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Study of the Relationship Between Temperature and Efficiency in Photovoltaic Systems

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Abstract. Photovoltaic solar energy has been growing due to the demand for diversification of the global energy grid and the concern about replacing fossil fuels with renewable energy. There is a great potential for this form of energy generation due to high levels of solar irradiation. However, the efficiency of commercial panels is still low and is negatively affected by temperature rises on the panel. To mitigate this effect, several cooling techniques have been previously proposed. This work focuses on studying the relation between the temperature of solar panels and the energy produced by them. It also uses thermoelectric cells acting as coolers for the system bringing down the panel temperature to increase its efficiency. The main goal is to build a plant consisting of a solar panel attached to one or more thermoelectric cells and connected to a data acquisition system. This setup will be used to evaluate the improvement in performance obtained through this strategy. The experiments will be carried out at the Petroleum Measurement Evaluation Laboratory - LAMP, and the results will be compared with mathematical and simulation models present in the literature.

Key words. Photovoltaic, energy, renewable, temperature, efficiency.

1. Introduction

The growing demand for electrical energy around the world combined with the search and necessity to move away from fossil fuels, motivated by the environmental impacts caused by their waste and their finite character, makes renewable energy sources, such as wind, biomass, and solar, increasingly adopted.
The sun is responsible for most of the energy on planet Earth. The sun rays, once they reach the surface, are converted into thermal, kinetic, and chemical energy, and through the photovoltaic effect, they can be converted directly into electricity. It is estimated that currently the technically available solar potential is around 613 PWh/year [1].

Photovoltaics cells (PV) convert light into electricity using semiconductor materials that exhibit a photovoltaic effect. Therefore solar cells are used to convert solar energy into electricity. And the energy generated by solar cells can be called "green energy" [2].
Solar panels require little maintenance, have no moving parts, are silent, are scalable, and can be used in residential installations or to compose solar plants of several kilowatts (kW) of capacity.
These characteristics have made photovoltaic solar energy expand around the globe in recent decades, relying on private sector investments and public sector incentives for its adoption in the most diverse regions.
Among the disadvantages of photovoltaic generation are: Intermittence, when the panels do not generate energy at night and produce less in shading conditions, such as cloudy weather;
Solar panels require inverters to connect them to the grid or batteries or other storage if operating in isolated systems; Unfortunately, 80% of the solar irradiation absorbed by the PV cell is not effectively converted into electricity [21] The efficiency of solar panels is low when compared to other forms of generation, hovering around 20%. [22] The residual illumination is dissipated as heat causing losses in the power output of the solar cell.[21, 22] Therefore, the efficiency depends mostly on sun radiation and operating temperature of its cells.
Solar radiation is associated with the amount of sunlight available to the photovoltaic panel, so that its maximum production point theoretically corresponds with the point where the cell receives maximum incidence.Therefore, radiation and efficiency have a directly proportional relationship.
Opposed to radiation, temperature has an inversely proportional relationship with efficiency. This effect can be explained by the influence of temperature on certain

