ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 11, Issue, 07, pp. 48690-48695, July, 2021
https://doi.org/10.37118/ijdr.22249.07.2021

RESEARCH ARTICLE

OPEN ACCESS

INFLUENCE OF THE INCLINATION OF PANELS ON THE EFFICIENCY OF PHOTOVOLTAIC SOLAR SYSTEMS: A CASE STUDY OF THE SYSTEM INSTALLED AT UNIOESTE, CAMPUS OF CASCAVEL, PR.

Laura Luana Foltz[1,*], Carlos Eduardo Camargo Nogueira[2], Marcelo Machado Marquez Zampiva[3] and Jair Antonio Cruz Siqueira[4]

[1]Master of the Postgraduate Program in Energy Engineering in Agriculture, State University of Western Paraná UNIOESTE; [2]Doctor in Electrical Engineering, Federal University of Santa Catarina / UFSC; [3]Doctoral Student of the Postgraduate Program in Energy Engineering in Agriculture, State University of Western Paraná / UNIOESTE; [4]Doctor in Energy Engineering in Agriculture, State University of West Paraná / UNIOESTE

ARTICLE INFO

Article History:
Received 20th April, 2021
Received in revised form
06th May, 2021
Accepted 07th June, 2021
Published online 28th July, 2021

Key Words:
Solar photovoltaic system,Dirty panels, Panel tilt, Solar radiation.

**Corresponding author:*
Laura Luana Foltz

ABSTRACT

This study aims to verify the influence of the inclination of the panels of a photovoltaic solar system connected to a grid installed at Unioeste, campus of Cascavel, PR. The system consists of ten photovoltaic modules of 330 Wp each (two panels with five modules in series) and a 4 kW inverter. Both panels were washed, and the inclination of Panel 1 was changed to 26°, which was maintained for seven weeks and three days. After this period, the slope of Panel 1 was changed to 18° and maintained again for eight weeks. The data collected from Panel 2, which remained at its original tilt of 21°, were used as a reference. The analysis of variance test was applied (ANOVA) on the average of daily panel efficiencies. When Panel 1 was maintained at 18° and Panel 2 at 21°, there was a significant difference in the average efficiencies of the panels. However, when Panels 2 and 1 were maintained at angles 21° and 26°, respectively, there was no significant difference in their average efficiencies.

Citation: ***Laura Luana Foltz, Carlos Eduardo Camargo Nogueira, Marcelo Machado Marquez Zampiva and Jair Antonio Cruz Siqueira.*** "Influence of the inclination of panels on the efficiency of photovoltaic solar systems: a case study of the system installed at Unioeste, campus of Cascavel, PR.*", International Journal of Development Research*, 11, (07), 48690-48695.

INTRODUCTION

Electric energy is of great importance for human development. However, given the concern for the environment caused by the pollutants emitted in the generation of electrical energy from conventional sources and the growth in energy consumption, there is a need to search for new alternative energy sources that do not harm the environment (Zago 2017). In this scenario, the importance of the generation of photovoltaic energy is evidenced by the significant use of solar energy. Hence, it is critical to study how solar power can be connected to the conventional distribution network, how to prevent losses in transmission lines, and how energy credits injected into the grid can be minimized, as production and consumption predominantly take place at the same point in the system. Photovoltaic generating plants have low maintenance costs, with the biggest expense being in the construction and installation of equipment.

Most importantly, the transformation of solar energy to electrical energy through photovoltaic plates does not harm the local environment. Owing to the growing demand for efficient photovoltaic generation systems, studies are being conducted on the factors that influence the performance of photovoltaic modules. The intensity of solar radiation, which is related to the tilt angle of the modules, air temperature, dirt, relative humidity, and wind are environmental factors that, when added together, affect energy generation. (Kazem, Chaichan, 2016). Solar irradiation is the environmental parameter that most affects photovoltaic plants; therefore, to conduct system sizing, it is necessary to obtain irradiation measurements of the place where the photovoltaic system will be installed to calculate its estimated generation. To make better use of the local irradiance, the inclination of the modules must also be in accordance with the local latitude (Nepal *et al.*, 2018).

