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Study of the Nebulosity Influence in Photovoltaic System Installed in the Green Office of UTFPR

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Abstract. Since 2015, the photovoltaic solar energy has had a significant increase of its installed power in Brazil, which has great potential for the generation of electrical energy with the use of photovoltaic systems due to its high irradiation index. However, a problem for the generation of electric energy by the means of photovoltaic systems is the fact that the shadow existence impacts directly the generation, as a result of the reduction of the incident irradiance in the panels. The factors which can cause shadow effect are the external solid bodies and cloudiness, which can have its effect on photovoltaic systems increased by the cloud position in relation to the sun. Thus, this article is a study about the cloudiness influence in a photovoltaic system connected to grid, denominated Green Office of the UTFPR. For that, clearness index analyses (Kt), the daily energy generation and the productivity (YIELD) have been analyzed for some different cloud conditions: clear skies, few clouds, high cloudiness, and considerable rainfall. The results showed the direct relation of the clearness index with the productivity and the electric generation of the panel, whose values were higher in the higher Kt cases.

Key words. Renewable energy, photovoltaic solar energy, cloudiness, productivity, clearness index.

1. Introduction

For [1], the solar energy is responsible for practically all the terrestrial cycles, then it is one of the most promising alternatives to provide the indispensable energy to human development. One of the forms of solar exploitation is photovoltaic solar energy, which can convert solar energy into electric energy [2].

According to [3], besides the fact that it is a clean and renewable energy, there are lots of favourable factors for the use of photovoltaic solar energy, such as the installation near the place where there is consumption, the low maintenance index, immediate power generation after installation, quiet operation and the possibility of reinstalling in other places due to its modularity.

This source of generation of energy is promissory and it is in expansion in Brazil, according to data presented for [4], there was significant increase since 2015 of the installed solar PV power in the country, whose annual installation was 1446 grid-connected systems in the above-mentioned year, followed by consecutive increases in subsequent years, as in the case of 2018 in which 35505 distributed generation systems were installed.

According to [5], some factors were preponderant to increase the use of this generation source in Brazil, such as: Normative Resolution 482/2012 of ANEEL, the increase of government incentives and the scientific development of related topics.

Nevertheless, for [6], the performance of the photovoltaic solar energy is susceptible to different external factors. For [7], lots of parameters can influence photovoltaic systems, such as temperature, soling effect, partial shadow and irradiation. Thus, as a result of the increase of the use of these systems in Brazil, there is the necessity of the study of the photovoltaic behaviour of the photovoltaic systems exposed to Brazilian weather conditions.

About the city of Curitiba, there are studies about the influence of several meteorological factors on the performance of photovoltaic panels, such as the study on the influence of the temperature performed by [8], and the soling effect by [9]. However, there are no studies regarding the impact caused by the cloudiness on the performance of photovoltaic systems in this city.

The influence of this factor is related to the shading phenomenon. For [10], there are two possible forms of shading of photovoltaic panels: external obstacles and the presence of clouds. The effect of solar radiation on solar radiation caused by blocking and scattering phenomena causes a reduction in the energy generated by photovoltaic panels, in addition to the transient generation that is incompatible with the distribution network standard [11].

Furthermore, according to [12], clouds that completely block the solar disk may be responsible for the total blockage of the direct component of solar radiation. This is a critical situation for the fact that, according to [6], although using the diffuse component of solar radiation, most of the solar photovoltaic energy utilization is of the direct component.

Then, the study of this meteorological factor influence in the productivity of photovoltaic systems has great relevance. For this, it is necessary the analysis of the conditions of cloudiness in a certain place and of the photovoltaic generation under these conditions.

One of the characterization ways of cloudiness condition in a certain place is the clearness index (Kt): when its values are high there is reduced quantity of clouds in the sky, while in cases whose values are low there is elevated quantity of clouds in the sky[13].

Because of the importance of the study of the influence of different nebulosity levels interacting with photovoltaic systems, this study performs the estimation of the clearness index on days with different cloudiness characteristics, together with the generation and productivity analysis of a photovoltaic panel installed in Curitiba, at a facility called Green Office of UTFPR.

2. Methodology

The study was carried out in relation to a polycrystalline photovoltaic panel, whose power is 2.1 kWp, installed in the UTFPR Green Office in Curitiba.

For the study of the influence of cloudiness, 13 days between May and June 2019 were selected with different cloud conditions: clear skies, few clouds, high cloudiness, and considerable rainfall.