material parameters, and an increase in temperature during cell operation generally reduces the performance of the photovoltaic module in producing electricity [17].
This means that the increase in temperature negatively affects the efficiency of photovoltaic cells.
However, an excess of solar energy causes high temperatures on the surface of the cells, impairing the functionality of these systems [3].
The performance of the output power of a photovoltaic module decreases by 0.4% to 0.5% per 1°C when it works above its ideal temperature, in most cases being 25°C [4].
The problems with the high environmental temperatures from some regions of the globe have led to the development of alternative cooling techniques [3].
It is advantageous to develop panel cooling techniques for regions with high average temperatures to improve their performance. Several techniques seek ways to reduce the unwanted effect of temperature, including forced ventilation, forced water circulation, and use of phase change materials [6].
This work focuses on studying the relation between the temperature of solar panels and the energy produced by them. And the effect of cooling the solar panel through the use of thermoelectric cells. It is necessary to make it clear that the use of Peltier cells has no aim to make the system energy efficient considering the energy expenditure of their energy expenditure, the aim of the experiment is to observe how the temperature variation affects the performance of the photovoltaic panels, to do this easily and quickly, this cooling system was chosen.
Thermoelectric cells, or Peltier cells, also have the advantage of having no moving parts; however, they must be electrically powered.
It should be clear that the use of Peltier cells in this study is not intended to make the system energy efficient, the purpose of the experiment is to observe how temperature variation affects the performance of the photovoltaic panels.
Yet, it is still necessary to find an operating point where the energy consumed by the cell to cool the solar panel is less than the excess energy produced by the panel operating at the lowest temperature.
This study has already been carried out in previous works at the simulation level, and it was shown that, for specific profiles of ambient temperature, solar irradiation, and natural ventilation, it would be worthwhile to use Peltier cells to cool the [7] panel.
[8] evaluated the performance of two hybrid systems (PV/TE/Water and PV/Water) to see which had the highest energy production. [9] verified the feasibility of a hybrid PV/TE system that seeks greater efficiency by cooling photovoltaic cells with thermoelectric cells. [10] studied an active cooling system of a photovoltaic panel using water channels at the back of the panel.
[11] proposed a system to improve the performance of a photovoltaic panel through the use of water in arid environments. [12] studied the effect of a flat heat exchanger on the back of a photovoltaic panel. [13] studied the feasibility of a hybrid photovoltaic-thermoelectric generator.
Another purpose of this work is to validate, from experimental tests, the results previously simulated in [7].
This work aims to analyze the energy efficiency of a hybrid photovoltaic-thermoelectric system, in which thermoelectric cells are used to cool the photovoltaic panel. The increase in the expected yield comes from the decrease in the operating temperature of the photovoltaic panel.

2. Material and Methods

In the proposed hybrid system, the thermoelectric cells will act on the cooling of the photovoltaic panel in order to improve energy production. The aim is to experimentally verify the possibility of obtaining a gain in energy efficiency similar to that of other works at the simulation level [22, 23].
The practical tests were carried out on the photovoltaic cell control bench (Figure1). Parameters such as STC solar irradiance (Standard Test Conditions) and system disturbance (heating, cooling, wind, shading) can be configured on this bench. The information is collected through a data acquisition system and presented to the user in a supervisory system.
A light radiation control scheme was applied using mixed lamps for this bench. Mixed lamps also work as a heat source, causing the internal temperature to reach 70°C. Figure 2 shows the block diagram of the system to be tested on the bench.
The energy from the photovoltaic panel is being used to find an operating range where the activation of the thermoelectric cell is advantageous. In this work, the thermoelectric cell functions as a cooling device, usually found in the literature as Thermoelectric Cooler (TEC). When the temperature of the cell increases, its efficiency decreases, the thermoelectric cooler (TEC) placed under the cell will cool it when an electric current I is applied on this TEC [21,24]. The cold side of the thermoelectric cells will be connected to the panel, so it can remove the heat through the contact with the back of the panel.
The thermoelectric cell is capable of transferring heat between its sides when electric power is supplied to its terminals.

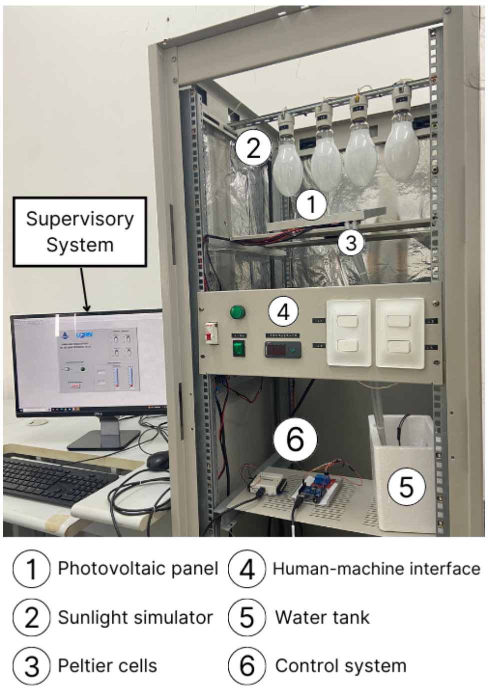

Fig. 1. Instrumented workbench for temperature testing.

