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REFRIGERATION OF PHOTOVOLTAIC MODULES WITH PELTIER CELLS

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Abstract. *Photovoltaic solar energy is in full development due to the need to diversify the world energy matrix to reduce dependence on fossil fuels. Despite the numerous advantages, the efficiency of energy conversion in photovoltaic panels is directly influenced its operating temperature, as the maximum power obtained decreases with increasing temperature. To cool the panels, thermoelectric exchangers, or Peltier cells, are an alternative with the potential to be extremely light, quiet, without vibration and more compact than the compression and absorption cycles. This research aims to verify the technical feasibility of a cooling system for photovoltaic panels using thermoelectric heat exchangers powered by the electric energy generated by the photovoltaic panel. The thermal modeling of the photovoltaic module was applied by means of a unidimensional analysis to determine its thermal behavior in conjunction with the modeling of the thermoelectric module to verify the effect of cooling on the performance of the equipment. The number of Peltier cells and the cell feed current were varied to an average irradiance value in the region of São Mateus-ES using the EES® software. Through the results for the temperatures of the layers, power and efficiency of the photovoltaic panel, it was possible to reduce the temperature of the photovoltaic cell by up to 20.2 ºC for the configuration of 9 thermoelectric modules. It was also verified that the gross electricity reached 38.76W, representing an increase of 10%, resulting in an electrical efficiency of 17.55%, representing a gain of 1.60%. Evaluating the point at which it is possible to cool the panel with the minimum power loss, being the current of 0.5 A, the configuration with 3 thermoelectric modules reduced the temperature by 9.62 °C. In order to enable the equipment to operate close to its ideal temperature, the cooling system can contribute to reducing the degradation of the photovoltaic panel over time.*

Keywords: *Energy, Photovoltaic, Cooling, Peltier, Efficiency.*

1. INTRODUCTION

Currently, there are several ways of using solar energy with the most varied applications. Much research on this energy source is being carried out, which increases the range of technologies and applications. One of the main advantages is the possibility of generating energy in remote locations that do not have access to the electricity network of energy concessionaires and in unproductive land, allowing for a better use of the soil. In these studies, the use of solar energy for heating water and generating electricity are the main alternative means in relation to this inexhaustible source of energy.

In the constitution of the photovoltaic modules, Silicon (Si) is used, which is one of the most abundant materials in the planet's crust. According to Pinho and Galdino (2014), more than 95% of the modules sold are made of crystalline silicon technology. However, when comparing crystalline silicon modules with thin film photovoltaic modules, it is noted that silica modules have a greater influence with increasing temperature.

The efficiency of energy conversion in photovoltaic solar panels is directly influenced by the operating temperature, since the maximum power obtained decreases with increasing temperature for the same solar radiation condition, as can be seen in the technical documents made available by the manufacturers for each type of panel (Araújo *et al*., 2016).

Photovoltaic systems rarely operate under rated conditions. The operating temperature of the photovoltaic cells is related to the variation of the solar radiation and the incident temperature. The current produced in the photovoltaic cells is directly proportional to the solar irradiance and is very little affected by the cell temperature. However, with the increase in temperature, the voltage and power generated are significantly reduced (Araújo *et al*., 2016).

Despite the numerous advantages linked to the photovoltaic system, studies related to the loss factors are of paramount importance for improving its energy efficiency and reducing the cost of implementing new systems to expand the market. According to Sampaio *et al*. (2019), this technology achieves the maximum energy efficiency that varies from 15% to 22% according to the material used.

To minimize the loss of power due to the increase in temperature, it is necessary to provide good heat dissipation in the installations of the photovoltaic modules. The situation becomes more critical when the panels are installed on the roof due to the lack of natural ventilation at the bottom and in desert regions where the ambient temperature is quite high. As the photovoltaic panel loses electrical efficiency with increasing temperature, the importance of studies on cooling systems that provide a gain in electrical efficiency for photovoltaic plates is observed. Despite having a durability of more than 25 years, over time, the panel suffers a gradual loss of performance due to component degradation.

According to Ndiaye (2013), the main degradation problems in photovoltaic panels composed of crystalline Silicon (Si) solar cells are: breakage of glass, interconnections and photovoltaic cells; corrosion on contacts; delamination and darkening of EVA (vinyl acetate). These problems are due to temperature, humidity and ultraviolet radiation, among others. Therefore, keeping the photovoltaic panel working at temperature levels close to standard conditions contributes to increasing the useful life of the equipment due to less wear on the components.

