ENCIT 2018

ABCM Associação Brasileira de Engenharia e Ciências Mecânicas

17th Brazilian Congress of Thermal Sciences and Engineering
November 25th-28th, 2018, Águas de Lindóia, SP, Brazil

ENCIT-2018-0786
THERMAL ANALYSIS OF A PHOTOVOLTAIC SYSTEM WITH SOLAR TRACKING MIRRORS

Domisley Dutra Silva, domisleydutra@gmail.com
Renato Candido Reis, renatocandidoreis@gmail.com
Reinaldo Rodrigues de Souza, reisartre@gmail.com
João Batista Campos Silva, campos.silva@unesp.br
Elaine Maria Cardoso, elaine.cardoso@unesp.br
UNESP- São Paulo State University, Department of Mechanical Engineering, Av. Brasil, 56, 15385-000, Ilha Solteira, SP, Brazil.

Abstract. *The present work consists of designing and performing an experimental analysis of a photovoltaic (PV) system with solar tracking mirrors for taking advantage of the direct and diffuse solar radiation. The solar system is installed in the northwest region of the state of São Paulo. V-trough photovoltaic (PV) concentrator systems are designed to increase solar input to photovoltaic cells but an increase in the cell temperature can occur by increasing the incidence of solar radiation on the photovoltaic assembly. The study aims to analyze the temperature distribution and the occurrence of hot spots - points with temperature higher than the Nominal Operation Cell Temperature (NOCT) - in the photovoltaic panel caused by the effect of the solar concentration. The analysis takes into account the temperature in the photovoltaic cells, the local meteorological data and also the voltage and current generated by the PV system. Based on the results and analysis, it will be possible to verify if this V-trough photovoltaic (PV) concentrator system reduces the useful life of a commercial PV module, and to develop new technologies for an optimized use of solar energy by using low-cost devices.*

Keywords: *Photovoltaic solar energy, V-trough concentration system, flat mirrors, temperature distribution, hot spots.*

1. INTRODUCTION

The National Institute of Space Research (INPE) recently published the second edition of the Brazilian Atlas of Solar Energy (INPE, 2017) highlighting the main regions with the greatest capacity for installation of photovoltaic systems, where the incidence of solar radiation is favorable. This study brought new perspectives for the implementation of new photovoltaic power generation plants in regions outside the so-called Solar Belt, such as the northwest region of São Paulo. This region presents annual averages of global irradiation in a range from 5250 to 5500 Wh/m day (INPE, 2017). Also, according to the Brazilian Electricity Regulatory Agency (ANEEL, 2018), although the production of electric energy through solar photovoltaic technology has grown rapidly, it represents only 0.66% of the Brazilian electricity generation matrix what motivates research in this area.

Low concentration photovoltaic (LCPV) systems have a concentration factor less than 10 suns (Fraidenraich, 1998; Bett *et al.,* 2006; Luque and Andreev, 2007) and present the following advantages: LCPV can make use of conventional high performance silicon solar cells and they are less demanding in terms of tracking accuracy as compared to high concentration systems (Kurtz, 2009).

Chandel and Sharma (2013) analyzed the main factors affecting the photovoltaic system performance such as ambient temperature, wind speed, solar radiation, different PV technologies and different tilt angle of the PV module. The others parameters such as accumulation of dust on the photovoltaic panels were also analyzed. In addition, the researchers discussed the reliability problems that can only be determined by testing the modules under real operating conditions.

The current scientific production in the field of use of a V-trough solar concentrator is mainly concerned with the increase of electric energy production (Cazzaniga *et al*., 2011), leaving aside the thermal behavior of the PV panel due to the increase of the solar concentration, which can lead to a reduction in its useful life (Chandel and Sharma, 2013).

Ali *et al.* (2011) studied the thermal behavior of the photovoltaic module, taking into consideration the effect of the cell arrangement configurations in the PV performance. The results indicate that the cell temperature is the prevailing parameter affecting the module output power, more than the solar irradiance.