A thermoelectric effect is a physical phenomenon consisting of the direct conversion of heat into electrical energy (Seebeck effect) or inversely from electrical current into heat (Peltier effect) without moving mechanical parts [15,20,21].
The information collected during the experiments are: Open circuit voltage; Short circuit current; Generated power; Panel temperature; Peltier cell power.

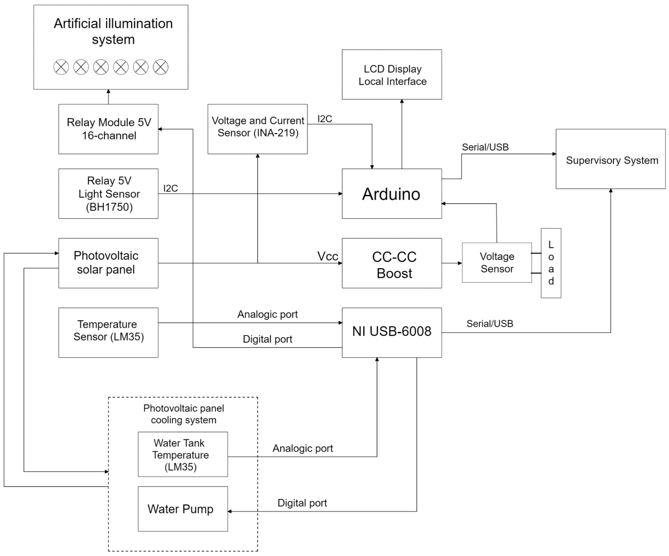

Fig. 2. Control system block diagram.

3. Results

The experimental IV curves of the photovoltaic panels were obtained using the resistive method. The method varies the load resistance from short circuit to open-circuit voltage.
During the load variation, the current and voltage values of the module under test are measured.
This method can be used to obtain curves in panels with low power. Figures 3 and 4 show some characteristic curves simulated with temperatures from 25°C to 60°C, highlighting the influence of temperature variation on the I-V and P-V curves.
It is possible to observe in Figure 3 that the temperature variation significantly modifies the value of the open-circuit voltage and causes small changes in the short circuit current.
Although the short-circuit current increases with temperature, this increase is not enough to compensate for the drop in the open-circuit voltage of the panel and, consequently, the generated power decreases with increasing temperature, as can be seen in Figure 4.

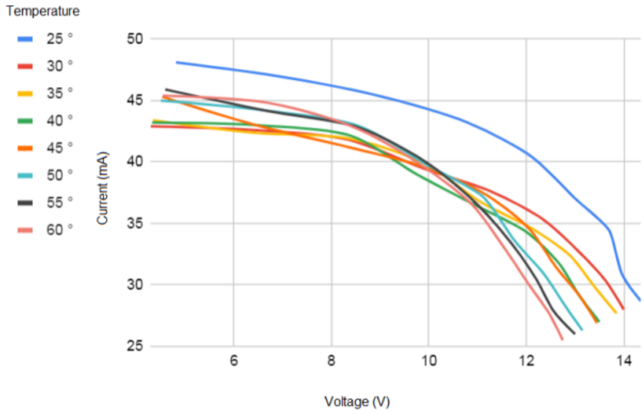

Fig. 3. Current x Voltage Graph.

	Power (mW) in different temperatures			
Voltage Range (V)	25 °C	30°C	35°C	40°C
4.3 ~ 4.8	231.4	184.0	188.4	186.6
6.4 ~ 7.1	329.9	272.2	269.7	277.4
8.26 ~ 9.1	410.4	349.4	351.1	354.5
9.7 ~ 10.8	466.6	390.1	396.0	380.3
10.9 ~ 12.1	489.6	424.1	406.3	399.7
11.5 ~ 12.9	481.7	436.1	419.0	411.8
12.1 ~ 13.7	470.6	427.7	417.3	402.0
12.5 ~ 14.1	432.5	413.1	399.6	381.1
13.1 ~ 14.3	411.8	392.0	383.6	364.5

Table 1. Electrical Power obtained under different temperatures.