Furthermore, the study of heat transfer phenomena in this equipment provides a better understanding of the critical operating variables and stimulates the advancement of research in this area so that the potential for generating photovoltaic energy is explored more efficiently.

One of the ways to integrate the use of thermal and electrical energy from solar radiation is by the thermoelectric effect, which gave rise to thermoelectric tablets, or Peltier tablets, which are used in small and medium cooling and heating applications such as: microprocessor chip coolers, portable refrigerators, etc. A possible strategy for temperature control in solar cells is to use a Peltier thermoelectric heat exchanger, considering that it is an extremely light exchanger, has precise temperature control, is completely silent, there is no vibration, requires less physical space than compression and absorption cycles and requires less maintenance (Campos *et al*., 2010).

According to Incropera and Dewitt (2014), semiconductor material chips use the Peltier effect to promote heating or cooling in various applications. By applying an electrical potential difference between the poles, a temperature differential is induced between the faces of the plate.

Currently, the most powerful modules can transfer a maximum amount of heat of 250W, which makes them unfeasible for use in an air conditioner, for example. However, the tablets can be used in series, to reach lower temperatures (Danvic, 2020). As the Peltier inserts need to be supplied with electricity so that they can cool the photovoltaic panel, it is necessary that the benefits resulting from the operation of the panel at lower temperatures are greater than the energy expenditure and the financial cost of the cooling system.

Therefore, the objective of this research is to check the feasibility of a cooling system for photovoltaic panels using thermoelectric heat exchangers, powered by the electrical energy generated by the panel.

2. METHODOLOGY

To analyze the behavior of the cooling system and the photovoltaic panel, an exploratory research of a quantitative character was developed through the Engineering Equation Solver (EES®) program. In the calculation memorial made in the program, the thermophysical properties of the materials of the panel and of the thermoelectric modules were inserted, as well as the equations of heat transfer and electric power generation necessary to describe the behavior of the panel integrated with the cooling system.

To assess the performance of the thermoelectric exchanger in cooling the photovoltaic panel, the modeling was applied to a structure that would allow the construction of a prototype, consisting of 9 photovoltaic cells, with a dimension of 470 x 470 mm, as shown in Figure 1.

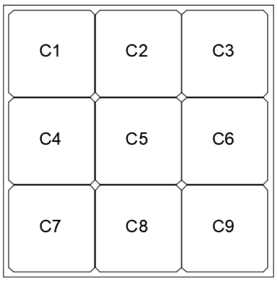

Figure 1. Top view of the photovoltaic panel.

To provide greater reliability of the system and guarantee a better condition of heat transfer, the thermoelectric exchanger was positioned inside the photovoltaic panel, in direct contact with the Tedlar®, as shown in the cross-section shown in Figure 2 for a photovoltaic cell. In order to make the system independent of external energy sources, it was considered that the exchanger is powered by part of the electrical energy generated in the panel and will cool the cell through conduction.

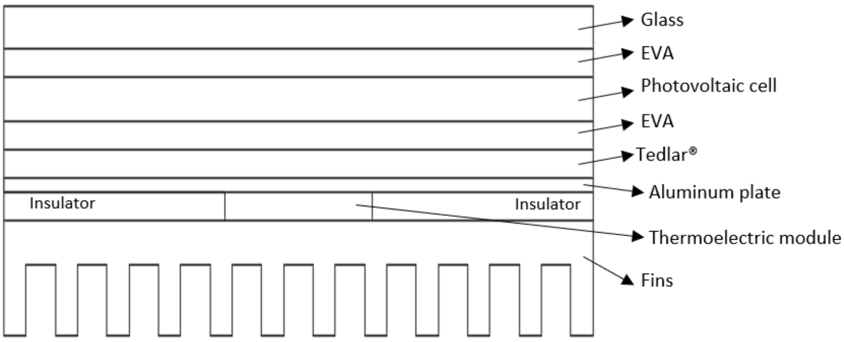

Figure 2. Cross section of the cooling panel prototype.

For the development of this research, the climatic conditions of São Mateus, a city located in the northern region of Espírito Santo, were considered. The data referring to Irradiance (G_{pv}) were obtained on the website of the National Institute of Meteorology (INMET, 2020) in relation to each hour of each day between the months of January 2020 to August 2020 (8 months).

The irradiance data collected during the months of the year showed a variation of 0 W/m² up to the maximum value of 1186.62 W/m². When observing the values for each hour of the day, it was observed that the period in which the irradiance begins to be relevant for the photovoltaic panel, reaching a value greater than 100 W/m² at least, is between 10:00 and 19:00. It was also observed that the irradiance rate for the same time varies according to the months of the year, being higher for the months with higher temperatures (summer) and lower for the coldest months (winter).

