Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XXXIX
Broj 1, 2014.
Strane: 39 – 47

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXIX
No. 1, 2014.
pp: 39 – 47

UDK:621.31

Originalni naučni rad
Original scientific paper

RESULTS FROM A STUDY ON THE TEMPERATURE OF SOLAR MODULES

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Abstract: A research was made on the influence of the temperature of stationary photovoltaic modules on the production of electricity. The modules are connected in groups, with a total maximum installed capacity of 117.24 kWp. They are mounted on the roof of a non-residential building, located in an uninhabited area. The study covers several typical months in the period from January 2009 to December 2012. The produced electricity changes in the interval 0 - 25.55kWh, for a temperature difference between the photovoltaic modules and the environment in the range of -5 to +30° C.

Key words: *photovoltaic modules, temperature of the modules, electrical energy, overheating, cooling*

INTRODUCTION

One method of converting the energy of the solar radiation is through the use of the photovoltaic effect [1]. It is used widely in the photovoltaic cells and panels for receiving electrical power. The biggest advantages of this technology are the availability of virtually unlimited amounts of free energy source (solar radiation) and the lack of hazardous waste [2]. Major disadvantage of the photovoltaic modules is their low efficiency (efficiency), the values of which decreases continuously during operation [3].

Several studies show that the characteristics of the photovoltaic modules depend on their temperature [4]. Therefore are proposed models of these relationships through which are examined and predicted the duration and effectiveness of the operation of photovoltaic modules [5].

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The purpose of this study is to analyse the changes in the power output, related to the overheating of photovoltaic modules in the region of Rousse, Bulgaria.

MATERIAL AND METHODS

Subject of the study

The examined object is a photovoltaic system with a total maximum power of the modules 117.24 kWp [6]. The modules are located on the roof of a non-residential building, located in an uninhabited territory at an altitude of 76 m and in a moderate continental climate. The site is located in the region of Ruse, near the Danube river.

The chosen site is unique for several reasons. The photovoltaic system is with power more than 100 kWp and is built on a roof structure. The area of the city of Ruse, where the system is established is characterized by the second largest in Bulgaria annual average intensity of solar energy 1450 - 1500 $kWh \cdot m^{-2}$ [7]. Another feature of the object is that it is composed of more than one type of photovoltaic modules, arranged in rows and sections. This is a prerequisite for making comparative analysis of the climate characteristics of the modules by types, sections and rows.

The total number of the modules is 824, and 528 of them have a maximum power - 130 Wp. They are arranged in 4 lines, with 3 sections (Fig. 1) and in each section are mounted 44 modules. The remaining 324 modules have a maximum power of 150 Wp each, and are located in the northern part of the roof (Fig. 1). These modules are divided into 6 sections, each comprising 54 modules, arranged in 2 rows.

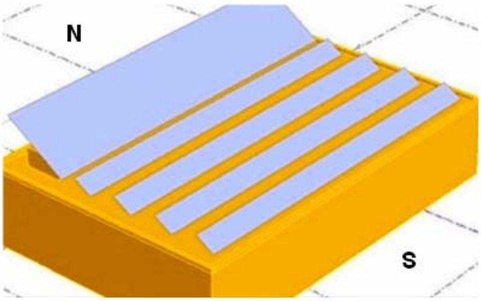

Figure 1. Location of the modules in sections and rows on the roof: N - north; S - south

The produced electrical energy is converted by inverters fitted to each section of photovoltaic modules. The total number of inverters is 18.

Methods and tools for the study

Solar irradiation and the temperature of the modules are the main factors determining the production of electricity from photovoltaic modules [1,3]. The first factor is decisive, because it also affects the temperature of the modules.

The electricity output is determined by the information received from the inverters, and recorded every 15 minutes.

The temperature of the modules and the environment is measured by a resistive transducers type Pt100, with range –40 to +125°C and accuracy of ± 0,5°C. The values of the temperatures recorded at the same interval as the electrical energy - 15 minutes.

Very often, rather than the temperature of the photovoltaic modules, it is convenient to monitor the temperature of their overheating compared to the ambient temperature [8]. It is represented as the difference between the temperatures of the modules T_m and the environment T_a, i.e. (T_m - T_a). Overheating temperature gives an idea of the thermal regime in which the modules operate at different ambient temperatures. This is particularly important in photovoltaic modules, because they are made of semiconductor cells, for which the parameters strongly depend on the temperature [1,3].

