RESIDUAL HEAT UTILIZATION OF PHOTOVOLTAIC CELLS

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ABSTRACT

This paper deals with the solution of thermal field distribution in the area of photovoltaic cells and its subsequent utilization possibilities.

1. INTRODUCTION

Photovoltaic (PV) cell is a semiconductor device that converts light energy directly into electricity using the photoelectric effect. Photovoltaic cells are present in many applications. PV cells are used for example to supply small devices, but they are used also to generate a high power output, where they are connected in the particular modules, those in the fields and they compose the solar power plants.

Efficiency of the PV cells depends on many factors. The most important factors influencing the efficiency of PV cells include:

- quality and type of PV cell material (monocrystalline Si, polycrystalline Si, amorphous Si, GaAs, CdTe, CdS, ...)
- location, where is the PV cell located (number of sunny days in a year, the amount of usable solar energy incident on the surface of PV cells, the ambient temperature at the site, ...)
- geometric layout of PV cell (inclination of PV cells, different shape, ...)
- etc.

As mentioned above, the ambient temperature quite considerably affects the efficiency of PV cells. Finding the exact distribution of the temperature field can help to design and choose the optimal shape, material, conductive current path of PV cell or add the additional cooling device for reducing the temperature around the panel (module).

In this paper there will be introduced the proposal of the solution of temperature field distribution of a typical solar silicon PV cells of dimensions of 125 × 125 mm.

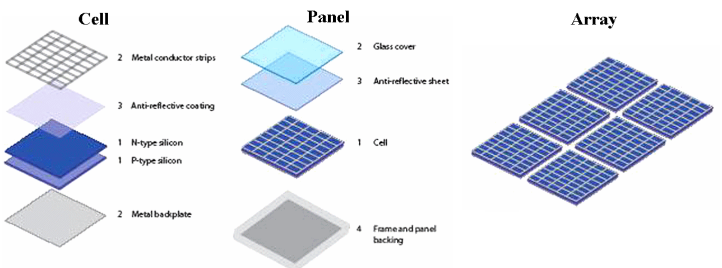

Figure 1 – Graphical representation of the PV cell, panel and array

2. MATHEMATICAL MODELLING OF THE TEMPERATURE FIELD

Mathematical modeling is one of the most frequently used methods for determining the distribution of temperature field. Theoretical models vary from a simple, that it is possible to calculate the simple formulas “on paper”, to complex, which requires several hours of numerical analysis calculations using modern supercomputers. Selection of a suitable theoretical model depends on several factors including the complexity of engineering tasks, the accuracy of the calculation, the calculation time and, not least, the cost.

Before the calculation, it is important to respect the fact that any computational method can at best produce only results that are derived from the physical equations. Therefore, the first and one of the most important steps in mathematical modeling is the selecting of the correct theoretical model, which correctly describes the technological process or phenomenon.

In general, the transient (time-dependent) heat transfer process in a metal work-piece (charge) can be described by the Fourier equation:

$$c \cdot \rho \cdot \frac{\partial \vartheta}{\partial t} + \nabla \cdot \left(-\lambda \cdot \nabla \vartheta\right) = q_{\mathrm{e}} \qquad (1)$$

where ϑ is temperature, ρ is the density of the metal, c is the specific heat, λ is the thermal conductivity of the metal and q_{e} is the relative thermal power of the internal energy source per unit time in a unit volume (heat generation). This heat source density q_{e} is obtained by solving the implicated radiation flux of heating source on investigated material surface.

Material quantities λ and c are nonlinear functions of temperature. In many applications of thermal stress can be these variables defined as constants. On the other hand, for a more precise analysis these variables are considered as the function of temperature.

Equation (1), together with the appropriate boundary and initial conditions, present a temperature distribution in three dimensions space at anytime and anywhere on the field. The initial temperature condition refers to the temperature distribution at time $t = 0$ s, this condition is determined as the time-varying fields of temperature, where the temperature is a function of spatial coordinates and time.

3. CALCULATION OF THE DISTRIBUTION OF TEMPERATURE FIELD OF PV CELL

To determine the distribution of temperature field there was selected the silicon PV cell shown in Fig. 2.

