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Influence of temperature on the efficiency of monocrystalline silicon solar cells in the South-eastern Poland conditions

J. M. OLCHOWIK[1*], S. GULKOWSKI[1], K. J. CIEŚLAK[1], J. BANAŚ[1], I. JÓŹWIK[1], D. SZYMCZUK[1], K. ZABIELSKI[1], J. MUCHA[1], M. ZDROJEWSKA[1], J. ADAMCZYK[1], R. TOMASZEWSKI[2]

[1]Lublin University of Technology, Nadbystrzycka 38, 20-618 Lublin, Poland

[2]State Higher Vocational School in Biała Podlaska, Sidorska 95/97, 21-500 Biała Podlaska, Poland

Recently, solar energy conversion has become a very actual item, especially when the world faces problems of petroleum supply and there has been a growing demand for using renewable energy sources. In this situation an important question araises how to use solar energy optimally. The quantum efficiency of solar cells depends on many factors: temperature, insolation, spectral characteristics of sunlight, etc. Some of these factors may be changed during exploitation of solar systems in order to increase their efficiency. The paper reports on the influence of temperature on the work efficiency of monocrystaline photovoltaic modules in hybrid solar systems in the conditions of south–eastern Poland.

Key words: *solar energy; solar cell; photovoltaic module*

1. Introduction

The world faces a big problem of depletion of conventional sources of energy which have to be replaced by new ones. The choice of a renewable source of energy depends, however. A very important issue is to know which kind of energy source will suit best the particular region. South-eastern Poland, where the investigation has been carried out, seems to be the best choice for the use of solar energy, as it has the best insolation conditions all over the country. The solar energy may by used to produce electricity in photovoltaic (PV) modules and heat in photocollectors (PT) by a photovoltaic and photothermal conversion. The photovoltaic effect, which is based on a direct conversion of sunlight into electricity, was observed for the first time by

[*]Corresponding author, e-mail: j.olchowik@pollub.pl

the French physicist, A.C. Becquerel in XIX century. From the exploitation point of view, the most important factor influencing efficiency of PV modules is temperature inside the p-n junctions of semiconducting solar cells. The solar cells may be produced from various materials but silicon still remains the most popular material and crystal silicon modules are most often used. The generation efficiency of the electron-hole pairs inside Si p-n junction depends not only on the quality of crystal structure but also on the insolation conditions as well as on temperature of the cell work. Usually, temperature negatively affects the efficiency of PV conversion, hence various types of cooling systems have been commonly used [1]. However, imperfections of semiconductor structures as well as the quality of atmosphere may give anomalous results. Therefore, to exploit the PV systems optimally, it seems reasonable to analyze their work in various situations.

2. Experimental

The aim of the investigation was to determine the response of PV modules of a hybrid solar system to changes of temperature as well as conditions of insolation. The system was installed on the roof of the Department of the Management and Fundamentals of Technology building of Lublin University of Technology, localized in the south-eastern region of Poland and its charcteristics have been described elsewhere [1]. The system created to investigate the influence of the temperature and the insolation on the efficiency of Si solar cells consists of two monocrystaline photomodules Sunset SM10L type, attached to an aluminum radiator. To stabilize precisely the temperature of one of the modules, it is cooled by the Peltier modules. The measured values of the parameters of PV modules were continuously recorded by a computer system supplied with an advanced software [2–4].

3. Results and discussion

Figures 1–4 present typical images of power obtained in PV modules during the 2005summer in the south-eastern region of Poland. Some fluctuations of the curves, presented in the figures, were caused by fluctuation of the sunlight spectrum reaching the surface of the analyzed modules. The experimental data were statistically calibrated due to a possible asymmetry of the static characteristic of the PV modules.

As can be seen in Figs. 1b and 2b, the cooled PV module gives more power obtained by PV conversion than the one that was not cooled. The other graphs (Figs. 1a, 2a, 3, 4) presenting the response of the modules to the sunlight in the morning hours of the sunny days and on the cloudy days show that there are anomalous differences between cooled and not cooled modules.

The photovoltaic conversion is the most effective in the area near the p-n junction of semiconductors, located close to the solar cell surface and it depends on several factors: sunlight spectrum, cell spectral sensitivity, reflectivity of a cell surface, semiconductor type, distance of a p-n junction from a surface and the temperature of the cell [5]. The increase of the solar cell temperature caused by the inductive load or by an increase of the environment temperature is usually the reason for a decrease of its efficiency. In particular environmental conditions, however, higher temperature can have a positive effect, as was mentioned in our previous paper [1].