The orientation and tilt angle, and the installation location of photovoltaic (PV) modules, considerably affect energy generation. To achieve ideal productivity of the PV system, modules must be oriented toward the equator. As Brazil is fully located in the southern hemisphere of the planet, to optimize use of solar radiation, modules must be oriented toward the northern geographic region. In addition to this factor, for maximum energy generation throughout the year, the slope of the panel to the horizontal plane must be equal to the latitude of the location where the PV generator will be installed (CEPEL-CRESESB, 2014). When photovoltaic systems are connected to the distribution network, the most important objective is to generate high values of current throughout the year. To obtain such values, the tilt angles of the modules must be less than the latitude, as the absorption of solar radiation will be greater in periods close to the summer solstice (BLUESOL, 2016; SEHNEM, MICHELS, ZIMERMANN, 2018). Equation 1 calculates the angle for grid-connected systems.

$$\beta = 3.7 + 0.69 * \varphi \qquad (1)$$

where $\beta$is the slope of the panel in relation to the horizontal plane (degrees) andφ is thelocation latitude (degrees). The module current is directly linked to the solar irradiance and is related to the inclination of the PV modules. Figure 1 (a) shows the characteristic curve of current versus voltage, and (b) shows the power versus voltage curve, proving thatthe greater the solar radiation, the greater the energy generation through PV systems. Moreover, the current versus voltage (*C–V*) curves in Figure 1 (a) verify that when the load demands a greater amount of current, the voltage tends to decrease; the inverse is also true. It can be seen that *C–V* chart represents a short-circuit current (when the electrical voltage is zero), and an open circuit voltage (when the electric current is zero, that is, the output terminals are operating empty) (LEITE, 2017; OLIVEIRA JUNIOR, 2018).

Figure 1 (b) shows the power versus voltage (*P–V*) curves of the PV modules. A short-circuit point is observed when the voltage is zero, and an open circuit point is perceived when the current is zero from the *P–V*graph. According to Villalva and Gazoli (2012), the curves of the two graphs, *C–V* and *P–V* indicate the maximum power points that are ideal for the photovoltaic board to work, as these points are where the greatest production of electricity occurs. Generally, both graphics and *C-V*, as the *P-V* graphics of PV plates, currently marketed, tend to have characteristics similar to those in Figures 1 (a) and (b) (Oliveira junior, 2018). Thus, to assess whether there is a significant difference in changing the inclination of the PV modules, this study presents an analysis on the influence of this factor on a photovoltaic solar system installed at the State University of West Paraná – Unioeste, campus of Cascavel-PR.