For the behavior to be evaluated in a more critical situation of temperature of the photovoltaic cell, an irradiance of 1000 W/m² was considered and the wind speed was disregarded. The ambient temperature was considered 25 °C and the atmospheric pressure equal to 1 bar.

In order to know the parameters of electric power generation and temperature of the photovoltaic panel without the presence of the heat exchanger, a modeling of the heat transfer was carried out through a one-dimensional analysis of conduction, convection and radiation. Aiming at a more representative modeling of the panel, 9 polycrystalline silicon photovoltaic cells were considered to compose the prototype because they are the most common type used in photovoltaic panels.

The mathematical model used is based on the model proposed by Najafi and Woodbury (2013) for the integration between the thermoelectric module and the photovoltaic panel, with contributions from the methodology of Procópio *et al.* (2016) to obtain the power generated by the photovoltaic panel. The distribution of thermal resistances according to the layers of the photovoltaic panel can be seen in Figure 3.

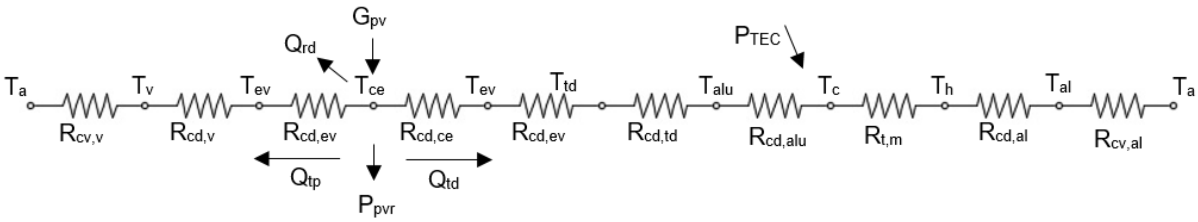

Figure 3. Proposed thermal resistance modeling.

Through Eq. (1), it is possible to relate the energy absorbed by solar irradiance (first term) with the thermal losses from the upper surface to the environment by conduction and convection (second term) and by radiation (third term). The fourth term in the equation represents the thermal energy that is transferred to the bottom of the Tedlar®. Finally, the last term is the portion of energy that is transformed into electrical energy.

$$G_{pv} * \beta_{ce} * A_{pv} * \tau_{\alpha} = U_{tp} * (T_{ce} - T_a) * A_{pv} + \varepsilon_v * \sigma * A_{pv} * \left(T_{ce} - T_{sky}\right) + U_{td} * (T_{ce} - T_{td}) * A_{pv} + \tau_{pv} * \eta_{el} * G_{pv} * \beta_{ce} * A_{pv} \quad (1)$$

where G_{pv}: Incident solar irradiation (W/m²); β_{ce}: Photovoltaic cell fill factor; A_{pv}: Photovoltaic panel area (m²); τ_{α}: Transmissivity-absorptivity coefficient of the photovoltaic module; U_{tp}: Global heat transfer coefficient at the top of the photovoltaic panel (W/m².K); T_{ce}: Cell temperature (K); T_a: Ambient temperature (K); ε_v: Glass emissivity; σ: Stefan-Boltzmann constant; T_{sky}: Sky temperature (K); U_{td}: Overall heat transfer coefficient at the bottom of the photovoltaic panel (W/m².K); T_{td}: Tedlar® temperature (K); τ_{pv}: Transmissivity coefficient of the photovoltaic panel glass and η_{el}: electrical efficiency of the panel.

From these equations and input data, the calculation of: T_{td}, T_{ce}, P_{el} (Electrical power) and η_{el} was performed for the photovoltaic panel without the cooling system in order to compare with the performance after the integration of thermoelectric modules and finned heat sinks.

For the cooling system, the Peltier thermoelectric exchanger model TEC1-12706 was used as the model meets the temperature ranges of the panel and has a current range suitable for this application.

With the operational parameters, it is possible to determine the equations that govern the heat transfer of the thermoelectric module through a one-dimensional conduction analysis, as proposed by Zhang (2010). In this way, the heat absorbed on the cold face (Q_c) can be determined by Eq. (2):

$$Q_c = S_m * I_m * T_c - \frac{{I_m}^2 * Re_m}{2} - k_m * \Delta T \tag{2}$$

where S_m: Seebeck Coefficient (V/K); I_m: Module electrical current (A); T_c: Cold side temperature (K); Re_m: Module electrical resistance (Ohm); k_m: Module thermal conductivity (W/K) and ΔT: Temperature difference between module faces.