Firstly, the estimations of the Kt were carried out for the days above mentioned, after that the data of the generation of the photovoltaic system installed in the Green Office UTFPR were collected, and the values of the productivity (YIELD) of each day were calculated.

For the estimation of the Kt values, the equation (1) was used, from [13], where H is radiation at the earth's surface, Ho is the extra-terrestrial radiation and Kt is the clearness index.

$$K_t = \frac{H}{H_o} \tag{1}$$

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The irradiation at the earth's surface data were retrieved from a pyranometer CMP 03, of the *Kipp&Zonen* manufacturer, utilizing a CR1000 datalogger from the Campbell Scientific manufacturer, installed in the UTFPR, while the extra-terrestrial irradiance data were calculated through of Eq. (2).

$$H_o = \frac{24}{\pi} \cdot G_{sc} \cdot \left[1 + 0.033 \cdot \cos\left(\frac{360}{365} \cdot n \right) \left(\cos\phi \cdot \cos\delta \cdot sen\omega + \frac{\omega\pi}{180} \cdot sen\phi \cdot sen\delta \right) \right] \tag{2}$$

In this equation δ is the declination angle, ϕ is the latitude, ω is the hour angle at sunset, Gsc is the solar constant and n is the day of the year. The UTFPR Green Office latitude was used for the calculus.

The generation data of the photovoltaic panel installed in the UTFPR Green Office was used for the performance analyses. From these data, the figure of merit YIELD (kWh / kWp) was calculated, considering only the generation day, by means of Eq. (3).

$$YIELD = \frac{E_n}{P_o} \tag{3}$$

Being *En* the daily generated energy (kWh), and *Po* the panel potency (kWp).

For the classification of weather condition of the studied days, data from 20 years of rain condition and 8 years of irradiation condition were used, represented for (Table I) and (Table II), respectively. (Table I) represents the monthly average provided by [15] divided by the number of days of the month, with the objective of an analysis of the daily average. While (Table II) represents the monthly average between the all daily values of each month.

Table I. – Average of rain condition in Curitiba on May and June (mm)[15]

YEAR	MAY	JUNE
1999	2.277419	2.703225806
2000	0.590323	3.812903226
2001	6.229032	4.667741935
2002	4.406452	1.503225806
2003	0.819355	3.14516129
2004	4.341935	1.883870968
2005	3.380645	2.135483871
2006	0.645161	0.929032258
2007	6.045161	0.064516129
2008	1.419355	3.232258065
2009	2.374194	2.032258065
2010	2.503226	2.696774194
2011	1.019355	3.264516129
2012	1.909677	7.090322581
2013	2.116129	10.29032258
2014	2.806452	6.787096774
2015	3.712903	2.651612903
2016	4.590323	4.222580645
2017	2.841935	6.15483871
2018	0.883871	2.935483871
2019	6.63871	3.964516129
Total Average	2.931029	3.62703533

Table II. – Average of Irradiation condition in Curitiba(kWh/m²) [16]

YEAR	MAY	JUNE
2012	2.78	2.15
2013	3.07	2.39
2014	2.96	2.59
2015	2.78	2.94
2016	2.61	2.59
2017	2.75	2.9
2018	3.51	2.43
2019	2.5	3.12
Total Average	2.87	2.63875

The low values of the (Table II) can be explained by the year period of them, in Curitiba, the studied city, May and June are months in autumn and winter, what cause reduction in the irradiation levels and, consequently, the energy generation reduction.

With the data values, the classification of the studied days was done according to (Table III). For being more conservative, the chosen values for (Table III) were related to the highest value of irradiation total average value (in May), and the lowest value of rain total average value (in May).

	IRRADIATION (kWh/m²)	DAILY RAIN (mm)
Considerable Rainfall	(lower than) 2.87	(Higher than) 2.93
High Nebulosity	(Lower than) 2.87	(Lower than) 0.293
Few Clouds	(Higher than) 2.87	0
Clear Sky	(Higher than) 2.88	0

Table III. – Classification of the weather condition in Curitiba in May and June

The difference between the classification in Few Clouds and Clear Sky days were done by the analyses of the daily irradiation curve. Besides, the rainy days with rain values lower than 0.293 mm were consider as high nebulosity days.

3. Results and Discussions

The obtained results were divided in three different sections: clearness index, electrical generation, and productivity (YIELD).

A. Clearness index

The results obtained for the means of the clearness index calculus has shown lower values in rainy days, due to the low daily irradiation on the earth's surface. Besides, the highest values were, as expected, in few clouds and clear skies days, in which the daily irradiation on the earth's surface was the highest. The clearness index days found for all the studied days are represented for (Table IV).

