



Development of model for monthly optimal tilt angle for Solar power system in Imo State using the tilt angle and the global solar radiation on the tilted plane

¹Ezeh, Ikechukwu H., ²Ezenugu, Isaac A.

Department of Electrical/Electronic Engineering, Imo State University, Owerri, NIGERIA.

Corresponding Author: Ezenugu, Isaac A.

Abstract: In this paper, the optimal tilt angle for each month in a year was determined for a location in Imo state based on the global solar radiation on the tilted plane. PVSyst software was used to download the solar radiation data for the site from NASA portal. Also, the PVSyst software was used to transpose the solar radiation from the horizontal plane to the tilted plane. Quadratic regression models were developed to determine the optimal tilt angle for some of the months that have increase in solar radiation capture due to transposition on a tilted plane. The results showed that the months of April to September require no tilted plane, as such their tilt angle is 0° whereas the rest of the months has their different optimal tilt angles. The month of December has an optimal tilt angle of 36.2° . The gains in using monthly optimal tilt angle over the yearly fixed optimal tilt angle of 8° for the study site were demonstrated. There is about 5% annual gain in solar radiation capture when the monthly optimal tilt angles were used whereas there was only 1% annual gain in solar radiation capture when the yearly fixed optimal tilt angle of 8° is used. Also, for the month of December, at the 8° tilt angle only 7.3 % gain can be realized whereas up to 18.8 % will be realized by tilting the plane at the December optimal tilt angle of 36.2° . In all, the study has demonstrated the needed for monthly adjustment in the tilt angle of the solar panels used in a solar power system,

Keywords: Solar Power, Tilt Angle, Optimal Tilt, Incident Plane, Global Radiation, Yearly-Fixed Tilt

I. Introduction

As the quest for greater adoption of green energy increases, the need for optimal utilization of the available solar resource becomes more prominent [1,2,3,4,5,6,7,8,9]. This is particularly important given that presently, the solar technology is still evolving, the efficiency of the various solar technologies are still low and the unit cost of solar power is high compared to the grid [10,11,12,13,14,15,16]. One way of improving on the efficiency of the solar power system is by ensuring optimal tilting of the solar panel to ensure optimal solar radiation captured by the panels [17,18,19,20].

Over the years, sun tracking technologies have been used to track the sun and position the solar panels for optimal solar radiation capture [21, 22]. However, the sun tracking mechanism attracts additional cost and adds to the complexity of the system. In any case, with minimal effort and additional infrastructure, it is possible to design a solar system that can be manually adjusted once a month. In view of this, this paper is focused on developing the monthly optimal tilt angle for such manually adjusted solar panels. The study is based on the global solar radiation incident on the tilted plane at various tilt angles.

Furthermore, the potential gains achievable by using the monthly optimal tilt angle are demonstrated by comparing the transposition factor of the yearly fixed tilted plane with the monthly adjusted tilted plane. The requisite procedures and analytical expressions are used to achieve the set objective of the paper are presented.

II. Methodology

A. Data collection for the global solar radiation on the tilted plane

The study site is located in Owerri, Imo state with 5.51 latitude and 7.04 longitude. The global solar radiation on the horizontal plane was downloaded from the NASA portal [23] directly into PVSyst software [24]. Then, by using Perez physical transposition model in the PVSyst, the software was used to determine the global solar radiation incident on an inclined plane. First, the inclined plane was set at 5° and the tilt angle was increased in the step of 5° each time till tilt angle of 50° . At each tilt angle, the global radiation on the inclined plane was captured. Based on the values of the global solar radiation on the tilted plane for the various months, the dataset was divided into two sets, the first dataset (Figure 1) is for those months (April to September) which do not have any increase in global solar radiation by using tilted plane; the second dataset (Figure 2) is for those months

(January to March and October to December) that showed significant increase in global solar radiation by using tilted plane.

