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Experimental Assessment of PV Panels Front Water Cooling Strategy

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Abstract. The electrical performance and reliability of flat-type photovoltaic (PV) modules can be severely affected by elevated cell operating temperature due to elevated ambient temperatures. In this work the free flow front water cooling solutions to enhance flat-type PV module electrical performance is experimentally explored on laboratory scale module operated outdoors under natural light luminance. Water-cooling is implemented using a perforated tube disposed on the top of the panel and a chilled water source, both attached to the module active surface. The cooling water directly wets the module active surface, thereby decreasing the light reflection loss and cleaning the panel surface in the same time. For given meteorological conditions, the efficiency of free water cooling was measured and the corresponding additionally electrical energy yield was determined. The equivalent electric circuit of the PV panel cooling system is developed and an appropriate algorithm for its parameters experimental determination is proposed.

Key words

Renewable energy, photovoltaic panels, efficiency improvement, front water cooling.

1. Introduction

Electrical power generation of photovoltaic systems depend on its operating temperature. The open circuit voltage decreases significantly with solar cell's increasing temperature. For mono- and multi-crystalline silicon solar cells the reduction of electric power output is of 0.4%/°C to 0.5%/°C. Also, the photovoltaic cells exhibit long-term degradation if the temperature exceeds a certain limit. Many researchers have investigated and proposed different methods of active cooling, consisting of forced air- or water-cooling, to increasing total energy output of the PV modules [1]-[7].

In this experimental study a PV module cooled by a thin continues film of water running on the front of the panel has been considered. The advantage of this cooling system, in addition to decreasing temperature of the panels, is in obtaining better electrical efficiency due to decreasing the reflection loss (refractive index of water is 1.3, which is intermediate between glass, with 1.5, and air, with 1.0).

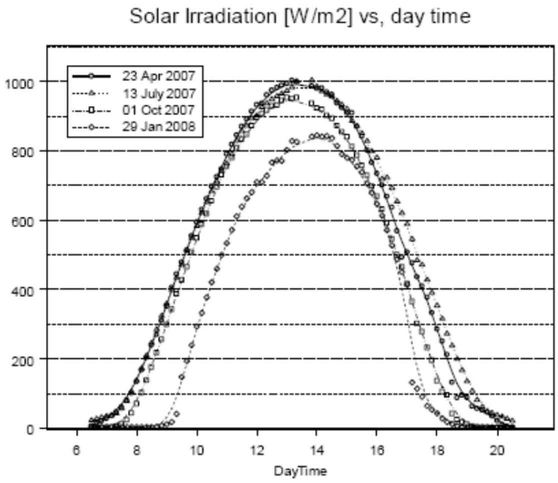
To produce a film water over the PV panel, a tube with 25 holes of 1.5 mm diameter been installed on the top end of the panel. Water at 24 °C added to the feeding tube, leaves the holes and flows over the panel as a thin film. The flow rate is 2 lit/min. Temperature of the front and of the back surfaces of the panel was measured with a Fluke thermo-vision camera. Temperature on the back of panel is reduced from 48 °C to 35.5 °C. The temperature difference between back- and front-side of the panel remains the same, about 7 to 8 °C. It is interesting to note that before the water cooling on the panel surface, there was a small temperature disturbance of about 2.5 °C because of a dirt deposition which was removed later by the water flow. Due to the front water cooling, the electrical yield has return a plus of about 8.4% which cover the power needed to pump the water from the bottom of the panel to its top end.

2. The experimental model

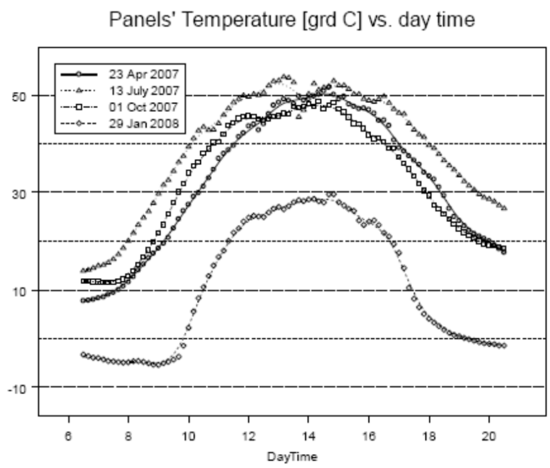
In figure 1 is shown a general view of the PV power plant installed at the University *Politehnica* of Bucharest where we intent to implement the free front water cooling system and in figure 2 it are shown the yearly representative solar irradiation and the corresponding measured PV panel temperatures.

