**Project Report**
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# Heat transfer in a photovoltaic panel

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## ABSTRACT

This project report presents a numerical analysis of heat transfer in a photovoltaic panel.

The temperature which a PV module works is equilibrium between the heat generated by the PV module and the heat loss to the surrounding environment. The different mechanisms of heat loss are conduction, convection and radiation. Conductive heat losses are due to different temperatures between the PV module and other materials with which the PV module is in contact. The ability of the PV module to transfer heat to its surroundings is characterized by the thermal resistance. Convective heat transfer arises from the transport of heat away from a surface as the result of one material moving across the surface of another. In PV modules, convective heat transfer is due to wind blowing across the surface of the module. The last way in which the PV module may transfer heat to the surrounding environment is through radiation.

## NOMENCLATURE

| | |
|---|---|
| $A$ | surface area of solar panel, $m^2$ |
| I | intensity of solar radiation, W/m2 |
| $\tau$ | transmittance, - |
| $\alpha$ | absorptance, - |
| $U_L$ | heat loss transfer coefficient, $W/m^2K$ |
| $Q_u$ | the rate of useful energy extracted by the solar cell, W |
| Tc | collector temperature, K |
| $T_\infty$ | ambient temperature, K |
| K | attenuation coefficient, $m^{-1}$ |

i=1,2,3 hence 1: glass cover, 2: solar cell, 3: frame

| | |
|---|---|
| $\delta_i$ | layer thickness, m |
| $c_{p_i}$ | specific capacity under constant pressure, J/kgK |
| $\rho_i$ | density, $kg/m^3$ |
| $q_i$ | heat flux W/m2 |
| $\alpha_i$ | thermal diffusivity $m^2/s$ |
| $T_i$ | temperature, K |
| $R_{s1}$ | Thermal contact resistance at the interfaces of glass and PV cells, $m^2K/W$ |
| $R_{s2}$ | Thermal contact resistance at the interfaces of glass and PV cells, $m^2K/W$ |
| $h_{c_1}$ | Heat transfer coefficient of convection in glass surface, $W/m^2K$ |
| $h_{r_1}$ | Heat transfer coefficient of radiation in glass surface, $W/m^2K$ |
| $h_{c_3}$ | Heat transfer coefficient of convection in frame surface, $W/m^2K$ |
| $h_{r_3}$ | Heat transfer coefficient of radiation in frame surface, $W/m^2K$ |
| $T_0$ | Initial temperature, K |
| $q_{cell}$ | Internal heat absorption |

## INTRODUCTION

A solar cell or photovoltaic cell is a device that converts sun energy directly into electricity by the photovoltaic effect. In the last years the manufacture of solar cells and photovoltaic arrays has expanded due to the growing demand for clean sources of energy.

Efforts have been made to combine a number of the most important factors into a single equation which will describe the thermal distribution.

Like all other semiconductor devices, the temperature is a very important factor because it affects the characteristic of the solar cell. Increases in temperature reduce the band gap of a semiconductor.

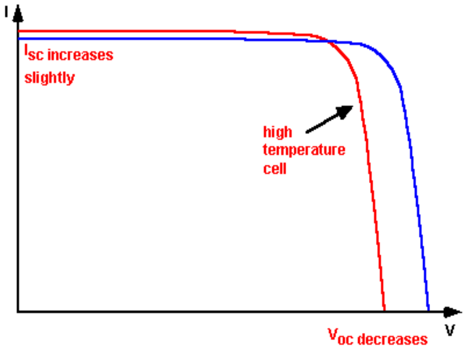

Figure 1 - The effect of temperature on the IV characteristics of a solar cell.

In the figure 1, it can see that the parameter most affected is the open-circuit voltage.

## PROBLEM STATEMENT

Figure 2 shows a schematic drawing of a solar panel which is considered as a multi-layer wall. A PV panel is composed of three layers, the glass cover, the solar cell and the frame.

