International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Enhancement of the Inclination of Photovoltaic Arrays

A Case Study for Muniguda, Odisha

Kakara Gjnana Teja[1], Karanam Naneswar[2], Dokku Guru Veera Sai Babu[3], Bendi Yamini[4], Suragala Manoj[5], N. R. Krishna[6]

[1,2,3,4,5,6] B. Tech Student, Department of Electrical and Electronics Engineering, GMR Institute of Technology, Vizianagaram District, A.P, India

A B S T R A C T

This paper explains a method for enhancing the inclination angle of solar PV arrays deployed in Muniguda, Odisha. Enhancement of inclination angles approach is based on an isotropic model with varying diffuse radiation coefficients on the inclined surface, which accounts for change in monthly inclination angles. In the northern part of India, a monthly optimum inclination angle change is recommended because of seasonal change. Using the monthly optimum inclination angle on a solar PV panel with different isotropic models will increase yield of collection by 9.09, 9.31, 8.02, and 9.31%, respectively. The optimization results showed that monthly optimal tilt angles with an enhancement of approximately 9% (0.57 kWh/m2/day) for different isotropic models in the site of Muniguda, Rayagada district, Odisha state.

Keywords: Optimization, tilt angle, active sun trackers, solar radiation, isotropic, anisotropic.

1. Introduction

The proportion of solar energy collected by PV panels is determined by solar irradiance, ground reflection characteristics, and solar panel inclination and orientation. In actuality, the quantity of yield obtained is greatly influenced by the orientation and inclination of solar panels. As a result, in order to capture the maximum energy from the sun at a particular site, the panels must be inclined and orientated at an appropriate inclination angle. A solar tracking system is the most reliable approach to enhance the inclination and placement of solar panels. Active sun trackers alter the inclination and position of a solar panel or solar array on a regular basis. which are electromechanical systems. However, such a device is costly to acquire and consumes a lot of energy while tracking. Changing the position of solar panel on monthly, seasonal or annual basis are more suitable than solar tracking systems.

2. Literature survey

In recent years many studies have done to improve orientation and inclination angles of solar panels in different locations. In order to enhance the inclination angles of solar PV panels in Malaysia, T. Khatib et al. [1] employed the Liu and Jordan model for solar energy fall on a slanted surface of the solar panels. The results showed that the PV module/array tilt angles required seasonal adjustment. With the exception of the diffuse solar radiation component on solar panels.

Ridha Ben Mansour et al. [2] observed that the Hay & Davies Klucher Reindle (HDRK) model and isotropic and anisotropic model have comparable mathematical representations of solar radiation. The combined impacts of inclination angle, radiation and ambient temperatures for five sites in Saudi Arabia were used to estimate the monthly and annual optimal tilt angles for the solar PV array system with HDKR model. Using the direct methodology, estimate beam and diffused radiation on inclined surfaces of solar panels to determine the best inclination PV angle.

According to M.A. Danandeh and S.M. Mousavi G. [3,] panels facing south are more prevalent than panels facing north. For several countries in Europe and Africa follows a direct technique is utilised to estimate the appropriate inclination angles and solar irradiation on slanted surfaces. Finally, they concluded that maximum irradiance is accumulated when the solar cells are constantly facing the sun. However, it necessitates the use of an active sun tracker, which is more expensive. As a result, solar PV panels are used in a fixed position while adjusting the tilt angle at specific time periods.

Empirical correlations were suggested by Tarek O. Kaddoura et al. for calculating diffuse radiation on horizontal surfaces [4]. Using anisotropic and isotropic models, the total solar energy accumulated on inclined surfaces facing south was also computed. The inclination angle was changed using MATLAB software to maximise solar energy collected. The sun moves slowly northward during the summer, causing a negative tilt angle and the need for PV panels to face north. The lowest figure of 14.6° was recorded in June. The ideal tilt angle reaches a high of 50.9° and 19.28° is the fixed yearly optimum inclination angle in the winter when the sun travels a shorter southern route.

The study and various methods used by A. Z. Hafez et al. [5] to optimize the inclination angle and examine how different solar radiation components influence design performance. To establish the optimum appropriate inclination angle at the site, the above-mentioned solar radiation components are combined with several models, primarily the isotropic model, which is used to compute the average daily solar radiation on a slanted surface. Based on the results, it has been determined that the photovoltaic system has a high system yield and employs the optimum annual inclination angle, but the other tracking system is not the optimal design due to inadequate maintenance.

Including solar active sun trackers usually result in an energy loss, as Chiemeka Onyeka Okoye et al. [6] shown, making the installed tracking system expensive. A fixed panel's optimum tilt angle changes with latitude and must be established before installation at each site. It was found that the yearly average inclination angles varied not just with tracking orientations but also with different modelling methodologies. The maximum yearly solar energy absorbed by a solar PV panel was calculated.

According to the findings of the K.Y. Lau et al. [7] research, tracking devices allow solar PV arrays to be tilted in response to sunlight. However, tracking device usage frequently exceeds solar PV system installation and maintenance costs, resulting in increased energy consumption during tracking. Furthermore, due to PV installation area constraints, these devices are not always applicable. On the other hand, fixed arrays are less expensive to install, run, and maintain than auto-tracking structure PV arrays, making them ideal for certain users such housing units that may be built into the structure.

Taher Maatallah et al. [8] optimized results show that a complete performance analysis of a solar PV system was evaluated using single and dual-axis tracking of PV panels. These devices are extremely useful for assessing solar PV systems and planning solar PV projects. They carried a case study in Monastir that shows the in the northern latitudes, the southern direction of PV panels is optimal, and that inclined PV panels with latitude angle may be achieved by employing single and dual-axis tracking system. The solar PV panel's annual optimum tilt angle is chosen to face south in Monastir. It is around 0.9 times the location's latitude angle. A fixed panel installed with the yearly optimum tilt angle is expected to have an annual gain of 5.76% lower than a module mounted on a single-axis tracking system.

