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INCREASING THE EFFICIENCY OF PHOTOVOLTAIC PANELS THROUGH COOLING WATER FILM

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Through this paper, we proposed a solution to increase efficiency photovoltaic panels. So we used a device that makes a water film on the surface of panels, obtaining simultaneously cleaning and decreasing the operating temperature of the panel. To highlight the results, the output parameters were measured when applying a water film. Throughout the experiment panel temperature was monitored using a thermo-vision camera, with or without water film.

Keywords: photovoltaic panel, water film, cooling, efficiency, temperature

1. Introduction

Currently sustained efforts are made to develop new processes to manufacture photovoltaic cells by looking for new ways to increase their effectiveness. The main target is to reduce the cost of renewable energy using photovoltaic technology compared to existing conventional sources. For example, various applications that include water pumping systems in remote areas, having the dual role of power generation and irrigation of large surface areas. The biggest problems encountered by using photovoltaic systems are generally caused by high costs of installation and low conversion rate of currently cells on the market. [1]

Another problem is the ambient temperature at which photovoltaic systems work, efficiency dropping with increasing temperature. For mono and poly-crystalline silicon cells, the reduced power is between 0.4% / ˚C and 0.5% / ˚C. This decrease is caused by power drops. We can make an estimate of the drops by using the catalog data provided by the manufacturer, which must specify the temperature coefficient and maximum working temperature of the cells.

Costs of photovoltaic systems are directly dependent on the working surface, so to reduce the costs, the panels must operate efficiently. The combination of photovoltaic systems and water pumping systems makes an interesting study in which cells are essential components, so increasing their efficiency is the main scope. [2]

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In the present study, we implemented a solution to eliminate losses caused by the presence of deposits on the surface of the panels by installing a special device. It is designed to disperse a water film on the panel surface, thus achieving cooling and cleaning of the module.

2. Experimental study description

In the current experiment we used a mono-crystalline panel which is cooled by a continuous film of water that pours on the working surface of the panel. The advantages of this system are besides the cooling of the panel, the loss reduction caused by radiation reflectivity (refractive index of water is 1.3, i.e. an intermediate value between 1.5 for glass and air with 1.0) and the possibility of cleaning deposits such as dust or dry leaves on the surface of the panels.

The mono-crystalline silicon panel has the following nominal parameters (Table 1):

Table 1

Measured values on mono-crystalline panel

Maximum Power (Pmax):	75 W
Voltage drop (Voc):	18.8 V
Short-circuit current (Isc):	5.4 A
Voltage in Pmax (Vmp):	15.2 V
Current in Pmax (Imp):	4.9 A

In the present experiment we used a device which creates water film on the working surface of the panel, device located on the top of the module. Also we used a multi-meter, a laser thermometer and a Fluke TI20 Thermo-Vision camera. The device for a single module consists of a cylindrical tube with 25 holes, each with a diameter of 1.5 mm. Tube diameter is 20 mm and length equal to that of the panel, i.e. 765 mm (Fig. 1.a) and b)).

Photovoltaic panel was placed on a fixed frame, with a tilt angle of 35 degrees. During the measurements the average of radiation level was 780 W/m^2. Water flow measured was $33.3 \cdot 10^{-6}$ m^3 / s.

Fig.1-a) System without water film

Fig.1-b) System with water film

3. Measurements results

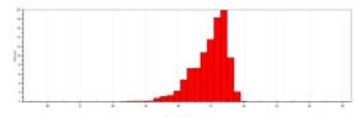
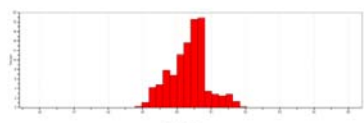
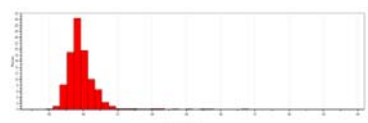
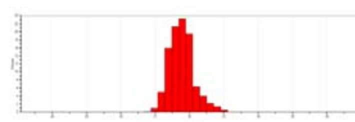
During the measurement, we monitored the temperature on both sides of the panel with thermo-vision camera, a laser thermometer and the output parameters with the help of a multi-meter. All images were processed with the software Inside Fluke IR 4.0. The results obtained for a series of measurements with and without water film were summarized in the following table (Table 2). The measured values for temperature on the face of the module, respectively on the back of the module without water film are shown in the first two lines of the table. Measurements show that the surface temperature of the panel without water film has a working interval of 38.5- 41.5 ˚C (as in diagram a)). On the back of the panel, under the same conditions, were measured temperatures in the interval 50-52 ˚C (as the temperature distribution from chart b)).