The PV module on which the experiment was developed is shown in figure 3. The PV panel is south oriented at a 350 tilt angle, like all the PV panels of the PV power plant of figure 1. The water feeding tube installed on the top end of the panel provides the water free flow on the front side of the panel.

Fig. 1. General view where the free front water cooling will be implemented



(a)

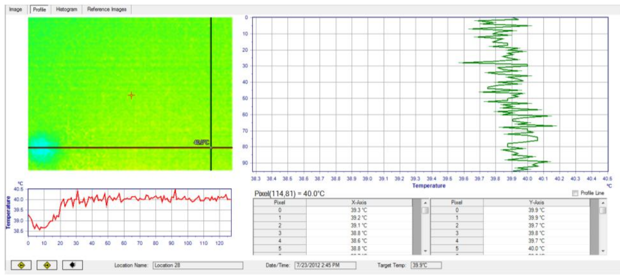


(b)

Fig. 2. Yearly representative solar irradiance (a) and corresponding PV panel cells' temperature (b)

3. Experimental results

In figure 3 are given experimental results obtained on the PV panel with natural cooling.



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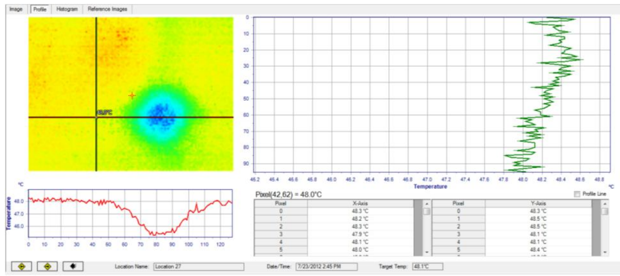
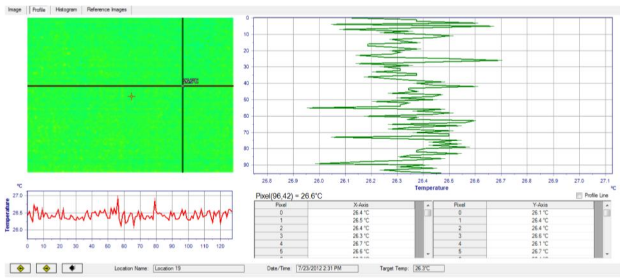


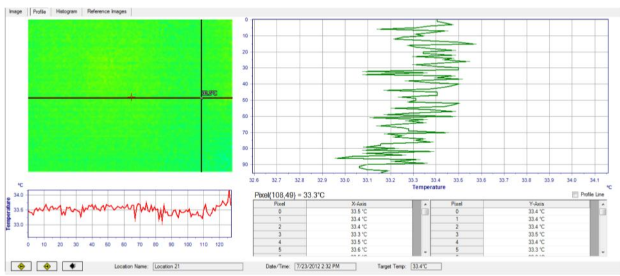
(b)

Fig. 3. PV panel with natural cooling surface temperatures: on the front surface (a) and on the back surface (b); the debris spot of the figure 3.b will be eliminate after water cooling.

In figure 4 are given experimental results obtained on the PV panel with free flow front water cooling.



(a)



(b)

Fig. 4. PV panel with free flow front water cooling surface temperatures: on the front surface (a) and on the back surface (b)

It is important to note from the results given in figure 3 and 4 that PV panel temperature distributions along its vertical lines have small values dispersions. This characteristic encourages the development and use of equivalent circuit with concentrated parameters for analyse of PV panels' thermal behaviour.

The thermic inertia of the PV panel is emphasizes in diagrams of figures 5÷7.

Temperature evolution of the PV module front and back surfaces, when the cooling water flow is turn on, for about 15 minutes, and after that it is turn off, are given in diagram of figure 5. There is a temperature difference of about 8 ^{0}C between back and front surfaces of the PV panel.

Open voltage and short-circuit current evolution, when the cooling water flow is turn on and then is turn off, are given in figure 6. The open voltages increases and short-circuit decreases when the cooling water flow is turn on.

The delivered electric power evolution and the corresponding open voltage evolution, when the cooling water flow is turn on and then it is turn off, are given in figure 7.

From the diagrams of figures 5÷7 can be estimate the thermic time constant of the PV panel. It is about 100 s. More precise determination will be made in a future work.