According to Kadir Bakirci [9], the optimum tilt angle of solar panels installed in different areas across Turkey to maximise energy collection in order to maximize energy collection and to generate broad correlations for calculating the ideal slopes that are accurate and practical to use. In this case study, he found that from June to December, the best tilt angles in Turkey ranged from 0 to 65.

S.S. Chandel and Amit Kumar Yadav [10-15] both looked at total solar radiation values on solar PV panels' horizontal surfaces as well as the angles from which the beam and diffuse radiation components are directed at the surface. Variable cloudiness and air clarity affect how diffuse radiation is dispersed in the atmosphere. In order to calculate the total solar radiation that strikes a slanted surface, the tilt angle is varied from 0^0 to 90^0. [16-23] This will provide researchers and the solar business useful Actually, one should provide an input of global solar radiation on the inclined surface (GSROTS) instead of a horizontal surface because the PV panels are always located with some inclination angle. The GSROTS can be calculated with any one of these scenarios.

i. If, the PV panel's positions are fixed permanently with their location latitude as a inclination angle, then that angle will be an enhancing the inclination angle (β) for the PV panels.

ii. If, the PV panels tilt angle is changing in twice of a year i.e., once in a summer and winter seasons, then PV panels inclination angle (β) will be $\varphi + 15^0$ and $\varphi - 15^0$ for winter and summer seasons respectively.

iii. If, the PV panels tilt angle is changing in each month of a year, then the inclination angles of the PV panels (β) for every month of a year can be obtained.

iv. Finally, the PV panels inclination angle (β) can be change continuously during the day hours is possible by using the solar tracking systems.

3. Angles on the inclined surface

1. Elevation angle (α): It is the angle made the horizon and an object located above it. The elevation angle is measured in degrees and can range from 0° to 90° An elevation angle of 45° indicates that the object is halfway between the horizon and the zenith.

2. Azimuth angle (γ): It is the angle made by the sun's position in the sky and the observers. It is measured in degrees, with positive values indicating an angle east of south and negative values indicating an angle west of south.

3. Declination angle (δ): The declination angle (δ) is an astronomical term that refers to the angular distance between the celestial equator and a celestial object, measured in degrees. It is used to describe the position of the sun, moon, planets, and stars in the sky relative to the Earth's equator [24-31].

4. Incidence angle (θ): It is the angle made by a ray of light or other electromagnetic radiation and a surface it encounters. It is also known as the angle of incidence.

5. Zenith angle: The angle between a vertical line and a celestial object in the sky. It is measured in degrees and represents the height of the object above the observer's horizon.

6. Latitude angle: Latitude angle, also known as solar altitude angle, it is unique for every location, it is depending on the height and latitude.

7. Inclination angle (β): The inclination angle (β) is an important parameter; it is the angle made by the earth surface and solar panel. It is also known as the Inclination angle.

4. Solar radiation

Global solar radiation: It is a simulation of direct, diffuse, and reflect radiations based on the diffuse radiation impacts. The adverse change in global solar radiation has taken place [32-40].

1.Direct radiation: The radiation from the sun (UV rays) directly strikes the earth without being scattered.

2.Diffuse radiation: The radiation from the sun is has been scattered in the atmosphere by clouds, air molecules and strikes the earth and the intensity of radiation is decreased is called diffuse radiation.

3.Reflected radiation: The radiation from the sun is strikes the earth surface and objects and reflected back and fall into the panel surface.

5. Modelling of solar radiation on the inclined surface

The modelling of global radiation on the inclined surface is expressed in equation (5.1):

$$G_{TLT} = B_{TLT} + D_{TLT} + R_{TLT} \tag{5.1}$$

components of solar energy on a horizontal surface rewritten in terms equation (5.2):

$$G_{TLT} = R_B + D \times R_D + G \times \rho \times R_R \tag{5.2}$$

R_B, R_D and R_R are a beam, diffuse and reflected solar radiations conversion factors respectively and ρ is the ground albedo and its value is taken here to be 0.2.

Declination angle: The declination angle (δ) is an astronomical term that refers to the angular distance between the celestial equator and a celestial object, measured in degrees. [41-45] It is used to describe the position of the sun, moon, planets, and stars in the sky relative to the Earth's equator.

$$\delta = 23.45 \times \sin\left[\frac{(284+n)}{365} \times 360\right] \tag{5.3}$$

Sunshine angle:

$$\omega_{ss} = \cos^{-1}(\tan\delta \times (-\tan\varphi)) \tag{5.4}$$

R_b, R_d, R_r are the coefficients of beam, diffuse, reflected solar radiations:

Reflected solar radiation coefficient component on the tilted surface.

$$R_R = \frac{1-\cos\beta}{2} \tag{5.5}$$

The Liu and Jordan model is most commonly used for the calculation of beam solar radiation conversion factor (R_B).

The value of R_B can be calculated for the locations located in both the northern latitudes and southern latitudes is given by the following equations respectively.

$$R_B = \frac{\cos(\varphi-\beta)\times\cos\delta\times\sin\omega_{ss} + \omega_{ss}\times\sin(\varphi-\beta)\times\sin\beta}{\cos\varphi\times\cos\delta\times\sin\omega_{ss} + \omega_{ss}\times\sin\varphi\times\sin\delta} \tag{5.6}$$

Equation (4.6) is proposed for northern hemisphere.

$$R_B = \frac{\cos(\varphi+\beta)\times\cos\delta\times\sin\omega_{ss} + \omega_{ss}\times\sin(\varphi+\beta)\times\sin\beta}{\cos\varphi\times\cos\delta\times\sin\omega_{ss} + \omega_{ss}\times\sin\varphi\times\sin\delta} \tag{5.7}$$

Equation (4.7) is proposed for southern hemisphere.

