ISSN 2229-5518

Performance Characterization of Building Integrated Photovoltaic Systems in Northern and Southern Hemisphere Locations

Martin C. Eze, Samuel C. Olisa

Abstract *— This research analyses Building-Integrated Photovoltaic Systems Performance in Northern and Southern Hemisphere Locations. Crystalline silicon BIPV system with peak power of 15KWp was used in the simulation and loss due to wire and inverter was set at 0.0%. The longitude was fixed at 30^0 and the latitude of the system was varied from 5^0 to 30^0 in each hemisphere. Based on the simulation result, it was observed that the annual output energy of BIPV systems increases with the increase in the latitude and systems in northern hemisphere produce higher energy compared to the system in the southern hemisphere. However, the system in the southern hemisphere is more efficient. The result showed that the optimum tilt angle increases with the increase in the latitude and system in the southern hemisphere have a higher optimum tilt angle compared to the system in the northern hemisphere and the hemisphere affects system orientation. The simulation was done using MATLAB and PVGIS.*

Index Terms— *Building-Integrated Photovoltaic System, Optimum Orientation Angle, Optimum Tilt Angle, PVGIS*, Northern Hemisphere, Southern Hemisphere, *Crystalline silicon*

———————————— ◆ ————————————

1 INTRODUCTION

Building-Integrated Photovoltaic (BIPV) system is a Photovoltaic (PV) system integrated to buildings to make homes net energy producer (Positive Energy Architecture) and this has provided savings in building materials, land area, transmission loss and the cost of energy consumed at home [1]. The output power of BIPV systems depends on the irradiance, tilt angle and orientation angle of the system [2], [3]. The tilt angle is the angle between the PV system face and the horizontal plane. A minimum tilt angle of 10^0 is recommended in PV systems installations to allow for natural cleaning of the module surface by rain [4]. On the other hand, the orientation is the angle between the system face and the South Pole when the South Pole is used as the reference longitude (longitude 0^0). The tilt angle and orientation angle determine the percentage of solar irradiance absorbed by BIPV systems. The solar irradiance is the average solar power that reaches a unit area of earth surface [5]. At sea level, the solar irradiance has value of $1000W/m^2$ at 25^0C, air mass of AM1.5 and wind speed of 0m/s [6]. The annual solar irradiance at the earth surface increases with the increase in the latitude [2]. The solar energy is particularly abundant in a belt within $\pm35^0$ about the equator and this belt corresponds to the latitudes where majority of world's population lives [7].

The maximum solar irradiance is absorbed by BIPV systems at an optimum tilt angle and optimum orientation [8]. The optimum orientation occurs when the angle between the system and the reference pole is equal to the azimuth angle which is the angle between the sun ray and the reference pole. The optimum orientation of BIPV systems depends on the earth's hemispheres and the actual location of the system. The earth is divided into the northern hemisphere and southern hemisphere using the Equator as the reference latitude (latitude 0^0) as shown in Figure 1. When a PV system is located in the northern hemisphere, it has to face south (see Φ in Figure 1) for optimum performance and system in the southern hemisphere has to face north (see Θ in Figure 1) for best performance. The optimum Tilt angle of BIPV depends on the latitude and hemispherical location of the building [8]. In fact, the optimum tilt angle is given as the sum of local latitude and the minimum tilt angle required for natural cleaning. In [4], it was recommended that the minimum tilt angle for every PV installation should be ten degrees (10^0). In [8], it was stated that the optimum tilt angle is a function of the latitude of the location.

————————————————

- *Martin C. Eze is currently pursuing PhD degree Program in Photovoltaic Systems in University of Nigeria, Nsukka, Nigeria, E-mail: martin.eze@unn.edu.ng*
- *Samuel C. Olisa is currently pursuing masters degree program in Digital Electronics and Computers in University of Nigeria, Nsukka, Nigeria, E-mail: Samuel.olisa@unn.edu.ng*

ISSN 2229-5518

$$\beta_{op} = f(\Phi L) \qquad (1)$$

Where β_{op} is the optimum tilt angle, $\boldsymbol{\Phi}_L$ is the latitude of the location. The latitude is the angular distance measured toward the South Pole or the North Pole when earth's equator as the reference latitude (latitude 0^0). The latitude angle measured toward the South Pole lies in the southern hemisphere while latitude angle measured toward the North Pole lies in the northern hemisphere. Since BIPV systems have fixed orientation, the optimum tilt angle of the solar module should be considered before construction [9].

