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Optimum yearly and seasonal tilt angle of solar system in the center of Babylon/Iraq using PVsyst software

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ABSTRACT

The photovoltaic system tilt angle is one of the more significant factors for obtaining the maximum solar energy that will fall on the PV panel. Consequently, then obtain maximum power output, the solar array needs to be angled properly. The analysis for a stand-alone system is simulated and modelled using PVsyst software version-7.2 for system power 3,120 Wp to obtain the optimum value of the tilt angles of maximum solar irradiation in the center of Babylon Governorate, Iraq. The ideal tilt angle for the south has been found for both yearly and the seasons. Different tilt angles were taken which were (29°, 30°, and 31°) annually, azimuth angle for all is (0°). The incident global irradiation in the collector plane, Incident beam irradiation in the collector plane is maximum at tilt angle (29°) that produces maximum available energy 5,132 kWh/kWp/year. same processing for annual different tilt angle was taken for seasonally; the results show that the angle (49°) for summer and (13°) for winter are the optimum tilt angle which obtains the maximum incident global irradiation in the collector plane, maximum incident beam irradiation in the collector plane at this angle then product maximum available energy 5,343 kWh/kWp/year.

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Nomenclatures

GlobHor.	global horizontal irradiation
GlobEff.	effective global irradiation
E_Avail	energy at the output of the array when producing-converter loss+Unused energy
DiffHor.	monthly diffuse horizontal irradiation
GlobInc.	incident global irradiation in the collector plane
θ	incidence angle
$\emptyset$	zenith angle
β	surface tilt angle from the horizontal
Z_s	surface azimuth angle

1. INTRODUCTION

The sun is a globular object made of highly burning gaseous substances with a diameter of 1.39×109 m. In reality, in the sun planet's permanent fusion reactor, hydrogen is converted to helium. The overall sun's energy output is 3.8×10^{20} MW that is tantamount to 63 MW/m^2 of the surface of a sun. This energy spreads outwards in all orientations. Only a small portion, $1.7x10^{14}$ kw of the overall energy radiated, is interrupted by the earth. Despite this tiny portion, it is considered that the amount of solar energy that falls on earth for 30 minutes would be sufficient to provide the global energy needs for a whole year. The tilt of a solar array with respect to the horizontal has a significant impact on its performance [1]. Because of the inclination angle, which is knew as the angle of photovoltaic (PV) arrays with regard to horizontal, is a main factor determining the collected energy of a fixed PV array, it changes the solar energy arriving the surface of the PV array.

Generally, the optimum static PV array tilt angle is associated to the domestic climate state, the period of using geographical latitude. As a result, in various locations for a solar PV array that is used annually, several optimal tilt angles will exist. Up to the present time, there have been several investigations on the best tilt angle for PV arrays [2]–[6], and the literature contains several empirical correlations for determining the ideal tilt-angle [3], [5], [7], [8]. The literature states that the ideal PV array orientation should face south in the northern hemisphere, directly towards the equator, and that the ideal tilt angle solely relies on latitude. Numerous methods to improve the tilt angle have evolved. The best approaches involve increasing solar radiation or energy gathered from the surface, genetic algorithm (GA) technique, the method of an artificial neural network (ANN), the optimal scheme of particle swarm optimization (PSO) technique, and simulated annealing (SA) algorithm. The following formulae compute the ideal tilt angle. Table 1 illustrates chronology of arithmetic equations of an ideal tilt angle with consideration of altitude calculations for numerous researches.

Ideal tilt angle equations with respect to altitude calculations. The summer season is used the minus mark, and the positive mark for the winter time season. The work, moreover, consists of the study and performance of the scheme with tilt and orientation of the PV Panel, which provides better simulation outcomes at related latitudes for any possible sizing.

The rest of this study is organized as surveys: section 2 covers the modelling of the tilted surfaces total radiation and angle at solar midday for the system. In addition, while in section 3 the in this analysis, by using PVsyst 7.2 program a stand-alone system is modelled and simulated, the central goal of this investigation is to limit the optimal tilt angle by maximizing and section 4 controlled to the conclusions and future work of this study.

