ENERGY EFFICIENCY OF PHOTOVOLTAIC SOLAR PLANT IN REAL CLIMATE CONDITIONS IN BANJA LUKA

by

Dragana D. MILOSAVLJEVIĆ [a*], Dragoljub Lj. MIRJANIĆ [b], Tomislav M. PAVLOVIĆ [a], Darko M. DIVNIĆ [b], and Danica S. PIRSL [c]

[a] Faculty of Sciences and Mathematics, University of Nis, Nis, Serbia
[b] Academy of Science and Arts, Banja Luka, Republic of Srpska, Bosnia and Herzegovina
[c] Faculty of Sport, University of Nis, Nis, Serbia

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In this paper comparison of experimentally obtained results of energy efficiency of photovoltaic solar plant of 2.08 kWp installed on the roof of the ASARS in Banja Luka in the real climate conditions in 2013 and 2014 are given. It was found that energy efficiency of photovoltaic solar plant from April till November 2013 was 12.28%, and in same period in 2014 was 13.03%. Also, it was found that the increase in the ambient temperature by 1 °C, photovoltaic solar plant efficiency decreases by 0.43% from April till November 2013, and by 0.27% in the same period in 2014.

Key words: *solar energy, photovoltaic solar plant, energy efficiency*

Introduction

Solar energy is the most abundant, inexhaustible, and cleanest of all renewable sources of energy to date. The power from the Sun intercepted by the Earth is about $1.8 \cdot 10^{11}$ MW, which is many times larger than the present rate of all the energy consumption [1]. Photovoltaic (PV) technology is one of the finest ways to harness solar power. There are many factors affecting operation and efficiency of the PV based electricity generation systems such as PV cell technology, ambient conditions and the selection of required equipment. PV industry is increasingly represented in the national energy strategies of the large number of countries. PV systems are considered to be most dominant technology among renewable energy technologies. Most important reason is that it is unlimited and the cleanest energy of the solar power systems. Many studies show that PV systems have an important share in the electricity and there is a growing number of countries in which the PV systems are used for commercial purposes. Application of the grid-connected PV solar plants aims at reducing conventional sources of energy and improving the environmental quality. Local climate conditions significantly affect the amount of generated electrical energy and before any energy planning it is very important to have measured energy output of PV system at the cite [1-3].

* Corresponding author; e-mail: dragana82nis@yahoo.com

Regarding solar potential Bosnia and Herzegovina (B&H) and especially Republic of Srpska can be counted among more favorable locations in Europe with solar radiation incident on horizontal surface of 1240 kWh/m^2 in the north of the country, and up to 1600 kWh/m^2 in the south [2-5]. The paper [4] cites that B&H has on average 1840.9 h of Sun annually, while in the south, this number reaches 2352.5 h, annually. The theoretical potential for B&H is estimated at around 74.65 PWh while the technical potential is about 1903 TWh, both of which are substantially more than the energy needs of the country [4]. Despite having significant solar potential Republic of Srpska shows a scarce use of PV systems for the generation of the electrical energy. Besides, the Solar energy sector in the Republic of Srpska, and generally in B&H is not developed yet and Republic of Srpska is largely inferior to the neighboring and developed countries in investigations of PV conversion of solar radiation and the application of PV systems. Also, available literature provides scarce information on the energy efficiency of PV solar plants in the Republic of Srpska, and there are not many studies presenting all factors affecting the efficiency and operation of the entire PV system. Besides, up to now there were no investigations, in real conditions, of the meteorologial parameters' influence on the energy efficiency of PV solar plants in the Republic of Srpska [2-9].

PV solar plant

PV solar plant of 2.08 kWp installed on the building of the Academy of Sciences and Arts (ASARS) in Banja Luka consists of 8 monocrystalline silicon solar modules (HYM-260 W, Seasun). The solar modules are based on the metal stainless steel with the foundation inclined at 32 º towards the south on the roof of the building and are serially interconnected in a string. Using adequate conductors solar modules are connected to a D. C. distribution box (RO-DC), single phase inverter (Sunny Boy 2000 HF-30, power of 2 kW), A. C. distribution box (RO-AC) and the city power grid. D. C. and A. C. distribution boxes contain protective components providing steady functioning of PV solar plant. At the output of A. C. distribution box there is alternating voltage 230 V, 50 Hz [10, 11].