Likewise, the heat rejected by the hot face of the thermoelectric module can be determined by Eq. (3):

$$Q_h = S_m * I_m * T_c + \frac{{I_m}^2 * Re_m}{2} - k_m * \Delta T \tag{3}$$

Once the Q_c and Q_h values are calculated, the power generated by the photovoltaic panel (P_{TEC}) that is consumed by the thermoelectric module can be determined by the energy balance showed in Eq. (4):

$$P_{TEC} = Q_h - Q_c \tag{4}$$

In this work, only rectangular fins with constant cross-sectional area were analyzed as they are easier to manufacture and cost-effective (Maschietto, 2018). The technical specifications of the chosen finned heatsink are in Table 1.

Table 1. Finned heatsink technical specifications.

Length x Width (mm) - C_{al}	150 x 150
Fin length (mm) - L_{al}	20
Number of fins - N_{al}	13
Fin thickness (mm) - t_{al}	3
Heatsink base thickness (mm) - t_b	5
Aluminum thermal conductivity (W/m.K) - K_{alu}	180

By integrating the cooling system into the panel's energy balance, the thermal energy that is transferred to the bottom of the Tedlar® can be calculated by Eq. (5), where the second term of the equation represents the heat removed by the number of thermoelectric modules (N_{TEC}) and transferred to the environment by the finned sink. The third term is related to heat transferred by convection between the aluminum plate and the environment.

$$U_{td} * (T_{ce} - T_{td}) * A_{pv} = N_{TEC} * Q_c + h_w * (T_c - T_a) * (A_{pv} - N_{TEC} * A_{al}) \tag{5}$$

where U_{td}: Overall heat transfer coefficient at the bottom of the photovoltaic panel (W/m².K); T_{ce}: Cell temperature (K); T_{td}: Tedlar® temperature (K); A_{pv}: Photovoltaic panel area (m²); Q_c: heat absorbed on the cold face (W); h_w: Natural convection coefficient (W/m².K); T_c: Cold side temperature (K); T_a: Ambient temperature (K) and A_{al}: Fin area (m²).

When integrating the cooling system to the photovoltaic panel, it is necessary to consider that the cooling capacity will positively influence the generation of electrical energy. However, the greater the cooling capacity, the greater the energy consumption by the cooling system. This is harmful for the photovoltaic panel, as its purpose is the generation of electrical energy. Thus, in order to make the cooling system more efficient, it is necessary to select an adequate configuration depending on the main operating parameters, which are: the number of thermoelectric modules (N_{TEC}) and the operating current of the thermoelectric modules (I_m).

As the dimensions of the proposed photovoltaic panel with 9 photovoltaic cells are greater than those of a thermoelectric module and the finned heatsink for each module has an area approximately equal to the area of the photovoltaic cell, calculations were performed for N_{TEC} ranging from 1 to 9. for each N_{TEC} value, a variation of I_m from 0.1 to 4.0 A was made to evaluate the performance of the panel integrated into the cooling system.

In order to assess whether there was an increase in electrical power with the integration of the cooling system, the variation between the electrical power of the panel with cooling (P_{pvr}) and the electrical power of the panel without cooling (P_{pv}) is calculated by Eq. (6), including the portion of power consumed by the cooling system (P_{TEC}).

$$\Delta P_{el} = (P_{pvr} - P_{pv}) - P_{TEC} \tag{6}$$

With the input data of the materials and the energy balance equations of the prototype, the equations were solved simultaneously and the output data for the combinations of N_{TEC} and I_C were obtained, namely: T_c, T_h, T_{td}, T_{ce}, Q_c, Q_h, P_{TEC}, P_{el}, η_{el}, COP, V_m, ΔP_{el} and $\Delta\eta_{el}$.

3. RESULTS AND DISCUSSION

From the data and equations covered in the methodology, the performance data of the photovoltaic panel without cooling were calculated, according to the results presented in Table 2.

Table 2. Behavior of the photovoltaic panel without cooling.

T_{td} (K)	T_{ce} (K)	P_{pv} (W)	η_{pv} (%)
340,2	340,9	35,23	15,95

Considering that the nominal operating temperature (T_{NOCT}) for the photovoltaic panel is 317.1 K, it is observed that a relevant heating occurs in the photovoltaic cell, representing an excess temperature of approximately 23.8 K. Due to this heating, there is a drop of approximately 17.6% in power in relation to the nominal power of the photovoltaic panel, which is 42.75 W. Consequently, there is a 1.35% reduction in the electrical efficiency of the photovoltaic panel.