Table 1. Optimum tilt angle relations in some publications

Optimum tilt angle	[Ref.]	Optimum tilt angle	[Ref.]
$\beta_{opt} = \varphi - \delta$	[9]	$Summer\ ; \beta_{opt} = \varphi - 21^o$; Winter $\varphi + 13^o$	[10]
$\beta_{opt} = \varphi + 17^o$	[11]	$\beta_{opt} = \varphi$	[12]
$\beta_{opt} = 34.783 - 1.4317\delta - 0.0081\delta^2 + 0.0002\delta^2$	[13]	$\beta_{opt} = \varphi - 3.5^o$	[14]
$Yearly\ , \beta_{opt} = \varphi$	[15]	$\beta_{opt} = \varphi \pm 8^o$	[16]
$Yearly\ , \beta_{opt} = \varphi - (17^o \to 12^0)$	[15]	$\beta_{opt} = \varphi \pm 11^o$	[17]
$\beta_{opt} = \varphi - (1^o - 10^o$	[18]	$\beta_{opt} = \varphi \pm 15^o$or $\beta_{opt} = 0.9\ \varphi$	[6]
$\beta_{opt} = 0.917\varphi \pm 0.321$	[19]	$\beta_{opt} = (\varphi \pm 15^o) \pm 15^o$	[20]
$Yearly, \beta_{opt} = \varphi$	[21]	$\beta_{opt} = (\varphi \pm 15^o)$	[22]
$Summer, \beta_{opt} = \varphi - 60$ $Winter\ , \beta_{opt} = \varphi * 90$	[23]	$\beta_{opt} = \varphi + (-10^o \to 15^o)$	[22]
$\beta_{opt} = \varphi - (26^o, 27^o, 28^o)$ Where φ varies from $36^o\ to\ 46^o$	[24]	$\beta_{opt} = \varphi \pm 5^o$	[14]
$Summer\ or\ Winter\ \beta_{opt} = \varphi \pm 15^o$ $March\ and\ Spetemper; \beta_{opt} = \varphi$	[25]	$\beta_{opt} = \varphi + 10^o$	[26]
$Summer\ ; \beta_{opt} = \varphi - 34^o$; Winter $\varphi + 90^o$	[25]	$\beta_{opt} = \varphi + (10^o \to 30^o)$	[27]
$\beta_{opt} = \varphi \pm 15^o$	[28]	$\beta_{opt} = \varphi + 20$	[29]
$\beta_{opt} = (\varphi \pm 15^o) \pm 15^o$	[11]	$\beta_{opt} = \varphi - 10^o$	[30]
$\beta_{opt} = \varphi \pm (4^o \to -10^o)$	[31]	$\beta_{opt} = \varphi + 10^o$	[32]
$\beta_{opt} = \varphi - 3^o$	[33]	$\beta_{opt} = \varphi +20$	[34]

2. METHODS AND MATERIALS

2.1. Solar radiation calculation

The diagram of solar angles as shown in Figure 1 the angle between the vertical to the surface as of correct south, west is designated as positive, the angle between the sun's rays and the normal on a surface is solar incidence angle in a horizontal plane θ, ∅ are same. The angle of incidence can be expressed generally as (1):

$$\cos\theta = \sin L \sin\delta \cos\beta - \cos L \sin\delta \sin\beta \cos Z_s + \cos L \cos\delta \cos h \cos\beta + \sin L \cos\delta \cos h \sin\beta \cos Z_s + cos\ \delta\ sin\ h\ sin\ \beta\ sin\ Z_s \quad (1)$$

for a sloping surface facing south, Zs=0°. In (1) will be decreases to (2).

$$\cos(\theta) = \sin L . \sin \delta . \cos \beta - \cos L . \sin \delta . \sin \beta + \cos L . \cos \delta . \cos h . \cos \beta + \sin L . \cos \delta . \cos h . \sin \beta \quad (2)$$

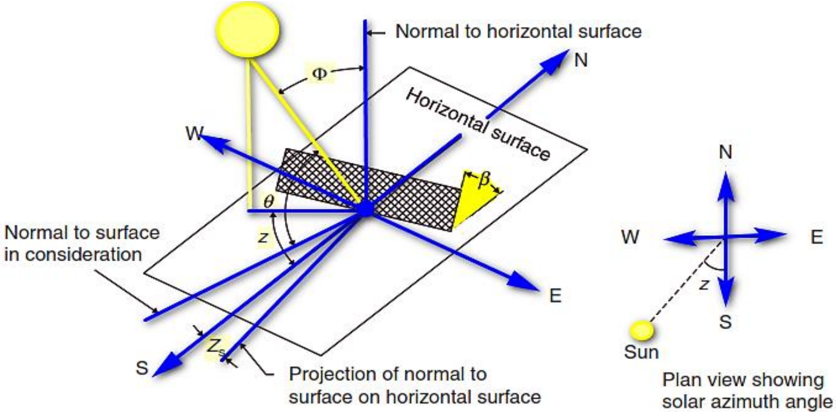

Figure 1. Diagram of solar angles incidence

2.2. Tilted surface's total radiation

Measured or approximated solar radiation data are required to design solar systems; however, these data are typically only available for horizontal or normal incidence surfaces. Consequently, these data must be converted to radiation on slanted surfaces. The orientation and slope of the surface affect the amount of insolation on a terrestrial surface at a specific location for a specific period. Solar radiation (G_t) absorbs the beam at a flat surface (G_{Bt}), diffuse (G_{Dt}), and ground reflected (G_{Gt}) can express [35].

$$G_t = G_{Bt} + G_{Dt} + G_{Gt} \quad (3)$$

The beam radiation acting on a horizontal and tilted surface is depicted in Figure 2. From Figure 2(a) the beam radiation acting on the horizontal surface (G_B) is equal to:

$$G_B = G_{Bn} cos\,(\phi) \quad (4)$$

similarly, from Figure 2(b) can obtaining the beam radiation acting on a tilted surface (G_{Bt}) and equal to:

$$G_{Bt} = G_{Bn} cos\,(\theta) \quad (5)$$

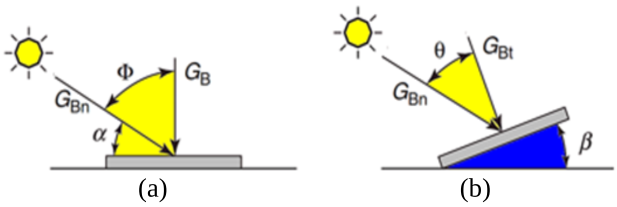

Figure 2. Beam radiation (a) horizontal surfaces and (b) tilted surfaces [35]

the beam radiation tile factor is (6).

