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Analysis of the energy conversion efficiency of photovoltaic panels installed on reflective and opaque surface

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Abstract. This paper analyzes the energy conversion efficiency of photovoltaic systems installed on surfaces with different albedo and emissivity indexes. Two sets (A and B) were set up, where, in Set A, a photovoltaic system was installed on galvanized steel roof and, in set B, a photovoltaic system was installed on the same roof, which was coated with reflective paint composed by hollow ceramic microspheres. Temperature data (roof surfaces and solar panel), voltage, current and electricity generation of the two photovoltaic systems were monitored. The results showed that panels installed on the roof coated with reflective paint have better energy conversion efficiency, producing about 2.56 % more electricity than photovoltaic panels installed on uncoated roof.

Key words

Albedo, energy conversion efficiency, photovoltaic panel, reflective paint.

1. Introduction

Solar radiation is the transmitted energy of the sun that reaches our planet through electromagnetic waves with frequency and different wavelengths [1, 2, 3].

Every earth's renewable energy sources are generated from solar radiation, which can be converted directly or indirectly into energy using various technologies [4].

Photovoltaic panels (PV) generate energy from the photovoltaic effect, which consists in transforming the energy contained in the light radiation into electrical energy. This effect occurs in certain semiconductor materials with the ability to absorb energy contained in the photons present in the incident light radiation, transforming it into electricity [5, 6, 7, 8].

There are a number of factors that make the use of photovoltaic solar energy unfeasible, mainly linked to solar cells, which, for the most part, have a high cost and low efficiency of converting the radiation into electricity. Studies presented by [9, 10]) indicate that the operating temperature of the solar cell interferes directly on the efficiency of these devices. The sunlight that hits the panel and is not converted into electricity is converted to thermal energy, increasing the junction temperature in the cell.

Cooling techniques of photovoltaic panels are becoming more widespread, promoting the dissipation of the heat causing the cells to work in ideal conditions [11].

The ideal conditions of PV installation correspond to places with high solar radiation indexes and low temperatures. This paper proposes to analyse the improvement on the energy conversion efficiency of photovoltaic panels installed on surfaces with different albedo indices. An experiment was carried out on galvanized steel roof at the Federal Institute Goiás, located in Goiânia city, Brazil, in order to monitor the temperature (environment, photovoltaic panel and roof surface), current, voltage and electricity generation data, of a photovoltaic systems installed on surface with different albedo and emissivity indices.

2. Methodology

Two areas of 20 m² each were delimited in order to evaluate the interference of the installation surface of photovoltaic systems in its temperature and energy conversion efficiency. In each area it was installed a photovoltaic system consisting of: i) two polycrystalline silicon photovoltaic panels of 250 Wp each, connected in parallel and installed without angulatuions over the roof surface and ii) a microinverter YC 500 (500W).

Each photovoltaic system installed in areas A and B are referred in this paper to Set A and Set B, respectively.

Figure 1 illustrates the arrangement of the two areas used for installation of the two PV systems, described in the image as areas A and B. PV system were installed in a galvanized steel roof in the dependencies of the Federal

Institute Goiás, located in the city of Goiânia, Goiás State, Brazil.

Fig. 1 – Roof areas used to install the PV systems

In Set A, characterized as a reference roof, the original characteristics of the roof were not changed. The roof of Set B was coated with a Nanothermic 1 reflective paint composed of hollow ceramic microspheres.

Each PV system was installed as shown in Figure 2, where I_1, I_2 and V_1, V_2 are photogenerated currents and output voltage of the two panels, respectively.

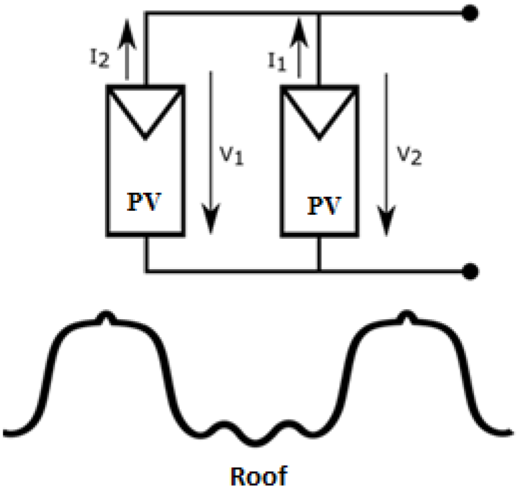

Fig. 2 - Configuration of each PV system

In both sets the output voltage, current, electricity generation and surface temperatures of the PV were monitored. Data were monitored in a period from July 15 to July 21, 2017. Measurements were performed from 8 a.m. to 6 p.m., with data acquisition intervals equal to 5 minutes.