RESULTS AND DISCUSSION

In the study are examined four years from the operation of photovoltaic modules - 2009 - 2012, in the specific geographic conditions. Processed data cover the months during which are produced the greatest amounts of electricity for the year. These months are May of 2009, August of 2010, and July of 2011 and 2012.

Produced quantities of electric energy *E* from the photovoltaic plant are different for each month throughout the year and the decisive point is the influence of solar irradiation. Its power intensity set for 1 m^2 area of photovoltaic panels is amended periodically. The maximum values of the intensity are observed during the summer months, and the minimum - in the winter. This is explained by the latitude at which the object is located.

Electricity output for the period 2009 - 2012 is presented in Fig. 2. Below are the total electrical energy per year (kWh) and the months with the highest production during the year (% of annual production). Comparing the values for the entire period shows that the amount of electricity produced is highest in July 2012 - 19 707.25 kWh. This year the production is also the largest - 154 315.8 kWh, as in July were generated 12.77% of this amount.

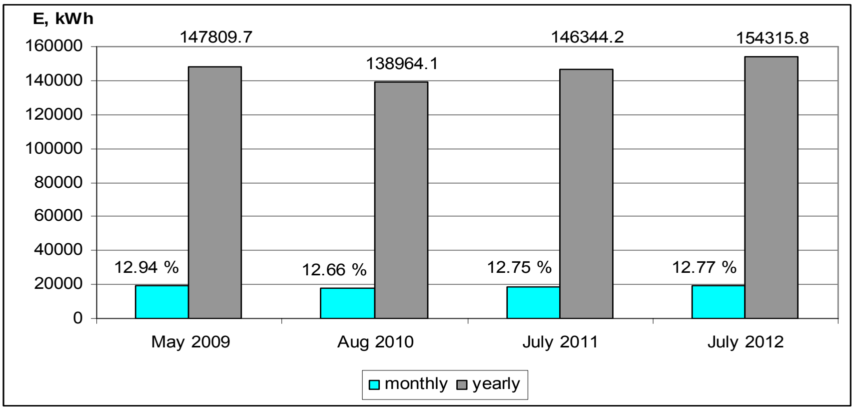

Figure 2. Generated electricity for the period 2009 - 2012 by year and month with the highest production in the respective year

The analysis of the data indicates that the total amount of electricity produced in 2009, is higher than that in 2011 by 1 465.5 kWh. This is 1% of the quantity produced during 2011. In addition, the share of the month with the highest production for 2009 - May is the highest for the four years - 12.94% (Fig. 2). For these reasons, the data for 2009 are an exception from the trend for changes of production in the period 2010 - 2012. Then there is an increase in both the total annual quantity of electricity, and the share of the month with the highest production. The generated electricity in May 2009 was 19119.34 kWh, and in July 2012 was 19707.25 kWh. The share of these amounts in the total annual production is respectively 12.94% and 12.77%. The difference in the final values is due to the fact that the total annual electricity production in 2009 was lower than in 2012.

The observed changes in electricity production are mainly due to the changes in weather conditions under which works the photovoltaic system. These changes affect the performance of the modules, as the main factor is the thermal regime. It is determined by the solar irradiation and the conditions of cooling. This requires to be studied the influence of the temperature of the modules on the production of electricity.

Collected and processed are data for the production of electricity for the months considered - May 2009, August 2010, July 2011 and 2012. The amounts of energy and module temperature T_m and the environment T_a are recorded every 15 min. PV modules generate electricity only during daylight when solar irradiation is large enough. In some clear nights, especially on a full moon, are registered very small amounts of energy produced (several tens Wh). This is due to the limited light flux of the moon. For these reasons, the data for the energy and temperature are presented and analyzed only for the hours of daylight.

In Fig. 3 - Fig. 6 are presented the dependencies of the produced electrical energy E, kWh, the difference in temperature (T_m-T_a), °C, for the four months considered, for each day of the month.

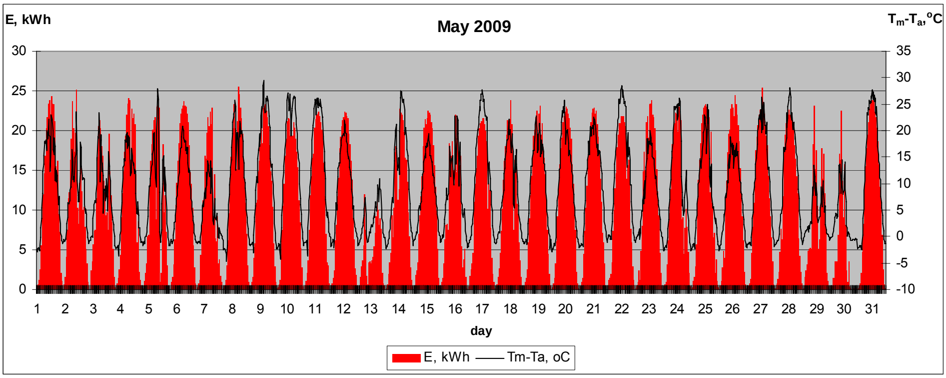

Figure 3. Changes of the produced electrical energy E, kWh, depending on overheating (T_m - T_a), °C, for each day of May 2009