$I_0$ is the intensity of solar radiation normal to the cover. However, as it is shown Figure 1, a part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the crystal and reaches the absorber photovoltaic cell.

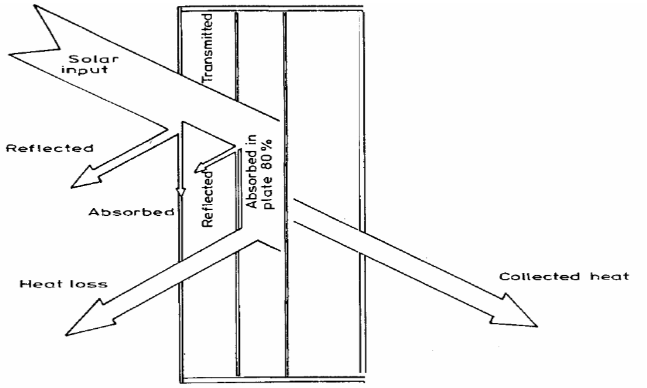

Figure 2 - Heat flow through a solar panel

## LITERATURE SURVEY

The amount of solar radiation, $Q_i$, received by the collector is:

$$Q_i = I_0 \cdot A$$

However, the energy flux, $Q_{trans}$, which has transmitted across the cover is, discounting reflected and absorbed part, is:

$$Q_{trans} = I_0 \cdot A \cdot \tau \cdot \alpha$$

Moreover, as the solar cell is hotter than the ambient there are losses by convection and radiation. Thus, the rate of useful energy extracted by the solar cell is expressed as follows:

$$Q_u = I_0 \cdot A \cdot \tau \cdot \alpha - U_L \cdot A \cdot (T_c - T_\infty)$$

## PROJECT DESCRIPTION

After it was explained the radiation what receive the solar cell, now a mathematical model is going to be described. The thermal physical properties of a PV panel are unchanged in this problem.

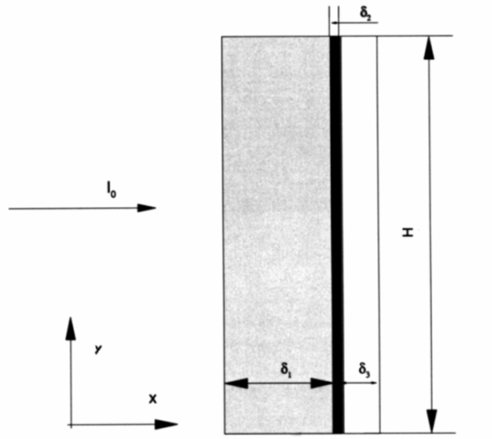

Figure 3 – Schematic of a PV panel

From equations of energy conservation in each layer, it is obtained:

For $y \in (0, H)$

$$(\partial T_{\downarrow}1)/\partial t = (_{\downarrow}1 \cdot [(\partial^{\uparrow}2\, T_{\downarrow}1)/(\partial x^{\uparrow}2) + (\partial^{\uparrow}2\, T_{\downarrow}1)/(\partial y^{\uparrow}2)] + I_{\downarrow}0/($$

*for* $x \in (0, \delta_1)$

$$(\partial T_{\downarrow}2)/\partial t = (_{\downarrow}2 \cdot (\partial^{\uparrow}2\, T_{\downarrow}2)/(\partial y^{\uparrow}2) + (q_{\downarrow}1 - q_{\downarrow}2 - q_{\downarrow}3)/(\rho_{\downarrow}2 \cdot$$

$$(\partial T_{\downarrow}3)/\partial t = (_{\downarrow}3 \cdot [(\partial^{\uparrow}2\, T_{\downarrow}3)/(\partial x^{\uparrow}2) + (\partial^{\uparrow}2\, T_{\downarrow}3)/(\partial y^{\uparrow}2)] \quad for$$

In the first layer, glass cover, there is conductivity transmission and moreover the glass absorbs part of the irradiation of the sun.