Reis *et al.* (2010) estimated the performance of a V-trough PV system mounted on a dual-axis tracking system. A numerical model to determine the energy yield of the DoubleSuns® solar concentration system was developed and showed an increase overall energy output of 86% attributed to both the tracking and concentration.

In this study, we analyze the temperature distribution in a PV panel with a low-cost tracking concentrator by using flat mirrors. Based on the experimental results, it is possible to verify the dependence of PV system performance, including its useful life, with the solar concentration and others parameters such as cell temperature distribution, ambient temperature, wind speed, and different tilt angle of flat mirrors.

2. METHODOLOGY

The experimental setup consists of a photovoltaic (PV) system with solar tracking mirrors with a uniaxial latitude tracking system. The installed PV panel is made by one polycrystalline silicon module (model RM60-6-270P) composed by 60 polycrystalline high efficiency cells (156 x 156 mm) distributed over an area of 1640 x 992 mm. Two flat mirrors, with dimensions of 3 x 1000 x 2000 mm and reflectivity of 85 to 90%, are responsible for concentrating the direct and diffuse solar radiation. Table 1 describes all the PV system components.

Table 1. Components of the photovoltaic system, including the solar tracking and concentration system.

Components	Function
Rigid tube base	Stabilization of the PV panel and the reflected mirrors, allowing the latitude rotation.
02 flat mirrors	Concentration of the solar radiation.
12 V linear actuator	PV system requires one actuator to rotate about a single axis.
12 V stationary battery	Power source for the tracking system.
Charge controller	Protects the battery from overcharging.
12 V halogen bulb	Resistive load.
64 digital sensors model DS18B20	Cell temperature measurements.
Arduino Mega 2560	Controls the tracking and the acquisition system.

The V-trough photovoltaic (PV) concentrator system is installed on a building rooftop (6 m height) allowing a realistic experimental approach to measure the individual cells temperatures in an open-circuit, short-circuit and in a resistive load scenario, and for two different conditions: with and without solar concentration. Current and voltage output is also measured for efficiency calculation. Based on the data obtained by the experimental apparatus shown in Fig. 1, the influence of the solar concentration on the photovoltaic conversion efficiency and on the temperature distribution on the PV panel are analyzed.

(a)

(b)

Figure 1. Experimental apparatus. (a) General view and (b) Front view.

In order to validate the PV system, tests without solar tracking mirrors (concentration system) were performed. The PV panel was adjusted facing north with a 20° tilt angle, which is close to the latitude of the investigated location (20° 25′ 58″ S) in northwest region of the state of São Paulo.

The electronic circuit responsible for data acquisition, treatment and storage is composed by an Arduino Mega 2560 and sub-components such as a timer clock control and a micro-SD card for data storage. In this development, Arduino is used as the main controller, including the tracking system.

The temperature distribution and energy efficiency are obtained from the following measurements:

- Temperature of each cell (T_{cell}, °C): measured on the back side of the PV panel at the center of the cell using a digital sensor (model number DS18B20), as shown in Fig. 2. The back side of the PV panel is thermally isolated.
- Ambient temperature (T_{amb}, °C): measured by using a thermometer located close to the assembly and isolated of the solar radiation.
- Current (I) and voltage (V): measured by the Arduino acquisition system.
- Wind speed (m/s), relative humidity (%) and global irradiation (W/m²): obtained by the CANAL CLIMA site (UNESP/Ilha Solteira).

Figure 2. (a) Digital temperature sensors (DS18B20) installed at the back side of the PV panel and, (b) diagram showing the location of each temperature sensor.

3. PRELIMINARY RESULTS

The temperatures of the cells were collected according described at the Section 2. Figure 3 shows the temporal surface temperature variation of the PV panel for the test performed on April 25th 2018, from 1:30 PM to 5:45 PM. The ambient temperature ranged from 28 °C to 33 °C. The cell temperature readings were taken every 10 seconds.