The comparison of the graphs (Fig. 3, 4, 5 and 6) for the impact of the difference in temperature (T_m-T_a) (overheating modules) on electricity produced E, for each day of the month makes it possible to be detected some particularities. Every day of the four months is characterized by a bell rescheduling of the energy produced. There are exceptions, which are least in July, 2012. The charts of the electricity produced are in accordance with the daily changes of solar irradiation [9], which is explained by the strong influence of the latter [10].

The maximum values of the electricity produced in the four months are registered during the midday hours and fluctuate between 20 - 25.55 kWh. It can also be noticed some exceptions - 13th day of May, 2009, 5th, 16th, 30th and 31th of August, 2010, the 3rd of July 2011 and 30th of July 2012. The considerably small and irregular performance of the photovoltaic system in these days is due to the dynamic changes in solar radiation. The latter are due to frequent changes in the cloud cover.

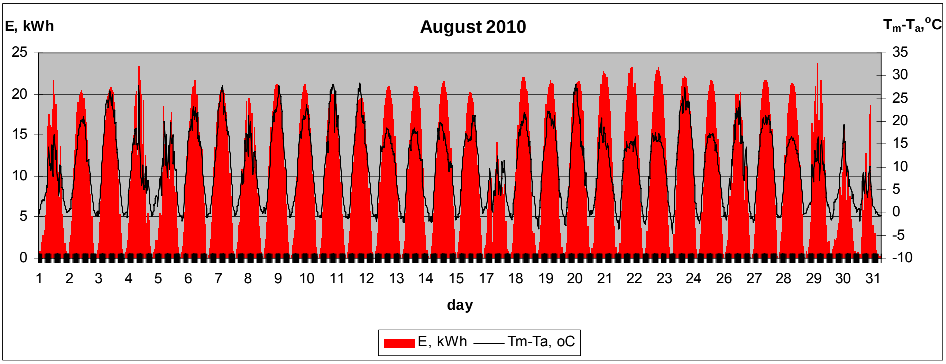

Figure 4. Changes of the produced electrical energy E, kWh, depending on overheating (T_m - T_a), °C, for each day of August, 2010

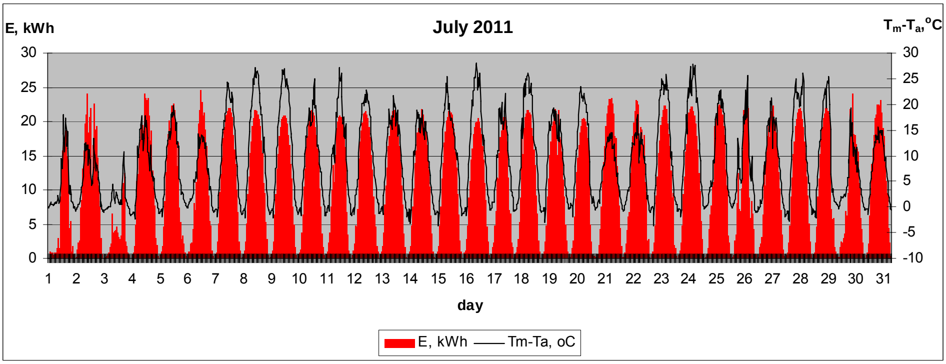

Figure 5. Changes of the produced electrical energy E, kWh, depending on overheating (T_m - T_a), °C, for each day of July, 2011

The graphs (Fig. 3, 4, 5 and 6) impede the analysis of the functional relationship between the studied variables - temperature of the overheating (T_m-T_a) of photovoltaic modules and their electricity output E. The analysis shows that it is more appropriate to present the changes of the energy output only depending on the temperature of overheating, without showing the changes in the individual days (Fig. 7, 8, 9 and 10).