Another factor that affects the performance of BIPV system is the module temperature. The increase in module temperature reduces the power output of PV system and makes the system degradation rate double for every 10K rise in temperature [10]. The rate at which temperature affects the power output of the PV system is measured using temperature coefficient (γ). Temperature coefficient depends on the PV technology with crystalline silicon PV having γ = -0.45%/K, Amorphous silicon PV having γ = -0.13%/K) and Copper-Indium-(Gallium)-Selenide having γ =-0.36%/K [11]. The module temperature varies inversely to the wind speed around the module and directly proportional to the PV cell packing density [4].

The obstacle to widespread use of BIPV systems is the lack of knowledge of the available PV performance parameter predicting applications. The accurate prediction of the possible output power, optimum tilt angle and optimum orientation of PV systems at any location helps in the design and installation of BIPV systems for efficient performance. For efficient electrical model, at least four parameters are taken into consideration depending on the PV module technology [12]. PVGIS, Transient Systems Simulation (TRNSYS) application, Solar Geographic Information System (SolarGIS) application and PVSOL are some of the applications that are used for predicting performance parameters. These applications are based on *Performance Ratio Maximum Power (PRMP) model.* PRMP requires the overall module efficiency, maximum power and the incident radiation, tilt angle, the azimuth angle and ambient temperature to calculate the output power [13]. It is suitable when the true behaviour of the PV array is unknown, but sensitivities of the module are required. The TRNSYS receives hourly climate data, like the radiation on a plane inclined at 30^0, ambient temperature T_{STC} and the wind speed (V) from climate database. On the other hand, PVSOL allows the user to input monthly global irradiation on the horizontal plane as well as the ambient temperature but does not allow the user to input wind speed.

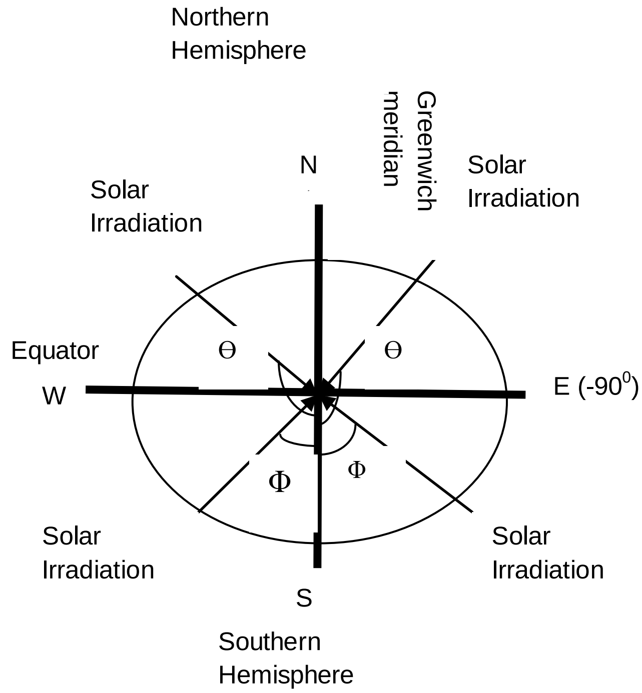

Figure 1: Partitio ... he Southern and the Northern Hemispheres by The Equator

2 PVGIS APPLICATION

PVGIS application is a web application based on PRMP model that predicts the actual power output of PV system install in any location within its scope. It works for stand-alone PV and BIPV system. PRMP is a model that takes the module efficiency, peak power of the PV system and the incident solar radiation, the tilt angle of the solar system and the azimuth angle to predict the actual output power of a PV system. The software does not allow the user to input the climate data but allows the user to select the location of the system, the tilt angle, the azimuth angle and expected power loss. Although PVGIS is the least accurate among the applications, it was used in this research because the application is free and user-friendly.

3 PERFORMANCE RATIO MAXIMUM POWER (PRMP) MODEL

The output generated by BIPV is estimated using PRMP model. The annual output energy (E_{PV} in kWh) of PV System using PRMP model is given by (2).