RESEARCH ELABORATIONS

The study was carried out at the State University of Western Paraná – UNIOESTE, campus of Cascavel, PR, with geographic location defined by the coordinates: latitude 24° 59' south, longitude 58° 23' west, and an average altitude of 785 m above sea level. The dimensions of the photovoltaic system installed on site wereset to meet the electrical consumption of a laboratory and two homes, one innovative and the other conventional. It was developed under the Alternative Energy Systems Analysis Center – Project CASA. The installed photovoltaic system consists of two panels connected in parallel (or two strings) containing five polycrystalline photovoltaic modules, each with a unit power of 330 Wp (totaling 3.3 kW of power). Both panels face geographic north, with a tilt angle of 21° that, according to Equation 1, would be ideal for obtaining the optimal use of solar radiation throughout the year, for a network-connected system. The system also includes a 4 kWp voltage inverter connected to the two panels. The pyranometer was an electronic component used to collect solar radiation at Unioeste. Solar radiation data, collected by the same, refer to incident radiation in the horizontal plane; they have been corrected to meet the actual slopes of the PV panels (which varied depending on the objectives of the work).To perform these corrections, several equations proposed by Duffie and Beckman (2013) were used. To conduct the study in relation to the inclinations, two new inclinations were determined for the panels that were initially at a 21° inclination. Panel 1 underwent slope modifications, whereas Panel 2 was kept at the original slope to obtain the reference data. On July 25, 2020, the two panels were washed, resulting in the same cleaning conditions. The inclination of Panel 1 was changed to 26° (maximum tilt allowed by the tilt device). Data from July 25 to August 5, 2020, were invalid, because the data logger was not recording solar radiation data. Therefore, the date of analysis of the panels with inclinations of 21° and 26° are from August 5, 2020 to September 26, 2020, totaling a period of 7 weeks and 3 days. On September 26, 2020, the two panels were washed again, and the inclination of Panel 1 was changed to 18° (minimum tilt allowed by the tilt device). From September 27 to October 12, 2020, the PV inverter did not securely collect the data to be analyzed. Therefore, the data taken into account for the slopes of 18° and 21° were for the period from October 13, 2020 to December 1, 2020, totaling 8 weeks. After the change in slope, the equations proposed by Duffie and Beckman (2013) were used to correct the solar radiation collected by the pyrometer for the different inclinations of Panel 1 and the fixed inclination of Panel 2. In the same period in which the change in the inclination of the panels was carried out, data were collected (global solar irradiance data, in kW/m²), and solar photovoltaic system generation data (generation data from the monitoring site kWh/day) was used to calculate the daily energy efficiency of the modules. We chose to calculate the daily efficiency of each PV panel to obtain a considerable number of samples, which makes the results more reliable. Equation **Error! Reference source not found.** is used to determine the daily efficiency of the panels.

$$Efficiency_{daily} = \frac{Power\ generation_{daily}}{Solar\ radiation_{daily}} \qquad (2)$$

where $Powergeneration_{daily}$ is the energy generated from the monitoring site (kWh/day);

$Solarradiation_{daily}$refers to the data from the solar radiation data logger corrected to an angle of 21° with the horizontal (kWh/day); and

$Efficiency_{daily}$is the daily efficiency of photovoltaic panels

To verify whether there was a significant difference in the efficiency of the panels, the ANOVA hypothesis test was used to compare the data means with a significance probability of 5%.

The hypothesis test is as follows:

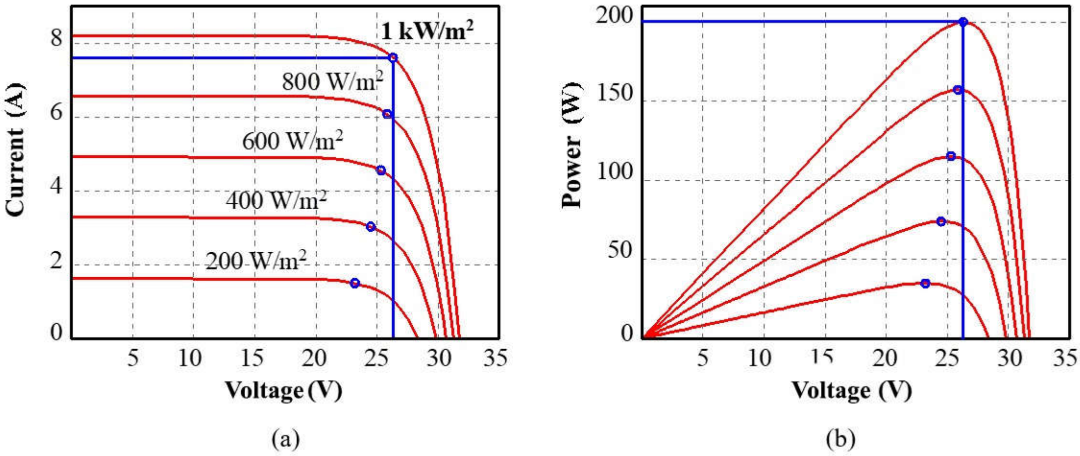
H_0= $Average_{week\ 1} = Average_{week\ 2} = \cdots = Average_{week\ 9}$

H_1= at least one $Average_{weekx}$ will be significantly different.

