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BLACK SEA SCIENCE 2018

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<u>5. RENEWABLE ENERGY SOURCES AND ENVIRONMENTAL PROTECTION</u>

<u>5. ВІДНОВЛЮВАНІ ДЖЕРЕЛА ЕНЕРГІЇ ТА ОХОРОНА НАВКОЛИШНЬОГО СЕРЕДОВИЩА</u>

MODELLING OF PHOTOVOLTAIC SOLAR CELLS BY MODIFYING FINS CONFIGURATION OF THE AIR-COOLED HEAT SINKS FOR POWER GENERATION

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The present research focus on three configurations ways of the cooling air-duct of a monocrystalline photovoltaic (PV) cell. The spacing within the fins, the fin's thickness, and the height of fins were examined to find out which is the best system configuration capable to decrease the PV cell temperature and thus, increase its efficiency. Economical approach was used to unbalance the decision where there's no much difference in terms of the achieved efficiency.

Lastly, models to predict the PV panel temperature were investigated and presented to provide a basic understanding of the change magnitude produced by these three configurations.

Objectives

General

The main goal of this research is to increase the electrical efficiency of photovoltaic solar cells for power generation system by modelling the effects of temperature and of the air duct system.

Specifics

In terms of the parameters to be analyzed, the study will focus on:

- ✓ Evaluation of different fins' configuration at the air duct;
- ✓ Temperature distribution at the interface between PV cell and air's duct;

With these parameters, through ANYSIS Fluent software were utilized to simulate the PV cell operation conditions and heat sink structure in order to increase the efficiency of the process.

Introduction

Energy is always present in our daily life. Fossil fuels are said to have some negatives impacts such as gaseous emissions, exhaustibility, and so on. Gaseous emissions are considered major concerns about greenhouse emissions and climate change at all. For instance, according to the United States for Environmental Protection Agency (US-EPA), it's reported that about 65% of carbon dioxide emissions is from fossil fuels and industrial activities [1].

Renewable energy (RE) has gained huge attention in last decades due to some advantages that they possess such, renewability (abundance of raw materials), non-pollution and/or less emissions, low operational costs, availability of source in worldwide, etc. Issues related to gaseous emissions and global warming are playing key roles toward the discovery and application of new renewable technologies. However renewable are promising solutions for the fossil fuels, the technologies applied to get this energy is still a challenge to make it possible at industrial scale or even to widely be applied due to some constraints related to the economy and technology itself. It's reported that oil and gas (fossil fuels) are still leading the energy grid in worldwide [2], what shows clearly that the utilization of renewable energy represents a long way to go throughout.

In this research, focus will only be given for modelling PV cell. PV cell is one of the most popular renewable energy technology. It converts solar radiation directly into electricity. It is reported that only about 15% of solar energy is converted into electricity while the remain goes to heat. The electrical efficiency of this process decreases with the increasing of the temperature of the PV modules. Decreasing PV module's temperature can boost the efficieny [1]. Air and water cooling are used to cool PV modules to maintain lower operating temperature and thus, increase the electric efficiency [4]. This study will address modelling of PV module's temperature by optmizing the air cooling distribution and configuration of fins of the system.

Case study

Problem statement

As mentioned previously, the temperature of the PV Cells increases during its operation. When this happen the conversion of solar into electricity is not favored then the heat production. The main goal of this study is to produce electricity rather than heat. Therefore, techniques to low the PV cell temperature will be evaluated to accomplish this aim.

Hypothesis

To care on this study, fins' configuration (thickness, height & space within fins) at the air duct was the main parameters analyzed for the desired goal. Two hypotheses were considered, and there are:

H_0*: *By changing fins configuration there is a decrease in PV cell temperature and though, increase in electrical efficiency.

H_1*: *Fins' configuration does not produce an improvement in electrical efficiency of PV cell module.

By analyzing these two hypotheses, the study will try to answer these questions and quantify the magnitude of the change produced by each system configuration considered.

Literature review

The electricity from photovoltaic cells can be used for a wide range of applications, from power supplies for small consumer products to large power stations feeding electricity into the grid [5]. According to Bloomberg report, the cost of solar panels installation will drop to 60% by 2040 from the roof tops, and about 15% of world's electricity will come from solar panels [3]. This is an illustration of how the future will looks like relying to the solar energy. As reported previously, some other solar technologies have been used.