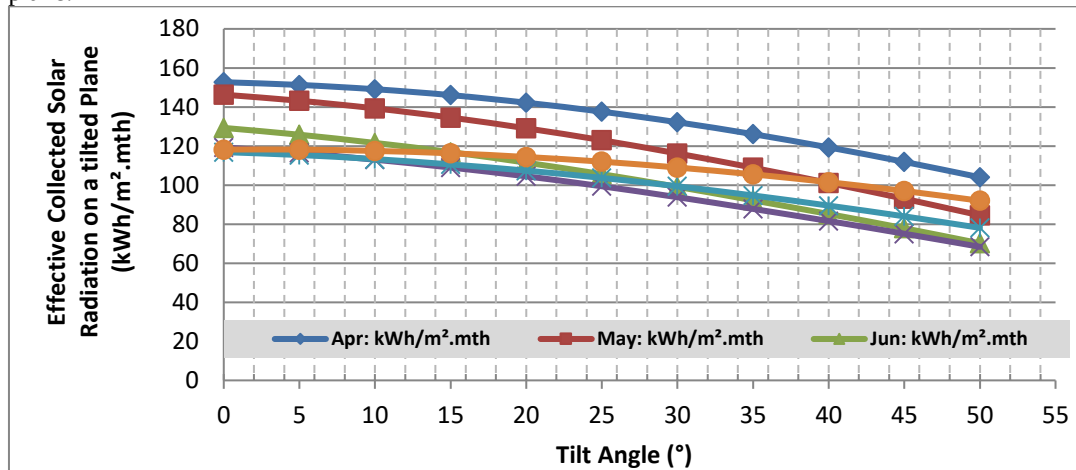


Figure 1 The Months without Potential Gain in Effective Collected Solar Radiation on a tilted Plane (kWh/m².mth)

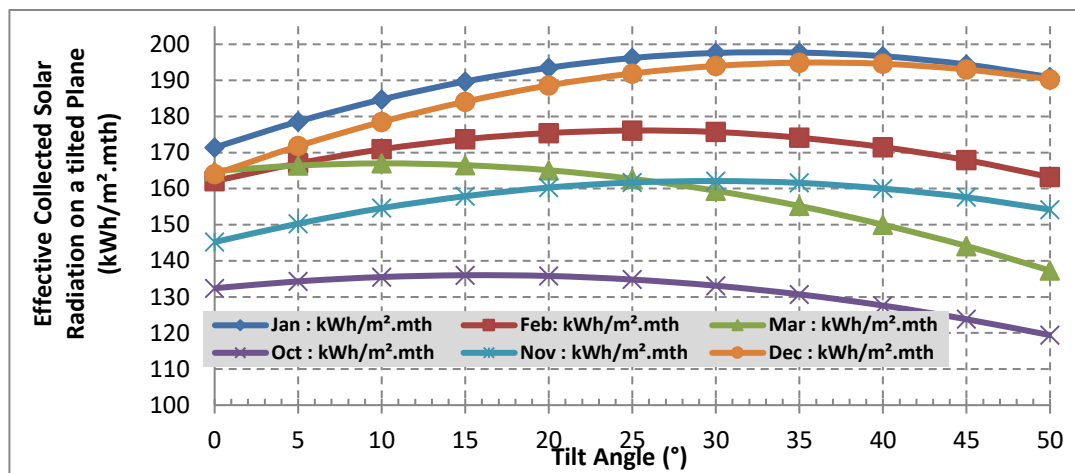


Figure 2 The Months with Potential Gain in Effective Collected Solar Radiation on a tilted Plane (kWh/m².mth)

B. Determination of the optimal tilt angle for the solar radiation on the tilted plane

Next, the quadratic regression models were developed for each of the months (January to March and October to December) in the second dataset to determine the global solar radiation on a tilted plane as a function of the tilt angle. The models are then used to determine the optimal tilt angle for the global solar radiation on tilted plane for the each of the months. On the other hand for those months (April to September) in the first dataset, the optimal tilt angle is set to zero degree (0°). The following parameters symbols were used;

H is the solar radiation on a tilted plane in kWh/m².mth

β is the tilt angle of the tilted plane in °

The quadratic regression model and the optimal tilt angle for the month of January is determined as follows;

H_{JAN} is the solar radiation on a tilted plane in kWh/m².mth for the month of January

$\beta_{JAN(opt)}$ is the tilt angle of the tilted plane in ° for the month of January

Then, for the month of January, H_{JAN} is given in terms of β as follows;

$$H_{JAN} = -0.02401864799 (\beta^2) + 1.595114218 (\beta) + 171.2657343 \quad (1)$$

The optimal tilt angle ($\beta_{JAN(opt)}$) for the month is obtained by differentiating the expression for H_{JAN} and equating it to zero and then solve for $\beta_{JAN(opt)}$ as follows;

$$\frac{\delta(H_{JAN})}{\delta(\beta)} = 0.04803729598 (\beta) + 1.595114218 \quad (2)$$