The diffused solar radiation conversion factor (R_D) can be calculated by using below equations proposed.

$$R_D = \frac{1+\cos\beta}{2} \tag{5.8}$$

Diffuse solar radiation coefficient proposed by Liu and Jordan Model (1962).

$$R_D = \frac{1}{3[2+\cos\beta]} \tag{5.9}$$

Diffuse solar radiation coefficient proposed by Koronakis model (1986).

6. Isotropic and Anisotropic models

Isotropic model:

An isotropic model is a model or system that exhibits the same properties or behaviour in all directions. The term "isotropic" comes from the Greek words "iso," meaning equal, and "tropos," meaning direction. In other words, an isotropic model is one that is symmetric in all directions and has no preferred direction [46-49].

Anisotropic model:

An anisotropic model is a model or system that exhibits different properties or behaviour in different directions. The term "anisotropic" comes from the Greek words "anise," meaning unequal, and "tropos," meaning direction. In other words, an anisotropic model is one that is not symmetric in all directions and has a preferred direction.

7. Enhancement of monthly inclination angle

To enhance the inclination of solar panels monthly, you will need to adjust the angle of the solar panels periodically and other way to choose the inclination angle, by various diffuse radiation coefficients using isotropic models.

(Liu and Jordan Model)

$$G_{TLT} = (G - D) \times \frac{\cos(\varphi - \beta) \times \cos\delta \times \sin\omega_{ss} + \omega_{ss} \times \sin(\varphi - \beta) \times \sin\beta}{\cos\varphi \times \cos\delta \times \sin\omega_{ss} + \omega_{ss} \times \sin\varphi \times \sin\delta} + D \times \frac{1 + \cos\beta}{2} + G \times \rho \times \frac{1 - \cos\beta}{2} \quad (7.1)$$

(Koronakis model)

$$G_{TLT} = (G - D) \times \frac{\cos(\varphi - \beta) \times \cos\delta \times \sin\omega_{ss} + \omega_{ss} \times \sin(\varphi - \beta) \times \sin\beta}{\cos\varphi \times \cos\delta \times \sin\omega_{ss} + \omega_{ss} \times \sin\varphi \times \sin\delta} + D \times \frac{1}{3[2 + cos\,\beta]} + G \times \rho \times \frac{1 - \cos\beta}{2} \quad (7.2)$$

8. Results and discussion

From below the Table 8.1 monthly optimum tilt angles are defined by based on PV panels i.e., global horizontal irradiance, diffuse solar radiation and latitude angle of that place. On an annual average the optimal inclination is about 20.83^0. The yearly average solar energy collection yield on a flat surface is about 5.18 kWhpm^{2}pday, whereas the annual average solar energy collection yield on the inclined surface is approximately 5.76 kWhpm^{2}pday.

The ideal tilt angle in January is 48^0 degrees. On a surface that is inclined, the monthly average solar energy collecting yield is around 6.61 kWhpm^{2}day. The improved yield of collecting is 1.68 kWhpm^{2}pday. A 25% improvement has been made since the beginning of January. The ideal tilt angle for the month of February is 39^0. On a surface that is inclined, the monthly average solar energy collecting yield is around 6.7 kWhpm^{2}pday. On the other hand, on a horizontal surface, it is 5.62 kWhpm^{2}pday. The improved yield of collecting is 1.08 kWhpm^{2}pday. On February, there has been an improvement of 16.1%. The ideal tilt angle in the month of March is 21^0. On a surface that is inclined, the monthly average solar energy collecting yield is around 6.37 kWhpm^{2}day. On the other hand, on a horizontal surface, it is 6.06 kWhpm^{2}pday. Improved yield collection is 0.31 kWhpm^{2}pday. On March, there has been an improvement of 4.87%. The ideal tilt angle in April is 4^0 degrees.

On a surface that is inclined, the monthly average solar energy collecting yield is around 6.43 kWhpm^{2}pday. On the other hand, on a horizontal surface, it is 6.42 kWhpm^{2}pday. Improved yield collection is 0.01 kWhpm^{2}day. Nothing has changed since April in terms of the situation. The ideal tilt in the months of May, June, July, and August is 0^0, which is also the horizontal tilt. Therefore, there has been no progress in the yield's collection in the months of May, June, July, and August. The ideal tilt angle in September is 130 degrees. On a surface that is inclined, the monthly average solar energy collecting yield is around 4.78 kWhpm^{2}pday. On the other hand, on a horizontal surface, it is 4.68 kWhpm^{2}pday. Improved yield collection is 0.01 kWhpm^{2}pday. On September, there has been an improvement of 2.09%. The ideal tilt angle in the month of October is 31^0 degrees. The average daily production from solar energy collecting on a slanted surface is around 5.75 kWhpm^{2}pday.

On the other hand, on a horizontal surface, it is 5.14 kWhpm^{2}pday. The improved yield of collecting is 0.61 kWhpm^{2}pday. On October, there has been an improvement of 10.61%. The ideal tilt angle in the month of November is 44^0. On a surface that is inclined, the monthly average solar energy collecting yield is around 6.23 kWhpm^{2}pday. On the other hand, on a horizontal surface, it is 4.88 kWhpm^{2}pday. The improved yield of collecting is 1.35 kWhpm^{2}pday. On November, there has been an improvement of 21.67%. The ideal tilt angle in December is 50^0 degrees. On a surface that is inclined, the monthly average solar energy collecting yield is around 6.51 kWhpm^{2}pday. On the other hand, on a horizontal surface, it is 4.68 kWhpm^{2}pday. Improved collection of yield is 1.83 kWhpm^{2}day. 28.11% of improvement has taken place on the month of December.

As a result, by using Liu and Jordan model, on an annual average of optimal tilt is 20.83^0. Enhancement of collection of yield by 0.58 kWhpm^{2}pday. Overall annual collection of yield is improved by 9.0%. The graphs plotted in the Figure 8.1. and Figure 8.2 Based on the results obtained from Table 8.1 using Liu and Jordan model.