The total absorbed energy in the glass can be written as, the transmitted minus absorbed heat flux:

$$\int_0^{\delta_1} \frac{I_0}{\rho_1 \cdot c_{p_1}} \cdot \exp(-k \cdot x) = I_0 \cdot A \cdot (\tau - \alpha)$$

In the second layer, It has been considered that $\delta_2$ is small, and heat is generally well conducted, so the temperature in the PV cell is close to uniform in the x direction, and

$$\frac{\partial^2 T_2}{\partial x^2} = 0$$

.

Furthermore, the solar cell is considered as a heat source, so it has internal heat absorption. The value of this heat source (defined positive if it is absorbed) has been calculated doing an energy balance in the solar cell, see the figure 4:

$$q_{cell} = q_1 - q_2 - q_3$$

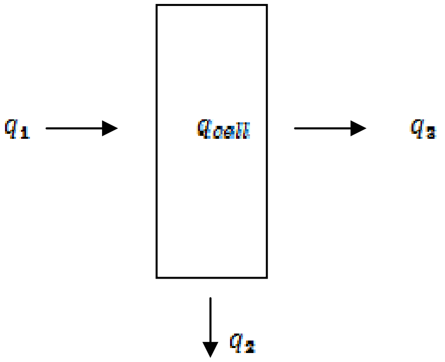

**Figure 4 – Energy balance in the solar cell**

In the last layer, it is a simple case of conduction.

For heat transfer in the exterior and interior surfaces the boundary conditions of thermal equilibrium is written as:

for $y \in (0, H)$

$$-\lambda_1 \cdot \rho_1 \cdot [c_p]_1 \cdot (\partial T_1)/\partial x = ([h_r]_1 + [h_c]_1) \cdot (T_\infty - T_1(x,y)), \qquad x = 0$$

$$q_1(x,y) = -\lambda_1 \cdot \rho \cdot [c_p]_1 \cdot (\partial T_1)/\partial x = (T_1(x = \delta_1^{-}, y) - T_2(x = \delta_1^{+}, y))/R_{s1}, \qquad x = \delta_1$$

$$q_3(x,y) = -\lambda_3 \cdot \rho \cdot [c_p]_3 \cdot (\partial T_3)/\partial x = (T_2(x = \delta_2^{-}, y) - T_3(x = \delta_2^{+}, y))/R_{s2}, \qquad x = \delta_1 + \delta_2$$

$$-\lambda_3 \cdot \rho_3 \cdot [c_p]_3 \cdot (\partial T_3)/\partial x = ([h_r]_3 + [h_c]_3) \cdot ([T_3(x,y) - T]_\infty), \qquad x = \delta_1 + \delta_2 + \delta_3$$

The thermal contact resistance affects the heat conduction rate and time required to arrive at steady state.

The last boundary condition to solve the problem is that for t=0:

$T_i(x,y) = T_0$ for i=1,2,3 $x \in (0, \delta_1 + \delta_2 + \delta_3)$ $y \in (0, H)$

## CONCLUSIONS

Using a mathematical model derived from energy conservation has been presented a numerical analysis of heat transfer in a photovoltaic panel.

In the current study, parameters affecting the temperature in the solar cell are the physical properties of each layer of the PV module, as diffusivity, thickness or density, the junction between theirs, contact resistance, and parameters dependence of the ambient characteristics, as the irradiation or heat transfer coefficient of radiation in the glass surface.

## REFERENCES

[1] "Introduction to Heat Transfer" Bengt Sunden, Lund March 2008.

[2] "Applied Photovoltaic" Wenham, Green Watt & Corkish. ISBN 978-1-84407-401-3

[3] Christiana Honsberg and Stuart Bowden. <http://pvcdrom.pveducation.org/index.html>

[4] "Analysis of a Flat-plate Solar Collector", Fabio Struckmann, 2008.

[5] "Numerical analysis of heat transfer in a photovoltaic panel, I: indoor cases" Z. Zhu, X. Zhu and J. Sun, China 2002.

[6] Wikipedia <www.wikipedia.org>