Then, when $\frac{\delta(H_{JAN})}{\delta(\beta)} = 0$; $\beta_{JAN(opt)} = \frac{1.595114218}{0.04803729598} = 33.217^\circ$ So, for the location considered in Owerri, the optimal tilt angle for the tilted plane in the month of January is 33.217° . Similarly, for the other months' quadratic regression models and optimal tilt angles are given as follows;

For the month of February,

$$H_{FEB} = -0.021501(\beta^2) + 1.096876(\beta) + 162.0825 \quad (3)$$

$$\beta_{FEB(opt)} = \frac{1.096876}{0.043002} = 25.50737^\circ$$

For the month of March,

$$H_{MARCH} = -0.018587(\beta^2) + 0.372098(\beta) + 165.0161 \quad (4)$$

$$\beta_{MARCH(opt)} = \frac{0.372098}{0.037175} = 10.00941^\circ$$

$$H_{OCT} = -0.014256(\beta^2) + 0.451002(\beta) + 132.4175 \quad (5)$$

$$\beta_{OCT(opt)} = \frac{0.451002}{0.028513} = 15.81753^\circ$$

$$H_{NOV} = -0.019198(\beta^2) + 1.140998(\beta) + 145.1371 \quad (6)$$

$$\beta_{NOV(opt)} = \frac{1.140998}{0.038396} = 29.71637^\circ$$

$$H_{DEC} = -0.023599(\beta^2) + 1.710135(\beta) + 163.8685 \quad (7)$$

$$\beta_{DEC(opt)} = \frac{1.710135}{0.047198} = 36.23311^\circ$$

For the months of April to September, their optimal tilt angle is zero (0°)

C. Comparison of the Yearly Fixed and Monthly Optimally Adjusted titled plane

Transposition factor is used to denote the gain or loss incurred by tilting the incident plane of the solar radiation. The transposition factor (**TF**) with respect to the solar radiation on the horizontal plane is given as follows;

$$TF = \frac{H_\beta}{H_0} \quad (8)$$

Where H_β the solar radiation incident on a tilted plane is inclined at an angle β and H_0 is solar radiation incident of the horizontal plane, that is, $\beta = 0$

Transposition factor in percentage is denoted as **TF**(%) where;

$$TF(\%) = \left(\frac{H_\beta}{H_0}\right) 100 \% \quad (9)$$

The optimal tilt angle in degree for the yearly fixed plane, denoted as $\beta_{YR(opt)}$ is given as [25, 26];

$$\beta_{YR(opt)} = 3.7 + 0.69|\phi| \quad (10)$$

Where ϕ is the latitude of the site, in this case, $\phi = 5.51$. So,

$$\beta_{YR(opt)} = 3.7 + 0.69|5.51| = 7.5019^\circ \approx 8^\circ$$

The results for the transposition factor for the tilted plane at the yearly fixed tilt angle of 8° and at the various monthly adjusted optimal tilt angle are given in Table 1 and Figure 3.

Table 1 Comparison of the transposition factor (%) for the solar radiation on the yearly-fixed optimal tilt angle of 8° and transposition factor (%) based on the monthly optimal tilt angle.

	Monthly Optimal tilt Angle (°)	Solar Radiation On 0° Tilted Plane (kWh/m ² .mth)	Solar Radiation On 8° Tilted Plane (kWh/m ² .mth)	Solar Radiation On Monthly Optimal Tilted Plane (kWh/m ² .mth)	Transposition Factor (%) for the Solar Radiation On 8° Tilted Plane	Transposition Factor (%) for the Solar Radiation On Monthly Optimal Tilt Angle Tilted Plane
Jan	33.2	171.4	182.4	197.7	106.4	115.4
Feb	25.5	162.1	169.5	176.1	104.6	108.6
Mar	10.0	164.9	166.9	166.9	101.2	101.2
Apr	0.0	152.7	150.1	152.7	98.3	100
May	0.0	146.3	140.9	146.3	96.3	100
Jun	0.0	129.3	123.4	129.3	95.4	100
Jul	0.0	119.3	114.5	119.3	96.0	100
Aug	0.0	116.9	114.2	116.9	97.7	100
Sep	0.0	118.2	117.9	118.2	99.7	100
Oct	15.8	132.4	135.1	136.0	102.0	102.7
Nov	29.7	145.2	153	162.1	105.4	111.6
Dec	36.2	164	175.9	194.9	107.3	118.8
Yearly Sum	150.5	1722.7	1743.8	1816.3	1210.3	1258.3
Yearly Average		143.6	145.3	151.4	100.9	104.9
Normalized With Respect To Radiation on The Horizontal Plane		0	1.2	5.4	1	5