Grid-connected PV solar plant, inverter and the ancillary equipment for the monitoring and data acquisition of the PV solar plant are shown in figs. 1 and 2, respectively.

Figure 1. Grid-connected PV solar plant

Figure 2. Inverter and the ancillary equipment for the monitoring and data acquisition of PV solar plant

In October, 2012 on the roof of the ASARS building in Banja Luka a fixed, on-grid PV solar plant was installed. In the period from October 2012 to February 2013 solar modules on the roof of the ASARS building were oriented towards the south at the angle of 7°. In March, 2013 the roof was reconstructed and solar modules were oriented at the optimal angle of 32°. Based on these grounds actual experimental measurements of the electrical parameters of PV solar plant started on 4th April, 2013.

Experiment

The experiment was performed to investigate the influence of the solar radiation and ambient temperature on the energy efficiency of PV solar plant of 2.08 kWp installed on the ASARS building in Banja Luka in real climate conditions. The experiment was conducted in the Solar Energy Laboratory of the ASARS. The total PV area is 13.63 m^2. The yearly optimum inclination angle for the fixed solar modules in Banja Luka is $\beta = 32°$.

Measurement of the meteorological parameters (energy of solar radiation falling on the square meter of the horizontal surface, wind speed, ambient temperature, *etc*.) was performed by the automatic meteorological station Davis Vantage Pro2 (USA) each 10 minutes during the day.

Having in mind that solar modules are oriented at the optimal angle in relation to the horizontal surface, to calculate the energy of the global solar irradiation $G(\beta)$ falling on a square meter of the solar modules in PV solar power plant following eq. (1) was used [12]:

$$G(\beta) = \frac{G(0^0)}{1 - 4.46 \cdot 10^{-4}\beta - 1.19 \cdot 10^{-4}\beta^2} \tag{1}$$

where β is the optimal angle of the solar modules installation (32°) and $G(0^0)$ [Whm^{-2}] the total amount of the solar energy falling during the day on one square meter of a horizontal surface.

Measurement of the electrical parameters of the PV solar power plant (D. C. and A. C. currency, voltage, power, *etc.*) was performed by Sunny WEBBOX (SMA Solar Technology AG, Germany), a communication device with the integrated webserver which through Bluethoot communicates with the inverter. Data on PV solar plant are each 5 minutes recorded in the internal WEBBOX memory where their acquisition is performed. Numeric values of the electrical parameters of PV solar power plant are directly recorded on SD memory card or by FTP server. Measured values are stored tabular in CSV or XML format while their visualization is performed by Sunny Portal software.

The Energy efficiency and Specific yield factor are calculated to understand the behavior of the PV solar power plant [13-18].

Energy efficiency of the PV solar power plant denotes a relation of the electrical energy generated by PV solar power plant and transmitted to the power grid at a certain point of time and the solar radiation falling on the solar modules of PV solar power plant at the same point of time. Monthly energy efficiency of the PV solar power plant is calculated [13-19]:

$$\eta_M = \frac{\sum_{i=1}^{n}(E_D)_i}{S\sum_{i=1}^{n}(E_s)_i} \tag{2}$$

where η_M [%] is the monthly energy efficiency of PV solar plant, n – the number of days in a month, E_D [Wh] – a total amount of electrical energy generated by the PV solar plant during the

day, E_S [Whm^{-2}] – a total amount of the global solar radiation falling during the day on solar modules, and S [m^2] – a total solar modules surface.

The specific yield factor (Y_f) of PV system represents the number of hours that the PV array would need to operate at its rated power to provide the same energy. The specific yield factor of PV solar plant is calculated [20]:

$$Y_f = \frac{E_{ACout}}{P_{\max,STC}} \tag{3}$$

where E_{ACout} [kWh] is the electrical energy generated by PV solar plant and transmitted to the power grid and $P_{max,STC}$ [kW$_p$] – the total installed power of PV array.