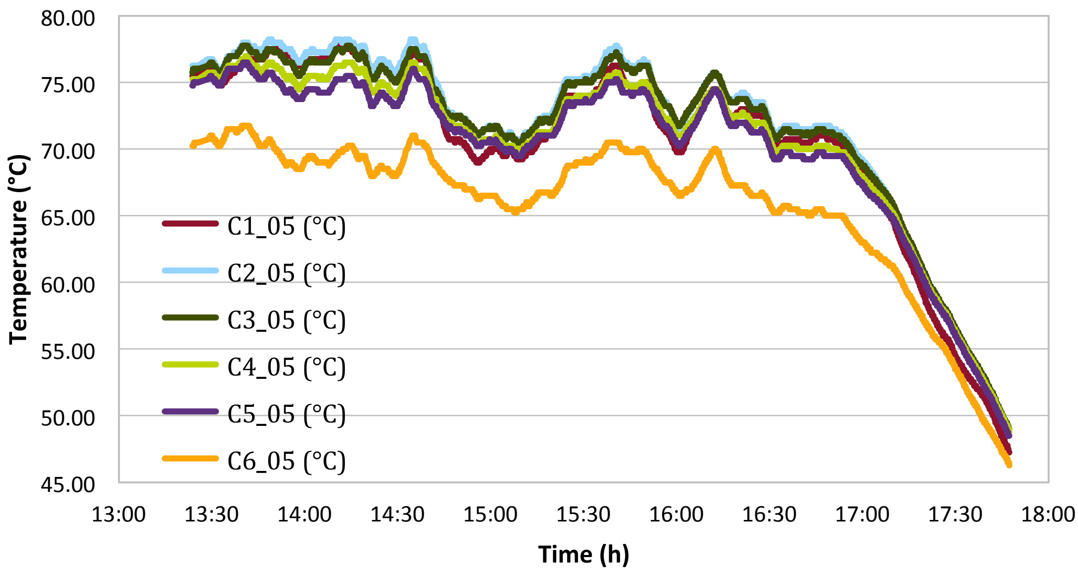

Figure 3. Temporal variation of the PV temperature measured at different points on the back surface of the panel.

The tracking system was not yet installed; therefore, the module was manually adjusted every 5 minutes. The adjustments were made measuring the voltage output. Each adjusted position corresponds to a maximum voltage value, which means that the module is facing directly at the sun.

Key to symbols of Fig. 3 represents the temperature distribution located at the central part of the PV panel, corresponding to the sensors highlighted in red in Fig. 2. The weather was sunny but some clouds appeared between 14:30 and 15:30 leading to a reduction in temperature as can be seen in Fig. 3. Moreover, it is observed a symmetric temperature distribution with the exception of sensor C6_05; this sensor is located at the left side of the panel (according to Fig. 1), whose position is farthest from the floor and the wall. Therefore, the lowest temperature showed by this sensor is probably due to the natural convection, which is more prominent on this side than that near the wall. Figure 4 shows the same temperature behavior, agreeing with the above explanation.

At 02:34 PM, the sensors recorded the maximum temperature for the experimental test; an interpolation of all measured temperatures in this period is shown in Fig. 4. The results show a temperature difference of around 10 °C between the sensors, being the sensors located at position C6 the ones with lowest temperature values.

