in a 5% increase in energy per unit area compared to panels with a fixed tilt angle throughout the year, and changing the tilt angle monthly increased this value to 8%.

Raptis et al. [10] calculated the solar radiation and the optimal tilt angle for maximum solar radiation in the Athens region, finding an annual optimal tilt angle of 30°. They recommended a special study on the impact of cloudy weather conditions. Babu et al. [14] found that factors like dust and dirt could reduce the efficiency of solar panels by 10% to 30%. Khadum and Hemza [15], in their comparison of fixed and movable solar panels, discovered that dual-axis solar panels were 61.68% more efficient than fixed panels.

Despotovic and Nedic [4] calculated the optimal tilt angles for solar collectors in Belgrade, Serbia, on annual, semi-annual, seasonal, monthly, bi-weekly, and daily levels. They recommended at least seasonal adjustments (twice a year) for the tilt angles of roof-mounted collectors. Ulgen and Hepbasli [11] worked on the daily and monthly global radiation in Izmir.

III. MATERIALS AND METHODS

A. Solar Radiation On Horizontal Plane

Before calculating the solar irradiance on an inclined plane, it is necessary to determine the solar irradiance values incident on a horizontal surface. The daily solar irradiance on a horizontal surface outside the Earth's atmosphere, H_0 (J/m^2-day), is calculated as follows;

$$H_0 = \frac{24 * 3600 G_{sc}}{\pi} * \left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right] * \left[\cos\varphi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\varphi\sin\delta\right] \quad (1)$$

In this context, Gsc is taken as the solar constant, with a value of 1367 W/m². The declination angle δ is the angle between the rays of the sun and the plane of the Earth's equator, and it is calculated using the following equation (Cooper 1969):

$$\delta = 23.45\sin\left(360 * \frac{284+n}{365}\right) \quad (2)$$

Here, n represents the number of days since January 1st. The sunset hour angle ωs is dependent on both the declination angle δ and the latitude ϕ and can be determined using the following equation [5];

$$\omega_s = \cos^{-1}(-\tan\delta\tan\varphi) \quad (3)$$

The monthly average daily solar irradiance is expressed as H;

$$\frac{H}{H_0} = a + b * \frac{n}{N} \quad (4)$$

The relative sunshine duration is represented by n/N, where n is the daily sunshine duration and N is the day length. The coefficients a and b in the equation vary depending on the location. For Turkey, these values are determined as (Kılıç & Öztürk [16];

$$a = 0.103 + 0.000017 * Z + 0.198\cos(\varphi - \delta) \quad (5)$$

$$b = 0.533 - 0.165\cos(\varphi - \delta) \quad (6)$$

Z=altitude of the location.

The clearness index (K_T) is crucial in solar energy production. The ratio of diffuse radiation to total radiation on a horizontal plane is determined by the clearness index (K_T) using the following equation, which also depends on the altitude Z of the location:

$$\frac{H_d}{H} = 0.703 - 0.414K_T - 0.428K_T^2 \quad (7)$$

The monthly average daily solar irradiance on a horizontal surface, H, can be obtained from (4) or alternatively from the following equation depending on the clearness index:

$$K_T = \frac{H}{H_0} \quad (8)$$

The daily average total radiation incident on an inclined surface is;

$$H_T = H\left(1 - \frac{H_d}{H}\right)\bar{\bar{R}}_b + H_d\left(\frac{1+\cos\beta}{2}\right) + H\rho\left(\frac{1-\cos\beta}{2}\right) \quad (9)$$

Here, ρ represents the ground reflectance ratio, considered as 0.7 when there is snow on the ground and also 0.2 when there is no snow. In this study, for calculations from November to March in Uludag region, ρ is accepted as 0.7. $\bar{\bar{R}}_b$ is the geometric factor, defined as the ratio of daily direct radiation on an inclined surface (H_{bT}) to daily direct radiation on a horizontal surface (H_b) [13]. This equation for the northern hemisphere is given by:

$$-\bar{\bar{R}}_b = \frac{\cos(\varphi-\beta)\cos\delta\sin\omega'_s + (\frac{\pi}{180})\omega'_s\sin(\varphi-\beta)\sin\delta}{\cos\varphi\cos\delta\sin\omega_s + (\frac{\pi}{180})\omega_s\sin\varphi\sin\delta} \quad (10)$$