	Power (mW) in different temperatures			
Voltage Range (V)	45°C	50°C	55°C	60°C
4.3 ~ 4.8	205.2	202.5	210.7	206.1
6.4 ~ 7.1	277.4	293.0	293.0	301.1
8.26 ~ 9.1	341.1	368.1	366.4	364.7
9.7 ~ 10.8	392.0	396.0	398.0	392.0
10.9 ~ 12.1	417.4	412.9	401.9	397.5
11.5 ~ 12.9	416.6	395.1	390.4	381.2
12.1 ~ 13.7	396.9	381.9	372.1	362.4
12.5 ~ 14.1	381.1	363.0	350.3	345.3
13.1 ~ 14.3	361.8	345.8	338.0	325.1

Table 2. Electrical Power obtained under different temperatures.

4. Conclusion

The proposed work presented the development of a photovoltaic system with active cooling accompanied by an instrumented bench to carry out the experiments. The possibility of light radiation variation under different temperatures provides a powerful tool to assist in developing studies and research related to photovoltaic energy.
The photovoltaic cell control bench works with the control of solar radiation, monitoring the temperature.

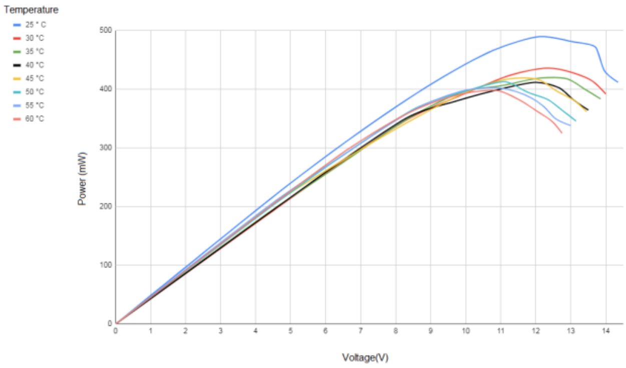

Fig. 4. Power x Voltage Graph.

	Current (mA) in different temperatures			
Voltage Range (V)	25 °C	30°C	35°C	40°C
4.3 ~ 4.8	48.1	42.9	43.4	43.2
6.4 ~ 7.1	46.9	42.6	42.4	43.0
8.26 ~ 9.1	45.3	41.8	41.9	42.1
9.7 ~ 10.8	43.2	39.5	39.8	39.0
10.9 ~ 12.1	40.4	37.6	36.8	36.5
11.5 ~ 12.9	37.1	35.3	34.6	34.3
12.1 ~ 13.7	34.3	32.7	32.3	31.7
12.5 ~ 14.1	31.0	30.3	29.8	29.1
13.1 ~ 14.3	28.7	28.0	27.7	27.0

Table 3. Current obtained under different temperatures.

	Current (mA) in different temperatures			
Voltage Range (V)	45°C	50°C	55°C	60°C
4.3 ~ 4.8	45.3	45	45.9	45.4
6.4 ~ 7.1	43	44.2	44.2	44.8
8.26 ~ 9.1	41.3	42.9	42.8	42.7
9.7 ~ 10.8	39.6	39.8	39.9	39.6
10.9 ~ 12.1	37.3	37.1	36.6	36.4
11.5 ~ 12.9	34.5	33.6	33.4	33
12.1 ~ 13.7	31.5	30.9	30.5	30.1
12.5 ~ 14.1	29.1	28.4	27.9	27.7
13.1 ~ 14.3	26.9	26.3	26.0	25.5

Table 4. Current obtained under different temperatures.

The proposed system in this work evaluated the behavior of a hybrid photovoltaic-thermoelectric, in which the photovoltaic module has increased power output when properly cooled by a group of thermoelectric cells. The results showed that the cooling system efficiency was optimal. Analysis of the result indicated an increase in the yield of the photovoltaic panel for a temperature range of 25°C to 60°C, when using thermoelectric cells to cool it, thus proving the applicability of this technique. This study concludes that the thermoelectric cells reduce the temperature of a solar panel and increase electrical efficiency as a result of cooling the system.

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