Cooling System for Photovoltaic Module

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Abstract: - The paper presents a solution focused on increasing efficiency of photovoltaic module by reducing losses due to warming photovoltaic cells. The solution consists in a water cooling system applied to the back of photovoltaic module. To achieve the cooling system was first made a numerical analysis of heat transfer in a photovoltaic panel. Simulation of numerical model for heat transfer in PV module was performed using dedicated software named Quick Field. Using an infrared camera the thermal processes have been viewed for the achieved system.

Key-Words: - PV module, cooling system, photovoltaic system, heat transfer, simulation, quick field software

List of symbols and abbreviations

Ac – PV module surface
Ga – solar radiation
PV- photovoltaic
Q_u - useful heat supplied by the PV
Q_l - heat loss of cooling system
$(\tau\alpha)\varepsilon$ - transmission-absorption product
T_p- upper surface of the absorbing plate temperature
T_a –ambient temperature
U_L- global coefficient of losses
$\dot{m}$ - mass flow of fluid
Cp – specific heat of fluid
α - absorbing plate absorbance
n- refractive index of the transparent plate
k - thermal conductivity of insulation
L- insulation thickness
U_e - lateral loss coefficient
U - thermal conductivity of the insulation side
L_{iz} – lateral insulation thickness,
A_l – lateral surface
U_t - loss coefficient from the top
N - number of transparent plates
e_p - thermal emissivity of the surface absorbing plate
ε_p - thermal emissivity of the transparent plate
β - angle of the PV module
σ - Boltzmann's constant
hw - convective heat transfer coefficient due to wind
V – wind speed
D - distance between the tubes
d_0- outside diameter of the tubes
di - inside diameter of the tubes
h_f - heat transfer coefficient of the absorbing plate
k_a – absorbing plate thermal conductivity
x - absorbing plate thickness.

1 Introduction

Crystalline silicon currently offers a yield of 15-16% and some studies consider that its limits would be reached approximately 25% under laboratory conditions [1]. Although other materials such as Ga, offering a yield of 30%, prohibitive price makes them suitable only for space applications. Recently, researchers of U.S. universities have announced that was obtained a photocell with a yield of 60%. It's a big step towards the upper limits of efficiency photovoltaic cells [3]. Very complex technology and materials used do remain only the state of laboratory. Therefore, in the next decade, nothing seems to threaten the supremacy of silicon. Recently more and more companies have been able to increase the yield offered by solar cells based on silicon. In March 2003, BP Solar announced an efficiency of 18.3%, while Sanyo has already put on the market a cell with an efficiency of 19.5% [9].

Overheating of a PV module decreases performance of output power by 0.4-0.5% per 1°C over its rated temperature (which in most cases is 25 degrees C). This is why the concept of "cooling of PV" has become so important [2].

To reduce this phenomenon can be applied on the back to panel a cooling water system, which can provide hot water for domestic applications [2].

2 Mathematic Model of Cooling System for Photovoltaic Panel

The temperature which a PV module works is an equilibrium point between the heat generated by the PV module and the heat losses to the surrounding environment. The different mechanisms of heat losses dissipation 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 [5].

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.

Cooling system efficiency used to PV panel expresses the conversion efficiency of solar radiation unused in the photovoltaic process into heat [7]. This is the impact on the physical and constructive parameters of subassemblies that make up the cooling system. Obtaining a maximum output requires an optimization process of building solar collectors. To this end it is necessary to know the analytical form of efficiency to identify parameters that it depends. Research is needed on the size of the collector efficiency parameters influence, followed by optimization of collectors building on the influential parameters for obtaining maximum yield [7].

Processes involved in these conversions are illustrated in Figure 1.

Figure 1 shows a schematic drawing of a solar panel which isconsidered as a multi-layer wall. A PV panel is composed of three layers, the glass cover, the solar cell and the frame.

Defining the analytical form of efficiency is based on the energy balance equation, considering the processes taking place in a photovoltaic panel.