Table- 8.1: Monthly averaged optimum tilt angle and Comparative analysis of monthly averaged solar energy on both horizontal and tilted surface (kWhpm²pday) using Liu and Jordan model.

Month	Optimum inclination angle in degrees	Monthly Averaged solar energy on a inclined surface (kWhpm²pday)	Monthly Averaged solar energy on horizontal surface (kWhpm²pday)	Improved solar energy (kWhpm²pday)	Percentage improvement (%)
Jan	48^0	6.61	4.93	1.68	25.42
Feb	39^0	6.7	5.62	1.08	16.12
Mar	21^0	6.37	6.06	0.31	4.87
Apr	4^0	6.43	6.42	0.01	0.16
May	0^0	6.44	6.44	0	0
Jun	0^0	5.01	5.01	0	0
Jul	0^0	4.15	4.15	0	0
Aug	0^0	4.12	4.12	0	0
Sept	13^0	4.78	4.68	0.1	2.09
Oct	31^0	5.75	5.14	0.61	10.61
Nov	44^0	6.23	4.88	1.35	21.67
Dec	50^0	6.51	4.68	1.83	28.11
Avg	**20.83^0**	**5.76**	**5.18**	**0.58**	**9.09**

Figure 8.1 Graph on averaged monthly optimum tilt angle on solar panels

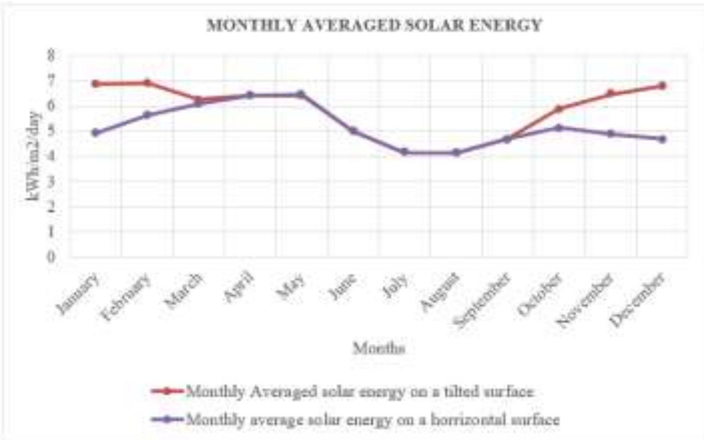
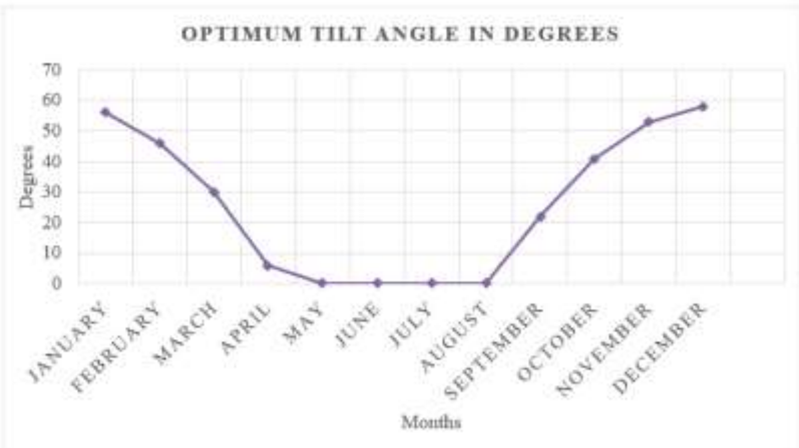


Figure 8.2 Graph on Monthly averaged solar energy on horizontal and tilted surfaces



From the below table 8.2 monthly optimum tilt angles are defined by based on PV panels i.e., global horizontal irradiance, diffuse solar radiation and latitude angle of that place. On a yearly average, the ideal inclination is at 22.5^0 degrees. The yearly average solar energy collection yield on a flat surface is about 5.77 kWhpm^{2}pday, whereas the annual average solar energy collection yield on a slanted surface is around 5.18 kWhpm^{2}pday.

The ideal tilt angle for the month of January is 50^0. On a surface that is inclined, the monthly average solar energy collecting yield is around 6.69 kWhpm^{2}pday. As opposed to 4.93 kWhpm^{2}pday on a horizontal surface. The improved yield of collecting is 1.76 kWhpm^{2}pday. An improvement of 26.30% has been made since January. The ideal tilt angle in February is 41^0 degrees. On a surface that is inclined, the monthly average solar energy collecting yield is around 6.76 kWhpm^{2}pday. On the other hand, on a horizontal surface, it is 5.62 kWhpm^{2}pday. The improved yield of collecting is 1.14 kWhpm^{2}pday. On February, there has been an improvement of 16.83%. The ideal tilt angle in the month of March is 24^0.

On a surface that is inclined, the monthly average solar energy collecting yield is around 6.36 kWhpm^{2}pday. On the other hand, on a horizontal surface, it is 6.06 kWhpm^{2}pday. The improved yield of collecting is 0.30 kWhpm^{2}pday. On March, there has been an improvement of 4.71%. The best tilt angle in April is 40^0 degrees. The output from the slanted surface's monthly average solar energy gathering is around 6.43. kWhpm^{2}pday. However, in a horizontal is 6.42 kWhpm^{2}day. Nothing has changed since April in terms of the situation.