ωs′ is the initial sun hour angle of solar rays on an inclined plane and differs from ω_s. This value is determined as follows;

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$$\omega'_s = \min\begin{bmatrix} \cos^{-1}(-\tan\varphi\tan\delta) \\ \cos^{-1}(-\tan(\varphi-\beta)\tan\delta \end{bmatrix} \quad (11)$$

The "minimum" in this equation signifies that the smaller value will be taken.

B. Panel Efficiency

When calculating panel efficiency, it is essential to know the panel cell temperature. For calm weather conditions, the panel cell temperature can be determined as follows [2];

$$T_c = T_a + \frac{T_{NOCT} - 20}{800} G_T \quad (12)$$

T_{NOCT} is nominal panel cell temperature and it is accepted 45º C. Solar panel efficiency is calculated using the following equation;

$$\eta_c = -0.05T_c + 12.57 \quad (13)$$

The calculation of optimal panel tilt angles for Bursa city center and Uludag region was mathematically simulated using MATLAB software, employing Equations 1-11. Each degree within the 0-90-degree range was individually computed for 365 days, based on the maximum irradiance incident on an inclined plane, determining the optimal tilt angles. Graphs were generated using MATLAB and other interface programs.

IV. RESULTS AND DISCUSSIONS

For Bursa, the elevation is 100 meters, and for Uludag region, it is 1877 meters [9]. Both locations share a latitude of 40.1 degrees [3]. In this study, a surface reflectance ratio of 0.2 was used for Bursa, while a value of 0.7 was applied for the snow-covered periods in Uludag [12]. In the mathematical model, regional variables were input to obtain the optimal panel angles and irradiance values. Table 1 shows the calculated optimal values for each month for the two regions. For Bursa, the optimal panel angle for February is 52°, and the irradiance value incident on the panel is 11.558 MJ/m²–day, whereas for Uludag region, the optimal panel angle is 64°, and the irradiance value is 15.737 MJ/m²–day. In June, the optimal panel angle for both regions was found to be 0°. The range of optimal angles for Bursa varies between 0° and 63°, while for Uludag, it ranges from 0° to 73°. When considering the total irradiance values, Bursa has a calculated value of 210.455 MJ/m²–day, while Uludag has a higher value of 238.937 MJ/m²–day. From November to March, Uludag region experiences snowfall, resulting in increased irradiance values compared to the city center due to the reflective effect of snow and the high altitude. During the months from April to October, the positive impact of altitude can also be observed.

TABLE I. MONTHLY OPTIMUM TILT ANGLES AND RADIATION VALUES

	REGION			
	BURSA		**ULUDAĞ**	
Months	**Optimum Angle (β⁰)**	**H_T opt (MJ/m2-day)**	**Optimum Angle (β⁰)**	**H_T opt (MJ/m2-day)**
January	60	9.118	71	12.39
February	52	11.558	64	15.737
March	37	14.035	51	19.025
April	22	17.943	22	19.201
May	9	23.174	9	24.509
June	0	25.736	0	27.123
July	4	26.383	4	27.736
August	18	24.049	19	25.347
September	34	20.363	35	21.645
October	49	15.815	50	17.063
November	60	12.327	70	16.428
December	63	9.954	73	12.733
Total	210.455		238.937	

Table 2 illustrates the seasonal optimum angles and the irradiance values obtained by seasonally adjusting the panels. Upon examining Table 2, it is evident that the total irradiance value for seasonally adjusted panel angles decreases compared to the monthly angle adjustments for both regions.