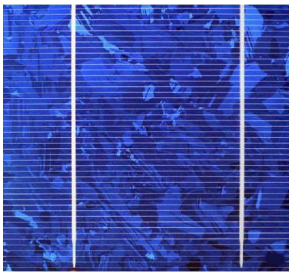

Figure 2 – Polycrystalline silicon photovoltaic cell

Material properties of the panel (assuming only Si) and contacts (Ag) specified in the simulation software are as follows:

Plate (Si):

- coefficient of thermal conductivity $\lambda = 149\ \mathrm{W \cdot m^{-1} \cdot K^{-1}}$
- specific heat capacity $c = 700\ \mathrm{J \cdot kg^{-1} \cdot K^{-1}}$
- density $\rho = 2329\ \mathrm{kg \cdot m^{-3}}$

Contacts (Ag):

- coefficient of thermal conductivity $\lambda = 429\ \mathrm{W \cdot m^{-1} \cdot K^{-1}}$
- specific heat capacity $c = 240\ \mathrm{J \cdot kg^{-1} \cdot K^{-1}}$
- density $\rho = 10490\ \mathrm{kg \cdot m^{-3}}$

Estimated ambient temperature is considered $\vartheta_{o} = 25$ C, as well as the initial temperature of the PV cell. It is considered that the power of a PV cell of dimensions of 125×125 mm is 5 W. Heat transfer coefficient α is set to 3 $\mathrm{W \cdot m^{-2} \cdot K^{-1}}$, since the particular PV cells are stacked side by side in the module (this factor was applied to the outer part of the cells).

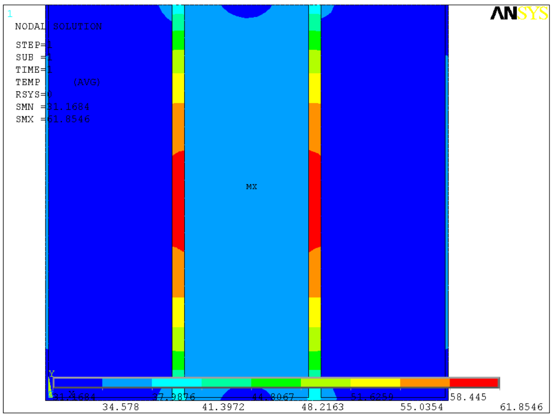

Figure 3 – The characteristics of the temperature distribution of the PV cell (front view)

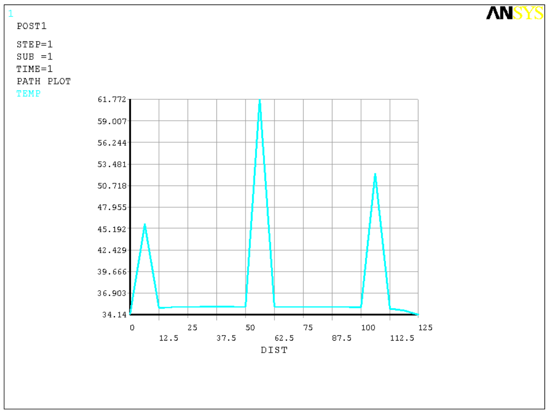

Figure 4 – Graphical dependence of temperature on a distance – “central line” front view)

Material properties for solving the distribution of temperature field from the side (in Fig. 1) are shown below:

Table 1 – Material properties of PV cell

Layer	λ [W·m^{-1}·K^{-1}]	c [J·kg^{-1}·K^{-1}]	ρ [kg·m^{-3}]
Glass	1,38	840	3800
Anti-reflective coating (SiO_2)	1,04	703	2648
Contacts (Ag)	429	240	10490
N-type silicon (Si + P)	155	–	–
P-type silicon (Si + B)	149	700	2329
Metal back plate (Al)	237	910	2700

