Thermo-electrical solar hybrid system

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Abstract

This paper presents a conception of a new solar hybrid system which integrates photovoltaic (PV) module with solar thermal collector. Such thermo-electrical hybrid device provides a direct conversion of solar energy into electricity and heat energy simultaneously. A preliminary project of described solution is proposed and a construction of the prototype is presented. Most significant operating parameters of PV module, such as: efficiency, maximum power or fill factor, have been researched including various performance of working medium in thermal collector. Results have been compared and analyzed. The optimum operation point has been chosen and the efficiency of the whole system has been calculated.

Advantages of integration those two devices into one hybrid system are presented and future plans for the development and industrial application of this solution are introduced.

1. Introduction

Sun is the greatest source of energy which is delivered on Earth. One can take advantage of solar energy in several ways. Among many methods of photoconversion (conversion of solar radiation), one can distinguish photovoltaic and photothermal conversions. The fist one is a direct production of electrical energy through the generation and separation of charges in the p-n junction of semiconductor. Second one is used to convert solar radiation into heat, commonly used in solar thermal collectors for preheating domestic water.

The aim of the project was to create a system that connects those two types of photoconversions, uses them in one integrated device. The idea of such solution arose according to the observations of decreasing efficiency of photovoltaic modules under the influence of high temperatures. Standard conditions for solar cell operation are defined by the temperature of 25ºC. In practice, photovoltaic module under real atmospheric conditions (in central Europe) can be heated up to 80ºC. The efficiency of such PV module drops by about 0,4% to 0,9% absolute for each Celsius of increasing surface temperature. In order to minimize this effect, applying of the copper pipes on the underside of the PV module is proposed. Working medium flowing through channels, located beneath the surface, cools the photovoltaic module and simultaneously, received thermal energy can be utilized for water heating. Similar systems were mentioned by other authors before, however one cannot find any experimental measurements of real construction performance and it was not precisely investigated. Fig. 1 shows the cross section of the thermo-electrical solar hybrid device.

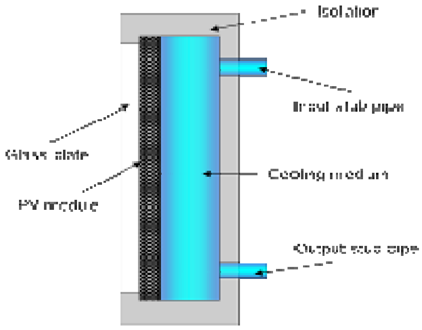

Fig.1. General idea of solar hybrid system.

2. Construction of the prototype

Proposed system prototype was constructed fallowing by the previously established project. The model device was designed for inside laboratory tests in undersized scale. It consists of nine single-crystalline silicon solar cells placed on previously isolated copper plate with copper coil pipe connected to it. Fig. 2 presents the preliminary project of constructed device.

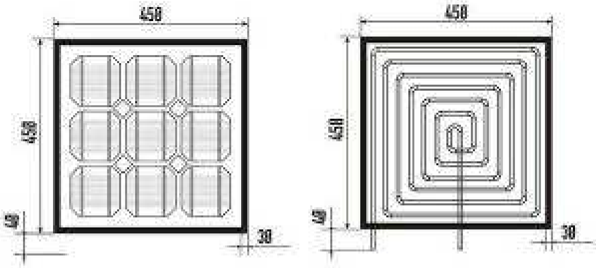

Fig.2. System design: left – front (top) side, right-back (bottom) side.

Final construction was fabricated using available techniques. Solar cells was connected in series-parallel way using metal tape and isolated from both sides with high temperature spray plastic. Top side was covered with glass coat. Copper pipe was soldered to the bottom side of the plate in the way shown in Fig. 2. Fig. 3 illustrates the realization of the project.

Fig.3. The realization of the solar hybrid system prototype: left – PV module, right- thermal collector.

The whole system was integrated, isolated and encapsulated in order to protect it from the influence of the outer environment.

To conduct research the installation must be obviously equipped with light source (solar simulator) and other indispensable peripheral apparatus (such as: meters, regulated load, pump and heat receiving system). Fig. 4 presents the system during measurements.