Teo *et al.* [4] studied an active cooling system for photovoltaic modules and, reports that for the case glass to glass PV with a cooling duct can give the highest efficiency and annual efficiency can vary between 9.75% and 10.41% for the cases considered. Many strategies have been developed in order to increase the efficiency of this process such as*: (1) increasing the roughness of absorber plate and wall of the* *channel* (this requires lot of power pump)*; (2) presence of ribs in air channels* (enhance heat extraction performance due to the frictions); (3) *a plane booster and a flat plat collector* (augment effective absorption). These are examples of what previous studies have been developing to increase the power conversion efficiency by altering the surfaces of the used devices in PV systems.

Naphon [6] performed the optimization of the solar air heating, where was found that increasing of air flow rate increases the efficiency of the process. Another issue toward enhancing PV modules is related to the material used in these devices. Pottler *et al.* [7] carried out the optimization of absorber geometry. Joshi *et al.* [8] found that PV module glass-to-glass has better overall performance of hybrid thermal collector than glass-to-Tedlar. Hill & Pearsall [5] reports that the electrical output of a single cell is dependent on the design of the device and the semiconductor material(s) chosen but is usually insufficient for most applications. In order to provide the appropriate quantity of electrical power, a number of cells must be electrically connected. There are two basic connection methods [5, 9] *in series* and *in parallel.* PV solar cells can be connected in series to increase voltage and in parallel, to increase current [9]. In series connection, the top contact of each cell is connected to the back contact of the next cell in the sequence, and parallel connection, the top contacts are connected together, as are all the bottom contacts.

Studies of PV panel modification increased along the time as the aim is to improve the electrical efficiency which is still challenging. One of those modifications include the incorporation of air duct at the back of PV panel. Others, attaches fins or heats sinks to provide more heat removal. These modifications are the one which was used in this study, concretely, the installation of fins at the air duct.

Pramod & Shashishekar [2] performed experiences for PV cells with and without heat sink (fins) are they found that putting fins increase the efficiency of the process by lowering the PV panel temperature. Work done by Gardas & Tendolkar [3], showed that the efficiency decreases with the increases of PV panel's temperature (Figure 1).

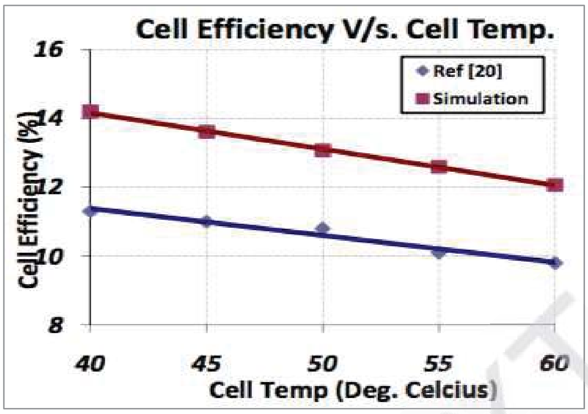

Figure 1. Relationship between the Electrical Efficiency and Cell Temperature at reference temperature of 25 °C

Methodology

Realization of the present work was chiefly conducted by executed from computer by simulating PV panel operating environment. Literature review (book, magazine, books, surveys, etc.) were the first action followed in order to get the background required to take ahead the desire of this research. The following section describe the numerical approaches considered for this aim.

Temperature Modelling of PV Cell

Figure 2 illustrate a typical PV cell module for power generation. The circled area (PV Cell & Air Duct) in orange color, represent the target area of this research. Modelling of PV Cell temperature distribution in the module was performed by ANSYS Fluent CFD Software (v.16.0). The design of fins configuration of the air duct was performed using **Autodesk Inventor Professional 2018**. The temperature profile simulation was firstly taken into Steady-State Thermal approach. Operating temperature of PV panel was assumed 80ºC of a clear day of summer in Tianjin (China), with an ambient temperature of 35ºC. The PV panel was a square shaped (0.5 x 0.5 *m*) of the length and width, considered vertically positioned. The air-cooling (air duct) was placed at back of the PV panel, with fins varying their thickness, height and the spacing within fins (see Figure). Dimensions of the air-cooled fins are presented in Figure 3 and the physical properties used in the PV model shown in Table 1. Please note that the anti-reflexive coating (ARC) was ignored due to its small layer (100×10^{-9}) and thermal conductive values.