Temperature monitoring

In order to storage data of roof, solar panel and ambient temperatures, three data loggers were attached to each set: i) in contact with the roof plate; ii) in contact with the panel; iii) in contact with air in the installation environment.

Monitoring of electrical quantities

For energy data analysis the Fluke 430 series II energy analyser was used. Figure 3 shows the connection of the energy analyzer to the distribution center

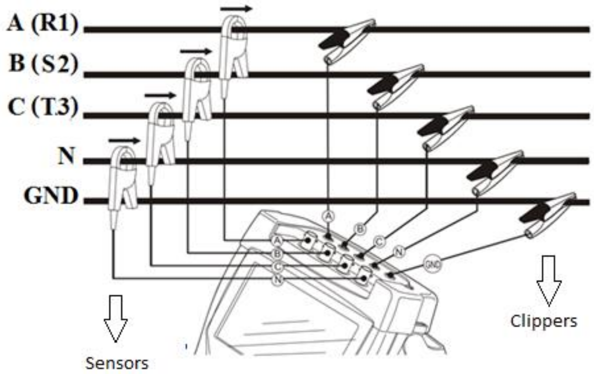

Fig. 3 - Connecting the Fluke Analyzer to the Power Distribution Bord

The clutches of the equipment were connected to the conductors of the switchboard. In order to obtain the current values, "hall" type sensors were used. To obtain output voltage values, the equipment clamps were connected to the electrical connections of each phase (A, B, C). The symbol N represents the neutral conductor and the GND the conductor of protection.

3. Results

The measurements in the two photovoltaic systems occurred during a period of 7 days. Temperature data (roof, panel and ambient), current, voltage and energy was performed from July 15 to July 21, 2017. Table 1 shows the energy produced by Set A and Set B at the end of 10 hours per day and the total energy produced during a week of measurements.

Table 1 - Energy produced by the Set A and Set B

Day	Energy produced in Set A (EP_A) [W]	Energy produced in Set B (EP_A) [W]	$EP_B - EP_A$ [W]
1	23108.19	23761.42	653.23
2	23913.54	24655,43	741.88
3	23746.79	24395.22	648.42
4	24079.98	24665.37	585.38
5	23558.49	24053.86	495.37
6	22113.53	22650.84	537.30
7	21475.58	21956.81	481.23
Total	**161996.14**	**166138.98**	**4142.84**

By analyzing Table 1 it is possible to note that the energy production of Set B is 2.56 % higher than the Set A. The difference of 4142.84W is due to the characteristics of the installation area of the Set B that has high emissivity and low absorbance indexes. This fact contribute to decrease the local ambient temperature at the place where the panels were installed. The drop in ambient temperature interfered in the operating temperature of the panels, increasing the voltage and output power, improving the panels efficiency.

Table 2 shows the maximum and minimum ambient temperatures (in the installation environments) of the two analyzed sets during the seven days of measurement.

Table 2 – Maximun and minimum ambient temperatures of Set A and Set B

Day	Maximum Temperature [ºC]		Minimum Temperature [ºC]	
	Set A	Set B	Set A	Set B
1	35.62	33.8	20.14	18.88
2	37.43	34.76	20.27	18.47
3	42.03	35.95	20.14	19.36
4	32.28	28.91	13.19	11.3
5	38.12	34.26	12.16	13.0
6	40.85	37.64	18.14	17.21
7	38.89	36.98	16.14	15.9

The maximum ambient temperature recorded in Set A was 40.85 °C in measurement 6, recorded at 1 p.m., while the minimum temperature in that set was 12.16 °C recorded in measurement 5 at 8 a.m.. In set B, the minimum temperature recorded was 11.3 ºC in the measurement 4 at 8:10 a.m., while the highest temperature in the whole measurement period was 37.64ºC at 0:40 p.m..