When the device was supplied with water, and the water film formed on the surface of the module, a new series of temperature measurements and output parameters were made. Temperature measured on both sides of the module decreased by over 10 ˚C. The water inside the tube had a temperature of 24 ˚C and ambient temperature was 31 ˚C.

More accurate readings on the front of the module were between 26 and 27 ˚C (see fig. c)), while the measured values on the back were in the range 31-32.5 ˚C (see fig d)).

Table 2

Measurements results using the thermo-vision camera

With/without cooling	Temperature measurement surface	Panel surface temperature distribution	Measured temperature value frequency
Without cooling	Module face	a) 	
	Module back	b) 	
With water film	Module face	c) 	
	Module back	d) 	

To observe the temperature evolution over time, we developed a new series of measurements after ten minutes, repeating the experimental-film of water, which now had a temperature of 27 ˚C. In the second set of measurements, we noticed an increase of recorded temperatures on two sides of the panel approximately 2 ˚C.

To easily track the evolution of parameters resulting from the experiment, we centralized some of the measurements in the table below.

Table 3

Measurements results after water film pooring

	Temperature [˚C]		I[A]	U[V]	P [W]	Hour
	Face	Back				
Panel module before first wash	41.0	50.1	4.45	16.43	73.11	14.05
	41.3	50.4	4.44	16.46	73.08	
Panel module during first wash	26.20	32.10	4.36	17.60	76.74	14.10
	26.40	32.60	4.28	17.90	76.61	
Panel module during the second wash	27.90	33.40	4.37	17.25	75.42	14.20
	28.10	34.20	4.39	17.09	75.05	
Panel module after wash	36.30	44.80	4.41	16.67	73.51	14.30
	39.20	48.10	4.43	16.51	73.14	

The measured data revealed the following characteristics:

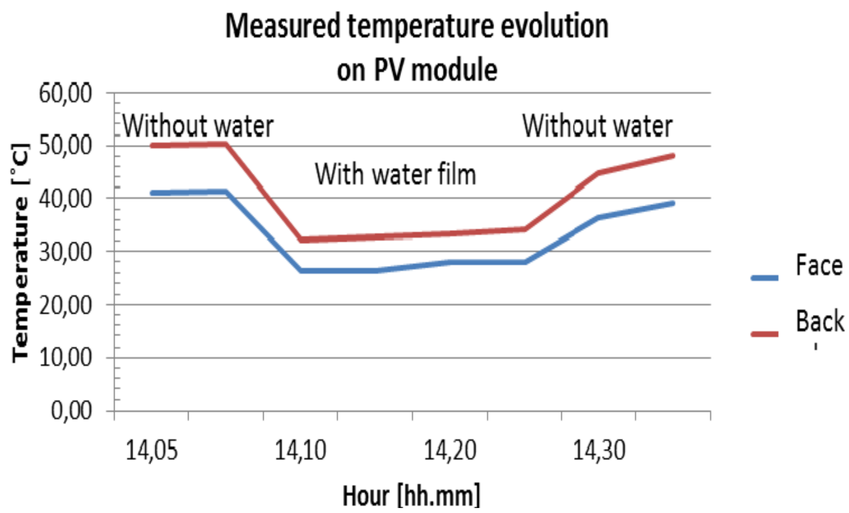


Fig.2. Temperature graphic on both sides of the module

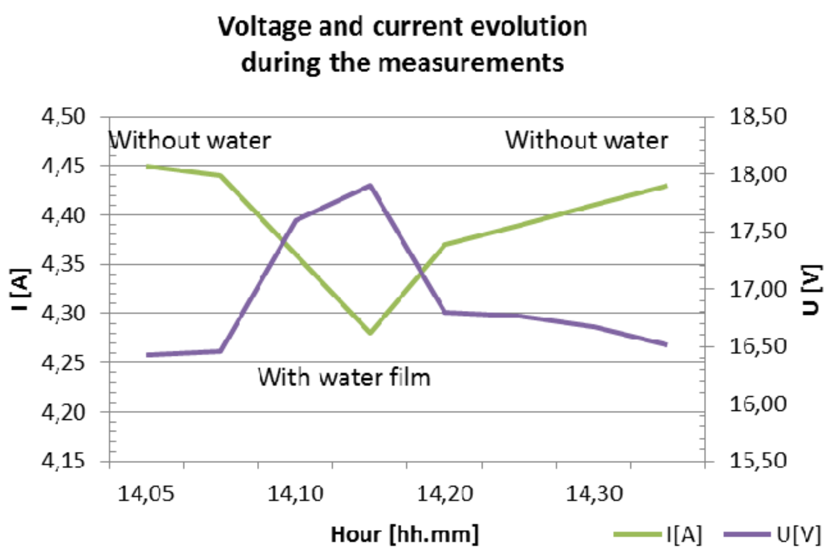


Fig.3. Voltage and current graphic

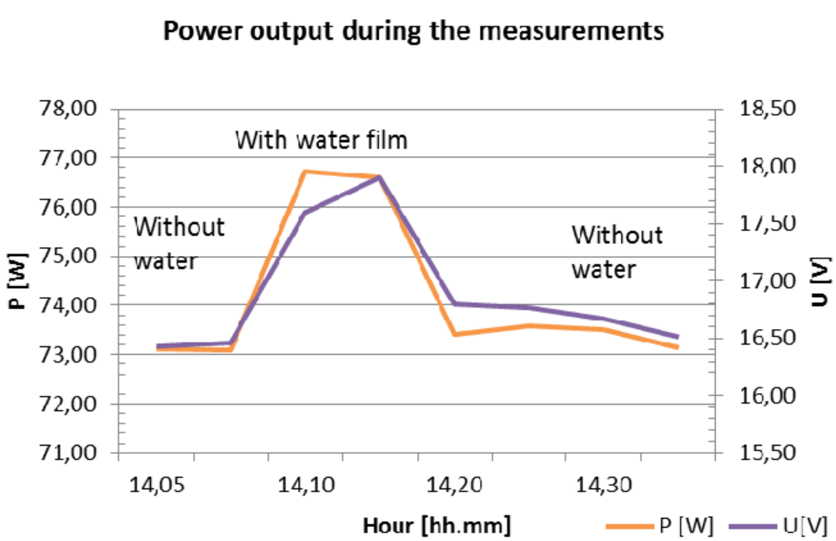


Fig.4. Power output graphic

Panel module working temperature is influenced by the water film, because it falls with 15-16 ˚C on both sides. In this case the module reaches the optimum temperature value recommended by the manufacturer (range 25-30 ˚C), when the water temperature is 24 ˚C.

Also we noticed that when the water supply system is off, after less than ten minutes the temperature is back to the initial measured value. All these variations in temperature affect the module's output parameters: current, voltage and hence power output.

If we look at Figure 3, we can see increases in voltage with temperature drop: 15-16 ˚C reduction in temperature brings a gain of 1.5 V voltage, and current values change by 0.2 A. Overall we can say that we have an increase approximately 3.5 W of power output, which equals 9.5%.

In Figure 5, it is shown the schematic diagram of a proposed system that can be used to achieve water film on the surface of a photovoltaic module.