Table 1 – Air duct parameter specifications

Characteristics of fins	Values (range)	Unit
Height of fins	3 – 9	*cm*
Thickness of fins	0.1 – 0.3	*cm*
Space within fins	2.44 – 9.84	*cm*
Holes in fins	0.6	*cm*
Space within holes	3	*cm*

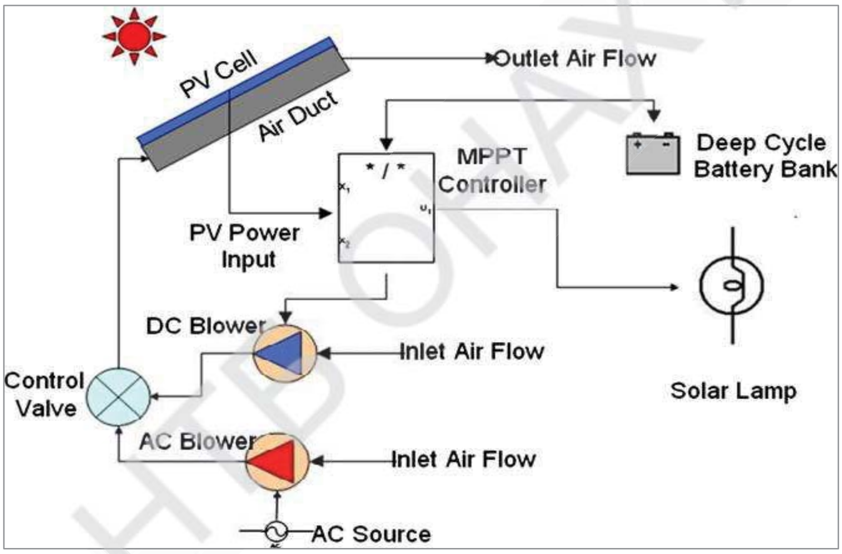

Figure 2. Schematic design of the PV cell module

Dimensions of the air-cooled fins are presented in Figure 3 and the physical properties of material used in the PV model shown in Table 1. The anti-reflexive coating (ARC) was ignored due to its small layer (100×10^{-9}) and thermal conductive values.

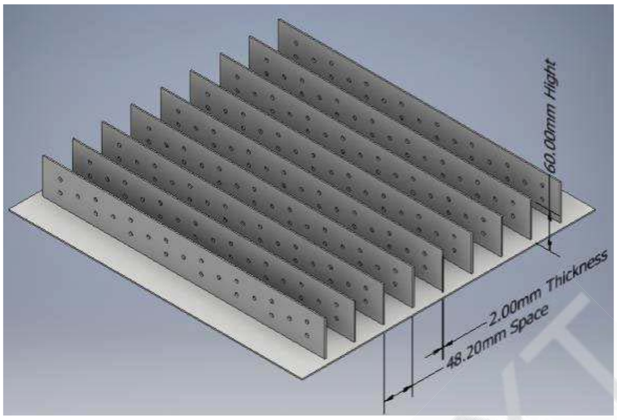

Figure 3. Typical fins' characteristics/ dimensions considered in this study

Mathematical formulations

The total energy absorbed by the PV cells, E_c, can be obtained by the relations developed by Cox and Raghuraman [10] and presented by Teo *et al.* [4].

$$E_c = p\alpha_C \tau_g G(t) \quad (1)$$

Due to solar irradiation, the electrical energy, E_{ce}, produced by the PV cell is expressed by the following equation:

$$E_{ce} = \eta_e p \tau_g G(t) \quad (2)$$

and the thermal energy, E_{ct}, released by the PV cell is as follows:

$$E_{ct} = \left(1 - \frac{\eta_e}{\alpha_c}\right) p\alpha_C \tau_g G(t) \quad (3)$$

Where p is the cell packing factor which is defined as the ratio of area of solar cell to the area of blank absorber; η_e is the cell efficiency represented as a function of the module temperature.

$$\eta_e = \eta_o[1 - \beta(T_c - T_a)] \quad (4)$$

Where η_o is nominal electrical efficiency under standard condition given by:

$$\eta_o = \frac{V_{mp} I_{mp}}{GA} \tag{5}$$

The D.C. output power from the PV panel is given by [4]:

$$P_o = V \times I \tag{6}$$

Results & discussions

Effects of variation of the spacing between adjacent fins

The steady state temperature spectrum from the maximum to the minimum can be seen throughout Figure 4. Comparing the three spacing (2.44 cm, 4.82 cm and 9.84 cm), it can easily be seen (Figure 5) that reducing the space within the fins offers advantages as the maximum temperature of the PV cell is 48.5ºC for spacing equal to 2.44 cm. Small spacing favors decrease of temperature because the air encounters more barriers than when the spacing is larger. Small spacing increases the fluid (air) residence time and thought, the amount of heat removal in the PV cell is greater than for long spacing. For about 4 times spacing lower, there was about ΔT=13.9ºC of the temperature gain for the current spacing.