Analyzing the specific yield factor, the PV plant the owner can have a permanent look of the time, in hours expressed, that the system works in STC (standard test condition: I = 1000 W/m^2, T = 25 °C, a. m. 1.5) and obtains indicate or a higher energy production [13-20].

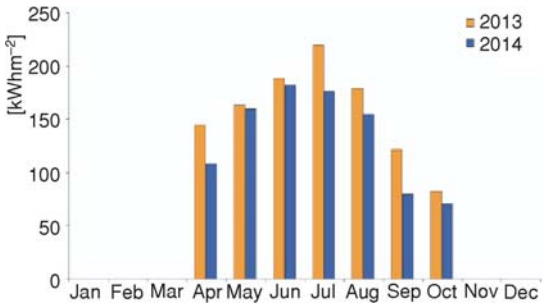

Figure 3. Graphic of the measurement results for solar radiation energy falling on a square meter of the surface oriented southward, at the optimal angle in relation to the horizontal surface in Banja Luka in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014

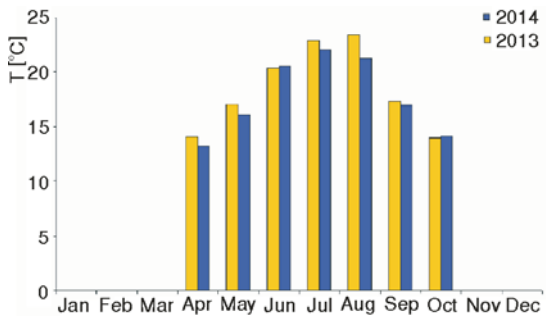

Figure 4. Graphics of the measurement results for the ambient temperature in Banja Luka in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014

Results and discussion

Taking into account actual experimental measurements of the electrical parameters of PV solar plant starting on April 4, 2013, comparison of solar radiation, ambient temperature, wind speed, output power, specific yield factor and energy efficiency of PV solar plant installed on the ASARS building in Banja Luka in the measuring period from April 4 to November 1, 2013, and from April 4 to November 1, 2014, are given in this section.

Solar radiation, ambient temperature and wind speed

Graphic of the measurement results for solar radiation energy falling on a square meter of the surface oriented southward, at the optimal angle in relation to the horizontal surface in Banja Luka in the measuring period is given in fig. 3.

In the period from April 4 to November 1, 2013, solar radiation energy falling on a square meter of the surface oriented southward, at the optimal angle in relation to the horizontal surface in Banja Luka was 1099.21 kWh/m^2, whereas in the period from April 4 to November 1, 2014, it amounted to 931.97 kWh/m^2 of solar radiation energy. Counting the total solar modules surface of 13.63 m^2, PV solar power plant solar radiation incidence was

14985.59 kWh/m^2 in the period from April 4 to November 1, 2013, and 12705.7 kWh/m^2 in the period from April 4 to November 1, 2014.

Graphics of the measurement results for the ambient temperature and wind speed in Banja Luka in the measuring period from April 4 to November 1, 2013, and from April 4 to November 1, 2014, are given in figs. 4 and 5, respectively.

Figures 4 and 5 show that the average values of the ambient temperature and wind speed in Banja Luka in the period from April 4 to November 1, 2013, were 18.43 °C and 0.74 m/s, respectively, and in the period from April 4 to November 1, 2014, they were 17.74 °C and 0.52 m/s, respectively.

Output power of PV solar plant

Graphics of the measurement results for the average values of the PV solar plant output power, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014, is given in fig. 6.

Electrical energy generated by PV solar plant

Graphics of the measurement results for the monthly amount of the electrical energy generated by PV solar plant, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014, is given in fig. 7.

Figure 7 shows that the total amount of the electrical energy generated by PV solar plant, in the period from April 4 to November 1, 2013, was 1765.313 kWh and 1594.652 kWh in the period from April 4 to November 1, 2014.

Specific yield factor of PV solar plant

Graphics of the measurement results for the specific yield of PV solar plant, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014, is given in fig. 8.