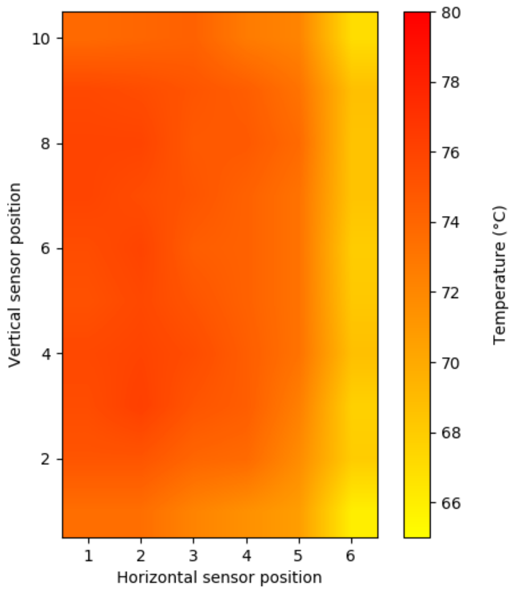

Figure 4. Temperature distribution on the PV panel for the maximum peak of temperature occurred at 02:34 PM (right side correspond to sensors located at position C6_01 to C6_10).

4. CONCLUSION

In the present work, we analyzed the temperature distribution over a PV panel with a uniaxial tracking system in a sunny day. The ambient temperature ranged from 28 °C to 33 °C. We observed a symmetric temperature distribution with the exception of sensor C6_05 (Fig. 3), probably due to the natural convection, which is more prominent on this side whose position is farthest from the floor and the wall. The temperature difference between the sensors ranged from 0°C to 5°C, showing that the panel has good uniformity, meaning that it has no manufacturing fault.

The temperatures of the cells reached values close to 78 °C, without solar concentration system installed; this value is close to the maximum operation temperature (85 °C), as recommended by the manufacturer. Thus, this fact may justify the use of a cooling system or a PV-thermal hybrid system, using water or alumina-based nanofluid.

The direction of this research is mainly to use the collected data for studying the relationship between PV performance and each climate parameter such as solar concentration, ambient temperature, relative humidity and wind speed. Moreover, it is important to take into account factors such as aging effect, orientation and pollution on the flat mirrors in order to improve the PV systems performance.

5. ACKNOWLEDGEMENTS

The authors are grateful for the financial support from the PPGEM – UNESP/FEIS, from CAPES, from CNPq (grant number 458702/2014-5) and from FAPESP (grant number 2013/15431-7).

6. REFERENCES

Ali, A. H. H., Matsushitaa, Y., Ookawarab, S., 2011. "Photovoltaic Module Thermal Regulation: Effect of the Cells Arrangement Configurations on the Performance", *Int. J. of Thermal and Environmental Engineering*, Vol. 2, 1-47.

ANEEL, 2018. "National Electric Energy Agency". Capacidade de Geração no Brasil-BIG-Banco de Informações em Geração. 13 Mar. 2018 < http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm>.

Bett, A., Ferrazza,F., Herzog,J., Marti,A., Wettling,W., 2006. "Report EU photovoltaic technology platform, SRA, WG3", Science, Technology and Applications.

Cazzaniga.R, Rosa-Clot.Marco, Rosa-Clot. Paolo, Tina. G.M, 2012, "Floating tracking cooling concentrating (FTCC) Systems". 38th IEEE.

Chandel, S. S. and Sharma, V., 2013. "Performance And Degradation Analysis For Long Term Reliability Of Solar Photovoltaic Systems"; *Renewable And Sustainable Energy Reviews*, No.27, pp. 753–767.

Fraidenraich, N., 1998. "Design procedure of V-trough cavities for photovoltaic systems", Prog. Photovolt. 6. 43–54.

INPE, 2017. "National Institute for Space Research". Atlas Brasileiro de Energia Solar, 2nd edition.

Kurtz, S., 2009, "Opportunities and challenges for development of a mature concentrating photovoltaic power industry", Technical Report, NREL/TP-520- 43208.

Luque, A. and Andreev,V., 2007, "Concentrator Photovoltaics". Springer-Verlag Berlin Heidelberg, 1nd edition.

Reis, F., Brito, M.C., Corregidor, V., Wemans, J., Sorasio, G., 2010, “Modeling the performance of low concentration photovoltaic systems”, Solar Energy Materials & Solar Cells 94, pp.1222–1226.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.