From the integration of the cooling system by thermoelectric modules to the photovoltaic panel, it was possible to evaluate the performance of the prototype using variations in the electric current (I_m) and the number of thermoelectric modules (N_{TEC}). Figure 4 represents the temperature curves of the photovoltaic cell (T_{ce}), the cold face of the thermoelectric module (T_c) and the hot face (T_h) for the configuration with 1 thermoelectric module.

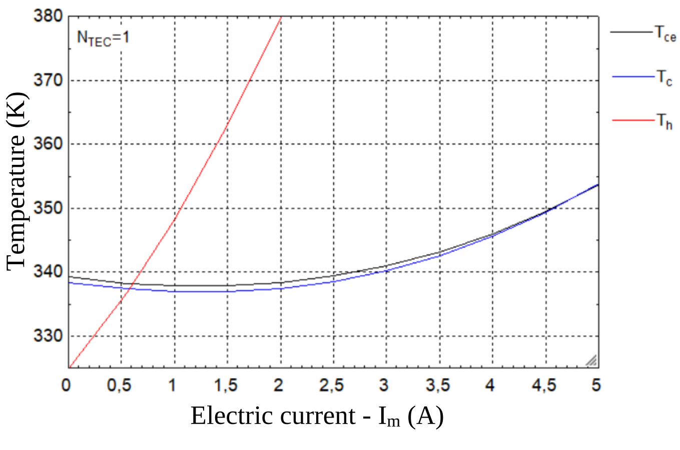

Figure 4. Temperature as a function of current.

It is observed in Figure 4 that the cooling system with only 1 thermoelectric module is not able to significantly reduce the temperature of the photovoltaic cell. Furthermore, for current values greater than 1.5 A, the thermoelectric module increases the cell temperature, which is harmful to the photovoltaic panel. This is due to the fact that the capacity and contact area of 1 thermoelectric module is insufficient to cool the panel that has much larger dimensions. Furthermore, for higher current values, the Joule effect becomes significant for the thermoelectric module, causing both sides to heat up and reduce the cooling capacity.

Another aspect to be noted is that, for electric current values below 0.6 A in the configuration with 1 thermoelectric module, the cooling capacity is so low that the cold and hot faces are inverted. This effect was evaluated for all 9 module configurations and, for 9 modules, the limit current value is 0.4 A. Therefore, it appears that values below this current range are not suitable for the thermoelectric module operation.

On the other hand, the increase in electrical current causes the hot face temperature to increase a lot, exceeding the maximum operating temperature (373.1 K) for current values greater than approximately 1.7 A, which makes the use of the equipment in that range. This is due to the increase in the Joule effect with increasing current, associated with low heat dissipation due to the absence of forced convection in the heatsink.

Through Figure 4, it is possible to verify that the temperature on the hot face of the thermoelectric module increases significantly with the increase in electrical current. It is also observed that the behavior is similar for different configurations of thermoelectric modules. This effect occurs because the heat dissipation capacity of the fins remains constant while there is an increase in current and consequently an increase in heat generation due to the Joule effect in the thermoelectric module.

The behavior of the temperature of the photovoltaic cell as a function of the electrical current can be seen in Figure 5 for configurations from 1 to 9 thermoelectric modules. As expected, the increase in the number of thermoelectric modules increases the capacity of the cooling system and makes it possible to reach lower temperatures of the photovoltaic cell, with the minimum temperature reached being approximately 320.7 K for a current of approximately 1.2 A, the which represents a reduction of 20.2 K compared to the panel without cooling.

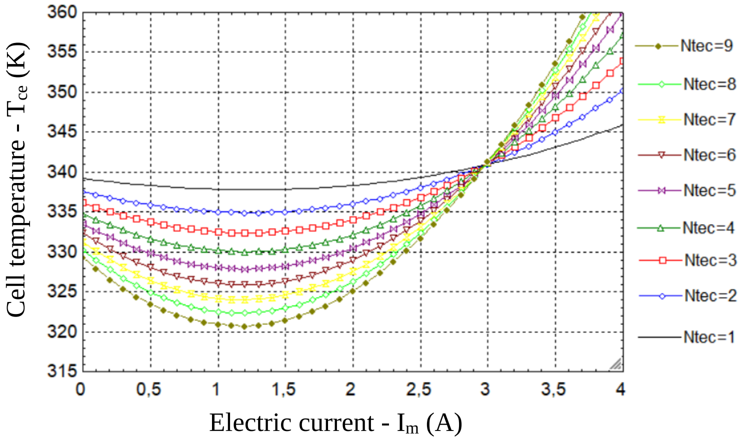

Figure 5. Cell temperature as a function of current.