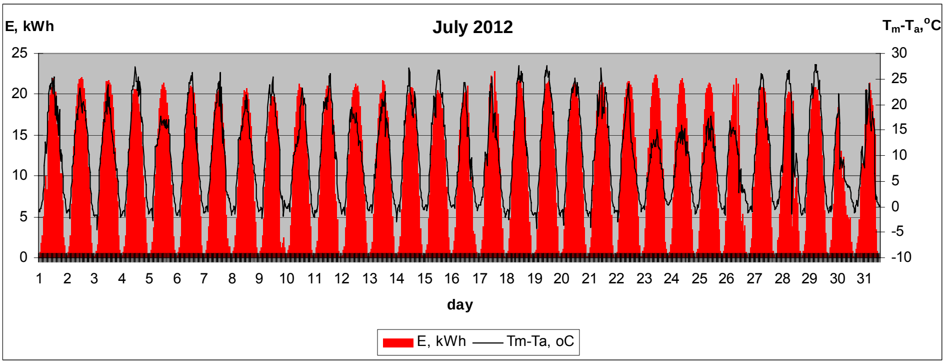

Figure 6. Changes of the produced electrical energy E, kWh, depending on overheating (T_m - T_a), °C, for each day of July, 2012

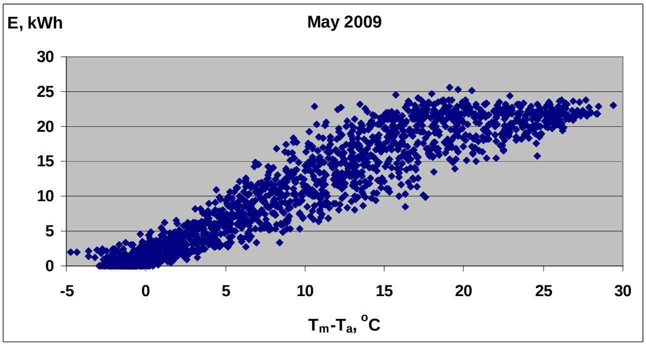

Figure 7. Effect of overheating (T_m-T_a) of photovoltaic modules on their electricity output E, in May 2009

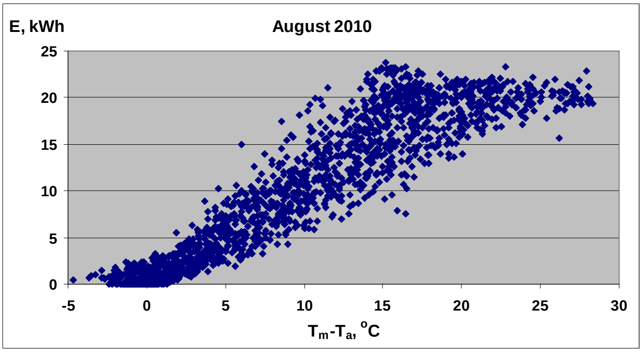

Figure 8. Effect of overheating (T_m-T_a) of photovoltaic modules on their electricity output E, in the month of August 2010

When comparing the graphical dependence E = f(T_m-T_a) for the four months considered, can be seen that they have approximately the same nature of change. The values of the electrical power are positive, increasing from 0 and reaching 22 - 25kWh. Only in May 2009, are reported several values above 25 kWh, the maximum of which is 25.55 kWh. These features can be explained by the relatively high solar radiation and better cooling conditions, in comparison with typical summer months.

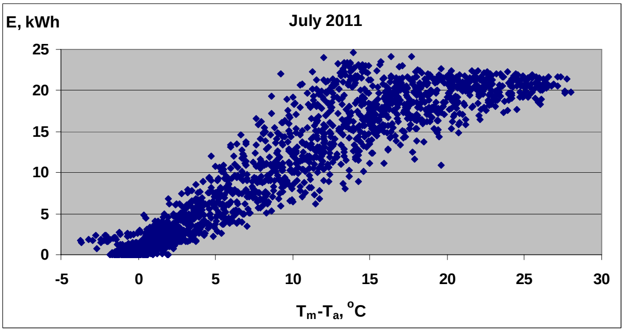

Figure 9. Effect of overheating (T_m-T_a) of photovoltaic modules on their electricity output E, in July 2011

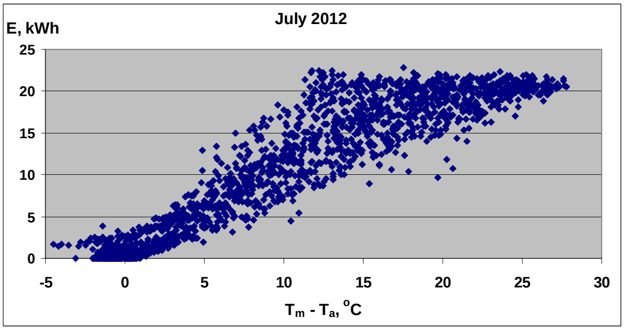

Figure 10. Effect of overheating (T_m-T_a) of photovoltaic modules on their electricity output E, in the month of July 2012