The ideal tilt in the months of May, June, July, and August is 0^0, which is also the horizontal tilt. The tilt corresponds to the location's latitude angle. Therefore, there has been no progress in the yield's collection in the months of May, June, July, and August. The ideal tilt angle in September is 15^0 degrees. On a surface that is inclined, the monthly average solar energy collecting yield is around 4.78 kWhpm^{2}pday. In contrast, the horizontal surface uses 4.68 kWh/m2 per day. The improved yield of collecting is 0.10 kWhpm^{2}pday. On September, there has been an improvement of 2.09%. The ideal tilt angle in the month of October is 33^0 degrees. 5.79 kWh/m2/day of solar energy is collected on the slanted surface on a monthly average. while 5.14 kWhpm^{2}pday on a horizontal surface. The improved yield of collecting is 0.64 kWhpm^{2}pday. On October, there has been an improvement of 11.05%. The ideal inclination angle in the month of November is 47^0.

On a surface that is inclined, the monthly average solar energy collecting yield is around 6.31 kWhpm^{2}pday. In contrast, the horizontal surface uses 4.88 kWh/m2 per day. The improved yield of collecting is 1.43 kWhpm^{2}pday. On November, there has been an improvement of 22.66%. The ideal tilt angle in December is 530 degrees. On a surface that is inclined, the monthly average solar energy collecting yield is around 6.51 kWhpm^{2}pday. In contrast, the horizontal surface uses 4.68 kWh/m2 per day. The improved yield of collecting is 1.83 kWhpm^{2}pday. On December, there has been an improvement of 28.11 percent. As a consequence, the ideal tilt according to the Liu and Jordan model is 22.25^0 on an annual average. The rise in yield of 0.6 kWhpm^{2}pday for collecting.

The annual collecting yield as a whole has increased by 9.31%. based on the outcomes of the Koronakis model as shown in Table 8.2. The graphs in Figures 8.3 and 8.4 were plotted based on the outcomes of the Koronakis model as shown in Table 8.2.

Table- 8.2: Monthly averaged optimum tilt angle and

Month	Optimum inclination angle in degrees	Monthly Averaged solar energy on a inclined surface (kWhpm^{2}pday)	Monthly Averaged solar energy on horizontal surface (kWhpm^{2}pday)	Improved solar energy (kWhpm^{2}pday)	Percentage improvement (%)
Jan	50^0	6.69	4.93	1.76	26.30
Feb	41^0	6.76	5.62	1.14	16.83
Mar	24^0	6.36	6.06	0.30	4.71
Apr	4^0	6.42	6.42	0	0
May	0^0	6.44	6.44	0	0
Jun	0^0	5.01	5.01	0	0
Jul	0^0	4.15	4.15	0	0
Aug	0^0	4.12	4.12	0	0
Sept	15^0	4.78	4.68	0.10	2.09
Oct	33^0	5.79	5.14	0.64	11.05
Nov	47^0	6.31	4.88	1.43	22.66
Dec	53^0	6.51	4.68	1.83	28.11
Avg	**22.25^0**	**5.77**	**5.18**	**0.6**	**9.31**

Comparative analysis of monthly averaged solar energy on both horizontal and tilted surface (kWhpm^{2}pday) using Koronakis model.

Figure 8.3 Graph on averaged monthly optimum tilt angle on solar panels

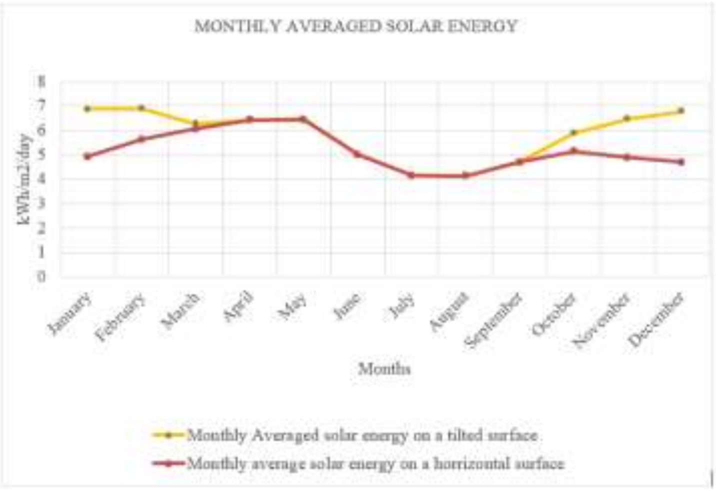


Figure 8.2 Graph on Monthly averaged solar energy on horizontal and tilted surfaces

9. Conclusion

From the case study, a comparative analysis has done for the monthly optimal tilt angles with an enhancement of approximately 9% (0.57 kWhpm^{2}pday) for different isotropic models in the site of Muniguda, Rayagada district, Odisha state.

References

[1] T. Khatib, A. Mohamed, M. Mahmoud, and K. Sopian, "Optimization of the tilt angle of solar panels for Malaysia," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, vol. 37, no. 6, pp. 606–613, Mar. 2015, doi: 10.1080/15567036.2011.588680.

[2] R. Ben Mansour, M. A. Mateen Khan, F. A. Alsulaiman, and R. Ben Mansour, "Optimizing the Solar PV Tilt Angle to Maximize the Power Output: A Case Study for Saudi Arabia," *IEEE Access*, vol. 9, pp. 15914–15928, 2021, doi: 10.1109/ACCESS.2021.3052933.

[3] M. A. Danandeh and S. M. Mousavi G., "Solar irradiance estimation models and optimum tilt angle approaches: A comparative study," *Renewable and Sustainable Energy Reviews*, vol. 92. Elsevier Ltd, pp. 319–330, Sep. 01, 2018. doi: 10.1016/j.rser.2018.05.004.

[4] T. O. Kaddoura, M. A. M. Ramli, and Y. A. Al-Turki, "On the estimation of the optimum tilt angle of PV panel in Saudi Arabia," *Renewable and Sustainable Energy Reviews*, vol. 65. Elsevier Ltd, pp. 626–634, Nov. 01, 2016. doi: 10.1016/j.rser.2016.07.032.

[5] 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. Elsevier Ltd, pp. 147–168, 2017. doi: 10.1016/j.rser.2017.03.131.

