

Case study on the efficiency improvement of photovoltaic panels by cooling

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Abstract. The paper presents a numerical study of the operation of photovoltaic panels integrated in ventilated facades of the buildings. In these circumstances, the position of the panels is fixed all the time and the possibility of the raising of the conversion efficiency is analysed from the point of view of the operating temperature of the photovoltaic cells. The model and the functioning parameters are obtained using TRNSYS software. The solution proposed for cooling the panels consists in using water heat exchangers attached to the backside of the photovoltaic panel.

1. Introduction

During the year 1876 Adams and Day observed the photovoltaic effect in solid selenium. The modern solar cell was discovered in 1954, when researchers from Bell Labs of Pearson reported silicon cells with 4.5% efficiency, which was raised to 6% a few months later [1].

Photovoltaic (PV) cells can be made of several semiconductor materials, but the vast majority of solar cells (95%) are made of silicon (Si). It is one of the most widespread chemical elements in the Earth's crust, representing approximately 25% of it. Therefore, is available in sufficient quantities, being accessible at a reasonable price. In addition, the processing of the material is not aggressive to the environment.

When photons from solar radiation strike a photovoltaic cell, they can be reflected, transmitted or absorbed. Only the absorbed photons with a certain level of energy can generate electricity. When a sufficient amount of energy is absorbed by the semiconductor material, electrons are disassociated from the atoms of the material. A special treatment applied during the production of PV panels to their surfaces, makes the front surface of the cells more receptive to free electrons, that are migrating to the surface.

Advantages of using photovoltaic panels:

- direct conversion into electricity;
- no moving elements (no noise);
- long life.

Disadvantages:

- dependence on climatic conditions (clouds, dust etc.);
- the diurnal variation of solar radiation;
- dropping of the operating parameters when cells temperature rises.

Almost all the solar energy captured by photovoltaic panels not converted into electricity, about 80%, is converted into heat [2].

The performance of photovoltaic panels is known to be temperature dependent [3]. There are studies regarding the dependence of the conversion efficiency to the cell temperature. Through the majority of the studies consider a linear variation of the temperature-efficiency dependence[4]. Thus, when a temperature increase occurs, the efficiency of converting the energy of solar radiation into electricity decreases. As a guideline value, a reduction of the efficiency of the photovoltaic panels by 0.3 ... 0.5% can be considered, for each degree of temperature increase [5].

The improvement of the performance of PV panels can be achieved by reducing the operating temperature of the cells, because it is more difficult to modify the other parameters implied. For example, in the particular case of the placement of photovoltaic panels on the building's facades, which are vertical and non-orientable surfaces, the solar radiation represents an uncontrollable parameter.

Skoplaki E. et. al. [6] presents various methods and relationships for determining the dependence between the conversion efficiency of photovoltaic modules and their temperature.

In literature there are presented various ways of cooling the photovoltaic panels but the main solutions are air cooling [7]and water cooling [8].

Most photovoltaic panel cooling solutions make energy available for other uses, so that the payback period is reduced compared to simple photovoltaicsystems [8].

A cooling method of the photovoltaic panels by using water as a heat transfer agent is presented in [9]. The study presents a hybrid photovoltaic panel behind which is attached a functionally graded material (material with variable thermal properties), and inside it is a serpentine through which the water circulates. This circuit has the role of both heat extraction from the panel and solar collector. An example of such a system is presented in [9]. The assemblies of this kind are known in the literature as photovoltaic-thermal systems (PV/T). The modelling of heat transfer in the case of photovoltaic systemsunder variable atmospheric conditions is studied by S. Armstrong et al [10].

Since the efficiency of the photovoltaic panels is lower than the solar thermal, it is opportune to use hybrid systems that ensure an optimized operation of the whole assembly [11].

2. Problem description

Within this work are studied the operating parameters of a photovoltaic panel of 1 m²surface, integrated in the double skin ventilated facade of a building. The photovoltaic panel consists of 36 solar cells connected in series.