If Fcal<Ftab, H_0 to 5% significance will be accepted; that is, there will be no significant difference between treatments. If Fcal>Ftal, H_0 with 5% significance will be rejected and the Tukey test will be applied to compare the means and verify which treatments differ or are equal to each other. These tests will be carried out to compare the averages of the calculated efficiencies, both for the different cleaning conditions and for the different inclinations of the panels.

RESULTS OR FINDING

Graphical and Statistical Analysis – Slope: The solar radiation was analyzed at different inclinations. Table 1 presents the data taken from the Sun Data portal, and it is possible to verify the radiation at two different inclinations, 25° and 21°. From the data obtained from the Sun Data portal, it is also possible to verify that in the months of July, August, and September, the greater the inclination of the panels in relation to the horizontal, the greater the solar radiation received by the panel. In October, November, and December, the opposite can be received by the modules.



Source: Marangoni, 2012.

Figure 1. Curves (a) *C–V*and (b) *P–V* due to variation in solar radiation

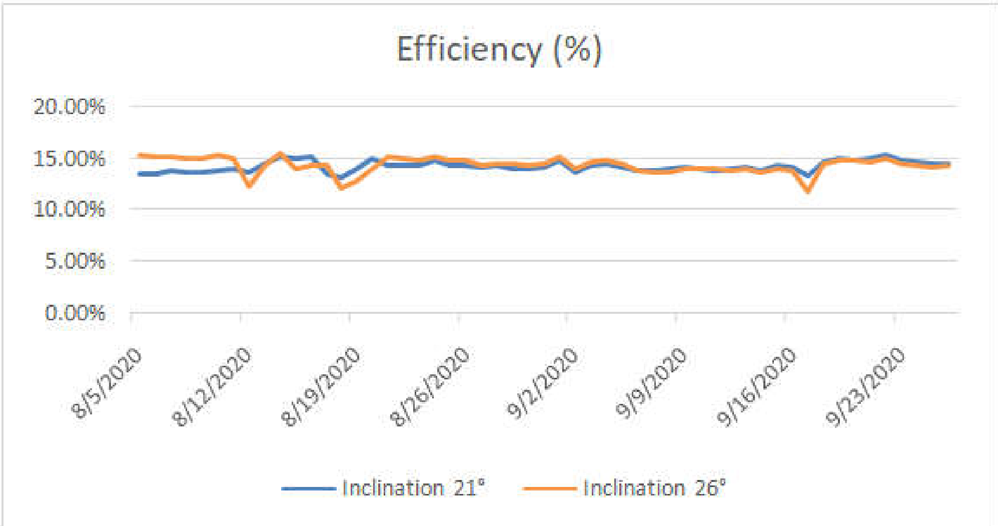


Figure 1. Efficiency (%) vs. time (day) for the 21° and 26° panel

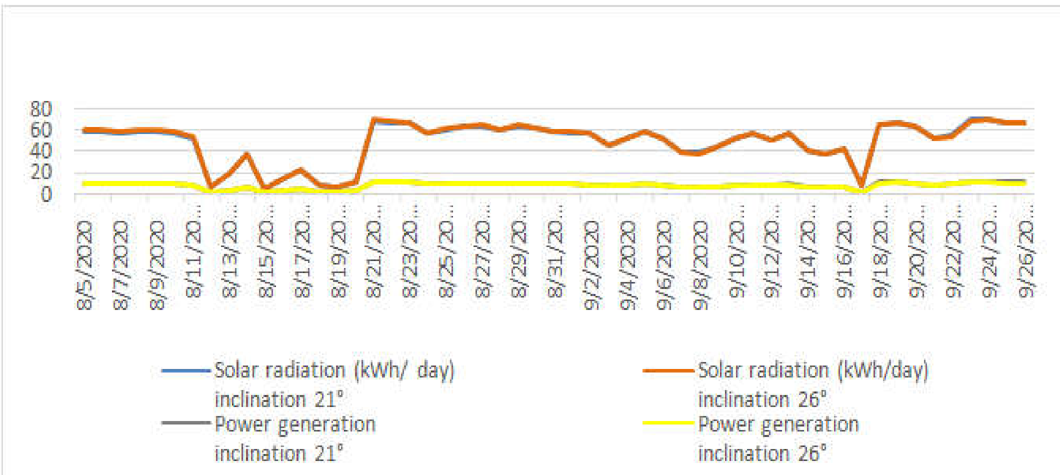


Figure 2. Solar radiation (kWh/day), 21° and 26° inclination, and power generation (kWh/day) 21° and 26° inclination.

