A Research On Determining The Panel Inclination Angle In Terms Of The Place And Seasons

Mehmet Sait Cengiz
Department of Technical Vocational School,
Bitlis Eren University, Bitlis, Turkey
msaitcengiz@gmail.com

Mehmet Salih Mamiş
Department of Electrical and Electronics Engineering,
Inonu University, Malatya, Turkey
mehmet.mamis@inonu.edu.tr

***Abstract*—In this study, a calculation was made for determining the optimum angle of solar panels to be established in different cities of our country that is located in mild temperate zone; and also a detailed analysis was carried out by using the angular values in question. According to the calculations made, it was observed that the use of a single angle annually for the solar pales, caused yield loss. In order to reduce these losses, it had been pointed out that it was essential to make an angular change in the panels at the beginning dates of the seasons. In order to reduce the margin of error that these complicated calculations caused, simple and practical relations that can be used seasonally, were given in tables. Thus, it was observed that if the latitude information is available, it would be easy to determine the optimum panel inclination angle for each season.**

Keywords—Solar energy, Renewable energy, Photovoltaic panel

I. INTRODUCTION

Fossil-based energy resources in the world, are consumed rapidly. Fossil-based energy resources cause adverse effects such as nitrogen oscillation, environmental pollution and global warming. Therefore, intense studies are carried out today on renewable energy resources. The cost of renewable and clean energy resources is reduced in time, along with the technological advancements, and their areas of use are expanded.

Solar energy is the most significant one among these resources. The use of PV systems in which the sun rays are directly transformed into electricity, has increased particularly in the last 20 years. Today, PV systems can operate with a much lower cost and much higher efficiency. While electricity was produced by 1%-2% yield in the first PV systems, today this ratio is around 17% for amorphous cells and around 25% for mono-crystalline cells. While the cost of PV cells was approximately 200 $/Watt in 1970s, today this number has decreased to the level of 1 $/Watt. Modulus that were previously created by the combination of small battery cells, can now be manufactured in one piece by super technology, and these can be used for almost 25 years without any maintenance. Thus, unit cost for each panel, can be reduced to minimum level.

Turkey is an energy poor country in terms of its known resources, and it imports 72% of the energy it consumes. In 2012, overall financial size of Turkey's energy market, was around 84 Billion dollars. 60,1 billion dollar of this amount, was imported. In order to close this gap, "Solar Energy", which has the biggest share among renewable energy resources, should be used. Because, Turkey is located in a region called as sunbelt, and it has the potential to generate 389 MWh electricity from solar energy in a year. Alongside Turkey; Spain, Italy, Greece, Syria, Egypt, Saudi Arabia, Libya, Algeria, Morocco, Iran, Pakistan, China, Japan, USA, Mexico, South Africa and Australia are also located in this region called as sunbelt.

Due to the rotation of the earth in the solar system and around its own axis, a dynamic and periodic change occurs. This change leads to the formation of different seasons and sunshine duration at different lengths in a 12-month periodic cycle. Sunshine durations means benefiting from the sun in the electrical sense, and electricity is produced by the sun rays that fall down on the solar panels. In these type of systems; Sun Tracking Systems and fixed systems are utilized in order to make production. While fixed systems are installed in a certain angle horizontally in accordance with the coordinates of the location looking towards south; Sun Tracking Systems begin tracking the sun right after sunrise, and this dynamic tracking ends with sunset.

Due to its elliptical orbit; earth, which rotates around sun and its own orbit, causes the formation of seasons in a 12-month periodic cycle. In order to follow the dynamic movements around the sun's own orbit, it is essential to know several declination angles related to the sun. These angles enable us to have knowledge about the orbit that the sun follows, and the sun's position according to the current location. By means of declination angles, it is possible to follow the sun's movement within the day. Therefore, thanks to the latitude and longitude values of the current location, the thought of Solar Tracking Systems has come to surface [1]. For instance; when the sun conducts its periodic and dynamic movements, there will be a difference between the sun's distance from the equator and its distance from the poles or any other location. And this means that, the sun's position will change hourly within the day. In other words, different locations on the earth will be exposed to insolation with different angles at the same time, and because of these different angles, the energy amount generated from the panels, will not be equal.