[6] C. O. Okoye, A. Bahrami, and U. Atikol, "Evaluating the solar resource potential on different tracking surfaces in Nigeria," *Renewable and Sustainable Energy Reviews*, vol. 81. Elsevier Ltd, pp. 1569–1581, Jan. 01, 2018. doi: 10.1016/j.rser.2017.05.235.

[7] K. Y. Lau, C. W. Tan, and A. H. M. Yatim, "Effects of ambient temperatures, tilt angles, and orientations on hybrid photovoltaic/diesel systems under equatorial climates," *Renewable and Sustainable Energy Reviews*, vol. 81. Elsevier Ltd, pp. 2625–2636, Jan. 01, 2018. doi: 10.1016/j.rser.2017.06.068.

[8] T. Maatallah, S. El Alimi, and S. Ben Nassrallah, "Performance modeling and investigation of fixed, single and dual-axis tracking photovoltaic panel in Monastir city, Tunisia," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 8. Elsevier Ltd, pp. 4053–4066, 2011. doi: 10.1016/j.rser.2011.07.037.

[9] 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.

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

[11] Kumar, V. S., Thiyagaraj, B., Kumar, P. P., Elangovan, D., & Saravanakumar, R. Design and Simulation of CSI FED Snubberless Half Bridge Isolated Front End DC-DC Converter for Solar Renewable Energy Application. *International Journal of Applied Engineering Research*, *8*(19), 2013.

[12] Kumar, P. U., Ramana, P., & Nuvvula, R. S. (2022). Prospective Assessment of Renewable Energy Generation using Machine Learning Algorithms. *Journal of Optoelectronics Laser*, *41*(7), 568-573.

[13] Krishna, N. R., & Elangovan, D. T. (2020). A Review on The Emerging Solar Technologies and Comparison in Solar Rooftop And Floating Technologies. *Solid State Technology*, *63*(6), 10281-10288.

[14] R. S. S. Nuvvula, E. Devaraj, R. Madurai Elavarasan, S. Iman Taheri, M. Irfan, and K. S. Teegala, "Multi- objective mutation-enabled adaptive local attractor quantum behaved particle swarm optimisation based optimal sizing of hybrid renewable energy system for smart cities in India," *Sustainable Energy Technologies and Assessments*, vol. 49, p. 101689, Feb. 2022, doi: 10.1016/J.SETA.2021.101689.

[15] T. Salameh *et al.*, "Best battery storage technologies of solar photovoltaic systems for desalination plant using the results of multi optimization algorithms and sustainable development goals," *J Energy Storage*, vol. 55, p. 105312, Nov. 2022, doi: 10.1016/J.EST.2022.105312.

[16] K. N. Shukla, S. Rangnekar, and K. Sudhakar, "Comparative study of isotropic and anisotropic sky models to estimate solar radiation incident on tilted surface: A case study for Bhopal, India," *Energy Reports*, vol. 1, pp. 96–103, Nov. 2015, doi: 10.1016/j.egyr.2015.03.003.

[17] P. P. Kumar and R. P. Saini, "Optimization of an off-grid integrated hybrid renewable energy system with different battery technologies for rural electrification in India," *J Energy Storage*, vol. 32, Dec. 2020, doi: 10.1016/j.est.2020.101912.

[18] P. P Kumar and R. P. Saini, "Optimization of an off-grid integrated hybrid renewable energy system with various energy storage technologies using different dispatch strategies," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 2020, doi: 10.1080/15567036.2020.1824035.

[19] P. Cholamuthu *et al.*, "A Grid-Connected Solar PV/Wind Turbine Based Hybrid Energy System Using ANFIS Controller for Hybrid Series Active Power Filter to Improve the Power Quality," *International Transactions on Electrical Energy Systems*, vol. 2022, 2022, doi: 10.1155/2022/9374638.

[20] R. S. S. Nuvvula, E. Devaraj, R. Madurai Elavarasan, S. Iman Taheri, M. Irfan, and K. S. Teegala, "Multi-objective mutation-enabled adaptive local attractor quantum behaved particle swarm optimisation based optimal sizing of hybrid renewable energy system for smart cities in India," *Sustainable Energy Technologies and Assessments*, vol. 49, p. 101689, Feb. 2022, doi: 10.1016/J.SETA.2021.101689.

[21] P. P. Kumar *et al.*, "Optimal Operation of an Integrated Hybrid Renewable Energy System with Demand-Side Management in a Rural Context," *Energies (Basel)*, vol. 15, no. 14, Jul. 2022, doi: 10.3390/en15145176.

[22] SCAD Institute of Technology and Institute of Electrical and Electronics Engineers, *Proceedings of the International Conference on Intelligent Sustainable Systems (ICISS 2017) : 7-8, December 2017*.

[23] P. P. Kumar *et al.*, "Optimal Operation of an Integrated Hybrid Renewable Energy System with Demand-Side Management in a Rural Context," *Energies (Basel)*, vol. 15, no. 14, Jul. 2022, doi: 10.3390/en15145176.

[24] R. Nuvvula, E. Devaraj, and K. T. Srinivasa, "A Comprehensive Assessment of Large-scale Battery Integrated Hybrid Renewable Energy System to Improve Sustainability of a Smart City," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 2021, doi: 10.1080/15567036.2021.1905109.

[25] T. Salameh, P. P. Kumar, E. T. Sayed, M. A. Abdelkareem, H. Rezk, and A. G. Olabi, "Fuzzy modeling and particle swarm optimization of Al2O3/SiO2 nanofluid," *International Journal of Thermofluids*, vol. 10, p. 100084, May 2021, doi: 10.1016/J.IJFT.2021.100084.

[26] Ayyarao, T. S., & RamaKrishna, N. S. S. (2022). Rajvikram Madurai Elavarasan, Nishanth Polumahanthi, M. *Rambabu, Gaurav Saini, Baseem Khan, and Bilal Alatas." War strategy optimization algorithm: a new effective metaheuristic algorithm for global optimization." IEEE Access*, *10*, 25073-25105.