Table 3 shows the temperature data (maximum and minimum) registered of the roof surface.

Table 3 - Maximun and minimum roof surface temperatures of Set A and Set B

Day	Maximum Temperature [ºC]		Minimum Temperature [ºC]	
	Set A	Set B	Set A	Set B
1	48.44	40.61	15.66	20.14
2	53.61	42.88	16.02	19.57
3	49.64	42.64	17.04	20.23
4	43.67	38.7	11.36	12.78
5	49.85	41.53	10.77	14.84
6	56.69	47.36	17.16	18.29
7	58.59	44.54	14.61	17.65

By analyzing Table 3, it can be observed that the maximum temperature of the roof surface recorded in the Set A was 58.59 °C, in the measurement 7, at 02:56 p.m., while the minimum temperature in the same conditions was 10.77 °C, in measurement 5, at 8 a.m..

Table 4 presents the values of maximum and minimum temperatures of the photovoltaic panels installed in Set A and Set B.

By analyzing Table 4, it can be seen that the maximum panel temperature installed in set A during the seven days of measurement was equal to 55.77 °C at 00:54 p.m., in measurement number 6, while the minimum temperature was equal to 11.82° C at 8 a.m., in measurement 5.

Table 4 - Maximum and minimum temperatures of the photovoltaic panels installed in the Set A and Set B

Day	Maximum Temperature [ºC]		Minimum Temperature [ºC]	
	Set A	Set B	Set A	Set B
1	44.93	44.55	18.74	20.43
2	53.13	49.32	18.11	20.01
3	50.53	50.44	20.45	21.4
4	41.64	44.64	13.32	14.23
5	48.75	48.5	11.82	22.52
6	55.77	52.53	18.58	19.51
7	54.15	51.73	15.22	18.24

The maximum temperature of the panels of Set B was recorded in the measurement 6 at 1:35 p.m., with value equal to 52.53 °C. This value is 3.24 °C less than the maximum panel temperature installed in the set B. Already the minimum temperature recorded under these conditions was 14.23 °C in the measurement 4 at 8:05 a.m.. This value is 2.41 °C higher than the panel temperature installed in the set A.

The temperature of the photovoltaic panel and the voltage are variables that contribute to the energy conversion efficiency increasing of the Set B in relation to the Set A. The following results shows the behavior of such variables during the measurement period. The x-axis represents the measurement period, in hours; the y-axis represents the temperature and the output voltage of panels, in °C and Volts, respectively.

Figure 4 shows the behavior of the output voltage and temperature of the PV installed in Set A and Set B, during the first measurement day.

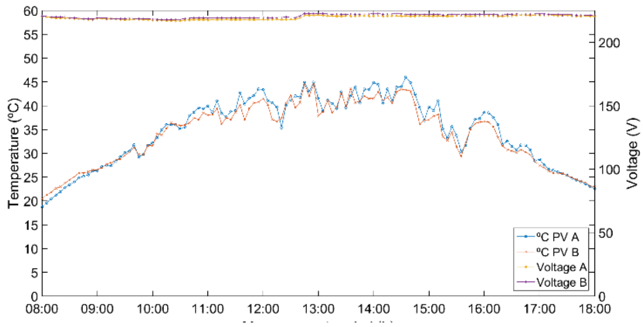

Fig. 4 - Behavior of the output voltage and temperature of the PV installed in Set A and Set B - First measurement day

The maximum voltage recorded on the day, analyzing the two sets, was equal to 222.95 V, with a temperature equal to 44.61ºC at 00:45 p.m. in the set B. At the same time, the voltage in the set A was equal to 221.06 V, with temperature equal to 44.96 °C. The voltage values in the two sets were lower in the period between 8:00 a.m. and

00:40 p.m., with a slight slope at 00:50 p.m., when the voltage remained stable without large oscillations until the end of the measurement.

Figure 5 shows the behavior of the output voltage and temperature of the PV installed in Set A and Set B, during the second measurement day.