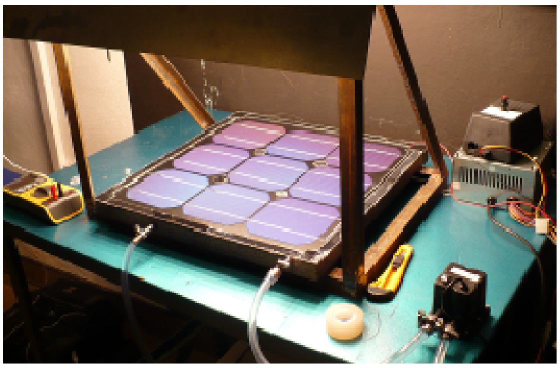

Fig.4. Thermo-electrical solar hybrid system under illumination.

3. Obtained results and conclusions

This section present preliminary measurements of system efficiency and in particular its dependence on the fluid flux that flows through pipes.

3.1 Applied equations

To obtain photovoltaic module efficiency one follows the formula:

$$\eta_{PV} = \frac{P_{\max}}{A_t \cdot E_c} \qquad (1)$$

where: P_{max} is electrical power in MPP (maximum power point) [W], A_t represents surface area of the module [m^2] and E_c is solar radiation that hits the surface [W/m^2].

To find efficiency of solar thermal collector (equation 2), two basic parameters are needed: collector effective thermal power Q_{eff} and collector applied power Q_{app}.

$$\eta_T = \frac{Q_{eff}}{Q_{app}} \qquad (2)$$

Whereas Q_{eff} is a product of working medium fluid flux m [kg/s], its specific heat $c_{p,f}$ [J/kgK] and temperature increment between input T_{in} and output T_{out}, and Q_{app} is represented by the value of absorber surface A_p [m^2] multiplied by incident solar radiation per area unit E_c [W/m^2], fallowing the formulas, respectively 3 and 4:

$$Q_{eff} = m \cdot c_{p,f} \cdot (T_{out} - T_{in}) \qquad (3)$$

$$Q_{app} = A_p \cdot E_c \qquad (4)$$

The efficiency of the whole hybrid system is marked $\eta_{PV/T}$ and determined as follows:

$$\eta_{PV/T} = \frac{P_{\max} + Q_{eff}}{A_p \cdot E_c} \qquad (5)$$

3.2 Measured parameters

As a first point of measurements, parameters of photovoltaic module without the support of solar collector were obtained. The results show that after about 20 minutes, device temperature raised up to 50 Celsius degrees. The consequence of increased temperature is efficiency drop. Its value at 50°C was 17% lower than the initial one (Fig. 5). This is only the confirmation of the literature reports of high negative heat influence on PV module performance. In this particular case, deterioration of efficiency was about 0.75% (absolute) for one Celsius of temperature increase.

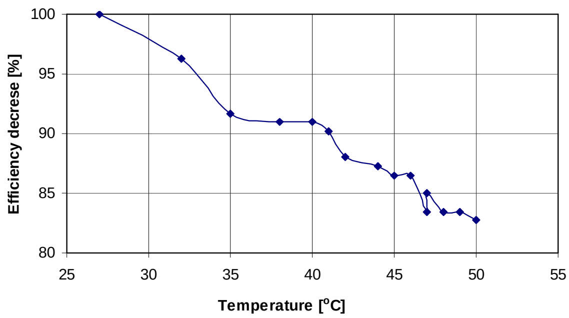

Fig.5. Absolute decrease of PV module under the influence of increasing surface temperature.

Second and essential point of research was to investigate the operation of hybrid device described above. Basic parameters of the system were obtained experimentally and efficiencies were calculated using formulas 1-5. Table 1 presents both measured and computed values. In this case, water was used as a fluid working medium. However for outdoor application water-glycol solution is more advisable due to its lower freezing temperature allowing system to work in winter time as well.

Parameters for thermo-electrical solar hybrid system were measured in laboratory conditions under the illumination intensity of 363 W/m². This is almost three times lower value than the one recommended for STC (standard test conditions: 1kW/m²), which is probably the reason of relatively bad efficiency of PV module. However, here preliminary research are presented and the major objective is to rather analyze the operation of integrated appliances (photovoltaic module and thermal collector) or achieving the highest efficiency.

Tab.1.
Properties of the hybrid system at different fluid flux.