[27] Nuvvula, R. S., & Devaraj, E. (2022). Rajvikram Madurai Elavarasan. *Seyed Iman Taheri, Muhammad Irfan, Kishore Srinivasa Teegala, Multi-objective mutation-enabled adaptive local attractor quantum behaved particle swarm optimisation based optimal sizing of hybrid renewable energy system for smart cities in India, Sustainable Energy Technologies and Assessments*, *49*, 101689

[28] N. S. S. R. Krishna, Elangovan, T. S. Kishore and G. Sowgandhika, "A review on technical-economic aspects of grid connected hybrid renewable energy power system," *2017 International Conference on Intelligent Sustainable Systems (ICISS)*, Palladam, India, 2017, pp. 355-360, doi: 10.1109/ISS1.2017.8389429.

[29] Kumar, P. U., Ramana, P., & Nuvvula, R. S. (2022). Prospective Assessment of Renewable Energy Generation using Machine Learning Algorithms. *Journal of Optoelectronics Laser*, *41*(7), 568-573

[30] M. Krishnamoorthy, M. Asif, P. P. Kumar, R. S. S. Nuvvula, B. Khan, and I. Colak, "A Design and Development of the Smart Forest Alert Monitoring System Using IoT," *J Sens*, vol. 2023, 2023, doi: 10.1155/2023/8063524.

[31] R. Muppidi, R. S. S. Nuvvula, S. M. Muyeen, S. K. A. Shezan, and M. F. Ishraque, "Optimization of a Fuel Cost and Enrichment of Line Loadability for a Transmission System by Using Rapid Voltage Stability Index and Grey Wolf Algorithm Technique," *Sustainability (Switzerland)*, vol. 14, no. 7, Apr. 2022, doi: 10.3390/su14074347.

[32] R. Raghutu, M. Sankaraiah, R. S. S. Nuvvula, and M. Venkatesh, "Dispatchable and Non-dispatchable Distributed Generation Reactive Power Coordination with Reactive Power-controlled Devices using Grey Wolf Optimizer," in *11th IEEE International Conference on Renewable Energy Research and Applications, ICRERA 2022*, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 33–41. doi: 10.1109/ICRERA55966.2022.9922857.

[33] T. S. L. V. Ayyarao *et al.*, "War Strategy Optimization Algorithm: A New Effective Metaheuristic Algorithm for Global Optimization," *IEEE Access*, vol. 10, pp. 25073–25105, 2022, doi: 10.1109/ACCESS.2022.3153493.

[34] T. S. L. V. Ayyarao and P. P. Kumar, "Parameter estimation of solar PV models with a new proposed war strategy optimization algorithm," *Int J Energy Res*, vol. 46, no. 6, pp. 7215–7238, May 2022, doi: 10.1002/er.7629.

[35] R. S. S. Nuvvula, E. Devaraj, and S. K. Teegala, "A hybrid multiobjective optimization technique for optimal sizing of BESS-WtE supported multi-MW HRES to overcome ramp rate limitations on thermal stations," *International Transactions on Electrical Energy Systems*, vol. 31, no. 12, Dec. 2021, doi: 10.1002/2050-7038.13241.

[36] M. Rambabu, N. S. S. Ramakrishna, and P. Kumar Polamarasetty, "Prediction and Analysis of Household Energy Consumption by Machine Learning Algorithms in Energy Management," in *E3S Web of Conferences*, EDP Sciences, May 2022. doi: 10.1051/e3sconf/202235002002.

[37] P. P. Kumar, V. Suresh, M. Jasinski, and Z. Leonowicz, "Off-grid rural electrification in india using renewable energy resources and different battery technologies with a dynamic differential annealed optimization," *Energies (Basel)*, vol. 14, no. 18, Sep. 2021, doi: 10.3390/en14185866.

[38] R. Nuvvula, E. Devaraj, and K. T. Srinivasa, "A Comprehensive Assessment of Large-scale Battery Integrated Hybrid Renewable Energy System to Improve Sustainability of a Smart City," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 2021, doi: 10.1080/15567036.2021.1905109.

[39] R. S. S. Nuvvula, D. Elangovan, K. S. Teegala, R. M. Elavarasan, M. R. Islam, and R. Inapakurthi, "Optimal sizing of battery-integrated hybrid renewable energy sources with ramp rate limitations on a grid using ala-qpso," *Energies (Basel)*, vol. 14, no. 17, Sep. 2021, doi: 10.3390/en14175368.

[40] G. S. Bharathi N and S. S. Ramakrishna, "PERFORMANCE ANALYSIS OF GRID CONNECTED HYBRID SYSTEM WITH PQ CONTROL TECHNIQUE WITH DIFFERENT PI VALUES AND HARMONIC EFFECT ON THE SYSTEM," 2017. [Online]. Available: http://www.ripublication.com385

[41] P. P. Kumar, R. S. S. Nuvvula, and V. Manoj, "Grass Hopper Optimization Algorithm for Off-Grid Rural Electrification of an Integrated Renewable Energy System," in *E3S Web of Conferences*, EDP Sciences, May 2022. doi: 10.1051/e3sconf/202235002008.

[42] M. Krishnamoorthy, M. Asif, P. P. Kumar, R. S. S. Nuvvula, B. Khan, and I. Colak, "A Design and Development of the Smart Forest Alert Monitoring System Using IoT," *J Sens*, vol. 2023, 2023, doi: 10.1155/2023/8063524.