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TABLE II. SEASONAL OPTIMUM TILT ANGLES AND RADIATION VALUES

REGION				
	BURSA		ULUDAĞ	
Season	**Optimum Angle (β°)**	**H_T opt (MJ/m2-day)**	**Optimum Angle (β°)**	**H_T opt (MJ/m2-day)**
Winter	**58**	8.547	**69**	11.785
		8.188		11.442
		10.741		14.953
Spring	**23**	13.457	**27**	18.014
		17.797		19.015
		22.764		23.832
Summer	**7**	25.625	**8**	26.977
		26.357		27.699
		23.740		25.048
Autumn	**48**	19.724	**52**	21.365
		15.325		15.755
		11.434		13.399
Total	203.700		229.285	

Table 3 shows the irradiance values obtained when using the annual optimum panel angles for both regions.

TABLE III. THE ANNUAL OPTIMUM TILT ANGLES AND RADIATION VALUES

REGION				
	BURSA		ULUDAĞ	
Months	**Optimum Angle (β°)**	**H_T opt (MJ/m2-day)**	**Optimum Angle (β°)**	**H_T opt (MJ/m2-day)**
January	**34**	7.771	**39**	10.625
February		10.615		14.390
March		13.627		18.448
April		17.514		18.523
May		21.951		22.677
June		23.663		24.203
July		24.631		25.198
August		23.419		24.287
September		20.170		21.427
October		15.007		16.443
November		10.841		14.479
December		7.918		10.734
Total	197.128		221.433	

When examining the optimal values based on monthly, seasonal, and annual adjustments of the panel angles, it is observed that as the frequency of panel angle adjustments decreases, the total irradiance value also decreases.

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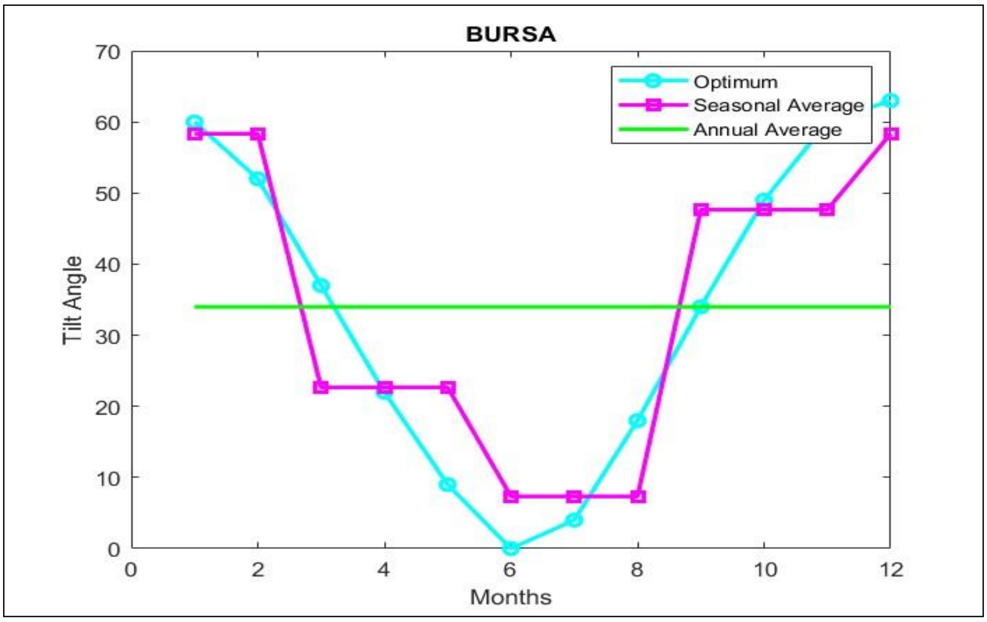