Earth rotates in the sun-oriented orbit at 23,45° angle. Thanks to this angle, the sun comes up at the right angle in the north hemisphere during summer months when compared to winter months [1]. Thus, in summer months, daytime will be longer than night time; and in winter months, night time will be longer than daytime.

I. SOLAR ANGLES

The amount of sun rays falling down on the surface of the panel on any plane, differs regarding the panel's geographical position and the current time zone [2].

A. Latitude Angle :

It is defined as the angle that the earth makes on the equatorial plane, and is indicated with the symbol "Φ". Latitude angle is taken as positive (+) in the north hemisphere, and as negative (-) in the south hemisphere. Latitude angle varies between -90° and 90° [2]. ($-90° \leq \Phi \leq 90°$)

B. Declination angle :

Declination angle is sun rays' angle of incidence on the earth on monthly and seasonal basis. In other words, it is the angle made by sun rays on the equatorial plane. The other name of declination angle is "the angle of deflection" and it is indicated with the symbol 'δ'. Declination angle stems from the angle of 23 degrees and 27 minutes that the earth makes on its own axis and on the orbital plane. If the earth wasn't inclined to the rotation axis, declination angle would always be "zero". Declination angle varies between $-23{,}45° \leq \delta \leq 23{,}45°$ angles.

This angle between the rotation axis and the earth's equatorial plane, has the angular value of maximum +23,45° on 21th June in the middle of summer, and minimum

-23,45° on 21th December in the middle of winter. And at the equinox points; declination angle would be "zero" in 21th March spring equinox and 22th September autumn equinox [3, 4].

The change of declination angle is shown in Figure 1, and it is calculated by using equation 1 [3, 4].

$$\delta = 23{,}45.\sin\left(\frac{(360.(284+n))}{365}\right)(^{o}) \qquad (1)$$

Here, January 1st is accepted as the beginning, and n = 1. This section of the paper describes the proposed requirements architecture used in the generation and creation of Mash-up applications; it uses three different levels and their respective roles in the creation of a Mash-up are described.

C. Zenith angle (Θ_Z) :

T It is the amount of angle between the sun's direction and the vertical axis. On horizontal plane, zenith angle is 90° between sunrise and sunset, and 0° at midday (12:00). The sun is reaches the peak point in the air at midday. The change between the latitude angle, declination angle and zenith angle, is calculated by equation 2 [3, 4].

$$\cos\theta_z = \cos\delta.\cos\varnothing.\cos w + \sin\delta.\sin\varnothing \qquad (2)$$

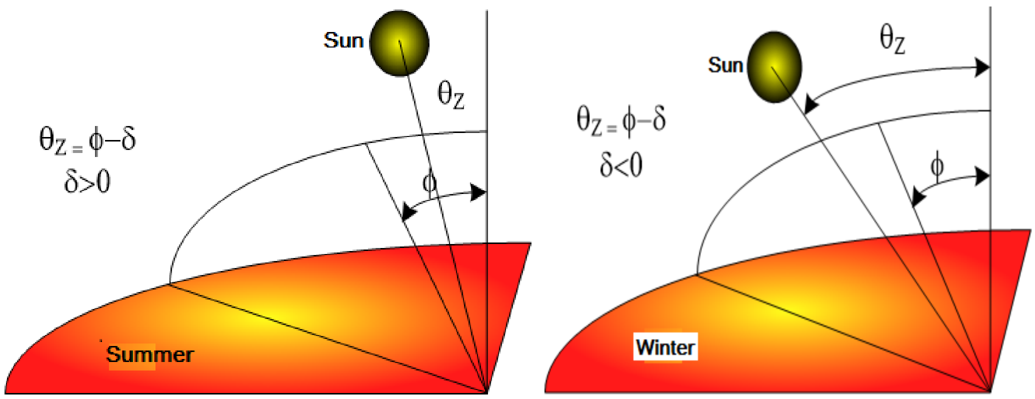

Figure 1. The change between the latitude angle, declination angle and zenith angle her is

w, hour angle. At the same time, zenith angle completes the solar elevation angle to 90°.