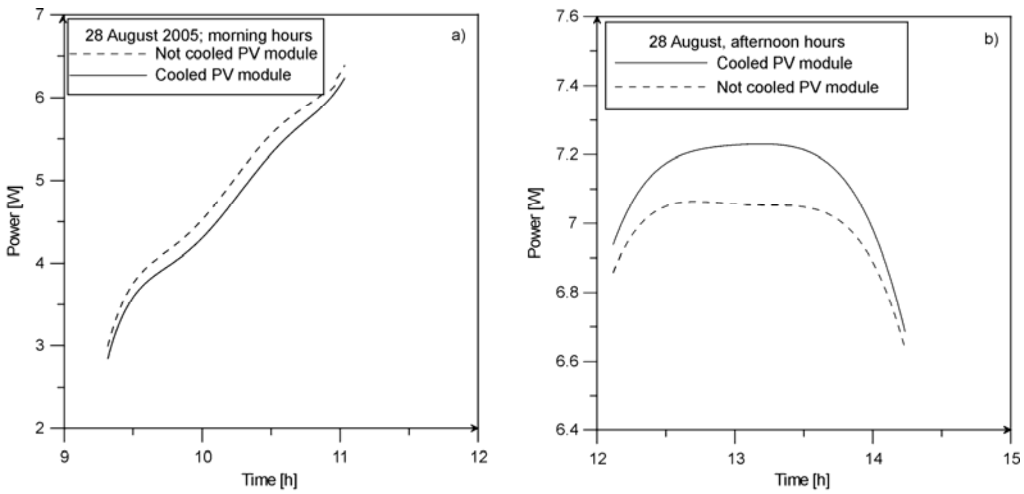

Fig. 1. Power generated in PV modules in a sunny day, in the morning (a) and afternoon (b)

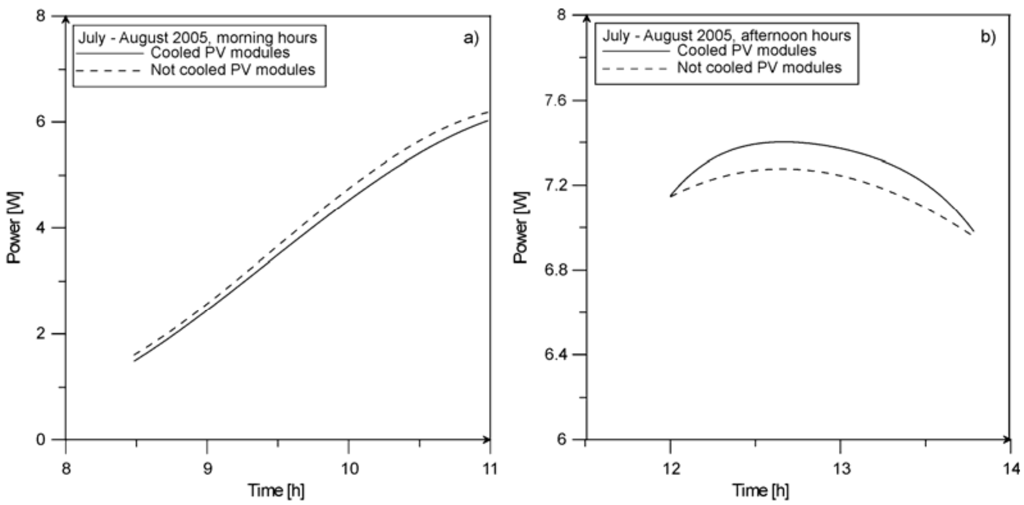

Fig. 2. Average power generated in PV modules in sunny days
of July and August 2005, in the morning (a) and afternoon (b)

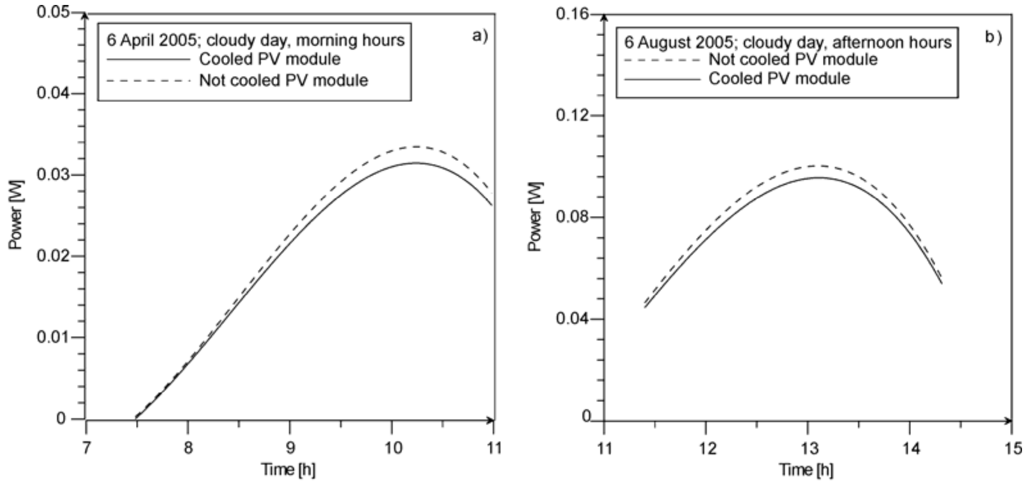

Fig. 3. Power generated in PV modules at a cloudy day in: a) morning and b) afternoon hours