Table1: Monthly average daily solar irradiation (kWh/m².day)

City	Inclination	July	August	September	October	November	December
Cascavel	21° (ideal)	4,00	4,97	4,68	5,13	5,58	5,78
- PR	25°	4,12	5,07	4,69	5,07	5,44	5,62

Source: SunData (2018).

Table 2. Monthly average daily solar irradiation corrected using the equations proposed by Duffie and Beckman (2013) (kWh/m².day)

Cidade	Inclination	July	August	September	October	November	December
Cascavel - PR	18°	3,91	4,86	4,63	5,17	5,67	5,89
	21°	4,00	4,94	4,64	5,13	5,59	5,79
	26°	4,14	5,04	4,64	5,05	5,43	5,59

Source: Own authorship (2020).

Table 2. Average efficiency values regarding the inclination of the panels: Panel A: 26° and Panel B: 21°

Treatment	Average	Test results
A	0,142171	a1
B	0,142533	a1

Means followed by the same letters in the columns do not differ significantly according to Tukey's 5% significance test.

Table 4. Average values of efficiency regarding the inclination of the panels: Panel A: 18° and Panel B: 21°

Treatment	Average	Test results
B	0,135762	a1
A	0,144140	a2

Means followed by the same letters in the columns do not differ significantly according to Tukey's 5% significance test.

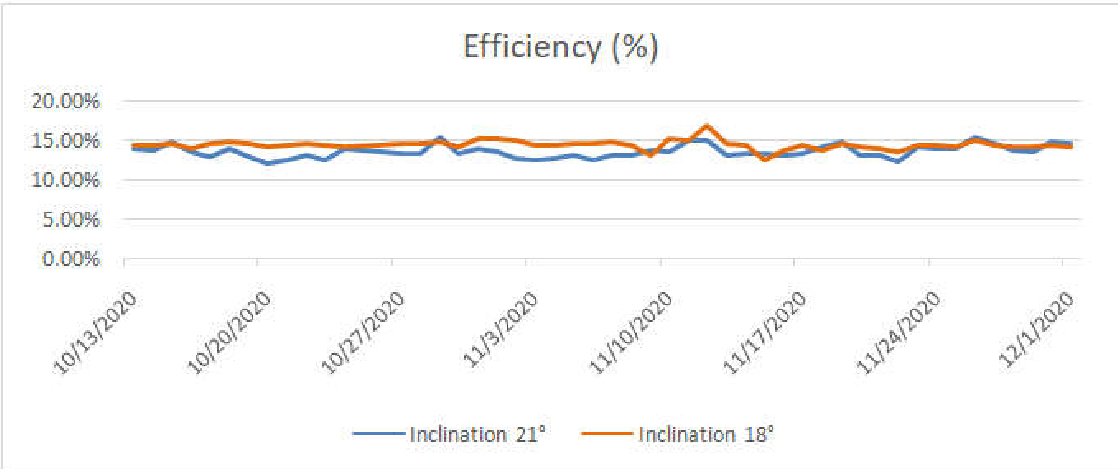


Figure 4. Efficiency (%) vs. Time (day) for the 18° and 21° panel.