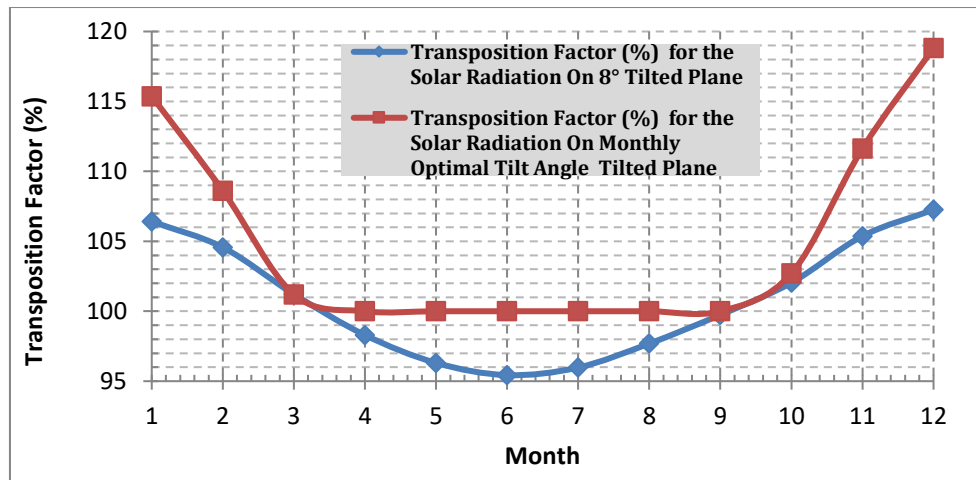


Figure 3 Comparison of the transposition factor (%) for the solar radiation on the yearly-fixed optimal tilt angle of 8° and transposition factor (%) based on the monthly optimal tilt angle .

The results in Table 1 show that in the month of December, at the 8° tilt angle only 7.3 % gain can be realized whereas up to 18.8 % will be realized by tilting the plane at the December optimal tilt angle of 36.2°. Similarly, for the month of November, at the 8° tilt angle only 5.4 % gain can be realized whereas up to 11.6 % will be realized by tilting the plane at the November optimal tilt angle of 29.7°.

On the other hand, for the months (April to September) with zero degree as there optimal tilt angle, for the month of May, at the 8° tilt angle there will be a loss of about 4 % captured solar radiation whereas by leaving the plane at 0° there would have been no loss.

In all, on annual bases, at the 8° tilt angle there is a total gain of 1% in captured solar radiation on the tilted plane whereas with the monthly adjusted optimal tilt angle there is a total gain of 5%. The implication of the finding is that in the months of April to September the solar module should be kept on the horizontal plane (at 0°) whereas, for the other six months, the tilted plane should be adjusted once in the month based on the optimal tilt angle listed in Table 1.

III. Conclusion

The implication of tilting the incident plane of solar radiation capturing solar panel is studied for a given case location in Imo state. The results showed that tilting the plane of the solar panel can result in gain or reduction in the overall captured solar radiation. The particular effect depends on the months of the year. Accordingly, relevant mathematical models were developed to determine the optimal tilt angle that will ensure maximum gain or avoid loss altogether in the captured global solar radiation in any given month. The solar radiation data for the study sited was used for the analysis and PVSyst software was also used to carry out the transposition of the solar radiation on the tilted plane. The results showed also that the months of April to September do not require any tilting of the plane but the other months require optimally adjusted plain for maximum solar radiation capture.