Another behavior observed in Figure 5 is that from approximately 1.2 A, the cell temperature starts to increase and reaches temperatures even higher than the initial ones for higher currents. This effect is explained by the temperature increase on the cold face of the thermoelectric module due to inadequate heat dissipation for higher currents. The greater the number of thermoelectric modules, the greater this effect. This explains the intersection between the temperature curves for a current of approximately 3.0 A, in which the system with more thermoelectric modules starts to have a lower behavior than the system with fewer thermoelectric modules. This behavior indicates that high current values are not suitable for this application.

Evaluating the electrical power generated by the cooled photovoltaic panel as a function of the thermoelectric module current, it is observed that the behavior is inversely proportional to the temperature of the photovoltaic cell. This was expected, since the temperature coefficient (γt) given by the manufacturer is linear and reflects the power loss for each increase in temperature. Through Figure 6, it is observed that the highest generated power occurs for a current of approximately 1.2 A, which corresponds to the minimum temperature ranges obtained in Figure 5. For this current range, the greater the number of thermoelectric modules, the greater the power generated. The maximum power reached was 38.76 W for the configuration of 9 thermoelectric modules, which represents an increase of 10% in the power of the photovoltaic panel without cooling, which is shown in Table 2.

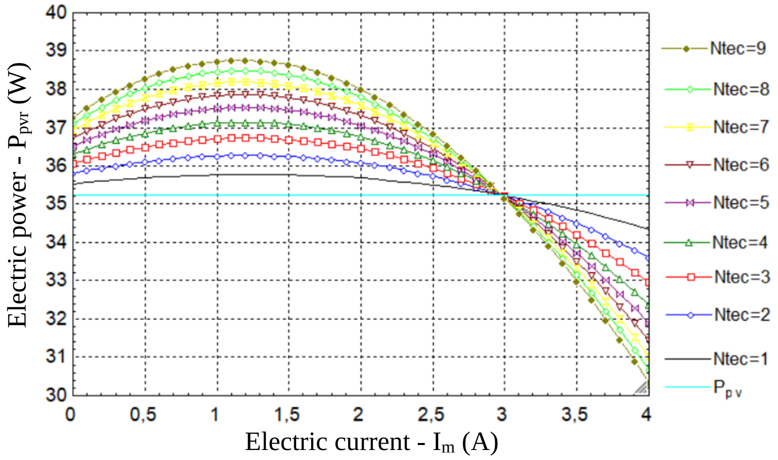

Figure 6. Electric power as a function of current.

From peak power generation, the increase in electrical current results in a decrease in power to levels even below the value recorded for the panel without cooling. This effect is intensified for a greater number of thermoelectric modules. This occurs due to the increase in the temperature of the photovoltaic cell as seen in Figure 5, which is harmful to the photovoltaic effect and makes the operation of the cooling system at high values of electrical current unfeasible.

As the electrical efficiency of the photovoltaic panel is directly related to how much electrical power is generated from incident solar irradiation (G_{pv}), a similar behavior is observed between Figures 6 and 7. The highest electrical efficiency values are obtained for the current range in which the cell temperature is minimum, corresponding to a current of approximately 1.2 A. The highest electrical efficiency value is 17.55% for the configuration of 9 thermoelectric modules, which represents an increase of 1 .60% in the electrical efficiency of the equipment.

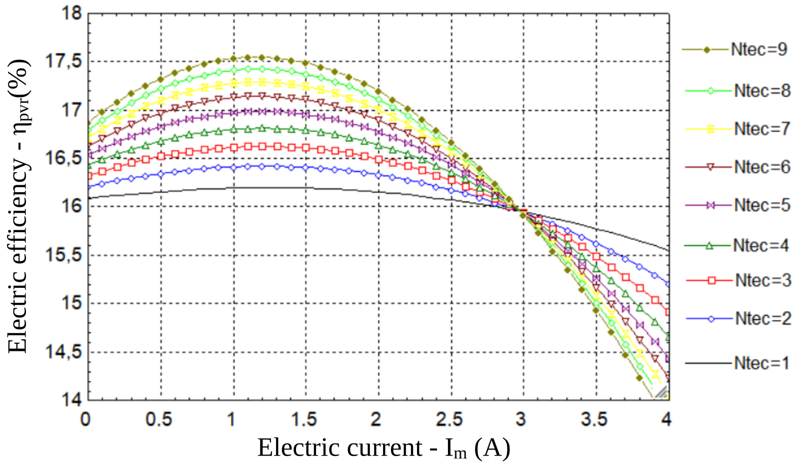

Figure 7. Electrical efficiency as a function of current.