$$R_B = \frac{G_{Bt}}{G_B} = \frac{\cos(\theta)}{\cos(\phi)} \quad (6)$$

2.3. The sun's altitude angle at solar midday

East and west are where the sun rises and sets, as everyone is aware, and peaks during the middle of the day. Knowing exactly where the sun will be in the sky at any given moment, in any place, on any given day of the year is important in many situations. With such knowledge, we may, for instance, build an overhang that lets the sun shine through a window during the winter to assist hotness a house while blocking the light during the summer. The choosing the ideal tilt angle for our photovoltaic modules that must consider the most exposure to the sun's rays, we may use our understanding of solar angles. Figure 3 accurately depicts the earth's rotation around the sun; nevertheless, using it to find different sun angles as seen from the surface of the earth is difficult.

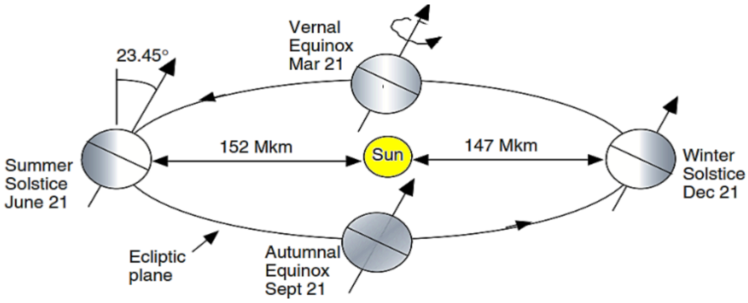

Figure 3. The earth's rotation round the sun which causes our seasons

In Figure 4 depicts a different viewpoint in which the earth is stationary and revolves about its equator while the sun be seated out in galaxy and gently rises and sets as the seasons change. The sun reaches its zenith on June 21 (the time of summer solstice), and a beam traced at that moment from the sun's midpoint to the earth's center produces an angle of 23.45° with the equator. At latitude 23.45° on that day, the sun is directly overhead the Tropic of Cancer. The sun is directly overhead the equator at the two equinoxes. The Tropic of Capricorn is the latitude at which the sun is 23.45° below the equator on December 21. The solar deviation (δ) is the angle produced between the plane of the equator and a route drawn from the sun's center to the earth's center, as shown in Figure 4. It ranges between 23.45° and a straightforward sinusoidal connection that supposes a 365-day year and places the equinox a springing on day n=81 offers an accurate estimate. The American Ephemeris and Nautical Almanac (AENA), a yearly publication, contains exact declination numbers, which change somewhat from year to year [36].

$$\delta = 23.45\ sin\ sin\ \left[\frac{360}{365}(n-81)\right] \quad (7)$$

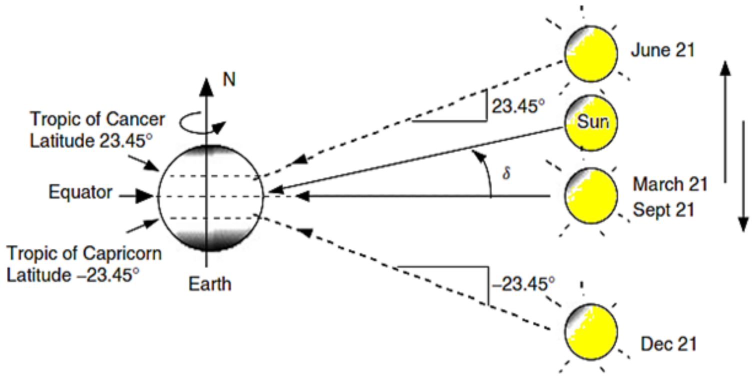

Figure 4. The view when earth fixed and moves of the sun up and down that create solar declination angle δ

The completely competent for depicting different latitudes and sun angles, despite the fact that it does not accurately depict the nuances of the earth's orbit. For instance, it is simple to see how the length of the day varies over the year. The summer solstice brings 24 hours of sunshine to the whole of an earth's surface over an earth latitude "66.55°" (90°-23.45°), however, under latitude in the southern hemisphere of the earth "66.55°" it is perpetually night. This is seen in Figure 5.