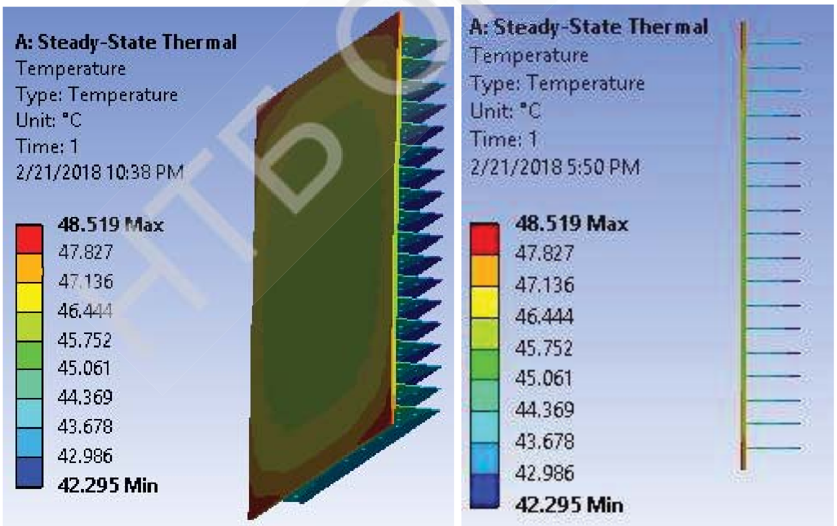

Figure 4. Spacing (2.44 cm) effect within the fins at the air duct. Front (left) & side view (right)

The yielded equation [$T\ (℃)\ = 1.8827x + 43.863$] is useful to determine the minimum temperature that can be reached with the considered system by changing the space within the fins at the air duct. It's clear that when the spacing (x) within the fins is to small ($x \to 0$), the minimum achievable PV temperature can be ~ 43ºC. However, reducing space to zero is not feasible from the economical point of view as this means to have a thicker and perforated bar as fin from the inlet to the outlet which can cost more money than small layers of fins. Therefore, optimal spacing needs to be found within 0 to 2.44 cm.

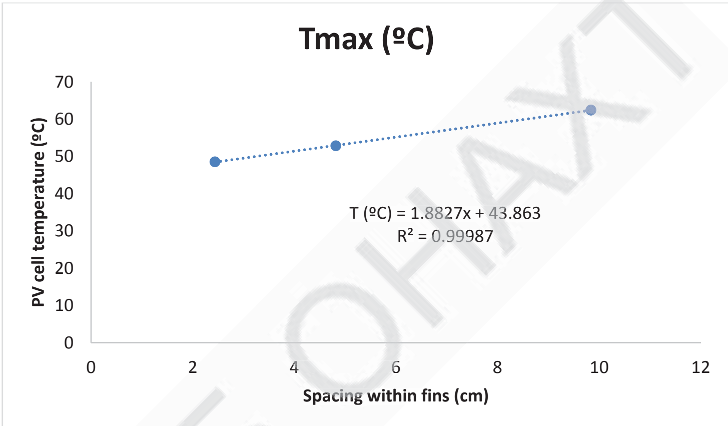

Figure 5. Effect of spacing within the fins of the air duct

Effects of varying the height of the fins at the air duct

Keeping the thickness (2 cm) and the space (4.82 cm) within different fins, the effect of fin's height variation (from 3 to 9 cm) is presented in Figure 6. Increasing fins' height favors the PV cell temperature to decrease. Increasing three (3) times in fin's height it decreases the PV temperature about 7ºC, what is equivalent to 2.3 ºC for each increasing in one (1) centimeter of fin's height (corresponding to 11.8%) from 3 to 6 cm. A linear module can be used to predict the temperature in the PV cell for quickly estimation in stages of dimensioning solar panels.