For current values greater than 1.2 A, the increase in the temperature of the photovoltaic cell results in lower electrical efficiency values, which reach values lower than the initial electrical efficiency of the photovoltaic panel without cooling.

In the previous figures, it was observed the benefit of the cooling system to reduce the temperature of the cell and the consequent increase in electrical power generation and electrical efficiency. However, to assess the feasibility of using thermoelectric modules, it is necessary to consider the power consumed by the cooling system as a function of the electrical current for the adopted N_{TEC} configurations, as shown in Figure 8.

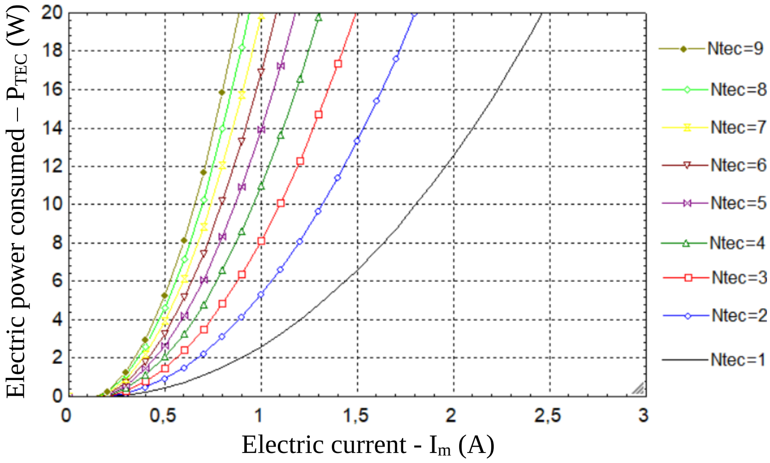

Figure 8. Electric power consumed as a function of current.

It is observed that the power consumed by the cooling system increases significantly as a result of the increase in electrical current and that this increase is proportional to the number of thermoelectric modules used. Considering that the minimum temperature of the photovoltaic cell is reached for a current of 1.2 A, it is verified that the power consumed for the configuration of 4 thermoelectric modules is 50% of the electrical power generated by the photovoltaic panel.

Consumption is even higher for the system with more thermoelectric modules, which shows that there will be no gain in electrical power if the cooling system operates aiming to reach the minimum temperature. It will be necessary to balance the temperature decrease of the photovoltaic cell with the power consumed by the cooling system to achieve an ideal operating range.

The cooling capacity of thermoelectric modules can be evaluated in Figure 9, in which it is possible to verify the amount of absorbed heat (Q_c) as a function of the electrical current for each configuration of modules. It is observed that the heat removal capacity increases until it reaches the peak for a current of approximately 1.2 A. From this point on, the amount of absorbed heat starts to decrease, reaching values below the initial values. This can be explained by the inadequate heat dissipation of the fins for higher electric current values and the consequent heating of the thermoelectric modules, impairing the cooling effect.

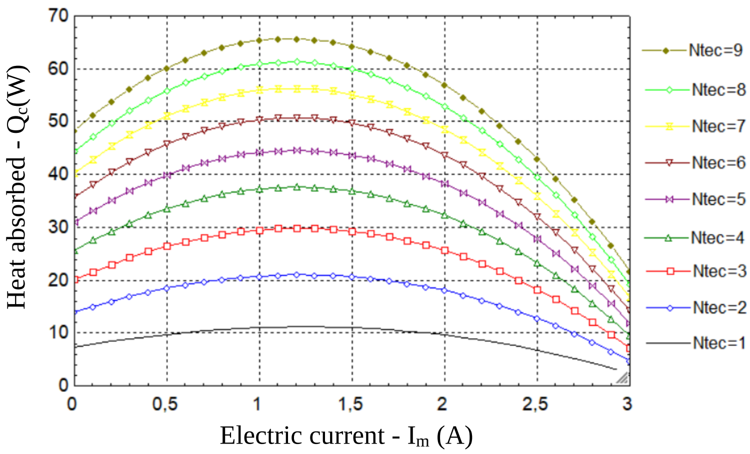

Figure 9. Heat absorbed as a function of current.

Assessing the difference between the power generated by the photovoltaic panel without cooling and with cooling and considering the power consumed by the cooling system, it is possible to evaluate the gain in electrical power as a function of the electrical current, as shown in Figure 10. Under the adopted conditions, it was not possible to obtain an electrical power gain for current values greater than 0.5 A. This is due to the fact that the thermoelectric modules have a high consumption of electrical power due to the increase in electrical power generated in the photovoltaic panel. Assessing the point at which it is possible to cool the panel with minimal power loss, represented by the current of 0.5 A, the configuration with 3 thermoelectric modules was able to reduce the temperature by 9.62 K, when compared at the temperature obtained for the photovoltaic panel without cooling, which is 340.9 K.