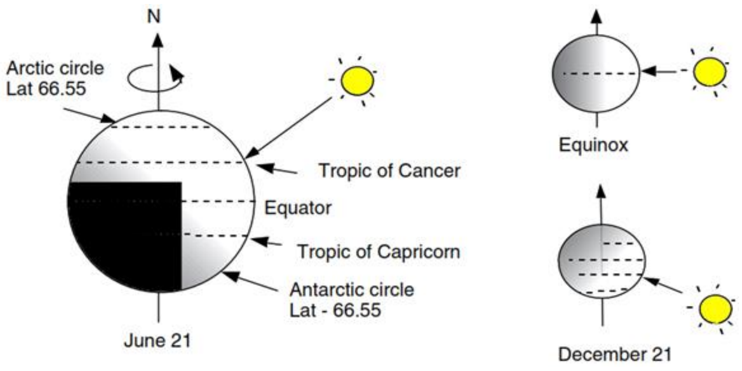

Figure 5. The earth sun system and define the planet's major latitudes

Those latitudes, naturally, match to the Arctic and Antarctic hemispheres. Figure 4 makes it simple to develop some sense of what could be a suitable for a solar tilt angle accumulator. Figure 6 depicts a collector whose are facing south. That is tilted upward at an angle the same to the domestic latitude, L, on the surface of the earth. As is evident, the collector is parallel to the axis of the earth at this tilt angle. At solar noon on an equinox, when the sun is specifically overhead the domestic line of longitude (meridian), the sun's beams will impact the collector at the optimal angle, that is, vertical on a collection surface. The sun appears to be tilted at a good angle on average, but during other periods of the year, it is either too high or too low for normal incidence. Almost all solar measurements need a reference point, which is solar noon. When the sun is directly south of the observer, solar noon occurs in the northern hemisphere at latitudes above the tropic of Cancer. It happens when the sun is directly overhead, for instance, in New Zealand south of the Capricorn tropic. And the solar noon in the tropics, the sun may be above, straight to the north or south, or anywhere in between.

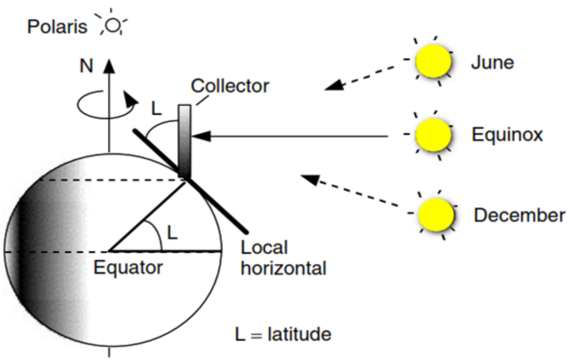

Figure 6. Solar noon occurs on equinoxes when a south-facing collector is perpendicular to the sun's beams and slanted up to an angle equal to its latitude

A decent general rule-of-thumb for yearly performance is to face a collector in the direction of the equator (this implies orienting it south for most northern hemisphere residents) then tilt it at an angle equal to the latitude of the area. Of course, you can desire a slightly higher angle to emphasise winter collecting and vice versa for better efficiency of the summer. It is simple to establish a crucial solar angle, explicitly the altitude angle β_N of the sun at solar noontime, by drawing the earth-sun system as illustrated in Figure 4. The altitude angle is the angle formed by the sun and the horizon in the area directly underneath it. From Figure 7 the resulting equation thorough review:

$$\beta_N = (90^0) - L + \delta \tag{8}$$

where: L is represented the location's latitude. For the figure word zenith is announced, which denotes to an axis depicted straight above at a site [37]. As illustrated in Figure 8, the tilt angle needed for the sun to be vertical on the module at midday is (9).

$$Tilt = 90^0 - \beta_N \tag{9}$$

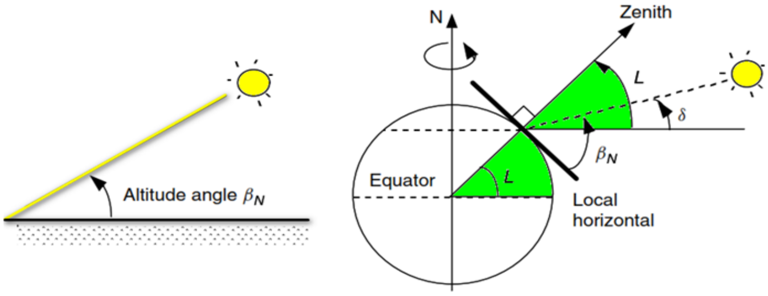

Figure 7. The sun’s angular position at solar noon

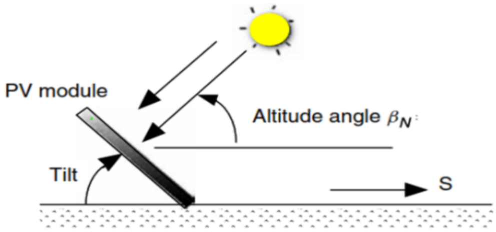

Figure 8. The sun’s beams are perpendicular to the module at noon due to the tilt angle

3. SIMULATION AND ANALYSIS USING PVSYST SOFTWARE

In this analysis, by using PVsyst 7.2 software a stand-alone system is modelled and simulated. The central goal of this investigation is to limit the optimal tilt angle by maximizing the straight solar incident on the collector.

- Location: the center of Babylon Governorate, Iraq. (latitude 32.468191° N, longitude 44.5501935° E, and elevation: (29 m).
- Different tilting angle and azimuth angle as shown in Figure 9.

In order to choose the optimum tilt angle to get maximum solar radiation effected to PV panels than obtain maximum power output. Different tilting angle taken which were (29°, 30°, and 31°) annually and (49°and 13°) tilt angle for winter (W) and summer (S) respectively. The azimuth angle for all is (0°).