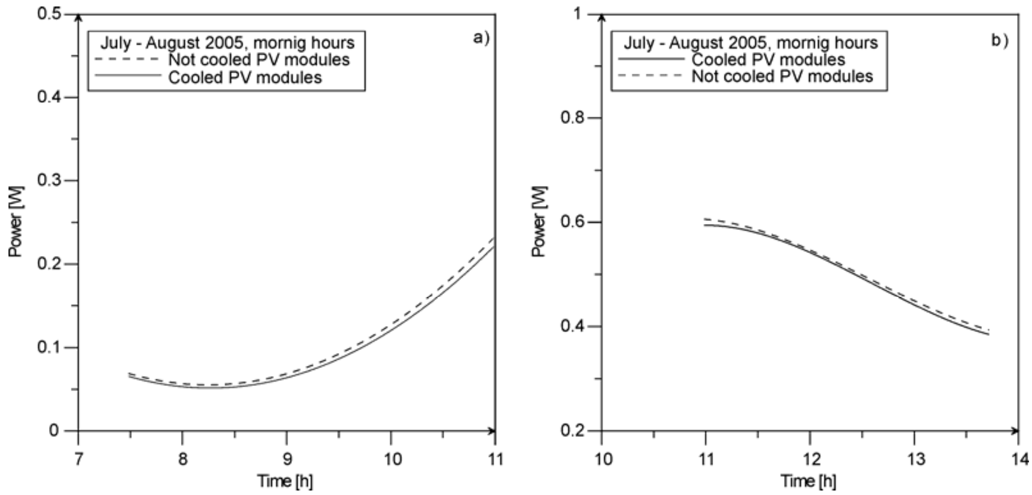

Fig. 4. Average power generated in PV modules in cloudy days of July and August 2005, in the morning (a) and afternoon (b)

According to the theory, the increase of temperature results in a decrease of the semiconductor band gap:

$$E_g(T) = E_g(0) - \frac{\beta T^2}{T + \gamma} \tag{1}$$

where $E_g(0)$ is the energy band gap at $T = 0$, γ and β are the coefficients for a specific semiconductor. The decrease of the energy band gap results in a decrease of the density of short-circuit current. The temperature dependence of the open circuit voltage U_{oc} is as follows:

$$U_{oc}(T) = U_{oc}(300) - \left(\frac{E_g(0)}{q} - U_{oc}(T)\right)\left(\frac{T}{300} - 1\right) - \frac{3kT}{q}\ln\frac{T}{300} \tag{2}$$

where q is the unit charge.

The differentiation of Eq. (2) gives:

$$\frac{\partial U_{oc}}{\partial T} = \frac{\dfrac{E_g(0)}{q} + \dfrac{3kT}{q} - U_{oc}(300)}{T} \tag{3}$$

What follows is that $\frac{\partial U_{oc}}{\partial T}$ diminishes when the open-circuit voltage increases. With the increase of temperature, the fill factor (*FF*) should also decrease:

$$\frac{\partial FF}{\partial T} = \frac{q}{kT}\left(\frac{\partial U_{oc}}{\partial T} - \frac{U_{oc}}{T}\right)\frac{\partial FF}{\partial U} = \frac{E_g(0) + 3kT}{kT^2}\frac{\partial FF}{\partial U} \tag{4}$$

where:

$$U = \frac{qU_{oc}}{kT} \tag{5}$$

The increase of temperature should always result in a decrease of the efficiency of the photovoltaic conversion. In order to improve the conversion efficiency it is necessary to apply additionally cooling devices. The question is: what are the reasons for the anomalies observed in South-eastern Poland?

Anomalous differences between cooled and not cooled modules were observed in morning hours of the sunny days and cloudy days, and were probably due to a specific solar spectrum which reaches the photomodule surfaces. In this part of a day the solar spectrum consists mainly of the scattered radiation, in which the relative intensity of longer wavelengths is higher. Additionally, the shape of the spectrum is modulated by the composition of the atmosphere including pollution of the air. The energy of the scattered radiation is not sufficient to generate the majority of intrinsic carriers, hence a higher contribution of carriers from impurity levels is observed. In this case, the energy of thermal oscillations of the crystal lattice could be sufficient to activate carriers and in this way to increase the efficiency of not cooled photomodules. It seems that using special cooling system is not always necessary.

4. Conclusions

The efficiency of a Si monocrystalline PVphotomodule depends on the sun insolation reaching its surface. Essentially, in order to increase the photoconversion power of Si photomodules, advantageous method is to use additional cooling systems. Such a cooling system may insure the hybrid bonding of PV and PT conversions [6]. However, it should be emphasized that in the region of South-eastern Poland, the cooling of solar cells during cloudy days as well as in the morning hours not only is unnecessary, but causes a decrease of their efficiency.

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