The purpose of the study is to determine the efficiency of PV panel both in normal operation and cooling conditions. Cooling is performed by using a heat exchanger, located at the rear of the PV. In order to achieve high efficiencies, the photovoltaic panel is cooled to a temperature close to the nominal one of 25 °C.

The heat exchanger must allow the heat energy to be dissipated from the rear area of the photovoltaic panel. It is necessary that the contact zone between heat exchanger and the photovoltaic panel is made of a material with a high thermal conductivity (copper).

3. Numerical simulation

The external conditions considered are those for a typical day of summer (July) in Constanta, Romania. The position of the photovoltaic panels is vertical, while the intensity of the solar radiation is considered to be variable during a day.

The numerical model is presented in Figure 1, with the following blocks corresponding to the climatic data, the photovoltaic panel, elements of conversion of the measurement units, tracking andoutput data.

The operating parameters of the PV panelstudied are:

- short-circuit current: $I_{sc} = 6.5$ A;
- open circuit voltage: $V_{oc} = 21.6$ V;
- the current at the maximum power point: $I_{max} = 5.9$ A;
- voltage at maximum power point: $U_{max} = 17$ V;

- operating temperature of the panel under nominal conditions $t_{NOCT} = 47\text{ }^{\circ}\text{C}$.
- module area: $S = 0.89\text{ m}^2$.

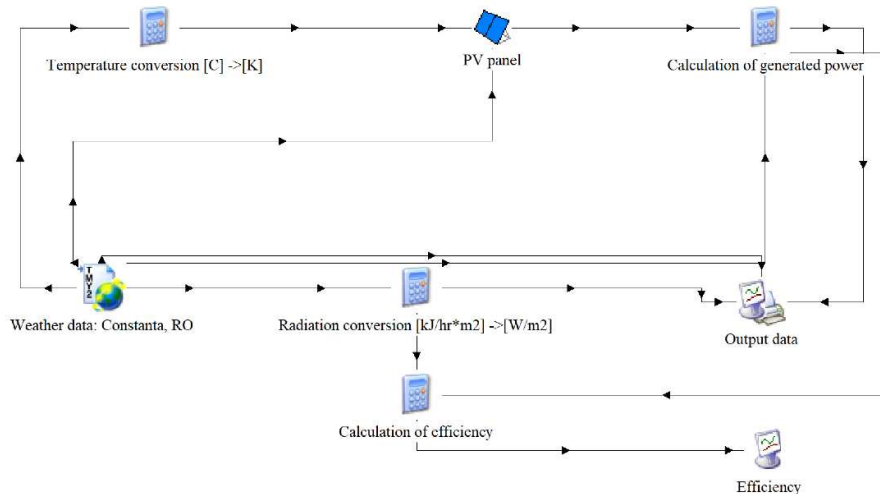


Figure1. Numerical modelling of the photovoltaic panel with the TRNSYS software

The input data required for numerical model:

- PV panel orientation: - south;
- PV panel position: - vertical, on the front of the building;
- climatic conditions: Constant, according to the Typical Meteorological Year (TMY);
- variable solar radiation intensity.

The output data from the software:

- operating temperature of the photovoltaic panel;
- the intensity, voltage and electrical power produced by PV panel;
- PV panel efficiency.

4. Results

Figure 2 shows the values obtained from the simulations under the conditions described above for the interest during a day. On the left-hand axis there are presented the values of solar radiation (W/m^2) and the power produced by the photovoltaic panel at its maximum operating point (W/m^2). On the right scale the values of the outdoor temperature as well as the operating temperature of the photovoltaic panel ($^{\circ}\text{C}$) are accessible. It can be observed that the temperature of the PV panel has a proportionate variation with the intensity of the solar radiation and with the temperature of the outside air. The power produced by the photovoltaic panel is also dependent on the intensity of the solar radiation, but inversely proportional to the temperature of the cells.