Fig. 1.Optimum Tilt Angles for Bursa

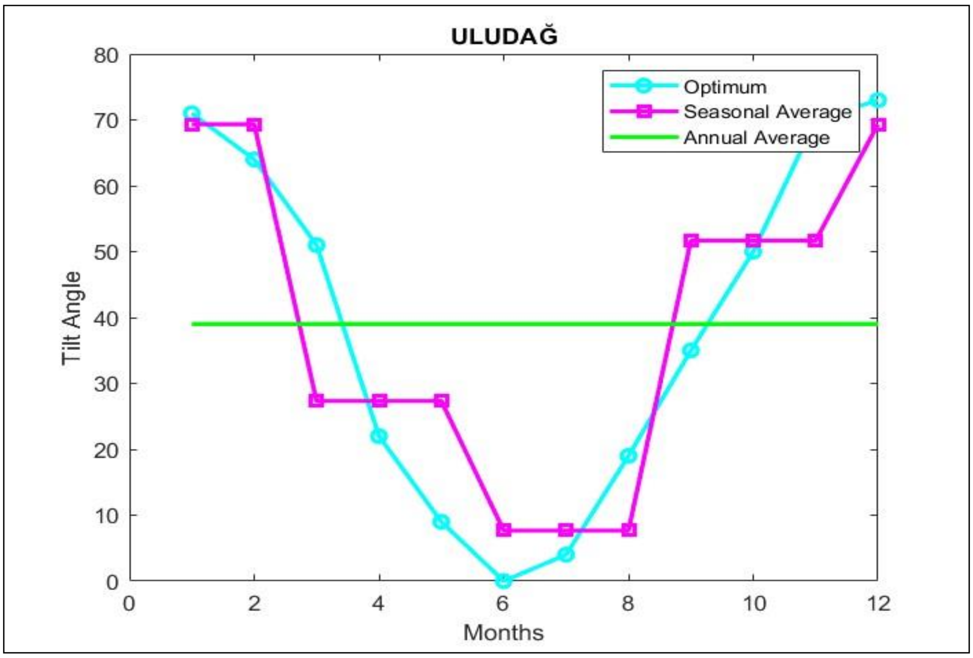

Fig. 2.Optimum Tilt Angles for Uludağ

Figure 1 presents the optimal panel angles for Bursa and Uludağ, while Table 4 calculates the total irradiance based on these optimal angles. In Bursa, adjusting the panel angle seasonally results in a 3.2% increase in irradiance compared to a fixed annual tilt angle, and a 6.8% increase when adjusted monthly. For Uludağ, seasonal adjustments yield a 4.1% increase in irradiance compared to a fixed annual angle, and monthly adjustments result in a 7.9% increase.

TABLE IV. TOTAL RADIATION VALUES FOR OPTIMUM VALUES (MJ/M2-DAY)

REGION						
	BURSA			ULUDAĞ		
Months	**Monthly (□□**	**Seasonal (°)**	**Annual (°)**	**Monthly (□□**	**Seasonal (°)**	**Annual (°)**
January	282.66	264.96	240.90	384.09	365.34	329.38
February	323.62	229.26	297.22	440.64	320.38	402.92
March	435.09	332.97	422.44	589.78	463.54	571.89
April	538.29	403.71	525.42	576.03	540.42	555.69
May	718.39	551.71	680.48	759.78	589.47	702.99
June	772.08	682.92	709.89	813.69	714.96	726.09

July	817.87	794.38	763.56	859.82	836.29	781.14
August	745.52	817.07	725.99	785.76	858.67	752.90
September	610.89	712.20	605.10	649.35	751.44	642.81
October	490.27	611.44	465.22	528.95	662.32	509.73
November	369.81	459.75	325.23	492.84	472.65	434.37
December	308.57	354.45	245.46	394.72	415.37	332.75
Total	6413.06	6214.82	6006.90	7275.44	6990.83	6742.65