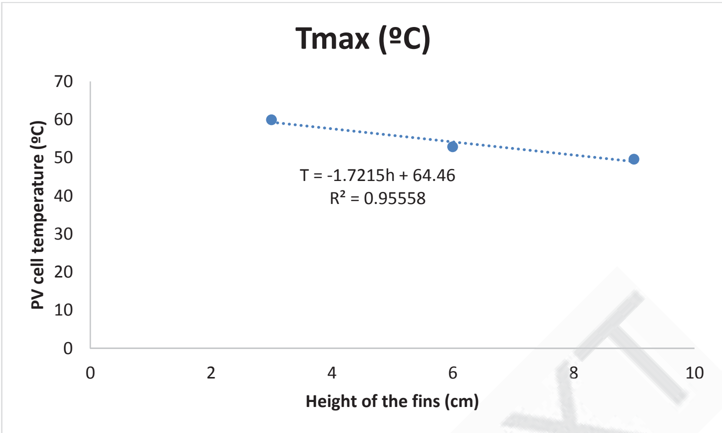

Figure 6. Fin's height influence in the PV panel.

From the yielded equation [$T(℃) = -1.7215h + 64.46$], it's possible to even extrapolate for case where there's no fins at the air-duct if the height of fins is zero ($h = 0$) and, the maximum temperature will be around 64.65 ºC.

Effects of varying the thickness of fins at the air duct

Increasing fins' thickness favors temperature to decrease (in less than 1.4% of its initial value). This behavior is observed due to large length available for heat transfer by conduction in a thicker fin than a thick one.

In Figure 7 it is observed an exponential decreasing of the PV panel temperature with the fin's thickness. However, the yielded equation [$T = 51.226t^{-0.019}$] possesses a big coefficient, its power is too small (-0.019), which by its turn tends to zero, making the thickness effects not much noticeable compared to other two system configurations.

Therefore, apart from its insignificant contribution in reducing the cell temperature, this finding is very important because it help in decision-making during design of the fins by telling the protectants to do not waste material in increasing the fins' thickness.

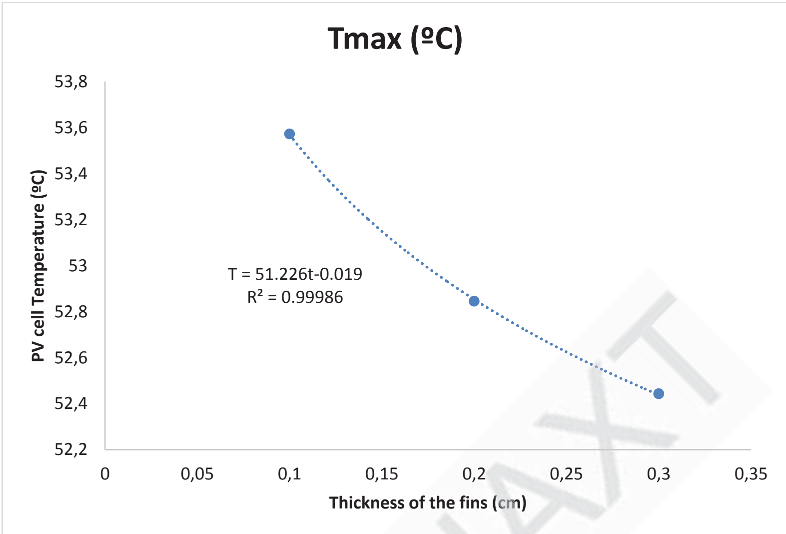

Figure 7. Effects of thickness variation with the PV cell temperature

Trade-off or Combination of three configurations

By combining the three configurations was to easily illustrate the temperature profile as function of height, thickness and space within fins. The main goal of this was to find out the best configuration in terms of low temperatures versus material cost (expressed in material length – centimeters).

Actually, increasing the fin's height (red line) is the best system configuration among all other considered in this study because:

1. The red line is decreasing, meaning reducing in material cost (up to ~2 cm);
2. The red line has interception with the two parameters (spacing & thickness) where (T=54.5 ºC, 6 cm) and (T=50.5ºC, 3 cm);
3. All other two curves are increasing what suggest that to lower the temperature through them, means investing more in material cost.