[43] N. S. S. Rama Krishna, D. Elangovan, and R. Banisetti, "A REVIEW ON POWER MANAGEMENT TECHNIQUE HYBRID MICRO-GRID SYSTEMS." [Online]. Available: www.tjprc.org

[44] P. Raghavendra, R. S. S. Nuvvula, P. P. Kumar, D. N. Gaonkar, A. Sathoshakumar, and B. Khan, "Voltage Profile Analysis in Smart Grids Using Online Estimation Algorithm," *Journal of Electrical and Computer Engineering*, vol. 2022, 2022, doi: 10.1155/2022/9921724.

[45] S. K. Ramu *et al.*, "A Novel High-Efficiency Multiple Output Single Input Step-Up Converter with Integration of Luo Network for Electric Vehicle Applications," *International Transactions on Electrical Energy Systems*, vol. 2022, 2022, doi: 10.1155/2022/2880240.

[46] Nuvvula, R.S.S.; Elangovan, D.; Teegala, K.S.; Madurai Elavarasan, R.; Islam, M.R.; Inapakurthi, R. Optimal Sizing of Battery-Integrated Hybrid Renewable Energy Sources with Ramp Rate Limitations on a Grid Using ALA-QPSO. *Energies* **2021**, *14*, 5368. https://doi.org/10.3390/en14175368

[47] Krshna, Rama. (2018). Techno Economic Based Approach of Reduction of Grid Dependency Using Renewable Energy System for a SMART City of India. Journal of Advanced Research in Dynamical and Control Systems. 10. 2214-2227.

[48] Ravikumar, N.V.A., Manoj, V., Ramakrishna, N.S.S. (2022). A Linear Quadratic Integral Regulator for a Variable Speed Wind Turbine. In: Panda, G., Naayagi, R.T., Mishra, S. (eds) Sustainable Energy and Technological Advancements. Advances in Sustainability Science and Technology. Springer, Singapore. https://doi.org/10.1007/978-981-16-9033-4_24

[49] Ramakrishna, N.S.S., Ayyarao, T.S.L.V., Manoj, V., Dinesh, L. (2022). Model Predictive Control for Load Frequency Regulation in Power Systems Using a Disturbance Observer. In: Panda, G., Naayagi, R.T., Mishra, S. (eds) Sustainable Energy and Technological Advancements. Advances in Sustainability Science and Technology. Springer, Singapore. https://doi.org/10.1007/978-981-16-9033-4_38

[51]. Manoj, V., Sravani, V., Swathi, A. 2020. A multi criteria decision making approach for the selection of optimum location for wind power project in India. EAI Endorsed Transactions on Energy Web, 8(32), e4

[52]. J. T. Bialasiewicz, “Renewable energy systems with photovoltaic power generators: Operation and modeling,” IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2752–2758, Jul. 2008

[53]. MNRE (Ministry of New and Renewable Energy), Grid Connected Power/Solar. 2018.

[54]. S. Kouro, J. I. Leon, D. Vinnikov, and L. G. Franquelo, “Grid-connected photovoltaic systems: An overview of recent research and emerging PV converter technology,” IEEE Ind. Electron. Mag., vol. 9, no. 1, pp. 47–61, Mar. 2015.

[55]. Dinesh, L., Sesham, H., & Manoj, V. (2012, December). Simulation of D-Statcom with hysteresis current controller for harmonic reduction. In 2012 International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM) (pp. 104-108). IEEE

[56]. Manoj, V. (2016). Sensorless Control of Induction Motor Based on Model Reference Adaptive System (MRAS). International Journal For Research In Electronics & Electrical Engineering, 2(5), 01-06.

[57]. V. B. Venkateswaran and V. Manoj, "State estimation of power system containing FACTS Controller and PMU," 2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO), 2015, pp. 1-6, doi: 10.1109/ISCO.2015.7282281

[58]. Manohar, K., Durga, B., Manoj, V., & Chaitanya, D. K. (2011). Design Of Fuzzy Logic Controller In DC Link To Reduce Switching Losses In VSC Using MATLAB-SIMULINK. Journal Of Research in Recent Trends.

[59]. Manoj, V., Manohar, K., & Prasad, B. D. (2012). Reduction of switching losses in VSC using DC link fuzzy logic controller Innovative Systems Design and Engineering ISSN, 2222-1727

[60]. Dinesh, L., Harish, S., & Manoj, V. (2015). Simulation of UPQC-IG with adaptive neuro fuzzy controller (ANFIS) for power quality improvement. Int J Electr Eng, 10, 249-268

[61]. Manoj, V., Swathi, A., & Rao, V. T. (2021). A PROMETHEE based multi criteria decision making analysis for selection of optimum site location for wind energy project. In IOP Conference Series: Materials Science and Engineering (Vol. 1033, No. 1, p. 012035). IOP Publishing.

[62]. Kiran, V. R., Manoj, V., & Kumar, P. P. (2013). Genetic Algorithm approach to find excitation capacitances for 3-phase smseig operating single phase loads. Caribbean Journal of Sciences and Technology (CJST), 1(1), 105-115.

[63]. Manoj, V., Manohar, K., & Prasad, B. D. (2012). Reduction of Switching Losses in VSC Using DC Link Fuzzy Logic Controller. Innovative Systems Design and Engineering ISSN, 2222-1727.

[64]. Manoj, V., Krishna, K. S. M., & Kiran, M. S. Photovoltaic system based grid interfacing inverter functioning as a conventional inverter and active power filter.

[65]. Vasupalli Manoj, Dr. Prabodh Khampariya and Dr. Ramana Pilla (2022), Performance Evaluation of Fuzzy One Cycle Control Based Custom Power Device for Harmonic Mitigation. IJEER 10(3), 765-771. DOI: 10.37391/IJEER.100358.

[66]. Manoj, V., Khampariya, P., & Pilla, R. (2022). A review on techniques for improving power quality: research gaps and emerging trends. Bulletin of Electrical Engineering and Informatics, 11(6), 3099-3107.

[67]. Manoj, V., Krishna, K. S. M., & Kiran, M. S. Photovoltaic system based grid interfacing inverter functioning as a conventional inverter and active power filter.