Table IV. – Clearness index (*Kt*)

DAY	Kt	CLOUD CONDITION
05/11/2019	0.219537861	considerable rainfall
05/12/2019	0.315283856	high cloudiness
05/23/2019	0.065774332	considerable rainfall
05/29/2019	0.160446782	high cloudiness
05/30/2019	0.194313005	considerable rainfall
05/31/2019	0.000110996	considerable rainfall
06/04/2019	0.748049206	few clouds
06/05/2019	0.3580285	high cloudiness
06/07/2019	0.717712443	clear sky
06/08/2019	0.699969019	few clouds
06/09/2019	0.699525956	clear sky
06/12/2019	0.626502124	few clouds
06/13/2019	0.651438213	few clouds
06/14/2019	0.647899837	few clouds

The clouds existence in determinate periods during the day reduces the daily measure irradiation, which causes lower clearness index values. There is a great difference between the values of clearness index in days with high cloudiness and of few clouds: the relation between the maximum values of days with high cloudiness and of few clouds was 47.86 %.

Some of the values found in the condition "few clouds" have results near to one of the values of the condition "clear sky". A situation that may be due to the number of clouds, the time in which the PV panel was shaded and the type of cloud present at the moment of shadowing.

Fig. 1 shows the relation of the clearness index with the cloudiness condition of the days studied.

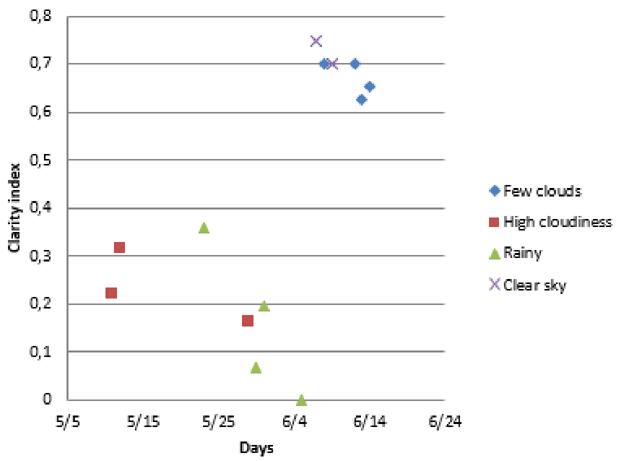

Fig. 1. Clearness index in each nebulosity condition

B. Electrical generation

The electrical generation of the UTFPR Green Office photovoltaic system was distinct in the studied days: in days with less cloudiness there was greater generation of energy and in days of greater cloudiness and rain there was less generation of energy.

There were two zero values, generated in rainy days, in which the daily irradiation measure were low. However, the other rainy days had different values, such as the case of the day 05/11 that got higher generation than the day 05/29, classified as "high cloudiness". In addition, the generation on the days of clear sky were superior in at least 1 kWh to the generation in the days with other conditions of cloudiness, because in the two days of clear sky the generation was of 9kWh, whereas in the days with few clouds the generation ranged between 6kWh and 8kWh. Table V shows the generation values found.

Table V. – Electric Power Generation

DAY	CLOUD CONDITION	DAILY ELECTRIC GENERATION(kWh)
05/11/2019	considerable rainfall	3
05/12/2019	high cloudiness	3
05/23/2019	considerable rainfall	0
05/29/2019	high cloudiness	2
05/30/2019	considerable rainfall	1
05/31/2019	considerable rainfall	0
06/04/2019	few clouds	6
06/05/2019	high cloudiness	4
06/07/2019	clear sky	9
06/08/2019	few clouds	8
06/09/2019	clear sky	9
06/12/2019	few clouds	7
06/13/2019	few clouds	8
06/14/2019	few clouds	7

Fig. 2 shows the generation in relation to the cloudiness condition in the days studied: in red they are the values of the days of clear sky, in yellow the days of sun with few clouds, in green the days of high cloudiness and in blue the days of rain.