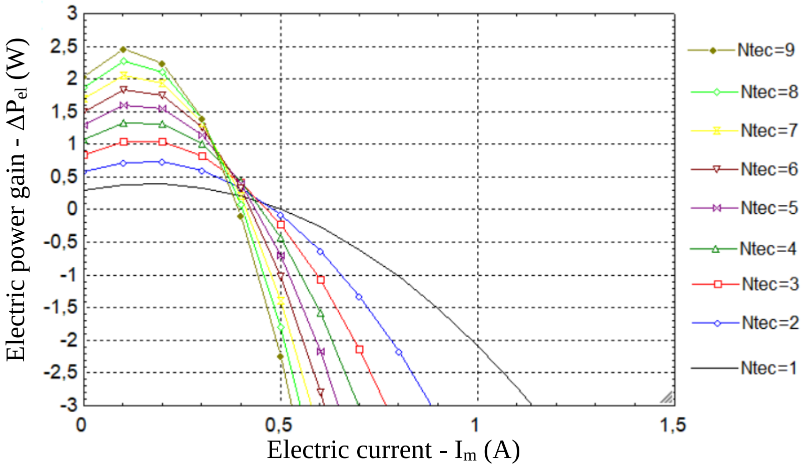

Figure 10. Electric power gain generated as a function of the thermoelectric module current.

It is verified that a small power gain occurs for very low current values. This can be explained by the low electrical power consumed by the thermoelectric module and the increase in electrical power generated by the panel caused by the temperature decrease of the photovoltaic cell. This decrease is due to the increase in heat dissipation due to the inclusion of the finned heatsink. This gain is canceled and the photovoltaic panel starts to generate less electrical power as the power consumed by the modules increases.

Regarding the performance of the thermoelectric module, it appears that the high-power consumption in relation to the cooling capacity significantly influences the feasibility of the cooling system. For the adopted thermoelectric module model, the merit index (Z) is 0.0027 1/K (T_a=300K). According to Najafi and Woodbury (2013), the electrical power gain is only possible for thermoelectric modules with indices above 0.005 1/K (T_a=300K). Therefore, the use of more advanced modules, with better performance materials, can result in a gain in electrical power in the photovoltaic panel or in a more cost-effective way to cool the photovoltaic cell without loss of electrical power.

4. CONCLUSIONS

This study aimed to verify the technical feasibility of a cooling system for photovoltaic panels using thermoelectric heat exchangers through the relationship between the gain in electricity generation and the cost of the system. The cooling system uses part of the electrical energy generated by the photovoltaic panel to absorb the energy available in the form of heat and dissipate it to the environment, promoting a reduction in cell temperature with a possible gain in electrical energy generation, in addition to prolonging life components and reduce the degradation effect of the photovoltaic cell, resulting in a lower loss of electrical efficiency throughout the life of the equipment.

For the level of irradiance considered, compared to the photovoltaic panel without cooling, the integration of the cooling system was able to reduce the temperature of the photovoltaic cell by up to 20.2 K for the configuration of 9 thermoelectric modules and 1.2 A current It was also observed an increase in the generation of electrical energy from the photovoltaic panel due to operation at lower temperatures, reaching a maximum power of 38.76 W for the configuration of 9 thermoelectric modules and the same current value, which represents an increase 10% in relation to the power of the photovoltaic panel without cooling.

Compared to a conventional photovoltaic panel, it was possible to observe that there was a gain in electrical efficiency with the reduction in temperature, reaching a maximum value of 17.55% for the configuration of 9 thermoelectric modules, which represents an increase of 1.60% in the cooling system. These data proved the benefit of the cooling system for improving the performance of the photovoltaic panel.

However, despite the improvement in the performance of the photovoltaic panel, it is necessary to evaluate the power consumed by the cooling system to determine whether there was an increase in the production of net electrical power. When performing this analysis, it was found that it was not possible to obtain an electrical power gain with the integration of the cooling system for any of the thermoelectric module configurations within the acceptable current range (above 0.6 A), resulting in a production of lower electrical power by the photovoltaic panel. This is due to the low heat dissipation of the finned heatsink, as coolers are generally used in cooling applications. Another significant factor is the thermoelectric module model used, since there are modules with a higher merit index on the market that can present a better performance, but with a higher cost of implementation.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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