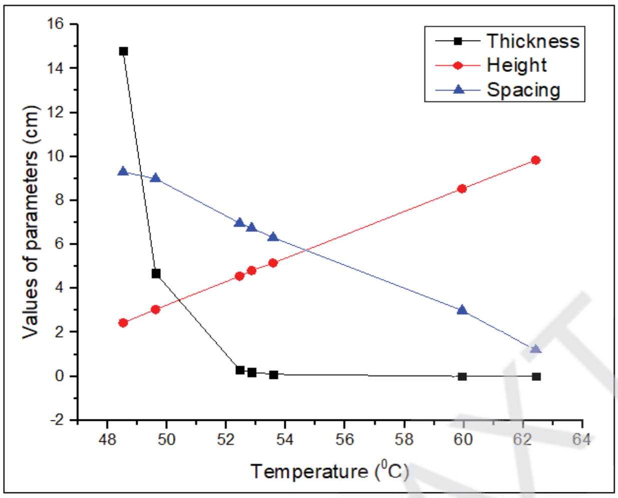

Figure 8. Summarization of temperature behavior with the spacing, thickness and fin's height

Comparison of PV temperature with and without fins at the air duct

PV cell maximum temperature was evaluated to know how much the fins contributes in increasing the panel electrical efficiency. Therefore, model without fins were compared with the one which possesses the highest cell temperature (indeed has lower efficiency than all proposed systems) to visualize how the fins are beneficial to increase the efficiency. From Figure 9, it can be seen that using fins the PV Cell temperature decreased from 81.288 ºC (without fins) to 62.469 ºC (with fins and 9.84 cm of spacing for a 0.2 cm of thickness and 6 cm of fins' height). This means that there is about 23.2% (18.8 ºC) of reduction in temperature even considering the worst case of fins configuration. Final conclusion is that the presence fins favors the efficiency to increase as the PV cell temperature decreases.

Temperature distribution across the PV panel

The temperature distribution along the PV length was evaluated for the system without fins comparing to the one possessing fins (the best configurations, with 6 cm of fin's height, thickness of 0.2 cm & spacing of 2.44 cm). It can be noted that temperature distribution in the PV cell without fins is uniform (constant), whereas the fins exhibited parabolic profile. The center of the PV cell is where the minimum temperature can be found and, the extremities, are where the maximum one falls.

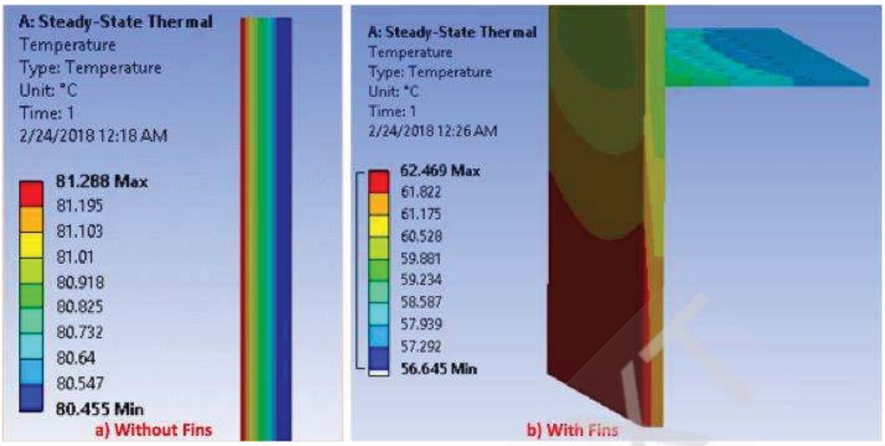

Figure 9. Comparison of PV maximum temperature without fins vs usage of fins at the air ducts. The characteristics of the fins are (Spacing 9.84 cm, thickness 2 cm & height 6 cm)

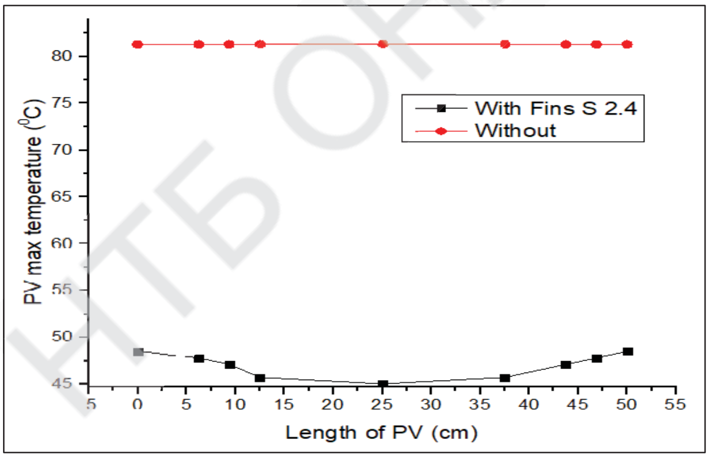

Figure 10. Temperature profile at the PV cell surface. Without fins (red line). With fins (black line)