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

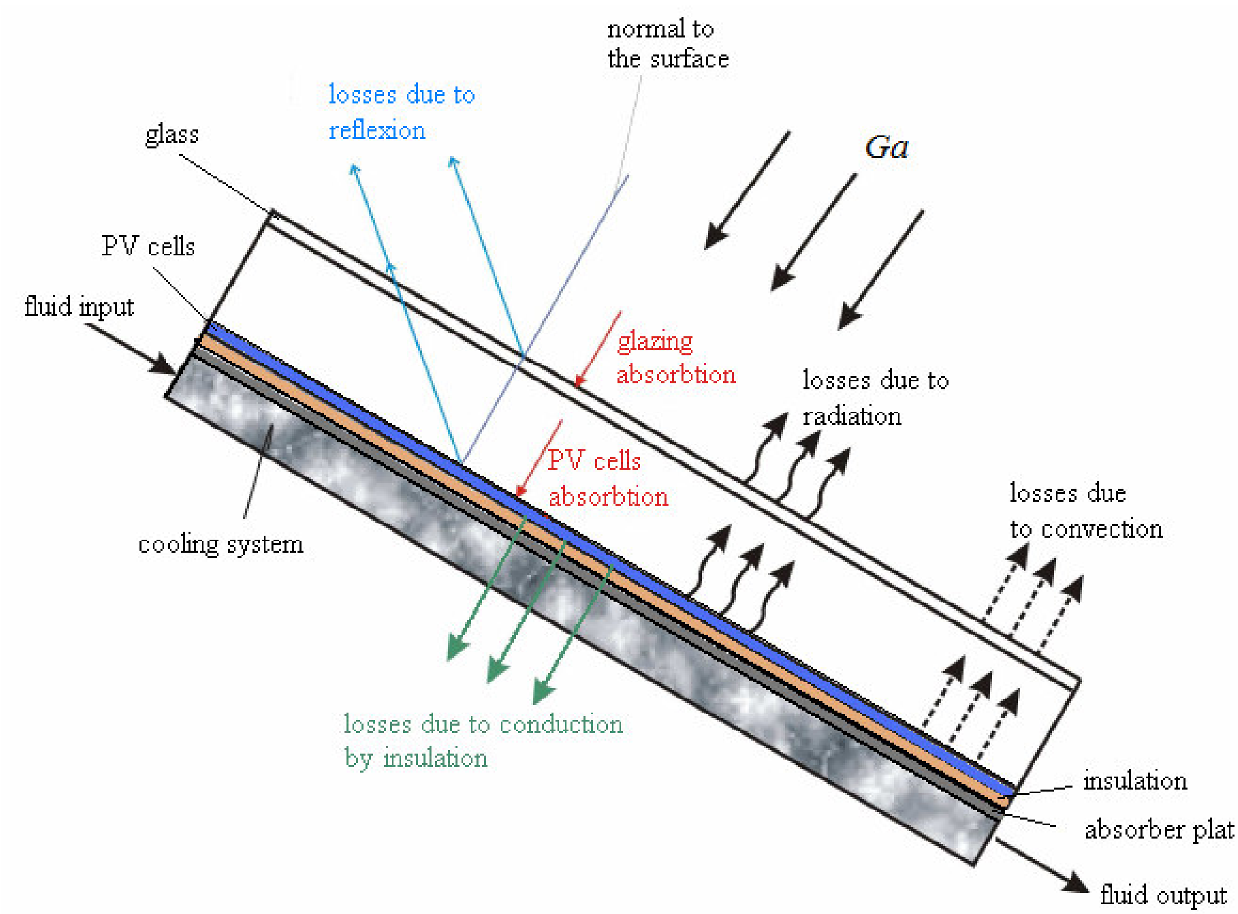

Figure 1: Thermal processes of PV panel

Energy balance equation for a cooling system in steady operating regime is described by the relation:

$$GaAc(\tau\alpha)_e = Q_u + Q_l \qquad (1)$$

Useful heat provided by the absorber plate is:

$$Q_u = Ac\left[Ga(\tau\alpha)_e - U_L\left(T_p - T_a\right)\right] \qquad (2)$$

Instantaneous efficiency of the cooling system is defined by the ratio of useful energy and energy absorbing by absorber plate.

$$\eta = \frac{Q_u}{Ga \cdot Ac} \qquad (3)$$

The final yield explicit equation is given by:

$$\eta = \frac{mC_p}{U_L \cdot Ac}\left\{1 - \exp\left[-\frac{U_L AcF'}{\dot{m}C_p}\right]\right\} \cdot \left[\frac{\tau\alpha}{1-(1-\alpha)(n-1)^2/(n+1)^2} - U_L\frac{T_i - T_a}{Ga}\right] \qquad (4)$$