D. Solar elevation angle (As) :

The amount of angle created by the sun's direction and the horizontal axis. As it completes the zenith peak to 90°, solar elevation angle is calculated by equation 3.

$$\alpha_s = 90° - \theta_z \qquad (3)$$

E. Sun's angle of incidence (Θ) :

The amount of angle between the light coming directly to a surface, and the normal to that surface. It represents the sun's angle of incidence and calculated by the relation in equation 4.

$$\cos\theta = \cos\theta_z.\cos\beta + \sin\theta_z.\sin\beta.\cos(\gamma_s - \gamma) \qquad (4)$$

Here, 'γ' is surface azimuth angle.

F. Inclination angle (B) :

The amount of angle created by the panel surface plane given horizontally. In the north hemisphere, it is considered that the sun is inclined to the south. Inclination angle varies between $0° \leq \beta \leq 180°$. The angle value can be calculated by the relation in equation 5 [3, 4].

$$\tan\beta = \tan\theta_z\,|\cos\gamma_s| \qquad (5)$$

Figure 2 The relationship between θz , δ and Ø angles at midday in the summer and winter. Some solar angles can be seen in Figure 3.

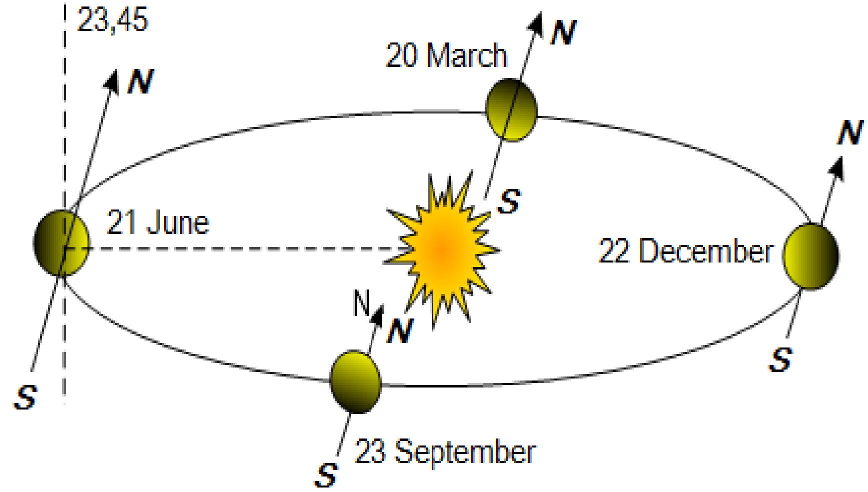

Figure 2. Earth's orbit and declination for Turkey

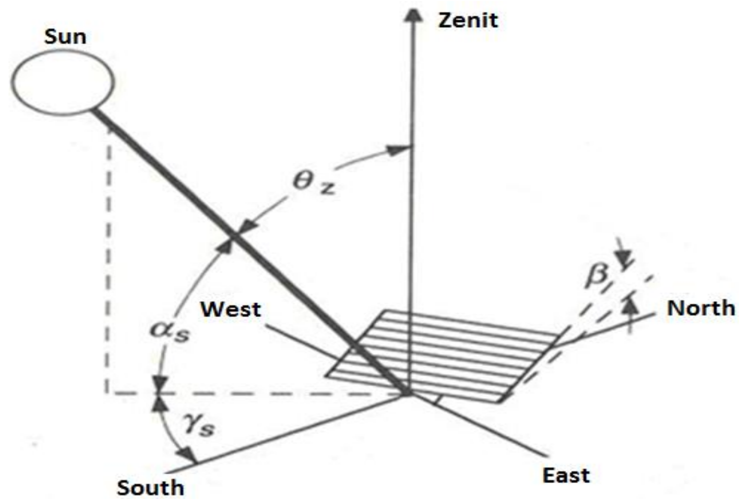

Figure 3. Solar Angles

At the commencement of this research there existed a single Mash-up architecture, entitled "the enterprise Mash-up architecture." This study has created more comprehensive requirements architecture for Mash-up development in HE.

In contrast to the enterprise Mash-up architecture, this study has created a layered architecture by "drilling down" and elaborating the roles and duties/responsibilities of the relevant individuals.

Following the stages in this requirements architecture carefully and thoroughly will help to ensure success in the development of a Mash-up.