Electrical efficiency of the PV Cell

The maximum efficiency achieved by the three-fin's configuration system is 17.70%, and the minimum is 16.46%. Increasing spacing within adjacent fins is the best case to enhance the PV cell efficiency (17.70%). In all three cases considered, the efficiency enhancement is not significant as the different within them does not exceed 1.23%.

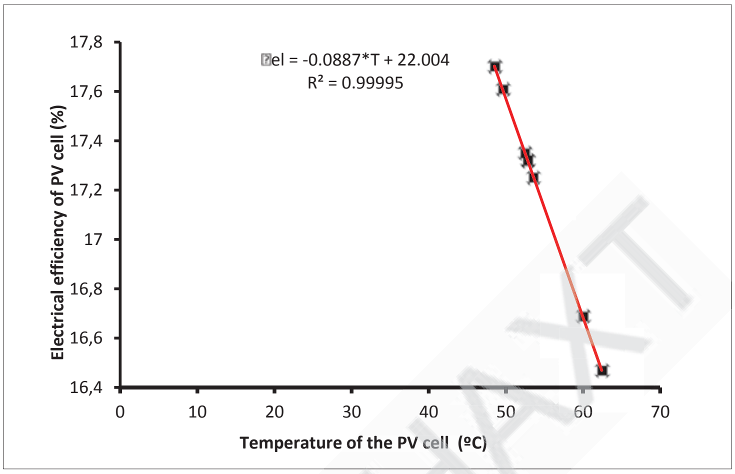

Figure 11. Efficiency as function of PV cell temperature

Comparison between the obtained results with the literature

The aim for this part was find agreement and/or disagreement between the results of this study and the one available in literature. Results of cell efficiency (17.7%) showed even better that the one produced by Najafi et al. [5], with 6% above their achievement (11%). As it can be seen Table 2 for similar researches, there are agreement in many case with the previous one.

Table 2 – Parameters range of this study compared the to the literature values

Parameters of the PV	This study	Previous studies [References]
Temperature (ºC)	48.5 – 62.4	41 – 59.2 [5], 32 – 42.5 [2], 40 – 60 [3]
Efficiency (%)	14.47 – 17.70	9 – 11 [5], 12 – 14 [3], 0 – 14 [6].

Conclusion

As a conclusion, reducing the PV cell temperature contribute to improve the efficiency of PV panel. Small distances within fins is beneficial to increase the efficiency for power production as it decreases the cell temperature. Increasing fins' height contribute do decrease the solar panel's temperature in 6.36% of its initial value. Changing fins' thickness does not contribute greatly to decrease PV cell temperature (about 2.1%) and thus, the electrical efficiency is less dependent its variation. Taking a look at the hypothesis proposed in the beginning of these study, it's undoubtable that the null hypotheses (H_0) is acceptable as the fine's configuration contributed to increase the electrical conversion of PV Cell system. Therefore, the hypotheses one (H_1) *is* rejected as the null one (H_0) is completely satisfied. The overall evaluation is that increasing fins' spacing is the best alternative to increase the PV cell efficiency because is the one which decrease the panel's temperature significantly if compared to increase in fins' height and thickness. Another taking point is that the magnitude of the results produced by this study falls into admissible region (good concordance) with the previous and related researches.

Recommendations

For further researches in the same or similar field, the following points: There's a need to find out the optimal (minimum) spacing to balance the investment required by small spacing. This cost result from two situations: (1) a thicker bar ($x = 0$) of fins, and (2) the installation of infinite fins very thick. This case provides a research gap to be fellfield with further studies. Increasing fins' height, the PV temperature reduces, however, by doing so, it overloads the supporting layer and fins can unstick from it. Fin's thickness is not a good measure to reduce significantly the PV cell temperature. Designers of fin's thickness are advised to use as small as possible (much thick), and thus save move with material. Lastly, there a need to evaluate the same system configurations under transient state and, correlate it with the steady state approach to find out how far is the

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