From the graphs can be observed the presence of "threshold" value of the temperature of overheated modules (T_m-T_a), above which the maximum electrical energy output is increasing. This limit is different for the different months and approximately is 17°C in May 2009 (Fig. 7), 15°C in August 2010 (Fig. 8) and July 2011 (Fig. 9) and 13°C in July 2012 (Fig. 10). Therefore, the greatest threshold value of overheating modules was observed in May 2009. The probable cause for this is the better cooling. It can be assumed that the changes in the latter, cause a larger scatter of the values of the produced energy *E*, when there is overheating of PV modules in the interval (T_m-T_a) = 5 - 20°C (Fig. 7, 8, 9 and 10).

On all the graphs (Fig. 7, 8, 9 and 10) can be seen that the values of the electric energy produced *E* is characterized by variable diffusion and ambiguity. The latter is expressed in the fact that a particular value of the energy E correspond to several values of modules overheating (T_m-T_a). The reason for this ambiguity may be explained by the differing conditions of the cooling of the photovoltaic modules.

Overheating of the modules (T_m-T_a) for all the months is characterized by small negative values. They are in the range -5 to 0°C and are in accordance with the electrical energy produced E = 0 - 5 kWh. Negative values of overheating are observed at the start and in some cases at the end of days. At the beginning of Day $T_m < T_a$, because the modules are cooled during the night and time passes while they are heated to or above the ambient temperature T_a. At the end of the day the modules are cooling and their temperature T_m decreased, and in most cases it is close in value to the ambient temperature T_a, but it does not fall below it. Therefore, overheating of the module (T_m-T_a) in the evening hours is in the range 0 - 1°C. In some days, with better cooling (e.g., wind), the modules cool down more rapidly than the surrounding air. Then $T_m < T_a$ and are recorded negative values of the overheating (T_m-T_a).

CONCLUSIONS

Collected and processed are data for the operation of a photovoltaic system with a total maximum power 177.24 kWp, located near the town of Ruse. Analysed are the data for the months with the highest annual quantity of electricity produced in the period 2009 - 2012. The study addresses the influence of the temperature of the PV modules Tm on the production of electricity E by the temperature of overheating (T_m-T_a).

It was found that the functional dependencies E = f (T_m-T_a), for all the months were similar, but ambiguous. This is due to the variety of operating conditions - the solar irradiation and thermal regime (cooling). It can be assumed that the ambiguity will be eliminated if the analyses are performed at unchanging solar radiation.

The values of electrical energy E vary in the range (0 - 25.55) kWh, rising continuously until they reach a maximum "threshold" value. The latter changes in the interval 13 - 17°C.

The temperature of overheating of the modules (T_m-T_a) changes in the interval -5 to + 30°C. The negative values -5 to 0°C, are due to changes in the conditions of cooling of the modules - the temperature of the modules T_m is less than the ambient temperature T_a, in the morning hours of the days and in some cases - in their evening hours.

Complete picture of the influence of the temperature of overheating of the modules (T_m-T_a) on electricity produced from photovoltaic modules E can be obtained by an investigation for more months. It is then possible to model the functional relationship E = f (T_m-T_a) even at various values of the solar irradiation.

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REZULTATI ISPITIVANJA TEMPERATURE SOLARNIH MODULA

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Sažetak: Prikazani su rezultati istraživanja uticaja temperature stacionarnih fotonaponskih modula na proizvodnju energije. Moduli su povezani u grupe, sa ukupnim maksimalnim instalisanim kapacitetom od 117.24 kWp. Postavljeni su na krov zgrade u nenaseljenom području. Istraživanje je izvedeno tokom nekoliko tipičnih meseci, u periodu januar 2009 - decembar 2012. Proizvedena električna energija se menja u intervalu 0 - 25.55 kWh, za temperatursku razliku između fotonaponskih modula i okoline u intervalu od -5 do +30°C.

Ključne reči*: fotonaponski moduli, temperatura modula, električna energija, pregrevanje, hlađenje*

Prijavljen: *Submitted*: 29.07.2013.
Ispravljen: *Revised*:
Prihvaćen: *Accepted*: 07.10.2013.