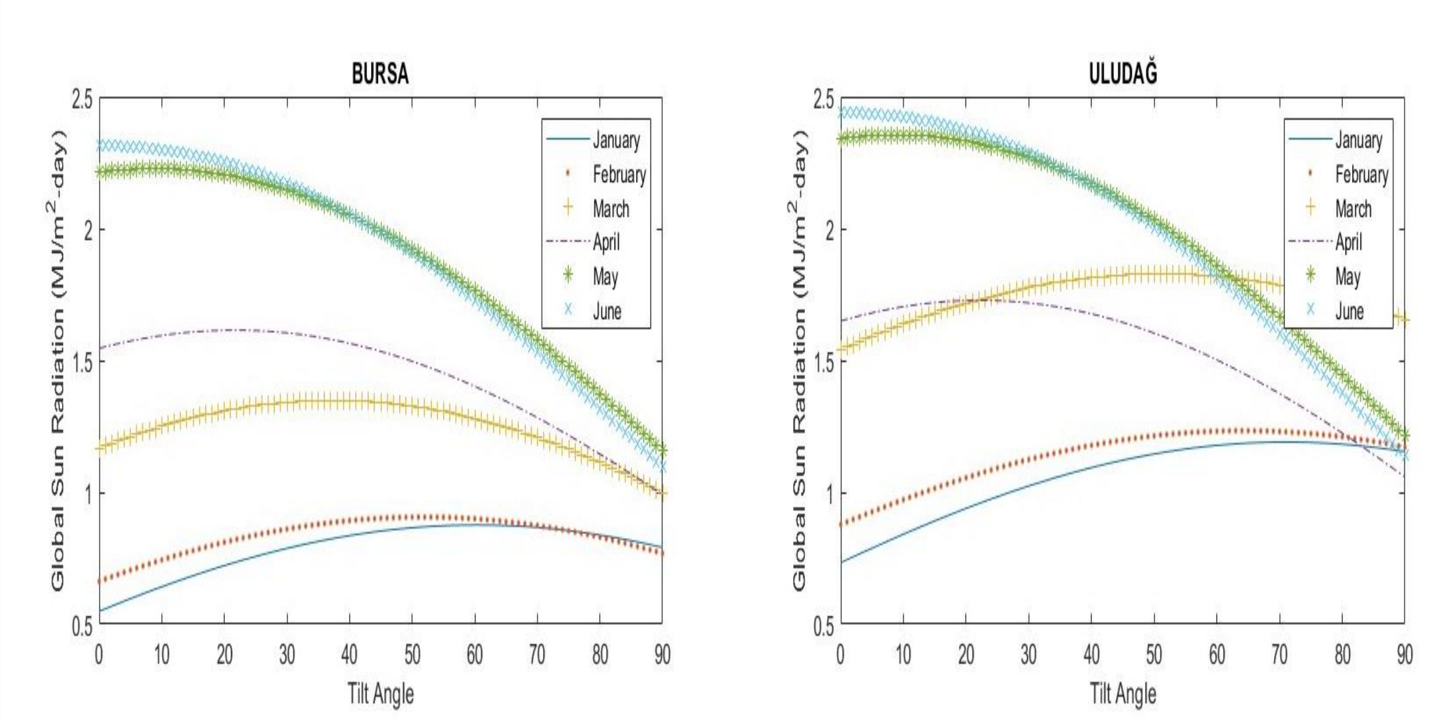

Fig. 3. Montly Tilt Angle-Radiation Relationship for Bursa and Uludağ for First 6 Months