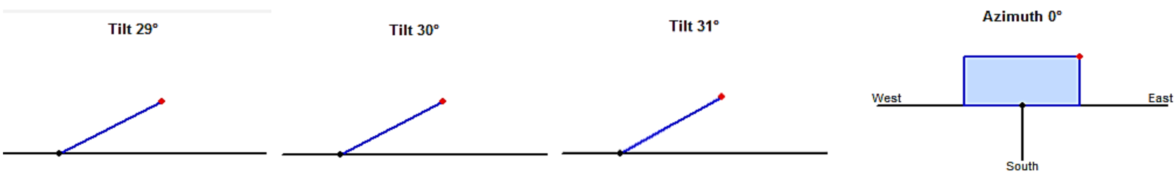

Figure 9. Simulation different tilting angle and azimuth angle

4. RESULTS AND DISCUSSION

The simulation model produced the findings of 3120 Wp, (6 Stringsx2 in series) solar PVsystem is modeled in PVsyst for different tilt angles (29°, 30°, and 31°). Incident global irradiation in the collector plane are (2076.1 kWh/m², 2075.3 kWh/m², and 2074.0 kWh/m²) respectively and according to this tilt angles and it’s irradiation the energy at the output of the array will be (5151.9 kWh, 5150.7 kWh, and 5148.3 kWh) and the virtual available energy at the maximum power point (5335.1 kWh, 5334.2 kWh, and 5332.1 kWh) respectively the other main annual results as shown in Table 2 and Figure 10.

Table 2. The annual main results different tilt angles

Tilt angle degree	GlobEff kWh/m²	GlobInc kWh/m²	BeamInc kWh/m²	E_Avail kWh	EArrMPP kWh	Available energy kWh/year
29°	2022.2	2076.1	1350	5151.9	5335.1	5132
30°	2021.4	2075.3	1348	5150.7	5334.2	5131
31°	2020.1	2074.0	1346	5148.3	5332.1	5128

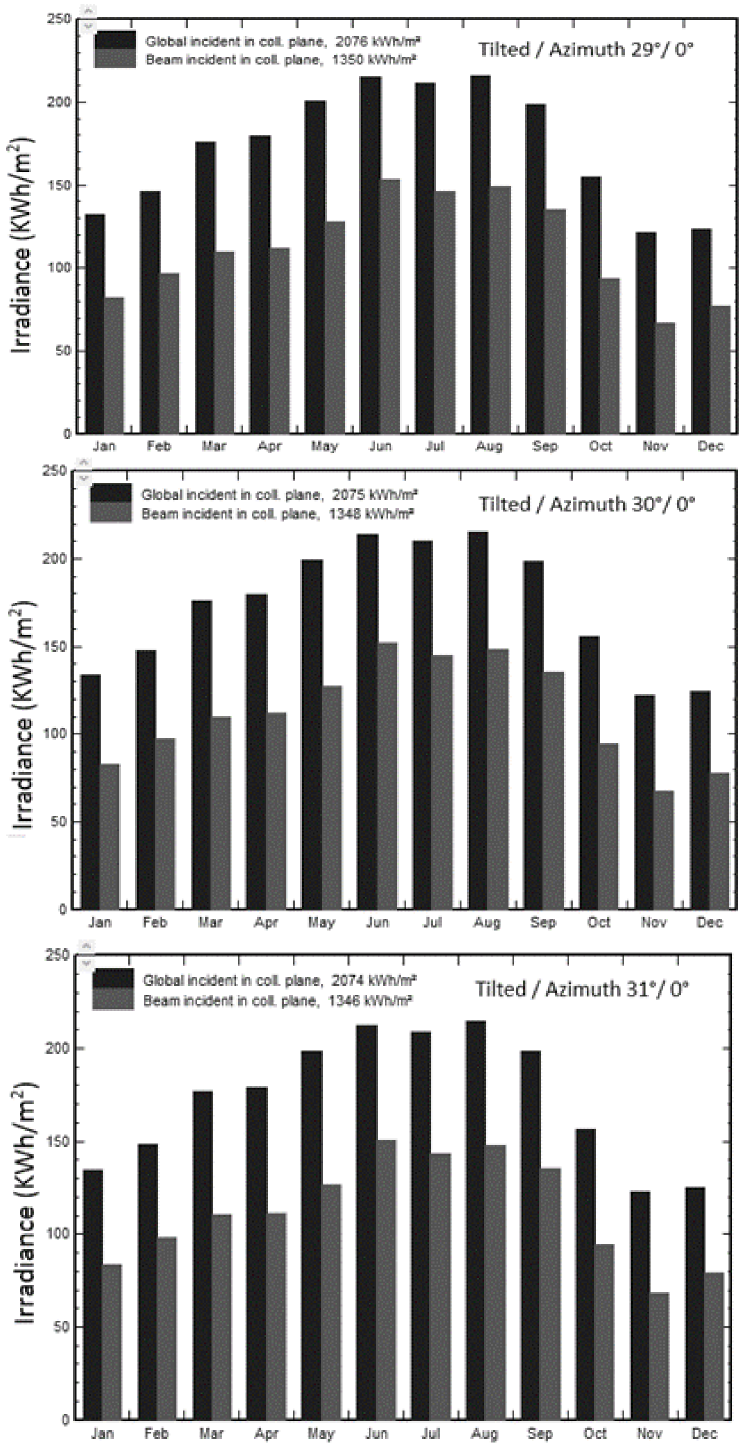

Figure 10. Incident beam and global irradiation in the collector plane for different tilting angle

From PVsyst software the suggested optimum seasonal tilt angle is (50°) for winter and (20°) for summer. As shown in Figure 11. Several tilt angles have been tested to get the maximum solar radiation to PV collector to obtain optimum seasonal tilt angles and then get maximum output energy for the solar system. the seasonal tilt angles are for winter (49°) (Oct.-Nov.-Dec.-Jan.-Feb.-Mar) and (13°) for summer at this angles the incident global irradiation in the collector plane is (2158.9 kWh/m²) and according to this tilt angles and irradiation the energy at the output of the array will be (5342.5 kWh) and the virtual available energy at the maximum power point (5547.0 kWh) as shown in Table 3 and Figure 12 the comparing of main results for choosing the optimum adjustment tilt angles.