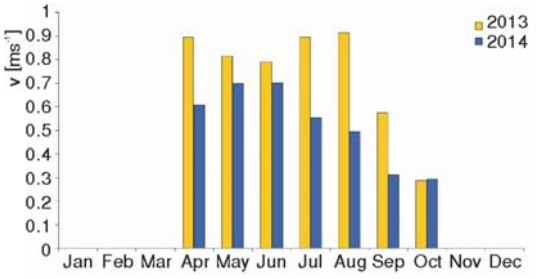

Figure 5. Graphics of the measurement results for the wind speed in Banja Luka in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014

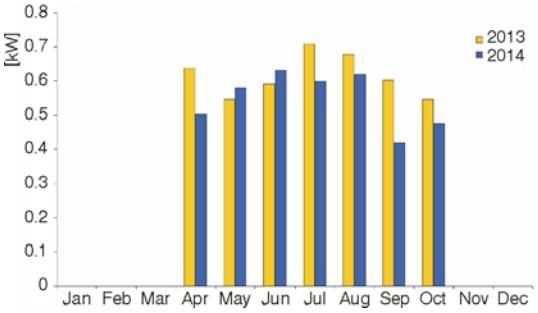

Figure 6. Graphics of the measurement results for the average values of the PV solar plant output power, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014

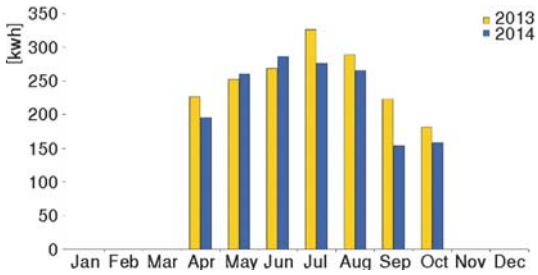

Figure 7. Graphics of the measurement results for the monthly amount of the electrical energy generated by PV solar plant, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014

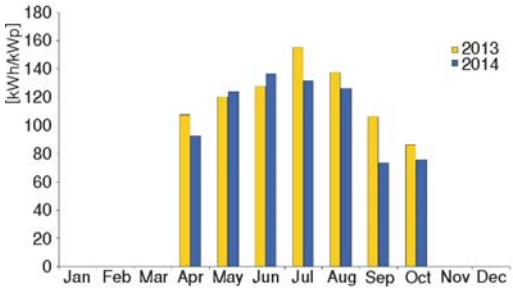

Figure 8. Graphics of the measurement results for the specific yield of PV solar plant, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014

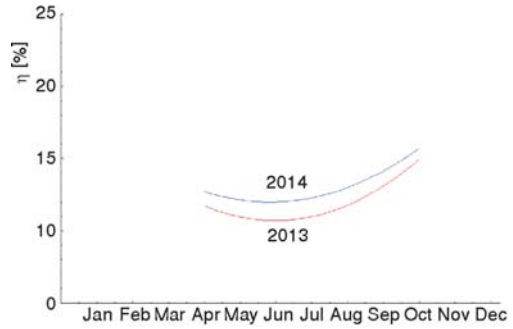

Figure 9. Graphics of the experiment results for the energy efficiency of PV solar plant, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014

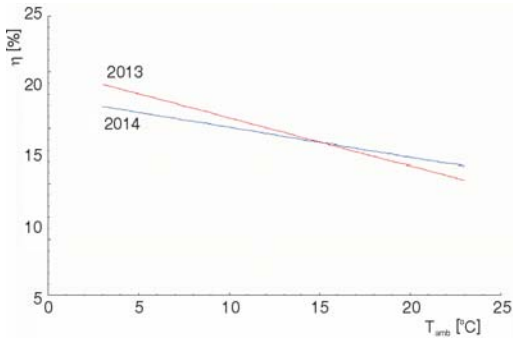

Figure 10. Dependence of the energy efficiency of PV solar plant on the average values of the ambient temperature, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014

In the period from April 4 to November 1, 2014, PV solar plant has generated 3,880.153 kWh of electrical energy. Most electrical energy (326.06 kWh) was generated in July 2013 when the solar radiation energy was 219.57 kWh/m^2.

Energy efficiency of PV solar plant

Graphics of the experiment results for the energy efficiency of PV solar plant, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014, is given in fig. 9.