U_L is given by:

$$U_L = U_b + U_e + U_t \qquad (5)$$

with:

$$U_b = \frac{k}{L},$$

Also, the losses coefficient sidewise in[W/m²K], is influenced by insulation and is described by the following expression:

$$U_e = \frac{U}{L_{iz}}\left(\frac{Al}{Ac}\right) \qquad (6)$$

Loss coefficient at the top depends on a complex of factors which include glass surfaces, PV cells, seals. This can result in [W/m²K] by relation:

$$U_t = \frac{1}{\dfrac{N}{\dfrac{C}{T_p}\left(\dfrac{T_p - T_a}{N+f}\right)^e} + \dfrac{1}{h_w}} + \frac{\sigma\left(T_p^2 + T_a^2\right)}{\dfrac{1}{\varepsilon_p + 0{,}00591Nh_w} + \dfrac{2N + f - 1 + 0{,}133\varepsilon_P}{\varepsilon_g} - N} \qquad (7)$$

Cooling system efficiency factor F′ is expressed [7]:

$$F' = \frac{1/U_L}{\left(D + d_o\right)\left(\dfrac{1}{U_L\left(d_0 + fD\right)} + R_b + \dfrac{1}{\pi d_i h_f}\right)}$$

$$f' = \frac{\tanh(y)}{y}$$

where:

$$y = 0{,}5D\left(U_L / k_a x\right)^{1/2}$$

3 Simulation of Heat Transfer in PV Module

Based on the numerical model developed previously was made heat transfer simulation using dedicated software named Quick Field [11].

Quick Field is a very efficient Finite Element Analysis package for thermal and stress design simulation with coupled multi-field analysis. It combines a family of analysis modules using the latest solver technology with a very user-friendly model editor (preprocessor) and a powerful postprocessor [14].

We started the simulation of heat transfer surface PV panel.

The simulations were done using standard dimensions of a specific existing PV panel in the Faculty of Electrical Engineering.

To obtain a correct result is necessary to define conditions on the surface boundaries [11].

These conditions have been defined in the program by specific blocks called by labels.

In simulation of heat transfer phenomena were taken into consideration specified in Figure 1.

Figure 2 encompasses the simulation results. It contains the heat transfer on surface of PV module.

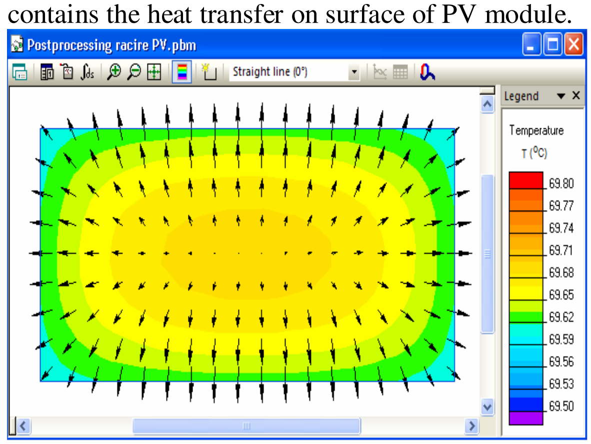

Figure 2: Simulation results of heat transfer on the PV module surface

In Figure 2 we can see that the boiling point of the PV panel surface is reached in its center.

Heat transfer is achieved in the direction of the arrow, i.e. from center to periphery. Also, notice that the coldest areas of the panel are situated on the corner panel.

In second time was made the simulation of heat transfer in PV module section. Results of simulation are shown in Figure 3.

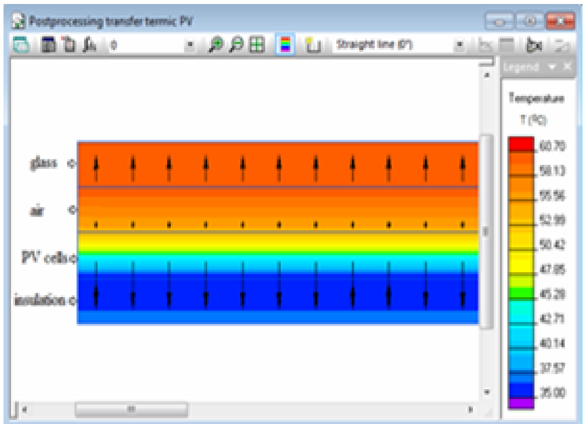

Figure 3: Simulation results of heat transfer on the PV module section

In the third time was made the simulation of heat transfer in cooling system.

The components of cooling system and the simulation results are depicted in Figure 4.