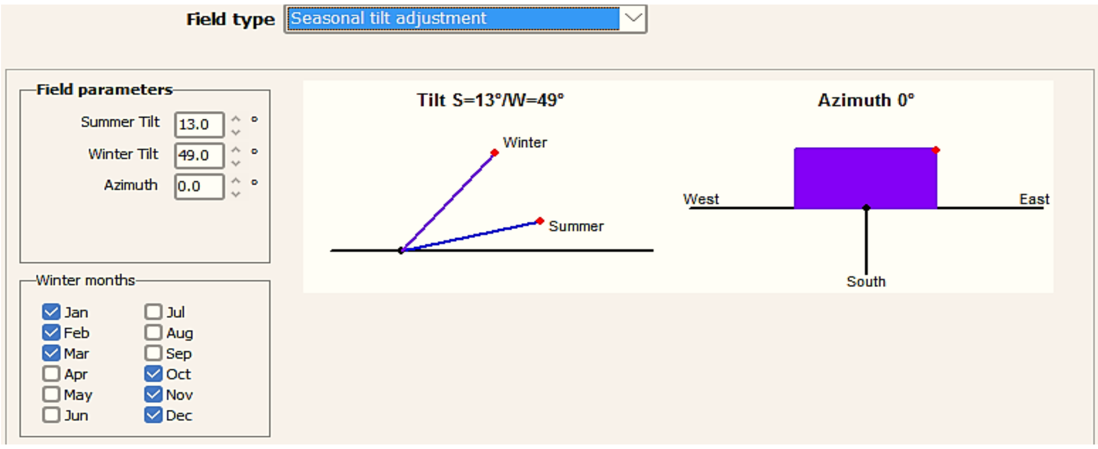

Figure 11. Seasonal tilted adjustment angle

Table 3. The seasonal main results for optimum tilt angle

Tilt angle W	Tilt angle S	GlobEff kWh/m²	GlobInc kWh/m²	E_Avail kWh	EArrMPP kWh	Available energy kWh/year
49º	13º	2109.4	2159	5342.5	5547	5343
50º	20º	2101.8	2150	5341.2	5525	5341

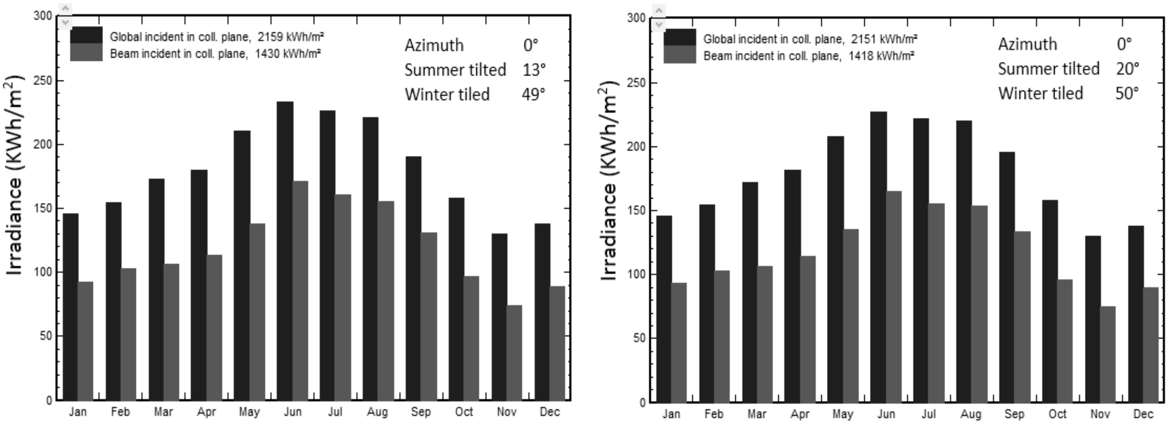

Figure 12. Incident beam and global irradiation in the collector plane for seasonal tilting angle

5. CONCLUSIONS AND FUTURE WORK

In this paper, using different tilt angles to optimize the solar system that increases the amount of incident solar irradiation on the surface of PV panels to get the maximum amount of generated output by the panels, the angles must be appropriately and accurately determined. For fixed tilt, angle the optimum yearly tilt angle is determined by changing the angle from (29°, 30°, and 31°). The PVsyst software gives an optimum yearly tilt angle of (30°) for this location. The study tests one angle before and after (30°). The results found that the maximum incident global irradiation in the collector plane, maximum incident beam irradiation in the collector plane, the maximum specific production energy at the output of the array and the virtual available energy at the maximum power point at a tilt angle (29°). According to the high cost of a tracking system. The seasonal tilted adjustment angle is used to obtain the seasonal tilt angle for winter and summer.