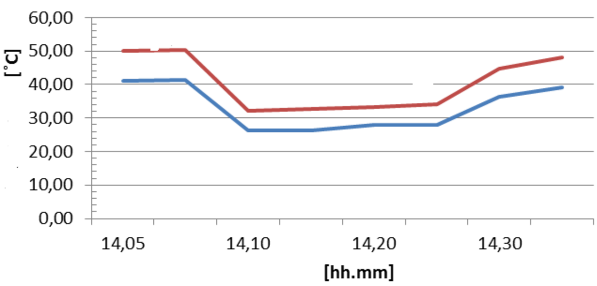


Fig. 5. PV module temperature evolution of the front and back surfaces, when the cooling water flow is turn on and turn off

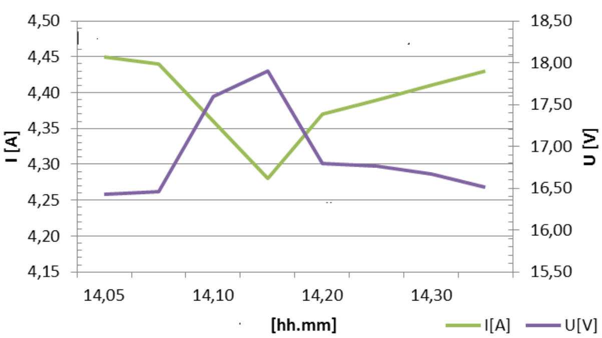


Fig. 6. PV open voltage and short-circuit current evolution, when the cooling water flow is turn on and turn off

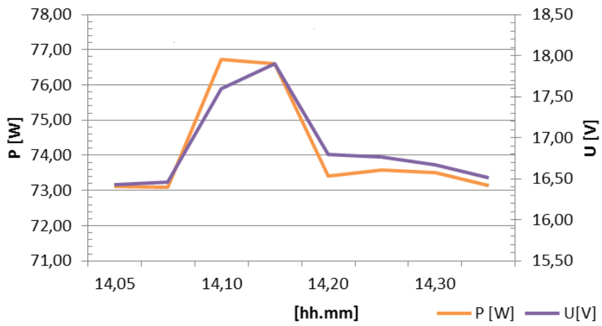


Fig. 7. PV delivered electric power and the corresponding open voltage evolutions, when the cooling water flow is turn on and turn off

4. Thermic equivalent circuit

In figure 8 is shown the thermic equivalent circuit of the PV panel with free flow front water cooling.

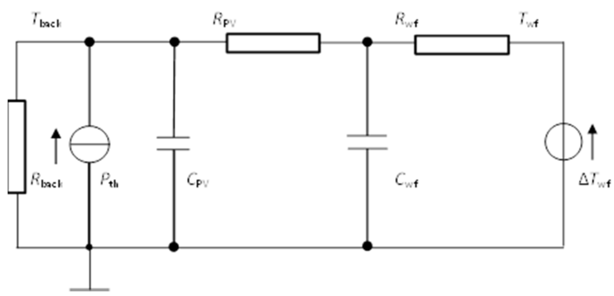


Fig. 8. Thermic equivalent circuit of the PV panel with free flow water cooing

This 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

In this work we propose an algorithm for thermic resistances experimental determination. The proposed algorithm steps are the following:

1. The determination of the sum $R_{PV} + R_{wf}$ of the thermic resistances of PV panel and water flow. By appropriate water flow temperature control have to establish the PV back surface temperature (T_{back}) equal with the environment temperature and in this case all the thermic flux generated by the PV panel will be directed through the front surface. Knowing the water flow temperature and the environment temperature we can calculate the above thermic resistances sum.
2. For a PV panel temperature T_{back} higher as the environment temperature, knowing the water flow and the environment temperature, for a

given thermic flux generated by the PV panel, we can determine the thermic resistance R_{back}.

3. For a PV panel without water cooling, knowing the PV panel surfaces temperatures and thermic flux generated by PV panel, we can determine the thermic resistance R_{PV}.

4. Conclusion

Free flow front water cooling of PV panels can improves the efficiency and reliability of photovoltaic energy conversion – the open voltage of the panels is increasing when its temperature decreasing and due to the lower operating temperature, its life cycle could be increased.

The accidentally debris spots, which could destroy the PV panel, can be eliminated by the water flow.

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 work.

The cooling process optimization and its economic analysis will be the subject of a future work.

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