E_c [W/m²]	362.7		
A_p [m²]	0.1764		
A_t [m²]	0.1406		
Q_{app} [W]	63.98		
m [kg/s]	0.0225	0.0173	0.0150
T_{in} [°C]	29.2	29.1	29.3
T_{out} [°C]	29.6	29.7	29.9
ΔT [°C]	0.4	0.6	0.7
FF [-]	0.43	0.42	0.42
P_{max} [W]	0.91	0.92	0.91
Q_{eff} [W]	37.63	43.56	43.91
η_{PV} [%]	1.79	1.80	1.78
η_T [%]	58.83	68.08	68.62
$\eta_{PV/T}$ [%]	60.25	69.51	70.05

The efficiency of solar thermal collector, and consequently the whole thermo-electrical hybrid system, is dependent on the working medium fluid flux. One can observe that the efficiency value of thermal collector reaches maximum at relatively low fluid flux factor and decrease with faster flow. The reason of such behavior is quite simple. Lower velocity of the liquid causes longer contact of the liquid with the inside surface of the pipe, which allows it to receive more heat. As a result input and output collector temperature difference is higher.

Photovoltaic module efficiency is less sensitive on the fluid flux value. One can see that it barely changed in comparison to thermal efficiency. This is the effect of relatively stable surface temperature of photovoltaic module, achieved thanks to the application of heat regaining system in the form of liquid-based thermal collector.

Fig. 6 and 7 show thermographic pictures of the system surface, respectively: before and after turning on the flow of working medium.

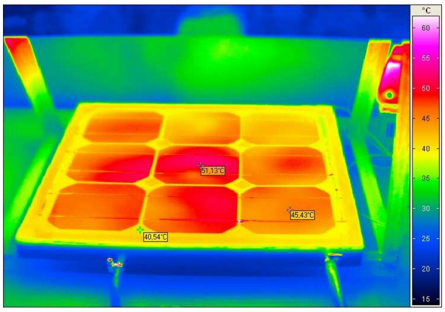

Fig.6. Illuminated solar hybrid system working without liquid flow (solar thermal system is turned off)

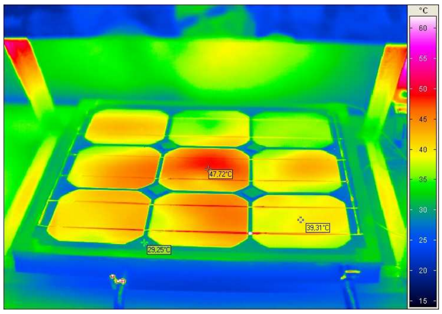

Fig.7. Illuminated solar hybrid system several minutes after turning on the liquid flow.

Temperature of the surface raised up from 27°C to 50°C in about 20 minutes while cooling system was not running. Ten minutes after fluid flux generation, surface temperature dropped to 36°C.

Even such short experiment shows that the thermal-electrical hybrid system is working properly - efficiently cools photovoltaic plate and simultaneously heats flowing water.

4. Future development

Designed system obviously requires further investigations and analysis of several omitted aspects. First of all measurements in standard test conditions according to solar radiation are needed. Further stage should include research in real atmospheric environment, as well as normalized mechanical, insulating and structural strength test. At the end indicated improvements should be made. However, after this preliminary analysis one can assume that this integrated thermo-electrical solar hybrid system is promising and future-oriented solution waiting for implementation.

Bibliography

[1] Jarzębski Zdzisław M: *Energia słoneczna: Konwersja fotowoltaiczna*, Państwowe Wydawnictwo Naukowe, Warszawa 1990.

[2] Smolec Włodzimierz: *Fototermiczna konwersja energii słonecznej*, Wydawnictwo Naukowe PWN, Warszawa 2000.

[3] Pluta Zbysław: *Słoneczne instalacje energetyczne*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2007.

[4] Chochowski Andrzej, Czekalski Dariusz: *Słoneczne instalacje grzewcze*, Centralny Ośrodek Informacji Budownictwa, Warszawa 1999.
[5] Januszewski Józef: *Zasady projektowania urządzeń słonecznych do celów ogrzewczych*, Wydawnictwo Politechniki Wrocławskiej, Wrocław 1986.
[6] Zawadzki Mirosław: *Kolektory słoneczne, pompy ciepła - na tak*, Polska Ekologia, Warszawa 2003.
[7] Wesołowski Maciej: *Analiza funkcjonowania cieczowej instalacji słonecznej*, Wydawnictwo Uniwersytetu Warm.-Maz., Olsztyn 2006.
[8] *Fotowoltaika - materiały szkoleniowe,* Politechnika Warszawska, Warszawa 2011.
[9] Lewandowski Witold M.: *Proekologiczne odnawialne źródła energii*, Wydawnictwo Naukowo-Techniczne, Warszawa 2007.

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