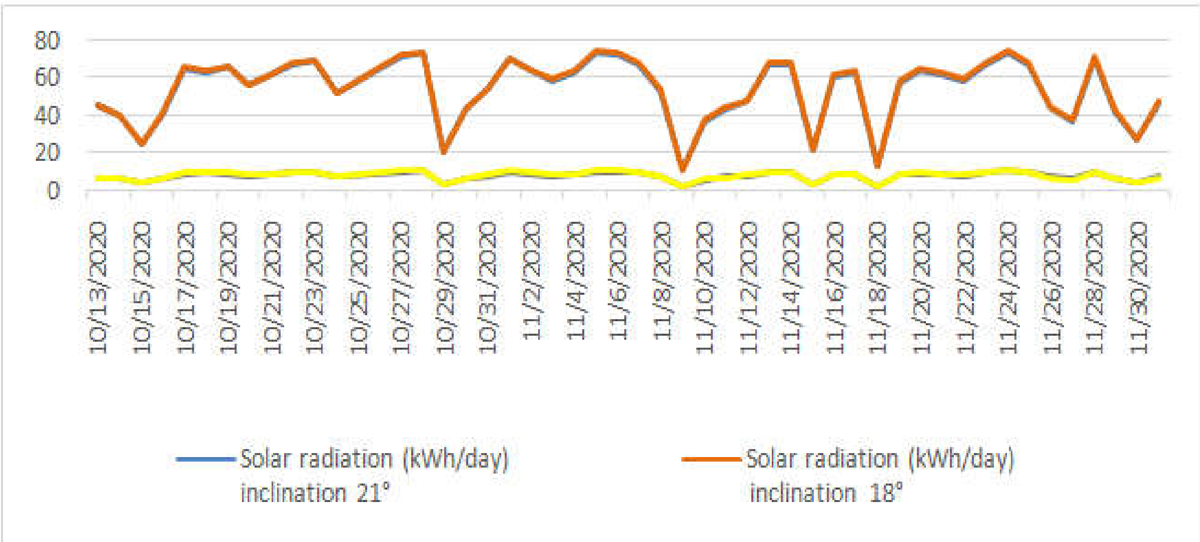


Figure 5. Solar radiation (kWh/day) at 18° and 21° inclination, and power generation (kWh/day) at 18° and 21° inclination

Table 2 is corrected solar irradiation for inclinations of 18°, 21°, and 26° with the equations proposed by Duffie and Beckman (2013) so that it can be compared with the data presented in Table 1. Table 2 is constructed from data collected from the solar irradiation of the pyranometer installed at Unioeste, and corrected for inclinations of 18°, 21°, and 26°. From the table, it is possible to observe that in the months of July, August, and September, the greater the inclination, the greater the capture of solar radiation received by the panel, and in September, the difference becomes negligible. In the following months, October, November, and December, the opposite can be observed; the lower the slope, the greater the solar radiation received by the panel, which is in accordance with Table 1.

Slope – Panel 1: 26° and Panel 2: 21°: From **Error! Reference source not found.**, we can verify the efficiency of each panel in the different inclinations that occurred from August 5 to September 26, 2020 (inclination of 21° in Panel 1 and 26° in Panel 2). It can be seen that the panel with an inclination of 26°(orange color)appears to have greater efficiency than the 21° tilt panel (blue color) in August and slightly lower efficiency than the 21° tilt panel in September. The average efficiency in the period estimated for Panel 1 was 14.22% and for Panel 2, it was 14.25%.

Finally, **Error! Reference source not found.** presents a graph of daily solar radiation (kWh/day) with the angle corrected to 21° and 26° and the energy generation of each panel. It is possible to verify that in August, the generation of energy and solar radiation in the panel with an inclination of 26° appears to be higher than that of the panel with a 21° angle. However, in September, the generation of the two panels seems to coincide, in accordance with Table 2, which presents the same radiation in September. The daily average of generation in the investigated period, for the respective slopes of 26° and 21°, was 7.08 kWh/day and 6.95 kWh/day.

When analyzing the results statistically, in the mean comparison test between the panels, we observe that Fcal<Ftal; hence, the hypothesis5_0 must be accepted. Here, the treatment means are statistically equal. The Tukey test was also applied to prove that the treatment means are equal to each other, as shown in Table 3. It is noted in Table 3 that the means do not differ from each other. This is in accordance with Figure 2 and Table 2, which shows that the solar irradiation in the analyzed period is very close when compared to the angles of 21° and 26°.