ISSN 2229-5518

$$E_{PV} = \mu_{pv} P_{PVP} \frac{H_n}{G_0} \left(1 - \gamma(T - 25^0C)\right) \qquad (2)$$

Where P_{PV} is the annual power output, μ_{pv} is the performance ratio of PV system, P_{PVP} is the maximum power rating of the PV system at STC, G_0 is the solar irradiance at STC, H_n is the annual solar irradiation normal to the PV system, T is the ambient temperature of the location and γ is the temperature coefficient of the PV technology. The unit of solar irradiation is Wh/m^2 and the unit of solar irradiance is W/m^2. PV systems are rated by manufacturers at Standard Test Condition (STC) where T=25̊C, G_0=1000W/m², wind speed =0m/s. Losses that occurs in the BIPV system include losses due to temperature, low irradiance, angular reflectance and inverter affects the performance ratio. The performance ratio, μ_{pv} of a PV system is a dimensionless factor with values ranging from 60% to 80% and it is given by (3) [13], [14]. At stc, $E_{PV} \times G_0 = P_{PVP} \times H_{abs}$ and the performance ratio is 100% [16].

$$\mu_{pv} = \frac{E_{PV} G_0}{P_{PVP} H_{abs} \left(1 - \gamma(T - 25^0C)\right)} \qquad (3)$$

Performance ratio is affected by temperature, wind speed, soiling. Given a PV system inclined at an angle of β to the horizontal as shown in Figures 2 and 3, the solar irradiation normal to an inclined surface (H_n) is given by (4).

$$H_{abs} = H \, \mathrm{Sin}(\beta + \alpha) \qquad (4)$$

Where H is the total incident irradiation, β is the tilt angle of the system and α is the sun elevation angle. Figures 2 and 3 use the South Pole as the reference orientation. Then ϴ and Φ are the orientations (azimuth angles) for PV systems located in the Southern and Northern Hemisphere respectively. When South Pole is the reference orientation, the azimuth angle (Θ_z) is given by 90-α for system located in the northern hemisphere. For PV system located in the southern hemisphere, the azimuth angle (Θ_z) is given by 90 +α. However, when the North Pole is the reference orientation, the azimuth angle (Θ_z) is given by 90+α for system located in the northern hemisphere while for PV system located in the southern hemisphere, the azimuth angle (Θ_z) is given by 90 –α. Equation (4) shows that the solar irradiation absorbed by the PV system depends on the angle of inclination of the sun and the tilt angle of the PV system.