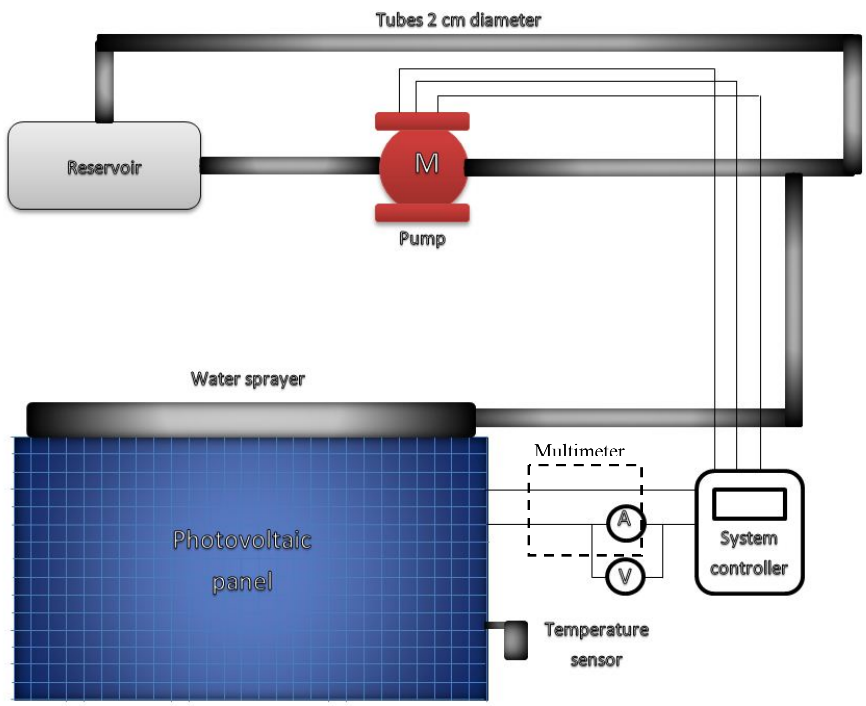


Fig.5. Schematic diagram for a fully automated system

In figure 6 is shown the thermic equivalent circuit of the PV panel with free cooling water flow:

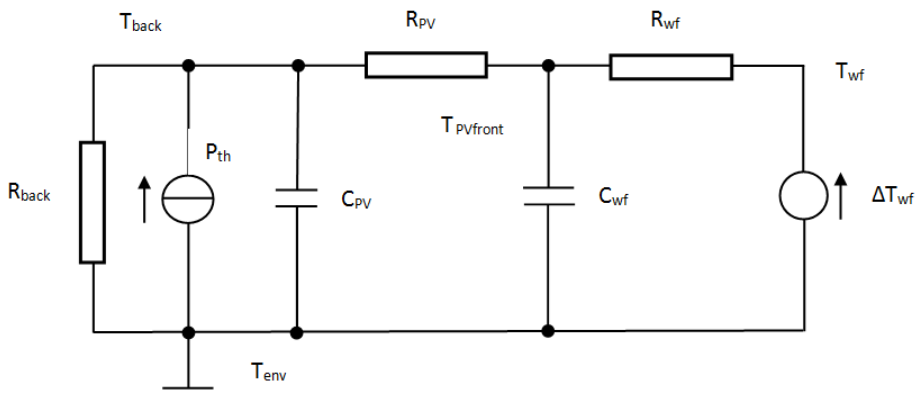


Fig.6. Thermic equivalent circuit

The equivalent circuit has three thermic resistances:

R_{back} – thermic resistance between back surface of the panel and the environment;
R_{PV} – thermic resistance of the PV laminate;
R_{wf} – thermic resistance of the free water flow.

The algorithm for experimental determination of thermic resistances uses the following system of equations:

$$\begin{cases} \Delta P = \Delta P_{back} + \Delta P_{wfront} & (1) \\ T_{back} - T_{amb} = R_{back} * \Delta P_{back} & (2) \\ T_{back} - T_{amb} = (R_{PV} + R_{water}) * \Delta P_{wfront} + (T_{amb} - T_{wf}) & (3) \end{cases}$$

In these three equations we have five variables which we need to determine: ΔP_{back} , ΔP_{wfront} , R_{back}, R_{PV} and R_{water}.

For this we can take into account the following cases:

a) In equation (1) we consider $T_{back}=T_{amb}$ and T_{wf} is measured, so $\Delta P_{back}= 0$ and $\Delta P = \Delta P_{wfront}$.
In these conditions, we can calculate in equation (3) the sum between thermic resistences R_{PV} and R_{water}.
b) When $T_{back}>T_{amb}$ and we know T_{wf} and T_{amb} for a given thermic flux generated by PV panel, we can find the thermic resistance R_{back}.

c) Without water cooling, knowing the surfaces temperatures and thermic flux generated by PV, thermic resistance R_{PV}, can be determined.