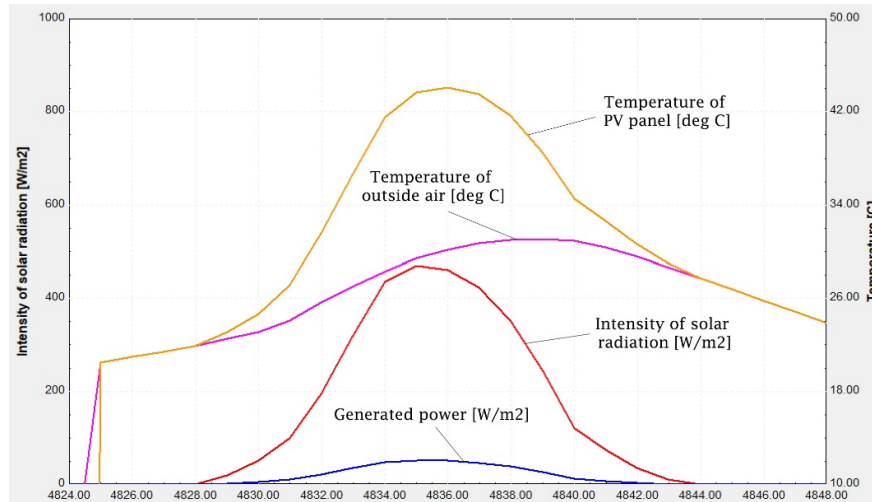


Figure 2. Daily variation of climatic and PV panel parameters

Under these conditions the photovoltaic panel operates according to the parameters in Table 1. It can be observed that the conversion efficiency has values below 12%, with a maximum around 11.4%.

Table 1. PV panel parameters under normal operating conditions.

Hour [h]	Intensity of solar radiation [W/m ²]	Temperature of PV panel [°C]	Efficiency - normal conditions [%]	Electric power generated [W/m ²]
5.00	20.6	23.2	10.59	2.2
6.00	51.9	24.7	11.08	5.8
7.00	100.7	27.2	11.36	11.4
8.00	195.4	31.6	11.52	22.5
9.00	318.9	36.7	11.49	36.7
10.00	437.5	41.6	11.36	49.7
11.00	471.0	43.7	11.29	53.2
12.00	461.8	44.1	11.28	52.1
13.00	423.5	43.5	11.31	47.9
14.00	353.9	41.7	11.37	40.2
15.00	244.7	38.5	11.40	27.9
16.00	121.3	34.6	11.25	13.6
17.00	76.0	32.7	11.07	8.4
18.00	36.1	30.7	10.70	3.9
19.00	10.8	29.0	10.01	1.1

The photovoltaic efficiency is directly influenced by the intensity of the solar radiation but also by the temperature of the panel, which reaches values up to 44.1 °C for a solar radiation of 461.8 W/m², Table 1. To improve the operating temperature of the photovoltaic panel and also the conversion efficiency, it would be necessary to cool it to the operating temperature toward the standard conditions one of 25 °C. Considering the values of the parameters in the Table 1, it is recommended that the cooling of the photovoltaic panel must be done between 08:00 and 15:00.

The energy balance of the PV panel is performed in order to determine the operating temperature of the photovoltaic panel after cooling. The energy balance was achieved on hourly intervals where the intensity of the solar radiation is high and the conversion efficiency can be improved by reducing the panel temperature. Under these conditions, taking into account the heat gained from solar radiation as well as the energy dissipated by the heat exchanger by convection with the outside air, the average total energy stored by the photovoltaic panel is obtained for each study interval. Using this value and knowing the thermal capacity of the panel, the new temperature is determined under the same environmental conditions by extracting the absorbed thermal energy [12].

In Table 2 the values of the parameters of the photovoltaic panel are presented under cooling conditions. The parameters are determined as the average calculated on the hourly intervals of interest.