II. Benefiting from the Solar Energy

Solar energy can be used for heating purposes and producing electricity. Solar panel systems are designed as Solar Tracking Systems or fixed Photovoltaic systems, in order to benefit more from the sunlight. Solar Tracking systems monitor the sun's movement instantaneously within the day. And fixed Photovoltaic systems are installed in the manner that would make a certain angle with the current location [3, 4]. Because the sun's angle of incidence changes depending upon the seasons and time, sunshine duration also changes consequently. In this case, the panel should be installed at an optimum inclination angle in the manner that would receive the maximum light from the sun's movement on the monthly and seasonal basis. In this study; in order to benefit from the sun rays at the maximum level, positional calculations were made, and evaluations regarding efficiency at monthly and seasonal angles, were carried out.

III. The Relationship Between the Inclination of Solar Panel and the Amount of Radiation

Total direct radiation amount coming from the sun; is proportional to the angle between the normal to solar panel plane and the cosine of the sunlight [1]. The impact of sun ray on the sunshine duration of one solar panel, is given in Figure 4.

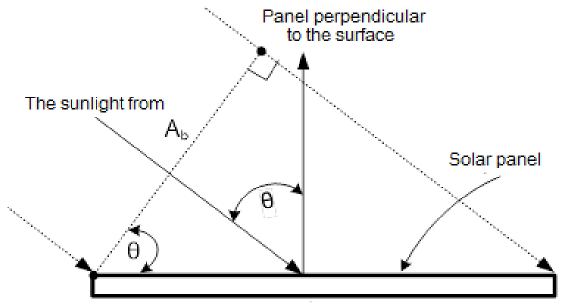

Figure 4. The impact of solar angle on the sunshine duration on the solar panel surface (Cosine law) [3, 4].

The amount of radiation on the panel = I_b. A_b= I_b .A_c.cosθ, here I_b: is the intensity of the light coming directly.

The purpose of power generation, is to generate maximum energy from the solar panel. To this end, Photovoltaic solar panel should be held towards the sun at the optimum angle. It is required to set the solar panel at different inclination and/or azimuth angle in the manner that would provide the optimum current and voltage ratings [5]. Therefore, calculations were made in order to increase the output performance of the fixed panels to be established on behalf of the solar panels installed with different inclination and azimuth angles.

If a solar panel is placed at a slope that has θ_z angle on the horizontal axis at midday, the sunlight that falls down on the solar panel, will be completely vertical to the panel surface (90°). In other words, it benefits from the sunlight at the maximum level. Because at midday, the sun's position in the air has the maximum value compared to its horizontal position. At midday, the sun has the minimum route in the atmosphere in response to the lowest air mass. In time, the intensity of sunlight reduces due to the increase in the air mass, and the angle between the incoming sunlight and the normal to the solar panel, also increases. In Figure 5, the average amount of electricity produced by a fixed-panel system seasonally for different seasons, is indicated [3, 4].

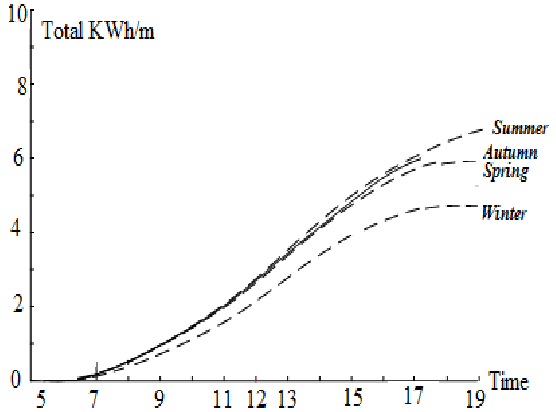

Figure 5. Hourly change of the average amount of electricity produced by a fixed-panel system seasonally for different seasons [3].

The inclination created by the solar panel on the horizontal axis, changes seasonally at the same time. For instance; on a location used in summer months, the inclination angle selected for the solar panel to collect the maximum sunlight, should also be evaluated for other seasons and months of the year [3, 4]. In Figure 6, we can see 400-days change of the sun's angle of incidence towards the panel surface for Elazığ province. In summer season, as the sun rays reach the panel surface with an inclination that is close to the vertical angle in the months of June, July and August, there was a maximum production in question; and as the sun rays reach the panel surface with the furthest inclination to the vertical angle, there was minimum production in December, January and February.