The PVsyst software gives winter tilt angle (50°) and summer tilt (20°); after testing different angles about these angles the simulation was found to get the maximum amount of incident solar irradiation which led to a maximum specific production, energy at the output of the array and the virtual available energy at the maximum power point at tilt angle (49°, 13°) for winter and summer respectively. Also, after comparing the results in this location for yearly and seasonal tilt angle and according to the low cost of tilted adjustment angle (winter and summer) tilt angle the results showed using seasonal tilted adjustment angle is best to get maximum output power.

REFERENCES

[1] A. Manes and A. Ianetz, “On the optimum exposure of flat-plate fixed solar collectors,” *Solar Energy*, vol. 31, no. 1, pp. 21–27, 1983, doi: 10.1016/0038-092X(83)90030-0.

[2] M. A. H. M. Yakup and A. Q. Malik, “Optimum tilt angle and orientation for solar collector in Brunei Durassalam,” *Renewable Energy*, vol. 24, no. 2, pp. 223–234, Oct. 2001, doi: 10.1016/S0960-1481(00)00168-3.

[3] H. P. Garg and A. Meinel, “Treatise on solar energy, volume 1: fundamentals of solar energy,” *Journal of Solar Energy Engineering*, vol. 106, no. 3, pp. 376–377, Aug. 1984, doi: 10.1115/1.3267614.

[4] A. H. Alami *et al.*, “Management of potential challenges of PV technology proliferation,” *Sustainable Energy Technologies and Assessments*, vol. 51, p. 101942, Jun. 2022, doi: 10.1016/j.seta.2021.101942.

[5] M. Tiris and C. Tiris, “Optimum collector slope and model evaluation: case study for Gebze, Turkey,” *Energy Conversion and Management*, vol. 39, no. 3–4, pp. 167–172, Feb. 1998, doi: 10.1016/s0196-8904(96)00229-4.

[6] M. Chinchilla, D. Santos-Martín, M. Carpintero-Rentería, and S. Lemon, “Worldwide annual optimum tilt angle model for solar collectors and photovoltaic systems in the absence of site meteorological data,” *Applied Energy*, vol. 281, p. 116056, Jan. 2021, doi: 10.1016/j.apenergy.2020.116056.

[7] Q. Hassan, M. K. Abbas, A. M. Abdulateef, J. Abulateef, and A. Mohamad, “Assessment the potential solar energy with the models for optimum tilt angles of maximum solar irradiance for Iraq,” *Case Studies in Chemical and Environmental Engineering*, vol. 4, p. 100140, Dec. 2021, doi: 10.1016/j.cscee.2021.100140.

[8] Z. R. Dogaheh and V. Puig, “Tilt angle optimization of photovoltaic panels,” in *2019 6th International Conference on Control, Decision and Information Technologies, CoDIT 2019*, Apr. 2019, pp. 1847–1852, doi: 10.1109/CoDIT.2019.8820549.

[9] A. Grover, A. Khosla, and D. Joshi, “Design and simulation of 20MW photovoltaic power plant using PVsyst,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 19, no. 1, pp. 58–65, Jul. 2020, doi: 10.11591/ijeecs.v19.i1.pp58-65.

[10] C. Stanciu and D. Stanciu, “Optimum tilt angle for flat plate collectors all over the world - a declination dependence formula and comparisons of three solar radiation models,” *Energy Conversion and Management*, vol. 81, pp. 133–143, May 2014, doi: 10.1016/j.enconman.2014.02.016.

[11] A. Shariah, M. A. Al-Akhras, and I. A. Al-Omari, “Optimizing the tilt angle of solar collectors,” *Renewable Energy*, vol. 26, no. 4, pp. 587–598, Aug. 2002, doi: 10.1016/S0960-1481(01)00106-9.

[12] K. K. Gopinathan, “Optimization Of tilt angle of solar collectors for maximum irradiation on sloping surfaces,” *International Journal of Solar Energy*, vol. 10, no. 1–2, pp. 51–61, Apr. 1991, doi: 10.1080/01425919108941451.

[13] K. Bakirci, “General models for optimum tilt angles of solar panels: Turkey case study,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 8, pp. 6149–6159, Oct. 2012, doi: 10.1016/j.rser.2012.07.009.

[14] M. M. El-Kassaby, “Monthly and daily optimum tilt angle for south facing solar collectors; theoretical model, experimental and empirical correlations,” *Solar and Wind Technology*, vol. 5, no. 6, pp. 589–596, Jan. 1988, doi: 10.1016/0741-983X(88)90054-9.

[15] I. H. Rowlands, B. P. Kemery, and I. Beausoleil-Morrison, “Optimal solar-PV tilt angle and azimuth: An Ontario (Canada) case-study,” *Energy Policy*, vol. 39, no. 3, pp. 1397–1409, Mar. 2011, doi: 10.1016/j.enpol.2010.12.012.

[16] K. Phodong, T. Supnithi, and R. Kongkachandra, “Development of computer-based learning system for learning behavior analytics,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 25, no. 1, pp. 460–473, Jan. 2022, doi: 10.11591/ijeecs.v25.i1.pp460-473.

[17] X. Gong and M. Kulkarni, “Design optimization of a large scale rooftop photovoltaic system,” *Solar Energy*, vol. 78, no. 3, pp. 362–374, Mar. 2005, doi: 10.1016/j.solener.2004.08.008.

[18] M. Lave and J. Kleissl, “Optimum fixed orientations and benefits of tracking for capturing solar radiation in the continental United States,” *Renewable Energy*, vol. 36, no. 3, pp. 1145–1152, Mar. 2011, doi: 10.1016/j.renene.2010.07.032.