Table 2. PV panel parameters in cooling conditions

Hourly interval	T_{med_cell} [°C]	T_{opt} [°C]	η_{eff} [%]	η_{opt} [%]	P_{sup} [W/m ²]
8-9	31.6	29.3	11.52	11.63	0.2
9-10	36.7	25.8	11.49	12.06	1.8
10-11	41.6	26.1	11.36	12.15	3.5
11-12	43.7	25.3	11.29	12.23	4.4
12-13	44.1	27.5	11.28	12.13	3.9
13-14	43.5	28.1	11.31	12.10	3.3
14-15	41.7	27.6	11.37	12.09	2.6

Where: T_{opt} - average cell temperature under cooling conditions;

η_{eff}, η_{opt} - conversion efficiencies before and after optimization;

P_{sup} - additional power produced by PV panel after cooling.

Considering that the efficiency decrease is 0.45% for each degree above the standard temperature of 25 °C, by cooling it is possible to obtain a power increase according to Figure 3.

According to Table 2, if the reduction of the temperature of the photovoltaic panel is applied to 25 °C between 08:00 and 15:00, the efficiency of the panel is increased up to 12.23%.

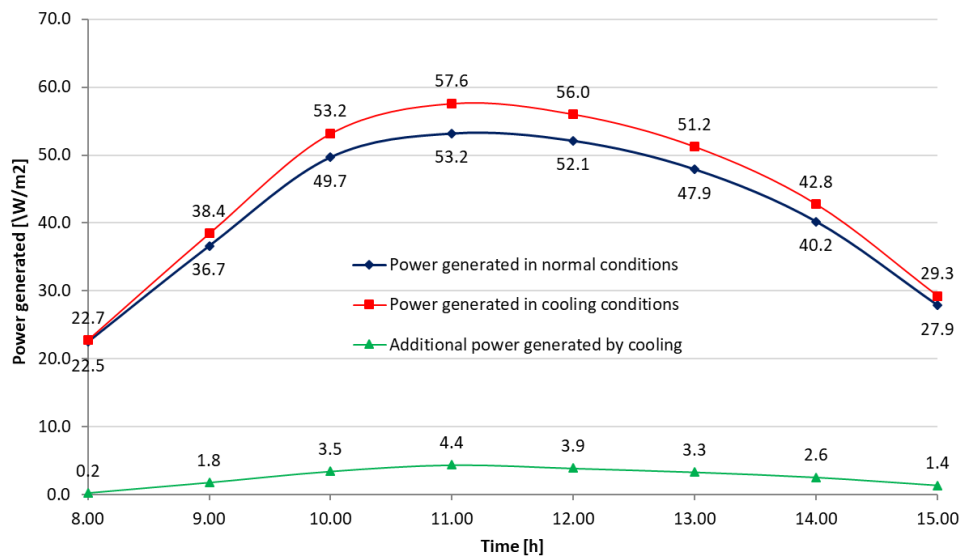


Figure 3. Power generated by PV panel for the two studied cases

Consequently, the electrical power produced by the photovoltaic panel under similar conditions of sunlight is higher than that obtained under real operating conditions. The energy gain during the cooling interval, 08:00 - 15:00, is about 21.14 Wh/m², which represents an increase of 6% compared to the normal operating conditions.

5. Conclusions

Cooling of photovoltaic panels is an advantageous solution for improving their conversion efficiency. The reduction of the operating temperature achieved by using water as a heat transfer agent has many advantages. Thus, the cold water available in the water supply system can be used, being a cheap source with optimal parameters for extracting the surplus of energy stored in the mass of the photovoltaic panel.

The using of a heat exchanger and a storage system for the extracted thermal energy determines a superior efficiency of the whole assembly evaluated globally, compared to the stand-alone photovoltaic system. In the case of PV/T systems, the highest efficiency of the photovoltaic panel must be always a priority and the extraction of the thermal energy must be done with lowest auxiliary consumption possible. Further numerical and experimental studies will analyse other possibilities to improve the performance of these systems, in the conditions of their integration in buildings with double glazed ventilated facades.

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