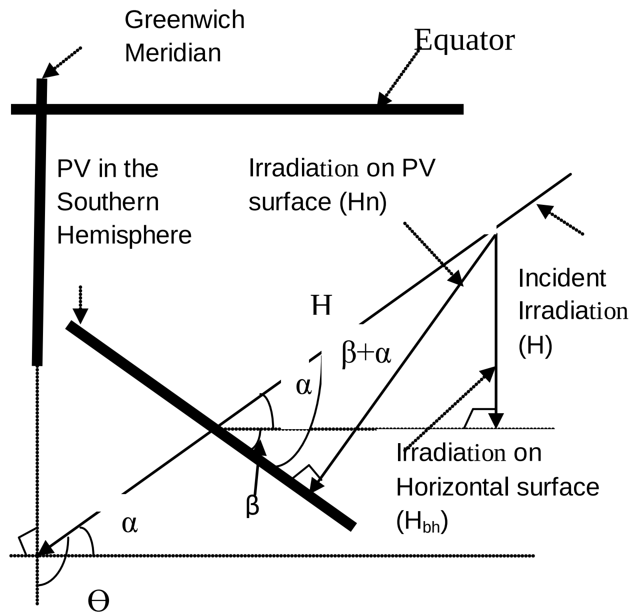

Figure 2: Solar irradiation on a Tilted Surface in the Southern Hemisphere

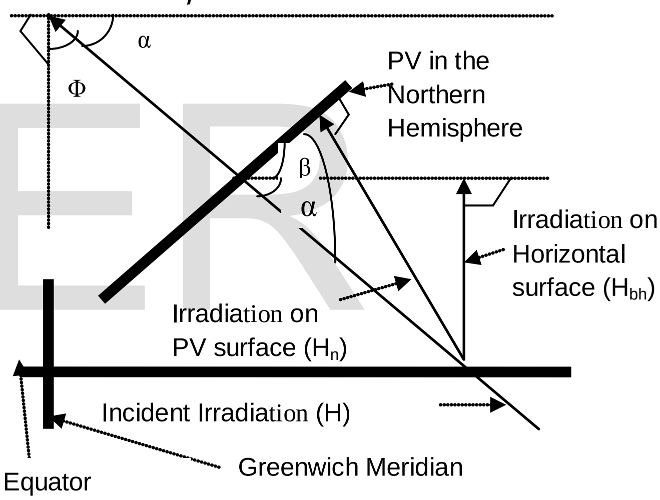

Figure 3: Solar irradiation on a Tilted Surface in the Northern Hemisphere

4 MATERIALS AND METHODS

The Building-Integrated Photovoltaic Systems Performance in Northern and Southern Hemisphere Locations was characterised in this paper. Crystalline silicon BIPV system with peak power of 15KWp was used and loss due to wire and inverter was set at 0.0%. The longitude of the locations was fixed at 30^0 and the latitude was varied from 5^0 to 30^0 in both northern and southern hemispheres. The effect of the latitude on the annual output energy, conversion efficiency, optimum tilt angle and the optimum orientation was investigated. The tilt angle of the BIPV systems at optimum orientation was also varied from 0^0 to 90^0 and the effect on the annual output energy was analysed. The data was collected using PVGIS while the plotting was done using Matrix Laboratory (MATLAB).

5 RESULTS AND DISCUSSION

The effects of the latitude on the annual output energy and performance ratio of BIPV systems in the Northern and the Southern hemisphere are shown in Table 1. From Table 1, it is observed that for BIPV system in the northern hemisphere, the energy output and performance ratio increase with an increase in the latitude. On the other hand, for a system in the southern hemisphere, the pattern of variation of energy output and performance ratio with latitude is not clear.

Figures 4 and 5 show clearly how annual energy output and performance ratio varies with the latitude. From Figure 4, it is observed that the annual output energy increases with the increase in the latitude in the northern hemisphere. On the other hand, the annual output power obtained from the BIPV system in southern hemisphere does not have a fixed pattern.

Table 1: The effects of latitude on the annual energy output and performance ratio of BIPV System

Northern Hemisphere			Southern Hemisphere		
Lat. (^{0})	Annual Energy Output (MWh)	Perf. Ratio (%)	Lat.(^{0})	Annual Energy Output (MWh)	Perf. Ratio (%)
5	25.0	78.4	5	23.7	78.8
10	25.9	76.8	10	26.8	79.7
15	28.2	77.0	15	26.3	79.6
20	28.9	76.9	20	27.4	80.9
25	29.9	78.4	25	26.7	80.7
30	28.9	80.6	30	23.4	81.7

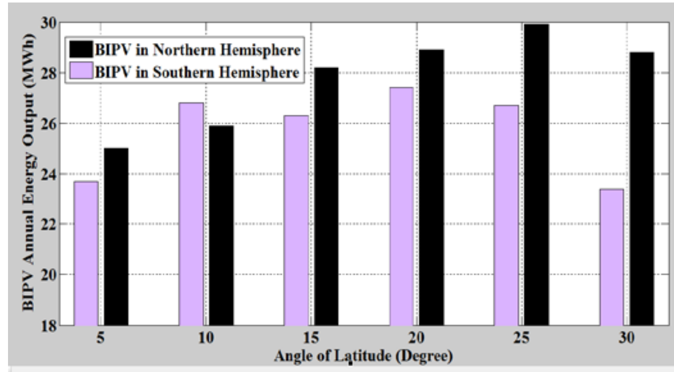

Figure 4: Plot of Annual Energy Output against Latitude at longitude 30^0 for BIPV in the Northern and the Southern Hemisphere

Figure 4 also shows that the BIPV system in northern hemisphere produces higher annual output energy compared to the system in the southern hemisphere. This is because the northern hemisphere is closer to the sun than the southern hemisphere and, therefore, receives a higher amount of irradiation from the sun. The variation of Performance ratio of BIPV systems in the Northern and the Southern hemispheres with latitude is shown in Figure 5. From Figure 5, it is observed that BIPV systems in the southern hemisphere are more efficient compared to the BIPV systems in the northern hemisphere. This is attributed to the fact that the northern hemisphere has a higher ambient temperature compared to the southern hemisphere.