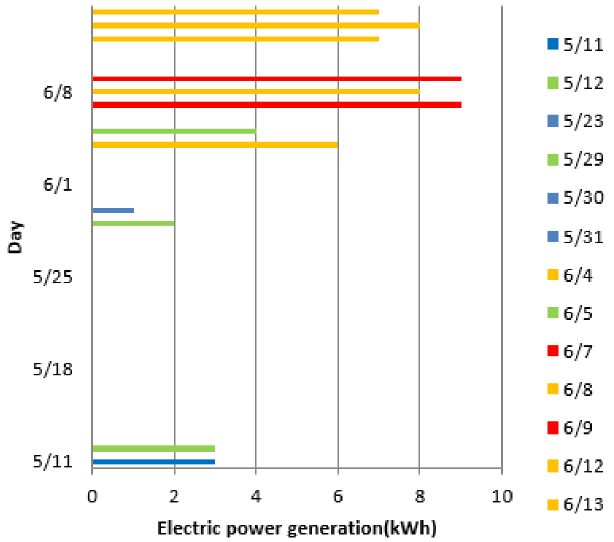

Fig. 2. Electrical power generation in each nebulosity condition

C. Productivity

The rainy day's YIELD values were the lowest, while the ones obtained in clear skies days were the highest. The days of few clouds obtained values considerably higher than the ones referring to the high cloudiness, even in the case of the lower value of this condition of cloudiness, whose value found was of 2.857143. Table VI shows the productivity values obtained on the days studied.

Table VI. – Productivity

DAY	CLOUD CONDITION	DAILY YIELD (kWh/kWp)
05/11/2019	considerable rainfall	1.428571
05/12/2019	high cloudiness	1.428571
05/23/2019	considerable rainfall	0
05/29/2019	high cloudiness	0.952381
05/30/2019	considerable rainfall	0.47619
05/31/2019	considerable rainfall	0
06/04/2019	few clouds	2.857143
06/05/2019	high cloudiness	1.904762
06/07/2019	clear sky	4.285714
06/08/2019	few clouds	3.809524
06/09/2019	clear sky	4.285714
06/12/2019	few clouds	3.333333
06/13/2019	few clouds	3.809524
06/14/2019	few clouds	3.333333

The highest value of a day with few clouds obtained YIELD value equivalent to 88.89% of a day with clear sky, while the highest value of a day classified as "high cloudiness" was equivalent to 44.44% of a day with clear sky, and the highest value of a day classified as "considerable rainfall" were 33,33% of the value of a day with clear sky.

The relation between the daily values of productivity and the clearness index, found for the same studied days, is presented in Fig. 3.

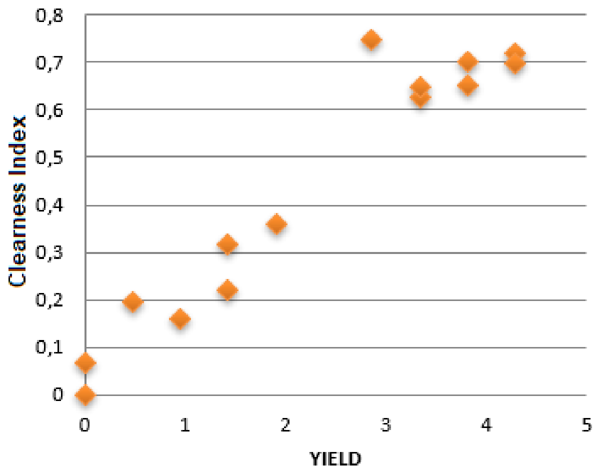

Fig. 3. Relation of YIELD and the clearness index

In general, in cases of higher values of atmospheric clearness, there were higher values of YIELD, and the days with a higher clearness index, between 0.6 and 0.75, obtained YIELD values of at least 2.857143. On the other hand, rainy and high cloudiness days obtained values of clearness index ranging from 0 to 0.35 and YIELD values between 0 and 1.91.

4. Conclusions

The clearness index allows the study that can characterize the atmospheric conditions of a certain day and then it is possible the analysis of the cloudiness, which is one of the main loss factors in photovoltaic systems.

The electrical generation values of the photovoltaic system were related in a direct form to the clearness index. The minimum generation difference between the days with clearness index inferiors to 0.4 and the days with clearness index superiors to 0.65 was approximately 50%.

The difference between the productivity of days with Kt values lower than 0.4 and higher than 0.62 was at least 57,14%. This fact confirms the direct relation of the increase of daily values of YIELD with the values of clearness index. Besides, the highest values were found in days with clear sky condition, with a minimum difference of 12.49% of the values of the days with few clouds.

The days with considerable rain obtained low values of generation, likewise of productivity, unlike what happens in days with few clouds and clear sky, in which the generation was high, as well as YIELD. Thus, there is a considerable influence of atmospheric conditions, and of cloudiness, in the generation and productivity of photovoltaic panels.

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