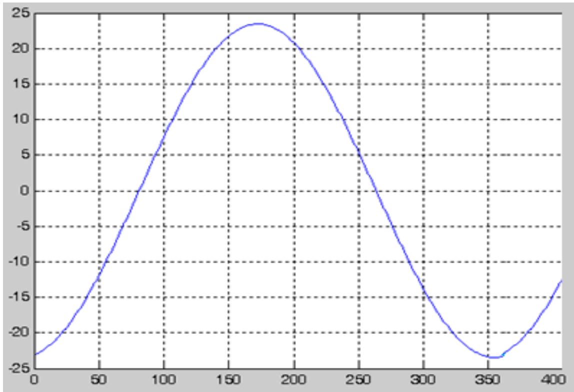

Figure 6. 400-days change of solar declination angle for Elazığ [3]

In order to deliver the maximum performance in a given day, a fixed solar panel system should be installed in the manner indicated in Figure 7, that would have Ø-δ plane angle on the horizontal axis [3]. This process will enable the sun rays coming at midday to reach the panel surface vertically, thus it will increase the amount of power generation.

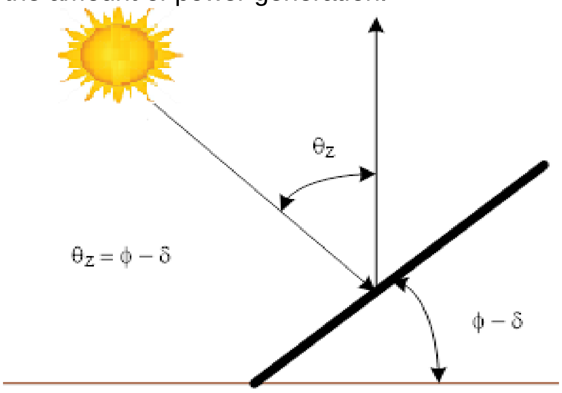

Figure 7. The position of photovoltaic solar panel for maximum power generation [7]

For maximum seasonal performance, an average δ value is selected seasonally. δ angle for summer season in the north hemisphere; varies from 0° to 23,45° between 21th March-21th June, and from 0° to 23,45° between 21th June-21th September. Therefore, inclination angle of the solar panel system, should be (Ø-15)° for optimum average summer performance, and (Ø+15)° for optimum average winter performance. For optimum spring and autumn or annual performance, the solar panel should be installed at the angle of (0,9.Ø) approximately [3, 4, 5].

IV. IMPLEMENTATION

Meteorological data of Malatya province were used for the study. Malatya is situated on the west side of Eastern Anatolia Region, and also in Yukarı Fırat Region of Euphrates River Valley. Malatya province, is located at 38˚21' northern latitude, and 38˚19" eastern longitude [8]. Even though it is surrounded by high mountains, center section of the city is covered with bottom lands. It has continental climate, and the climate is partially mild due to the impact of the dam reservoirs around.

From the south to the north of Turkey, calculations were made for Şanlıurfa, Adıyaman, Diyarbakır, Malatya, Elazığ, Tunceli, Erzincan and Trabzon provinces respectively. In Figure 8, the direction followed for the aforementioned cities, is indicated.

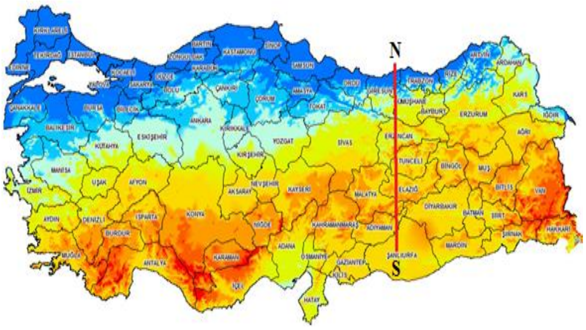

Figure 8. South-North line on which the cities whose panel inclination angles were calculated, are located [3]

Within the year, inclination angle related to each day, was calculated. Then, by means of these daily data, the approximate monthly average values were calculated. In Table 1, optimum inclination angles related to monthly average values calculated for different cities, are given.

After that, with the thought that it would cause extra work load to access the power plant or to replace the inclination angles regularly on a monthly basis; it was considered that the inclination angles of solar panels could be replaced on the first day of each season in a year, and the calculations were made accordingly. It was regarded as advantageous to determine the optimum inclination angles seasonally and to replace the inclination with the manual or automation systems at the end of the season in accordance with to these calculations. In Table 2, optimum inclination angles related to seasonal average values calculated for different countries, are given.