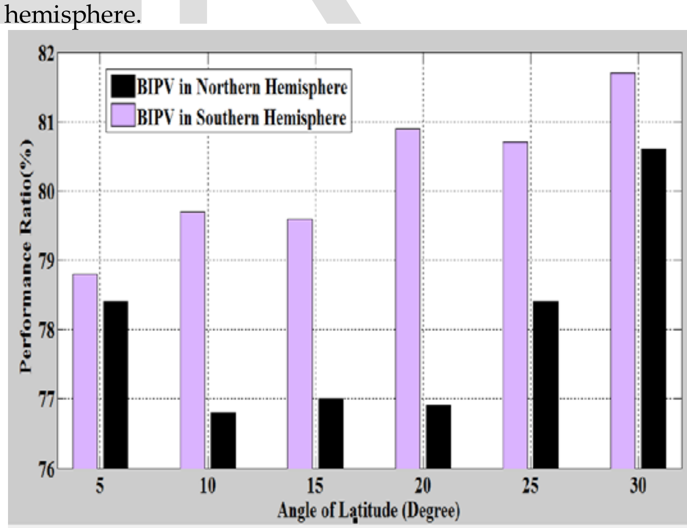

Figure 5: Plot of Annual Performance Ratio against Latitude at longitude 30^0 for BIPV in the Northern and the Southern Hemisphere

ISSN 2229-5518

The effects of the latitude on the Optimum orientation and Optimum tilt angle of BIPV systems in the Northern and the Southern hemisphere are shown in Table 2. From the Table 2, it is observed that for BIPV system in the northern hemisphere, the optimum orientation is very low while for the system in the southern hemisphere, the orientation angle is very high when South Pole is used as the reference orientation angle (0^0). On the other hand, for the system in the Northern and the Southern hemisphere, the optimum tilt angle increases with the increase in the latitude with the system in the Southern hemisphere having higher optimum tilt angle.

Table 2: The effects of latitude on the Optimum orientation angle and optimum tilt angle of BIPV System

Northern Hemisphere			Southern Hemisphere		
Lat. (^{0})	**Opt. Orient. Angle (^{0})**	**Opt. tilt angle (^{0})**	**Lat.(^{0})**	**Opt. Orient. Angle (^{0})**	**Opt. tilt angle (^{0})**
5	4	8	5	178	12
10	4	14	10	178	18
15	5	17	15	175	19
20	4	20	20	178	24
25	5	25	25	169	27
30	2	28	30	180	35

The variation of optimum orientation angle and optimum tilt angle with latitude is shown in Figures 6 and 7. Considering Figure 6, it is seen that the optimum tilt angle of BIPV systems increases with the increase in the latitude of the location for both northern and southern hemispheres. This is because the tilt angle of a PV system depends on the latitude. It was also observed that the system located in the Southern Hemisphere has a higher optimum tilt angle compared to the system located in the Northern Hemisphere for the same latitude magnitude.

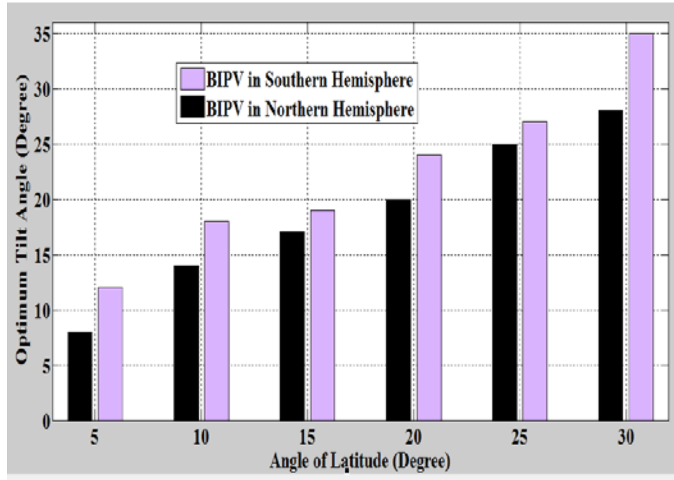

Figure 6: Plot of Optimum Tilt Angle against Latitude at longitude 30^0 for BIPV in the Northern and the Southern Hemisphere

Figure 7 shows the variation of the orientation of PV system with the latitude in both the Southern and the Northern Hemisphere. From Figure 7, it is observed that the orientation of PV systems is highly independent of the latitude of the location but highly dependent on the hemisphere. The result showed that in the Northern Hemisphere, the PV system has optimum performance when it faces the southern hemisphere while the PV system has to face northern hemisphere when in the Southern Hemisphere for optimum performance.