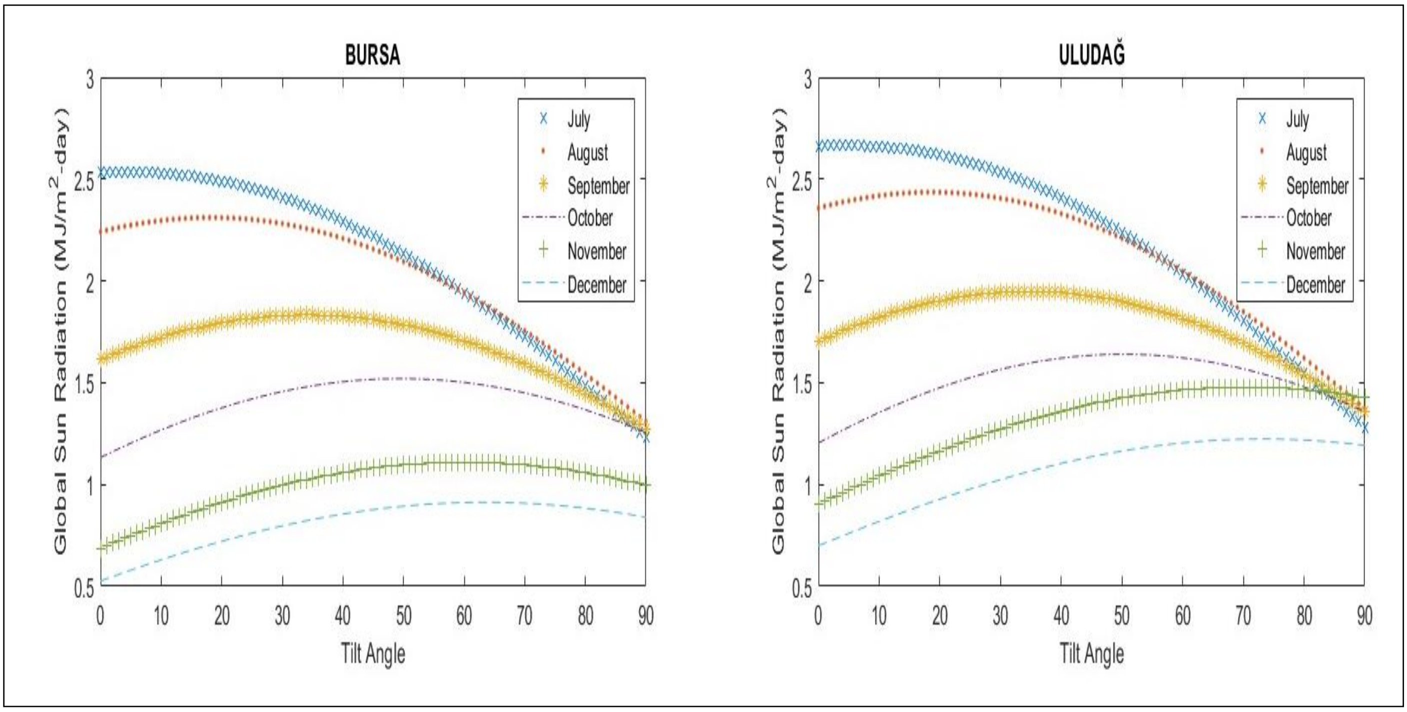

Fig. 4. Monthly Tilt Angle-Radiation Relationship for Bursa and Uludağ for Last 6 Months

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Figure 4 illustrates the solar irradiance values based on the tilt angle of the panel for both regions. As evident from the figure, behaviorally, both regions exhibit high irradiance levels during the winter months and lower levels during the summer months.

V. CONCLUSION

In this study, the optimum tilt angles for solar panels in Bursa and Uludag were determined. The tilt angle was calculated as 34º annually for Bursa and 39º for Uludag. The seasonal tilt angles were found to be 23º for spring, 7º for summer, 48º for autumn, and 58º for winter in Bursa, and 27º for spring, 8º for summer, 52º for autumn, and 69º for winter in Uludag. Upon examining the monthly tilt angles, the largest angle difference of 12º between Bursa and Uludag was observed in February, while the optimal tilt angle remained the same for April, May, June, and July. Especially in winter months, the increasing difference indicates the influence of altitude and surface reflectance coefficient. Since the reflectance coefficient varies, it was assumed to be 0.7 for Uludag during the snowy months of November to March in this study. The total irradiance values obtained show an increase of 3.2% and 4.1% for Bursa and Uludag, respectively, with seasonal changes in panel tilt angles, while the change based on monthly optimal angles results in a 6.8% and 7.9% increase. Based on these results, it is recommended to periodically adjust the panel tilt angles in both regions to maximize the benefits from solar panels. Adjustable mounts are necessary during installation to enable the periodic adjustment of panel tilt angles. Solar tracking systems can also be preferred for greater utilization of solar energy.

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