IV. References

- [1]. Hsu, A., Rosengarten, C., Weinfurter, A., Xie, Y., Musolino, E., & Murdock, H. E. (2017). Renewable Energy and Energy Efficiency in Developing Countries: Contributions to Reducing Global Emissions-Third Report.
- [2]. Dieu-Hang, T., Grafton, R. Q., Martínez-Españeira, R., & García-Valiñas, M. (2017). Household adoption of energy and water-efficient appliances: An analysis of attitudes, labelling and complementary green behaviours in selected OECD countries. *Journal of environmental management*, 197, 140-150.
- [3]. Wörter, M., Stucki, T., Arvanitis, S., Rammer, C., & Peneder, M. (2017). The adoption of green energy technologies: the role of policies in an international comparison. In *23rd Annual Conference of the European Association of Environmental and Resource Economists (EAERE)*. EAERE.
- [4]. Van Vuuren, D. P., Stehfest, E., Gernaat, D. E., Doelman, J. C., Van den Berg, M., Harmsen, M., ... & Girod, B. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. *Global Environmental Change*, 42, 237-250.
- [5]. Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering*, 3(1), 1167990.
- [6]. Rahman, Z. A., & Elinda, E. (2016, March). The drivers to adopt renewable energy among residential users. In *IOP Conference Series: Earth and Environmental Science* (Vol. 32, No. 1, p. 012041). IOP Publishing.
- [7]. Islam, M. A., Hasanuzzaman, M., Rahim, N. A., Nahar, A., & Hosenuzzaman, M. (2014). Global renewable energy-based electricity generation and smart grid system for energy security. *The Scientific World Journal*, 2014.
- [8]. Timmons, D., Harris, J. M., & Roach, B. (2014). The economics of renewable energy. *Global Development And Environment Institute, Tufts University*, 52.
- [9]. Lyon, T. P., & Yin, H. (2010). Why do states adopt renewable portfolio standards?: An empirical investigation. *The Energy Journal*, 133-157.
- [10]. Chu, S., Cui, Y., & Liu, N. (2017). The path towards sustainable energy. *Nature materials*, 16(1), 16.
- [11]. Bouznada, K., & Obeidi, B. E. (2016). *Improving the efficiency of photovoltaic power systems* (Doctoral dissertation).
- [12]. Wagh, S., & Walke, P. V. (2017). REVIEW ON WIND-SOLAR HYBRID POWER SYSTEM. *International Journal of Research In Science & Engineering*, 3.
- [13]. Green, M. A., & Bremner, S. P. (2017). Energy conversion approaches and materials for high-efficiency photovoltaics. *Nature Materials*, 16(1), 23.

- [14]. Sampaio, P. G. V., & González, M. O. A. (2017). Photovoltaic solar energy: Conceptual framework. *Renewable and Sustainable Energy Reviews*, 74, 590-601.
- [15]. Lin, C. L. (2015). Case study of solar power producing efficiency from a photovoltaic system. *Open Journal of Energy Efficiency*, 4(03), 45.
- [16]. Chu, Y., & Meisen, P. (2011). Review and comparison of different solar energy technologies. *Global Energy Network Institute (GENI), San Diego, CA*.
- [17]. Zang, H., Guo, M., Wei, Z., & Sun, G. (2016). Determination of the optimal tilt angle of solar collectors for different climates of china. *Sustainability*, 8(7), 654.
- [18]. Li, D. H., & Lam, T. N. (2007). Determining the optimum tilt angle and orientation for solar energy collection based on measured solar radiance data. *International Journal of Photoenergy*, 2007.
- [19]. Ajao, K. R., Ambali, R. M., & Mahmoud, M. O. (2013). Determination of the Optimal Tilt Angle for Solar Photovoltaic Panel in Ilorin, Nigeria. *Journal of Engineering Science and Technology Review*, 6(1), 87-90.
- [20]. Lave, M., & Kleissl, J. (2011). Optimum fixed orientations and benefits of tracking for capturing solar radiation in the continental United States. *Renewable Energy*, 36(3), 1145-1152.
- [21]. Krishna, B., & Sinha, K. (2013). Tracking of sun for solar panels and real time monitoring using LABview. *Journal of Automation and Control Engineering Vol.*, 1(4).
- [22]. Nnadi, D. B. N., Oti, S. E., & Ahiabuike, D. C. (2014). Mechanical Sun-tracking Technique Implemented for Maximum Power Point Tracking of a PV System for Effective Energy Supply. *Nigerian Journal of Technology*, 33(2), 230-237.
- [23]. NASA (2018) POWER DATA ACCESS VIEWER online free tool. Available at: <https://power.larc.nasa.gov/data-access-viewer/> Accessed on 21st October 2018
- [24]. Mermoud, A. (2012). Pvsyst: Software for the study and simulation of photovoltaic systems. ISE, University of Geneva, www.pvsyst.com.
- [25]. Ahmad M. J, Tiwari G. N. (2009) "Optimization of tilt angle for solar collector to receive maximum radiation". *The Open Renewable Energy Journal*, 2 (1), 19-24, 2009.
- [26]. Anyanime T. U., Mbetobong U. F., Emmanuel A. U. , (2016) Development of Site Specific Optimal Tilt Angle Model for Fixed Tilted Plane PV Installation in Akwa Ibom State, Nigeria . *Science Journal of Energy Engineering* ; 4(6): 50-55