Table 1. Monthly change of North-South directional optimum panel inclination angle (degree)

Cities	January	February	March	April	May	June	July	August	Septem ber	October	Novem ber	Decem ber
Şanlıurfa	57,92	50,4	39,46	27,58	18,27	14	15,97	23,78	35,08	46,92	56,13	60,17
Adıyaman	58,3	50,78	39,84	27,96	18,65	14,38	16,35	24,16	35,46	47,3	56,51	60,55
Diyarbakır	58,39	50,87	39,93	28,05	18,74	14,47	16,44	24,25	35,55	47,39	56,6	60,64
Malatya	59,05	51,53	40,59	28,71	19,4	15,13	17,1	24,91	36,21	48,05	57,26	61,3
Elazığ	59,25	51,73	40,79	28,91	19,6	15,33	17,3	25,11	36,41	48,25	57,46	61,5
Tunceli	59,91	52,39	41,45	29,57	20,26	15,99	17,96	25,77	37,07	48,91	58,12	62,16
Erzincan	60,28	52,76	41,82	29,94	20,63	16,36	18,33	26,14	37,44	49,28	58,49	62,53
Trabzon	61,84	54,32	43,38	31,5	22,19	17,92	19,89	27,7	39	50,84	60,05	64,09

Table 2. Seasonal values of optimum inclination angles according to the provinces in different regions.

Fixed Solar Panel Optimum Inclination Angle (degrees)							
Turkey				Season			
	Altitude (m)	Latitude (N)	Longitude (E)	Spring	Summer	Autumn	Winter
Şanlıurfa	547,1	37,08	38,46	28,44	17,92	46,04	56,16
Adıyaman	672	37,46	38,17	28,82	18,3	46,42	56,54
Diyarbakır	674	37,55	40,14	28,91	18,39	46,51	56,63
Malatya	947,8	38,21	38,19	29,57	19,05	47,17	57,29
Elazığ	989,7	38,41	39,14	29,77	19,25	47,37	57,49
Tunceli	980	39,07	39,32	30,43	19,91	48,03	58,15
Erzincan	1218,2	39,44	39,29	30,8	20,28	48,4	58,52
Trabzon	30	41	39,43	32,36	21,84	49,96	60,08

The individual calculation of aforementioned panel inclination angles for each point and residential area, might cause several mathematical operation complexity. In the event that latitude information is available, several simple and practical solutions were applied for Turkey, in order to prevent this operational complexity. Thus, it would be possible to reach a fast and easy solution by using these relations without making complex calculations. The relations that were compared to the calculation results for each season and that provided the correct results, are indicated in table 3.

Table 3. The relationship between seasons and latitude for optimum panel inclination in Turkey

Season	Equation
Spring	Latitude - 8,65
Autumn	Latitude + 8,97
Summer	Latitude - 19,17
Winter	Latitude + 19,09

CONCLUSION

The solar energy is mostly preferred because of the advantages such as its continuity, its low operating costs, as it has almost no adverse effect on the environment, as these type of plants can be installed in a short time, and because the energy generated, can be stored. Generating energy by the intensive use of renewable energy resources, enables the use of fossil-based power generation in a longer term. While the electric energy is produced by means of solar panels; fixed panels are installed in the manner that would provide inclination angles that change in accordance with the geographical position, in order to benefit from the sunlight at the maximum level. Monthly, seasonal and annual optimum values of this inclination for different cities, were calculated. When these values are analyzed, it can be seen that there is almost 3-fold difference between the sun's angle of incidence in winter and in summer. For instance, while the average panel inclination angle is 19,05 for Malatya province in summer season; its panel inclination angle in winter season, is 57^{o} 29'' degrees. And this proves that, more electricity production will be made in case the optimum panel inclination values changing on a seasonal basis, are used instead of annual average values. At the beginning of each season, while the efficiency of solar production system can be fulfilled by adjusting the panel inclinations manually, the aforementioned inclination angles can also be made by the automation system at the first day of each season.

This paper provides a partial solution to the task of Mash-up development and application by introducing a novel requirements architecture. Usage of this architecture has been made and there is clear evidence of its impact.

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