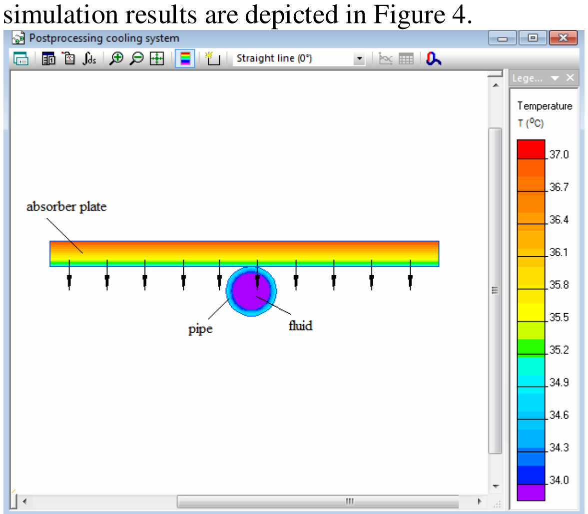

Figure 4: Simulation results of heat transfer on the cooling system

4 Experimental Results

The PV panel made in the present study comprises a commercial PV module and a cooling system (figure 5). A USP 150 mono, crystalline solar PV module (1600 mm x 800 mm) (rated 150Wp, 42 V peak voltage) was adopted to be combined with a water cooling system. The cooling system adheres to the back of the commercial PV module. Thermal grease was used between the plate and the PV module. For better contact. Below the heat collecting plate, a PU thermal insulation layer is attached using a fixing frame.

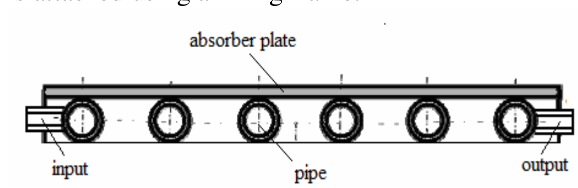

Figure 5: Section of cooling system

The experimental system was built using the PV module and cooling system combined with a water storage tank (Figure 6). To enhance the heat transfer of cooling system, we installed a DC pump to circulate the water from the tank through the cooling system.

For a solar water heater, there exists a critical inlet water temperature that is proportional to the ambient temperature, the solar radiation intensity, and the thermal parameters of the cooling system

Ensuring water circulation pump is controlled by a microcontroller that collects information on the panel temperature by two temperature sensors mounted on it.

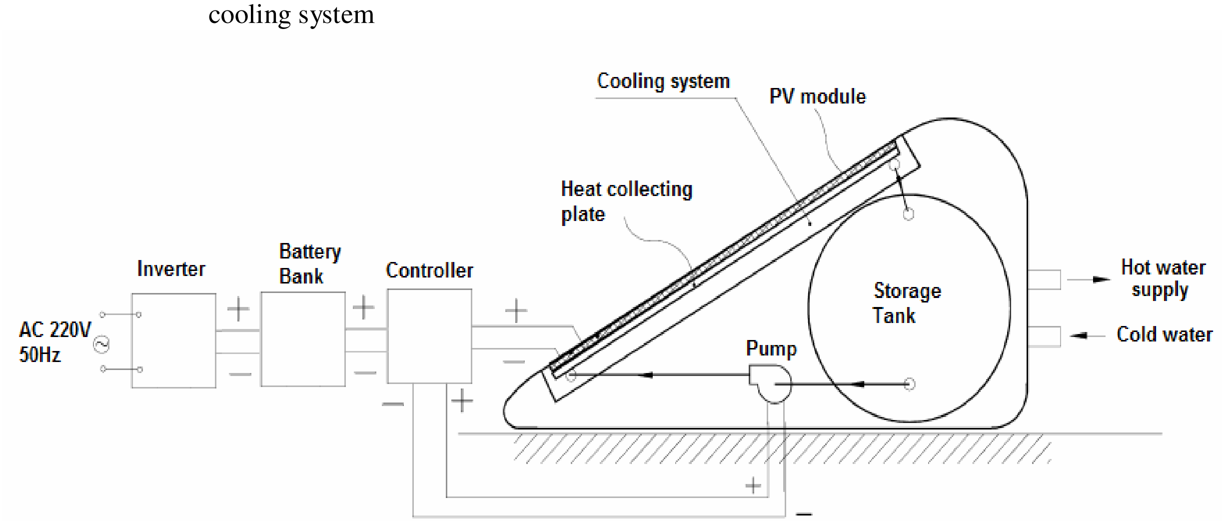

Figure 6: Experimental PV system

For view online thermal processes in the system developed was used an infrared camera.