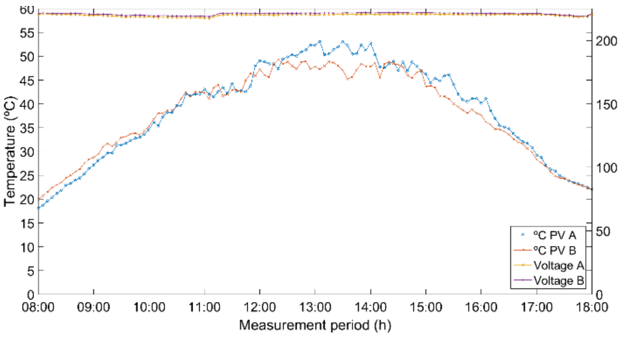

Fig. 5 - Behavior of the output voltage and temperature of the PV installed in Set A and Set B - second measurement day

The analysis of Figure 5 shows a slight decline in the voltage values of the two sets between 8 a.m.. and 11a.m.. From 11:10 a.m. on, the values increased and remained unchanged until 5:10 p.m.

Figure 6 shows the behavior of the output voltage and temperature of the PV installed in Set A and Set B, during the third measurement day.

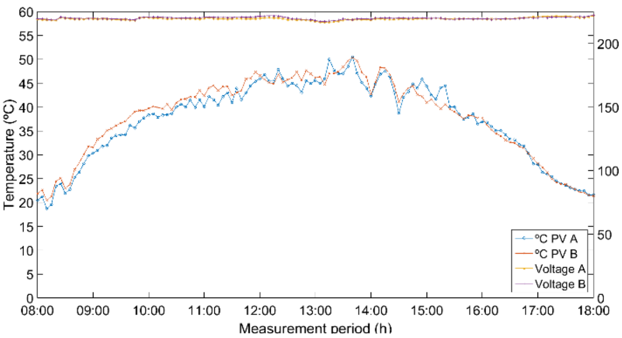

Fig. 6 - Behavior of the output voltage and temperature of the PV installed in Set A and Set B - third measurement day

On the third day of measurement, as well as in the other measurements that occurred from this day, the voltage values presented greater fluctuation than the previous measurements. This fact can be explained due to the activation of the most varied types of load that promotes small variations in the voltage values. In laboratory studies the voltage values are maintained by the constancy of the load, but the same does not happen in places with variable load, as the case of the Federal Institute of Goiás, where the experiment was set up.

The maximum output voltage equal to 211.77 V was recorded in Set B, with temperature equal to 44.88 °C. At the same time output voltage and the temperature of the panels installed in Set A recorded was equal to 220.26V and 45.43 °C, respectively.

Figure 7 shows the behavior of the output voltage and temperature of the PV installed in Set A and Set B, during the fourth measurement day.

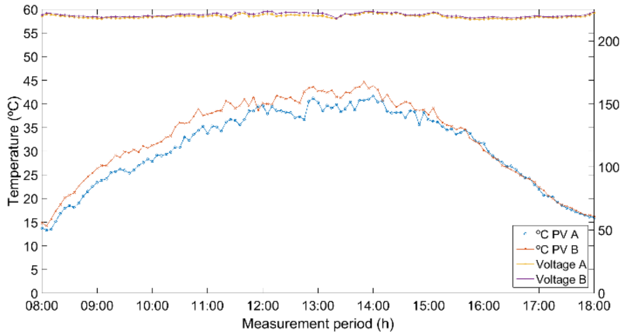

Fig. 7 - Behavior of the output voltage and temperature of the PV installed in Set A and Set B - fourth measurement day

The maximum output voltage was equal to 211.77 V recorded in Set B at 00:05 p.m., for a temperature equal to 44.88 °C. At the same time the output voltage and the temperature of the panels installed in Set A was equal to 2201.75 V and 39.9 °C, respectively.

Figure 8 shows the behavior of the output voltage and temperature of the PV installed in Set A and Set B, during the fifth measurement day.