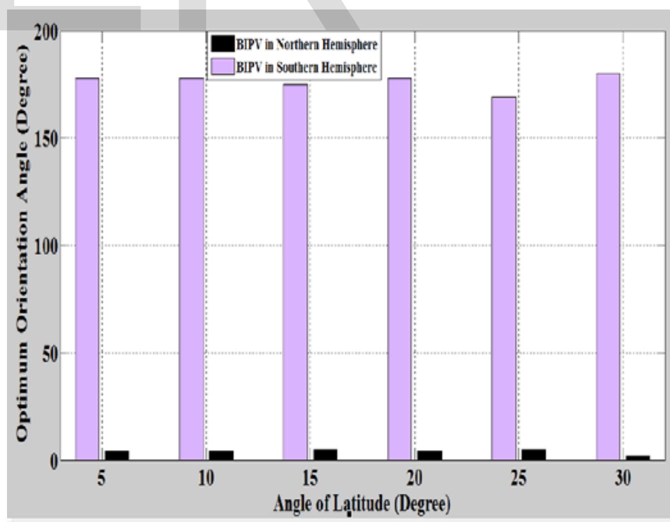

Figure 7: Plot of Optimum Orientation Angle against Latitude at longitude 30^0 for BIPV in the Northern and the Southern Hemisphere

From the figure, it is seen that the orientation angles for PV systems at different latitudes in the northern hemisphere are very small and nearly equal while the orientations for the system in the southern hemisphere are large and nearly equal. Having used South Pole as the reference orientation (0^0) in the simulation, the result in Figure 6 implies that PV system in the Northern Hemisphere must have an orientation in the southern direction while PV system in the Southern Hemisphere must have an orientation in the northern direction.

Table 3: Effects of tilt angle and orientation angle on the annual energy output for BIPV systems

Effect of Tilt Angle			Effect of Orientation Angle		
	North. Hem.	South. Hem.		North. Hem.	South. Hem.
Tilt Ang. (^{0})	Annual Energy Output (MWh)	Annual Energy Output (MWh)	Ori. Angl (^{0})	Annual Energy Output (MWh)	Annual Energy Output (MWh)
0	24.90	23.30	0	25.00	22.40
5	25.00	23.60	10	25.00	22.40
10	25.00	23.70	20	25.00	22.40
15	24.90	23.70	30	25.00	22.40
20	24.60	23.50	40	24.90	22.50
25	24.30	23.30	50	24.90	22.60
30	23.80	23.00	60	24.80	22.70
35	23.20	22.50	70	24.80	22.80
40	22.40	21.90	80	24.70	22.90
45	21.50	21.20	90	24.70	23.00
50	20.50	20.30	100	24.60	23.10
55	19.30	19.30	110	24.60	23.20
60	18.10	18.20	120	24.50	23.30
65	16.70	16.90	130	24.50	23.40
70	15.30	15.60	140	24.50	23.50
75	13.80	14.20	150	24.40	23.60
80	12.40	12.80	160	24.40	23.60
85	11.00	11.30	170	24.40	23.70
90	9.56	9.85	180	24.40	23.70

Table 3 shows the effects of the tilt angle and the orientation angle of BIPV system on the annual energy output for BIPV systems located in the Northern Hemisphere (lat. 5^0, long. 30^0) and the Southern Hemisphere (lat. -5^0, long. 30^0). The effects of tilt angle and orientation angle on the annual output energy are clearly shown in Figures 8 and 9. Figure 8 showed the effect of tilt angle on the annual output energy for BIPV systems located in the Northern Hemisphere (lat. 5^0, long. 30^0) and the Southern Hemisphere (lat. -5^0, long. 30^0). The orientation angles were fixed at 4^0 for the system in the Northern hemisphere and 178^0 for the system in the Southern hemisphere. The Figure 8 also showed that for the latitudes under consideration, maximum annual output energy was obtained for tilt angle ranging from 5^0 to 10^0 for the system in the northern hemisphere.