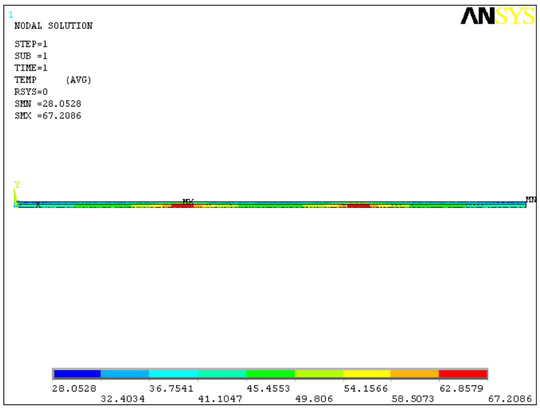

Figure 5 – The characteristics of the temperature distribution of the PV cell (side view)

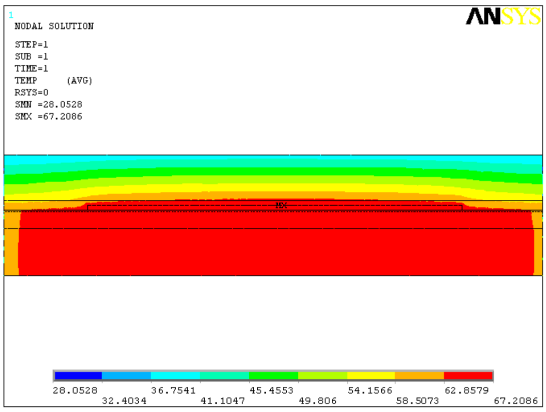

Figure 6 – A detailed view at Fig. 5 in place of contact

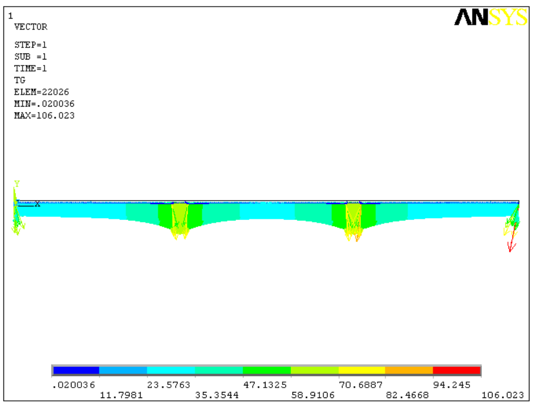

Figure 7 – The characteristics of the distribution of temperature gradient of PV cell (side view)

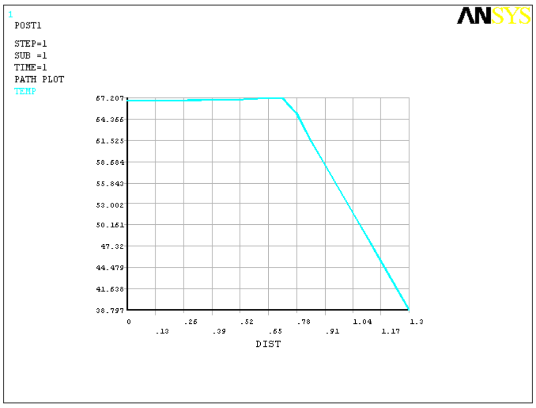

Figure 8 – Graphical dependence of temperature on a distance – “central line” side view at the contact – direction: from the bottom plate to the rear glass)

Also in the side view simulation there was assumed the ambient temperature $\vartheta_0 = 25$ C, as well as the initial temperature of the PV cells. It was thought that the power of a PV cell of the dimensions of 125 × 125 mm, is 5 W. Heat transfer coefficient α was set to 3 $W \cdot m^{-2} \cdot K^{-1}$ (from the side walls), 5 $W \cdot m^{-2} \cdot K^{-1}$ (from the glass area) and , 2 $W \cdot m^{-2} \cdot K^{-1}$ (from the bottom).

4. CONCLUSIONS

In this paper there were presented the results of the solution of temperature field distribution of silicon photovoltaic cells. The characteristics in Fig. 3 and Fig. 5 show (according to input data of heat transfer coefficients), that the highest temperature is in the place of contacts by passing the direct current. Considering the higher ambient temperature (in sunny days) and surface emissivity of solar cell (dark surface) there will be reached significantly higher temperatures of PV cells than they were presented in this paper.

It is therefore necessary to suggest the appropriate cooling of PV cells or utilize the residual heat for another application (e.g. hot water storage systems, thermal couples (TEG, TEC), cooling/heating generation systems, etc.).

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