The following figure shows images taken with infrared camera.

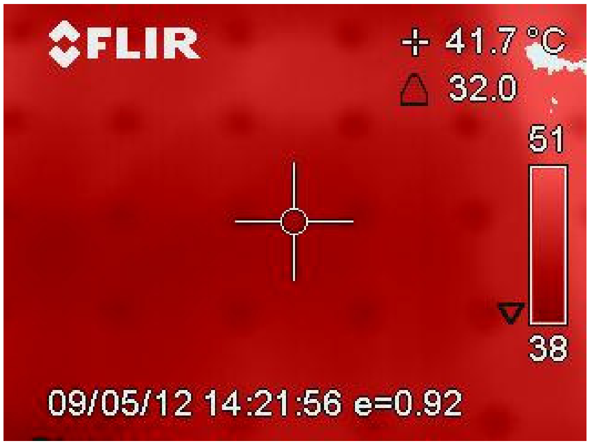

Figure 7: Captured image on the front surface of PV module

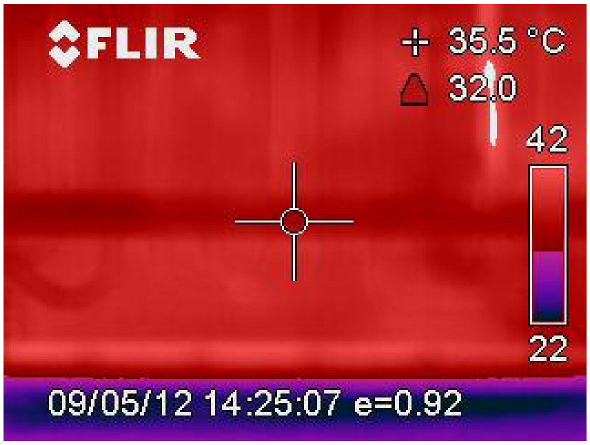

Figure 8: Captured image on the back surface of PV module with disconnected water pump

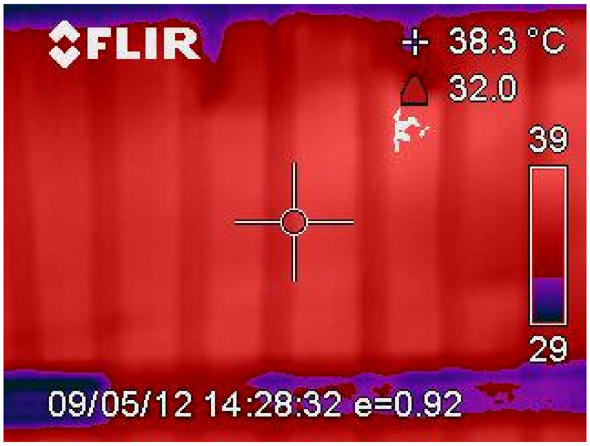

Figure 9: Captured image on the back surface of PV module with connected water pump

In figure 10 is shown the water temperature of cooling system to entrance and exit.

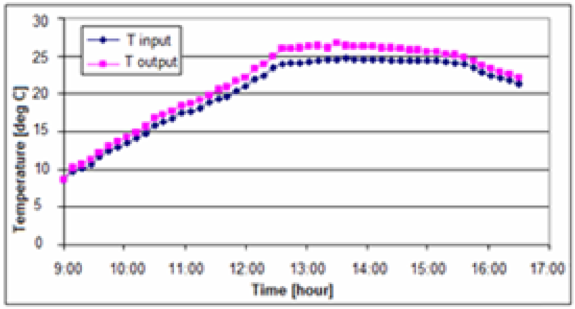

Figure 10: Evolution of water temperature

In captured images are seen in the maximum temperature attained on surfaces, as follows: 51°C for front surface of PV module, 42°C for back surface of PV module with disconnected water pump, 39°C for back surface of PV module with connected water pump.

5 Conclusion

The analysis of mathematical models, graphs obtained by simulation and experimental results shows the influence of temperature on monocrystalline silicon PV module performance, USP 150.

The experimental results emphasize the good side of a PV system operation and on the other hand, accuracy and efficiency of the cooling system designed for photovoltaic panel that can be applied successfully in domestic solar applications.

Acknowledgment

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