For a system in the southern hemisphere, the maximum annual output energy was obtained for tilt angle varying from 10^0 to 15^0. In general, the result showed that at a tilt angle above the optimum tilt angle, the annual energy output decreases with the increase in tilt angle.

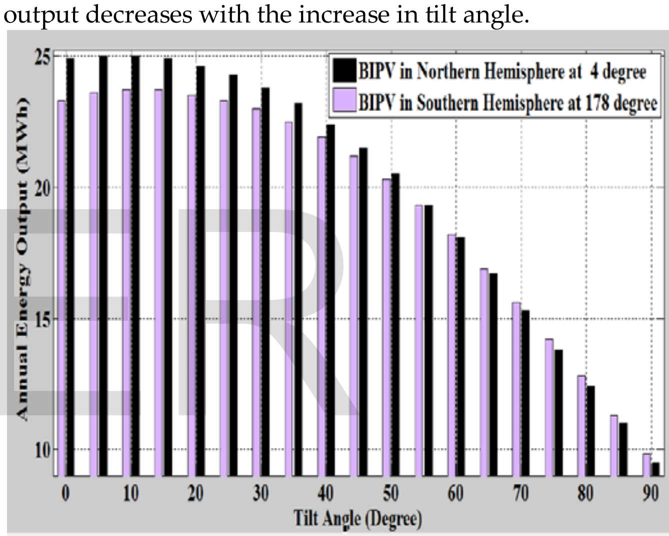

Figure 8: Plot of Annual Energy output against the tilt angle at longitude 30^0 and latitude 5^0 for BIPV in the Northern and the Southern Hemisphere

Figure 9 showed the effect of orientation angle on the annual output energy for BIPV systems located in the Northern Hemisphere (lat. 5^0, long. 30^0) and the Southern Hemisphere (lat. -5^0, long. 30^0) hemisphere. The tilt angle was fixed at an optimum tilt angle shown in Figure 6. The figure showed that for the latitudes under consideration, maximum annual output energy was obtained for orientation angle ranging from 0^0 to 30^0 for the system in the northern hemisphere. For a system in the southern hemisphere, the maximum annual output energy was obtained for orientation angle varying from 170^0 to 180^0.

In general, the result showed that the output energy directly proportional to the orientation angle for the system in the southern hemisphere and inversely proportional the orientation angle for the system in the northern hemisphere.

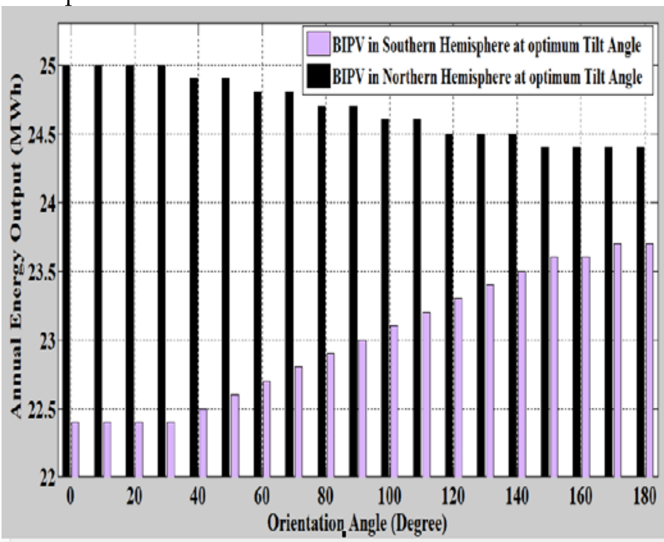

Figure 9: Plot of Annual Energy output against the orientation angle of longitude 30⁰ and latitude 5⁰ for BIPV in the Northern and the Southern Hemisphere

6 CONCLUSION

This research characterises Building-Integrated Photovoltaic Systems Performance in Northern and Southern Hemisphere Locations using PVGIS. It was observed that system in the northern hemisphere produces more annual output energy compared to the system located in the southern hemisphere. The result also shows that the annual output energy output also increases with the increase in the latitude of the location. On the other hand, the results showed that the system in the southern hemisphere has better Performance Ratio. The simulation also shows that the optimum tilt angle of the PV system increases with the increase in the latitude of the PV location for both northern and southern hemispheres. The research also shows that PV system located in northern hemisphere must face south for optimum performance while the PV system in the southern hemisphere has to face north for better performance. In summary, the results of this research presented a solution on where to locate, how to orientate and tilt a PV system for best performance.