Slope – Panel 1: 18° and Panel 2: 21°: In Figure 4, it is possible to analyze the efficiency of each panel at different inclinations. It can be noted that the generation with an 18° tilt of the panel was graphically superior to the generation of the panel with a 21° tilt. Table 2 also indicates that the use of irradiation is higher with the lowest slope in the months of October, November, and December, which matches the time span of the period analyzed in this case study, from October 13 to December 1, 2020 (inclination of 21° in Panel 1 and 18° in Panel 2).The daily average efficiency of Panel 1 was 14.41%, and that of Panel 2 was 13.58%.

Figure 5 shows a graph of daily solar radiation (kWh/day) with the angle corrected for 18° and 21°,in addition to the energy generation of each panel. Note that energy generation and solar radiation are slightly higher at the 18° tilted panel compared to the panel that remains tilted at 21°.The average daily generation in the period studied for the respective 18° and 21° slopes of Panel 1 was 7.84 kWh/day and 7.19 kWh/day.

Using the same tests as in Section 3.2.1, in the mean comparison test, Fcal>Ftal. Hence, the 5_0 hypothesis should be rejected, in which the treatment means are statistically different. The Tukey test was also applied to confirm that the treatments differ from each other. The results are shown in Table 4. Table 4: Average values of efficiency regarding the inclination of the panels: Panel A: 18° and Panel B: 21°

significantly according to Tukey's 5% significance test.

By exploring Table 4, it can be concluded that changing the inclination of the modules in the period analyzed resulted in the averages of their efficiencies being different from each other. Furthermore, it was observed that the average of Panel 2 (B) is lower than the average of Panel 1 (A), which was to be expected, as in Table 2,we observe that the irradiation on the panel with lower slope is higher. Several studies have already been carried out in relation to the generation of electricity through PV panels and their inclination. Moncos (1994) presented a study in which he changed the angle of inclination of solar panels eight times a year, in the city of Assuit in Egypt, and achieved an annual gain of 6.85% of the total radiation, when compared to a panel, in the same city, which had a fixed angle of 27° at equal latitude. Notton, Lazarov, and Stoyanov (2010) emphasized in their study the importance of the orientation of photovoltaic systems, as the generation performance is directly dependent on the bank angle and azimuth orientation. Kormann *et al.* (2014) compared the effect of change in the inclination of panels in two cities, one close to the Equator (Petrolina) and another located in southern Brazil (Florianópolis).It was concluded that the smallest influence on energy generation, by varying the angles of inclination of the panels, occurred in the city of Petrolina.

Gasparin and Krenzinger (2016) analyzed annual energy production in their study, using different inclinations of the PV modules, and found a range of inclination and orientation of the PV arrangement in which the annual production of electricity differed by approximately 1% in relation to the reference PV system. Sedraoui *et al.* (2017) showed in a study in the city of Jeddah, Saudi Arabia that it was possible to make optimal use of radiation during the year when the inclination of the modules is changed monthly; monthly modification presented a greater energy generation than changes made over larger periods (quarterly, semiannually, and annually). Thus, the works mentioned in this section also showed that there were differences in energy generation when a change in the angle of inclination of the panels occurs. Some studies agree that changing the slope of the modules during the year makes the gain in power generation greater than keeping the angle fixed throughout the year.

CONCLUSION

This study presents evidence that the efficiency of the PV arrangement is influenced by the inclination of the panels. Analyzing the slope, in the first case study (Panel 1: 26° and Panel 2: 21°),the difference between the daily efficiency averages of the two panels was not significant. However, in the second case study (Panel 1: 18th and Panel 2: 21st), Panel 1 had an average efficiency of 14.41%, whereas Panel 2 had an efficiency of 13.58%.Therefore, when the inclination changed from 21° to 18°, in the period analyzed, there was an increase in the average efficiency of 6.11%.