With some calculations and for measured values in thermic stationary regime, without water cooling flow we obtain the following results:

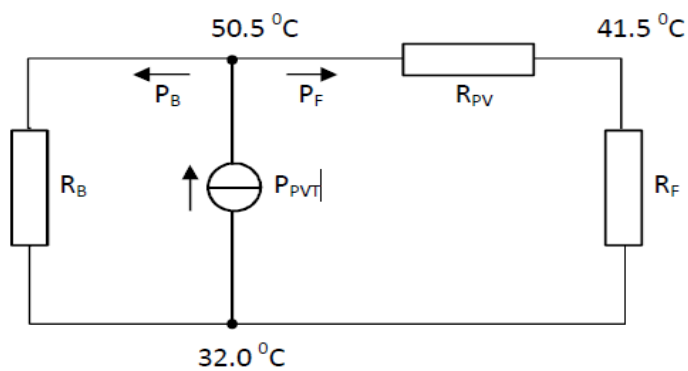


Fig.7. Thermic equivalent circuit in stationary regime, without water cooling flow

By examining the resulting values of measured temperatures, we obtain the equality: $R_{PV} = R_F$. So, for a known value P_{PVT}=60.6W, we obtain P_B=40.4 W and P_F=20.2 W. Knowing the power flows and the measured temperatures from the figure, we obtain the following thermic resistances: R_B=0.458°C/W ; R_{PV}=R_F=0.458°C/W.

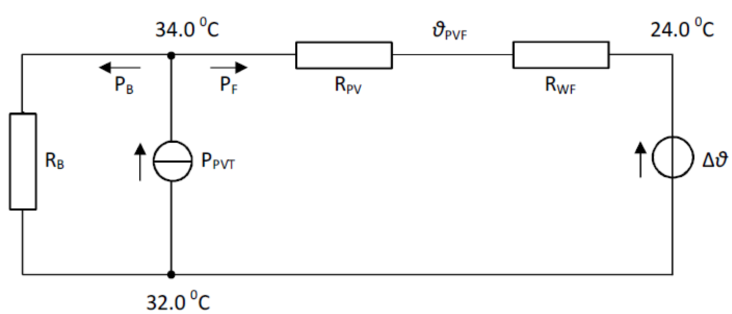


Fig.8. Thermic equivalent circuit in stationary regime, with water cooling flow

With the new temperature values (the temperature from the back of the panel and water cooling temperature) and with the help of obtained values from the test without water cooling, we can determine the following values: P_B= 4.367 W, P_F= 56.233 W, Θ_{PVF}=25.75˚C, R_{WF}=0.03˚C/W .

4. Conclusions

In this experimental study, a PV module cooled by a thin film of water running on the front of the panel has been considered. The advantage of this cooling system, in addition to decreasing the temperature of the panels, leads to obtaining better electrical efficiency due to decreasing the reflection loss.

Due to the front water cooling of the panel, the electrical yield has return a plus of about 9.5%, which can cover the power needed to pump the water from the bottom of the panel to its top end. A thermic equivalent circuit can be developed and used for permanent and transitory regimes analysis. The thermic resistances of this circuit can be experimentally determined with the algorithm proposed in this paper and the cooling process optimization and its economic analysis will be the subject for a future work.

This analysis can be used also for developing an automatic system for water pumping for an entire PV power plant and for making an advanced model of cooling influence in Comsol Multiphysics software.

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R E F E R E N C ES

[1] *S. Krauter*, RIO 02 – World Climate & Energy Event, 2002, January 6-11, 101-107.
[2] *S. Krauter,* Journal of Solar Energy Materials & Solar Cells, 2004, 82, 131-137.
[3] *M. Abdolzadeh, M. Ameri*, Journal of Renewable Energy, 2009, 34, 91-96.
[4] *S. Odeh, M. Behnia*, Heat Transfer Engineering, 2009, 30, 6, 499-505.
[5] *G. Jianqiang, Z. Ying, L. Yanfeng and G. Xin,* International Conference on Intelligent System Design and Engineering Application, 2010, 502-505.
[6] *V. Eveloy, P. Rodgers, S. Bojanampati,* The 28th IEEE Semiconductor Thermal Measurement and Management Symposium (SEMiTHERM), 2012, March 18-22, San Hose,USA, 87-97.