REFERENCES

[1] L. Cholakkal, “Cost-benefit analysis of a Building Integrated Photovoltaic Roofing system for a school located in Blacksburg , Virginia by Cost-benefit analysis of a Building Integrated Photovoltaic Roofing system for a school located in Blacksburg , Virginia,” *MSc Thesis, Virginia Polytechnique Institute and State University*, pp. 1–57, 2006.

[2] O. Idowu, “Determination of optimum tilt angles for solar collectors in low-latitude tropical region,” *International Journal of Energy and Environmental Engineering*, vol. 4, no. 1, p. 29, 2013.

[3] H. A. Ekadewi, I. Djatmiko, and Prabowo, “The optimal tilt angle of a solar collector,” *Energy Procedia*, vol. 32, pp. 166–175, 2013.

[4] S. R. Wenham, M. A. Green, M. E. Watt, and R. Corkish, *Applied Photovoltaics*, 1st ed. London: Earthscan, 2007.

[5] M. S. Okundamiya and a. N. Nzeako, “Estimation of Diffuse Solar Radiation for Selected Cities in Nigeria,” *ISRN Renewable Energy*, vol. 2011, pp. 1–6, 2011.

[6] Y. Huang, C. Chan, S. Kuan, S. Wang, and S. Lee, “Analysis and Monitoring Results of a Building Integrated Photovoltaic Façade Using PV Ceramic Tiles in Taiwan,” *International Journal of Photoenergy*, vol. 2014, pp. 1–12, 2014.

[7] Å. Skaaland, M. Ricke, K. Wallevik, and R. Strandberg, “Potential and Challenges for Building Integrated Photo- voltaics in the Agder Region,” *Agderforsking, Technical Report*, no. 6, pp. 1–120, 2011.

[8] H. Yang and L. Lu, “The Optimum Tilt Angles and Orientations of PV Claddings for Building-Integrated Photovoltaic (BIPV) Applications,” *Journal of Solar Energy Engineering*, vol. 129, no. 2, p. 253, 2007.

[9] S. Chowdhury, M. Al-Amin, and M. Ahmad, “Performance Analysis of Building integrated photovoltaic application with tilt and azimuth angle in Bangladesh,” *Global Journal of Researches in Engineering*, vol. 13, no. 8, pp. 896–899, 2013.

[10] R. Ross and M. Smokler, “Flat-plate solar array project final report–volume VI: engineering sciences and reliability,” *Jet Propulsion Laboratory Publication*, 1986.

[11] S. Lindig, M. David, A. Stefano, and R. Lollini, “Performance evaluation towards improved BiPV-Systems – Simulation of BiPV-systems installed on existing building facades using TRNSYS,” in *Second*

ISSN 2229-5518
Conference on Building Simulation Applications, Italy, February, 2015, pp. 1–564.

[12] Y. B. Assoa, S. Zamini, W. Sprenger, S. Misara, and M. Pellegrino, "Numerical analysis of the impact of environmental conditions on BIPV systems, an overview of BIPV modelling in the SOPHIA project," in *27th European Photovoltaic Solar Energy Conference and Exhibition*, 2012, pp. 4143–4149.

[13] N. Blair, M. Mehos, C. Christensen, and C. Cameron, "Modeling Photovoltaic and Concentrating Solar Power Trough Performance, Cost, and Financing with the Solar Advisor Model Preprint," in *American Solar Energy Socienty, May*, 2008, pp. 1–7.

[14] "Application Note – Monitoring Portal Performance Ratio Calculation," *Solaredge*, no. July 2014, pp. 1–4, 2015.

[15] B. Marion, J. Adelstein, K. Boyle, H. Hayden, B. Hammond, T. Fletcher, D. Narang, A. Kimber, L. Mitchell, and S. Richter, "Performance parameters for grid-connected PV systems," in *Photovoltaic Specialists Conference, 2005. Conference Record of the Thirty-first IEEE*, 2005, vol. 31, no. February, pp. 1601–1606.

[16] "Performance ratio," *Techical Paper, SMA SolarTechnology AG*, no. UEN100810, pp. 1–9, 2015.