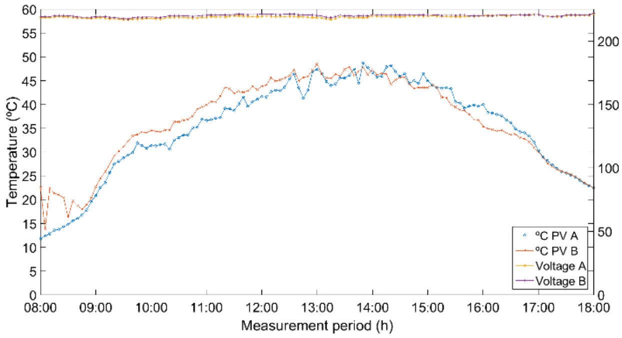

Fig. 8 - Behavior of the output voltage and temperature of the PV installed in Set A and Set B - fifth measurement day

The maximum output voltage value recorded on the fifth measurement day was equal to 221.38V in set B at 12:05p.m., with a temperature equal to 44.1 °C. At the same time, the maximum voltage recorded in the set A was equal to 219.7 V with a temperature equal to 41.57 ºC. From this moment on, there is a decrease on the output voltage of the Set A equal to 1.68V when compared to the output voltage of the Set B.

Figure 9 shows the behavior of the output voltage and temperature of the PV installed in Set A and Set B, during the sixth measurement day.

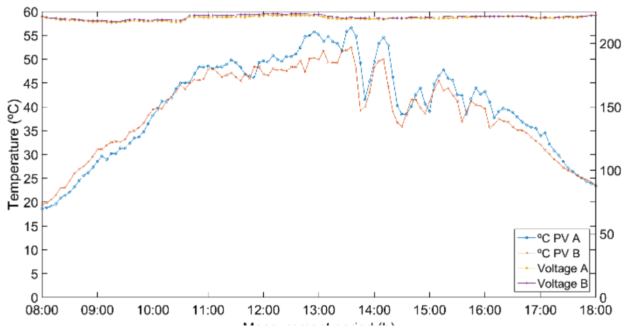

Fig. 9 - Behavior of the output voltage and temperature of the PV installed in Set A and Set B - sixth measurement day

The maximum output voltage value recorded on the sixth day of measurement was 223.63 V in set B at 12:05p.m., with a temperature equal to 49.36 ºC. At the same time the output voltage and the temperature of the panels installed in the set A was equal to 222.37 V and 49.36 ºC, respectively.

Figure 10 shows the behavior of the output voltage and temperature of the PV installed in Set A and Set B, on the last day of measurement.

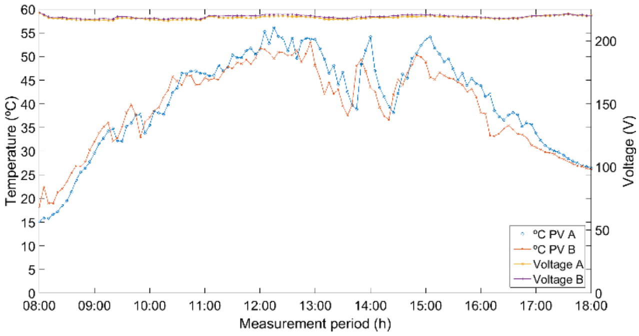

Fig. 10 - Behavior of the output voltage and temperature of the PV installed in Set A and Set B - seventh measurement day

The maximum output voltage value on the seventh day of measurement was 221.48V, recorded at 8 a.m. in set B, and the temperature was equal to 18.24 ° C. At the same time, the output voltage and temperature of the panel installed in set A and were 22.20 V and 18.24 ° C, respectively.

4. Conclusion

Photovoltaic panels installed on galvanized steel with reflective surface have higher energy efficiency than panels installed on galvanized steel surfaces. Energy efficiency varies according to the installation mode, such as the angulations of e panels and the roof surfaces. Roof surface material should have a low albedo index so that that the reflected heat be emitted to adjacent areas.

The results presented in this paper proved the efficacy of reflective paint, especially at high temperatures with high solar irradiance indexes. It has been found at the first and last measurement hours that when the level of solar irradiance is low, the uncoated roof exhibits lower temperature than the roof with the paint. At other times, the reflective paint cooled the roof by up to 17 ºC when compared to the galvanized steel roof.

High emissivity indices of the paint in consonance with low albedo indices promote the surface cooling due to the so called dissipation phenomenon of infrared wavelength.

The indices related to the thermal capacity of the material where the PV panels are installed interfere in their temperature, thus impacting the generation of energy by this kind of renewable source.

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