[19] H. Moghadam, F. F. Tabrizi, and A. Z. Sharak, “Optimization of solar flat collector inclination,” *Desalination*, vol. 265, no. 1–3, pp. 107–111, Jan. 2011, doi: 10.1016/j.desal.2010.07.039.

[20] J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes: Fourth Edition*. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2013.

[21] M. Benghanem, “Optimization of tilt angle for solar panel: case study for Madinah, Saudi Arabia,” *Applied Energy*, vol. 88, no. 4, pp. 1427–1433, Apr. 2011, doi: 10.1016/j.apenergy.2010.10.001.

[22] A. Z. Hafez, A. Soliman, K. A. El-Metwally, and I. M. Ismail, “Tilt and azimuth angles in solar energy applications – A review,” *Renewable and Sustainable Energy Reviews*, vol. 77, pp. 147–168, Sep. 2017, doi: 10.1016/j.rser.2017.03.131.

[23] G. N. Tiwari and M. J. Ahmad, “Optimization of tilt angle for solar collector to receive maximum radiation,” *The Open Renewable Energy Journal*, vol. 2, no. 1, pp. 19–24, Feb. 2009, doi: 10.2174/1876387100902010019.

[24] E. Calabrò, “Determining optimum tilt angles of photovoltaic panels at typical north-tropical latitudes,” *Journal of Renewable and Sustainable Energy*, vol. 1, no. 3, p. 033104, May 2009, doi: 10.1063/1.3148272.

[25] H. Gunerhan and A. Hepbasli, “Determination of the optimum tilt angle of solar collectors for building applications,” *Building and Environment*, vol. 42, no. 2, pp. 779–783, Feb. 2007, doi: 10.1016/j.buildenv.2005.09.012.

[26] J. Kern and I. Harris, “On the optimum tilt of a solar collector,” *Solar Energy*, vol. 17, no. 2, pp. 97–102, May 1975, doi: 10.1016/0038-092X(75)90064-X.

[27] N. S. Kanianthara, S. P. Ang, A. F. K.Sulayman, and Z. Hj. A. Hamid, “Optimising monthly tilt angles of solar panels using particle swarm optimisation algorithm,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 23, no. 1, pp. 75–89, Jul. 2021, doi: 10.11591/ijeecs.v23.i1.pp75-89.

[28] H. K. Elminir, A. E. Ghitas, F. El-Hussainy, R. Hamid, M. M. Beheary, and K. M. Abdel-Moneim, “Optimum solar flat-plate collector slope: case study for Helwan, Egypt,” *Energy Conversion and Management*, vol. 47, no. 5, pp. 624–637, Mar. 2006, doi: 10.1016/j.enconman.2005.05.015.

[29] A. K. Yadav and S. S. Chandel, “Tilt angle optimization to maximize incident solar radiation: a review,” *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 503–513, Jul. 2013, doi: 10.1016/j.rser.2013.02.027.

[30] A. Barbón, C. Bayón-Cueli, L. Bayón, and C. Rodríguez-Suanzes, “Analysis of the tilt and azimuth angles of photovoltaic systems in non-ideal positions for urban applications,” *Applied Energy*, vol. 305, p. 117802, Jan. 2022, doi: 10.1016/j.apenergy.2021.117802.

[31] R. Tang and T. Wu, “Optimal tilt-angles for solar collectors used in China,” *Applied Energy*, vol. 79, no. 3, pp. 239–248, Nov. 2004, doi: 10.1016/j.apenergy.2004.01.003.

[32] H. Abdel-Mawgoud, S. Kamel, S. Q. Salih, and A. S. Alghamdi, "Optimal integration of capacitor and pv in distribution network based on nomadic people optimizer," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 23, no. 3, pp. 1237–1248, Sep. 2021, doi: 10.11591/ijeecs.v23.i3.pp1237-1248.
[33] T. Khatib, A. Mohamed, and K. Sopian, "A review of solar energy modeling techniques," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, pp. 2864–2869, Jun. 2012, doi: 10.1016/j.rser.2012.01.064.
[34] S. Yadav, S. K. Panda, and M. Tripathy, "Performance of building integrated photovoltaic thermal system with PV module installed at optimum tilt angle and influenced by shadow," *Renewable Energy*, vol. 127, pp. 11–23, Nov. 2018, doi: 10.1016/j.renene.2018.04.030.
[35] O. A. Al-Shahri *et al.*, "Solar photovoltaic energy optimization methods, challenges and issues: A comprehensive review," *Journal of Cleaner Production*, vol. 284, p. 125465, Feb. 2021, doi: 10.1016/j.jclepro.2020.125465.
[36] M. Irwanto, "Solar irradiance and optimum tilt angle of photovoltaic module in Tanjung Morawa, North Sumatera, Indonesia," *International Journal of Research in Advanced Engineering and Technology Online*, vol. 1, no. 1, pp. 2455–0876, 2015.
[37] I. R. Alnaab, H. M. Taha, Z. A. Abdulwahab, and M. S. Al-Radhi, "Performance comparison between fixed tilt angle and solar tracking systems at Basra governorate: A case study," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 26, no. 1, pp. 184–193, Apr. 2022, doi: 10.11591/ijeecs.v26.i1.pp184-193.

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