REFERENCES

Bluesol, Energia Solar 2016. Livro Digital de Módulos Fotovoltaicos: Características Técnicas e Rendimento Energético.

CEPEL - CRESESB.Manual de Engenharia para Sistemas Fotovoltaicos. 2014. Disponível emhttp://www.cresesb.cepel.br/publicacoes/download/Manual_de_Engenharia_FV_201 4.pdf

Duffie, JA, Beckman, WA 2013. Solar Engineering of Thermal Processes, 4nd ed. University of Solar Energy Laboratory of Wisconsin-Madison, Nova Jersey.

Gasparin, FP, Krenzinger, A 2016. Desempenho de um sistema fotovoltaico em dez cidades brasileiras com diferentes orientações do painel. Revista Brasileira de Energia Solar Ano 8, Vol VIII, Número 1, pp. 10-17.

Kazem, H.A., Chaichan, M. T. 2016. Experimental analysis of the effect dust's physical properties on photovoltaic modules in

Desenvolvimento de mapas de avaliação do desempenho de sistemas fotovoltaicos em diferentes ângulos de inclinação e de azimute. Avances en Energias Renovables y Medio Ambiente. Vol. 18,pp 04.01-04.08.*ISSN: 2314-1433*.

Leite, Acqb 2017. Rastreamento da Máxima Potência utilizando o método baseado na medição de temperatura com modulação OCC Digital.Dissertação de Mestrado. Universidade Federal do Rio Grande do Norte, Natal, Brasil.

Marangoni, F 2012. Inversores Monofásicos para Conexão de Sistemas Fotovoltaicos à Rede. Dissertação Mestrado em Engenharia elétrica. Universidade Tecnológica Federal do Paraná, Pato Branco, Brasil.

Moncos, V. H.2014. Optimum tilt angle and orientation for solar collectors in Assiut/Egypt. Renewable Energy. Vol 4, pp. 291-298. 2014. *DOI: 10.1016 / 0960-1481 94 90032-9*

Nepal, P.,Korevaar, M.,Ziar, H., Isabella, O., Zeman, M. 2018 Accurate soiling ratio determination with incident angle modifier for pv modules. *IEEE Journal of Photovoltaics*. Vol 9, pp. 295-301. *DOI:* 10.1364/OSE.2018.OM3D.3.

Notton, G., Lazarov, V., Stoyanov, L. 2010. Optimal sizing of a grid-connected PV system for various PV module technologies and inclinations, inverter efficiency characteristics and locations. Renewable Energy. Vol 35, pp. 541-554. *DOI:* 10.1016/j.renene.2009.07.013.

Oliveira Junior, C.J. *et al*. 2018. Design, analysis and performance of a bidirectional solar inverter with a global and independent maximum power extraction technique. IET Power Electronics. Vol 11, pp. 221 - 228. *DOI: 10.1049/iet-pel.2017.0342.*

Sedraoui, K., Ramili, M. A., Mehedi, I. M., Hasbi, M., Hiendro, A. 2017 Optimum orientation and tilt angle for estimating performance of photovoltaic modules in western region of Saudi Arabia. Journal of Renewable and Sustainable Energy. Vol. 9. *DOI:* 10.1063/1.4979138

Sehnem, J. M., Michels, L., Zimermann, H. R. 2018. Simulações numéricas para determinação de inclinações ótimas para módulos fotovoltaicos. VII Congresso Brasileiro de Energia Solar. Departamento de Física. Universidade Federal de Santa Maria. Gramado, Brasil.

Villalva, M,Gazoli, J R 2012. Energia Solar Fotovoltaica – Conceito e Aplicações. 1nd ed. Érica, São Paulo, Brasil.

Zago, EA2017 Desempenho de um sistema de irrigação por gotejamento utilizando energia fotovoltaica. 2017. Dissertação Mestrado em Engenharia de Energia na Agricultura. Universidade Estadual do Oeste do Paraná,Cascavel, Brasil.

****