Average energy efficiency of PV solar plant on the ASARS building, in the period from April 4 to November 1, 2013, was 12.28% and 13.03% in the period from April 4 to November 1, 2014.

Dependence of the energy efficiency of PV solar plant on the average values of the ambient temperature, in the period from April 4 to November 1, 2013, and from April 4 to November 1, 2014, is given in fig. 10.

Figure 10 shows that the ambient temperature increase causes decrease in the energy efficiency of PV solar plant, in the period from April 4 to November 1, 2013, and in the period from April 4 to November 1, 2014.

Energy efficiency dependence on the ambient temperature curves in fig. 10 were obtained by a simple linear regression, based on the method of least squares. Data in fig. 10 show that with the increase in the ambient temperature by 1°C experimental energy efficiency decreases by 0.43% in the period from April 4 to November 1, 2013, and by 0.27% in the period from April 4 to November 1, 2014.

Energy efficiency dependence of the PV solar plant on the solar radiation incidence in the period from April 4 to November 1, 2013, and in the period from April 4 to November 1, 2014, is given in fig. 11.

Energy efficiency dependence of the PV solar plant on the solar radiation incidence and the ambient temperature in the period from April 4 to November 1, 2013, and in the

period from April 4 to November 1, 2014, are given in figs. 12 and 13, respectively.

The increase of the solar radiation induces increase of the ambient and solar modules temperature. The increase of the solar modules temperature enhances thermal vibration of cristal lattice atom of the materials used to produce solar cells, which in turn impedes directed movement of free carriers of charging resulting in open circuit voltage decrease and solar cells power degradation and thus their reduced efficiency.

Conclusions

The first monitoring of a rooftop grid-connected PV solar plant of 2 kWp on the ASARS building in Banja Luka has been investigated in this paper. Based on the presented results following can be concluded.

- On one square meter of the south-oriented surface at the optimal angle in relation to the horizontal surface in Banja Luka, in the period from April 4 to November 1, 2013, there was by 15.2% more solar radiation incidence than in the period from April 4 to November 1, 2014.
- Average ambient temperature in Banja Luka in the period from April 4 to November 1, 2013, is by 3.74% higher than in the period from April 4 to November 1, 2014.
- Average wind speed in Banja Luka in the period from April 4 to November 1, 2013, is by 29.73% higher than in the period from April 4 to November 1, 2014.
- Total amount of the electrical energy generated by PV solar plant was by 9.67% higher in the period from April 4 to November 1, 2013, than in the period from April 4 to November 1, 2014.
- Average energy efficiency of the PV solar plant was by 6.1% lower in the period from April 4 to November 1, 2013, than in the period from April 4 to November 1, 2014.

The presented results can be useful to people working on the theory, design and/or application of the PV based electricity generation systems in the Republic of Srpska.

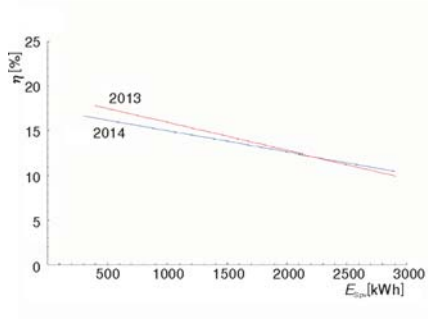

Figure 11. Energy efficiency dependence of the PV solar plant on the solar radiation incidence, in the period from April 4 to November 1, 2013, and in the period from April 4 to November 1, 2014

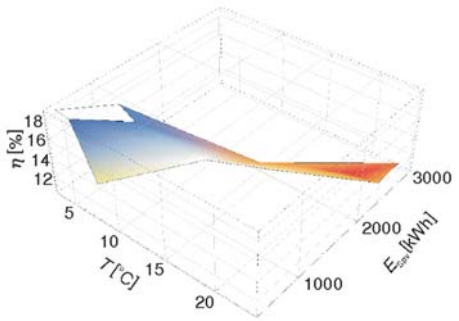

Figure 12. Energy efficiency dependence of the PV solar plant on the solar radiation incidence and the ambient temperature in the period from April 4 to November 1, 2013

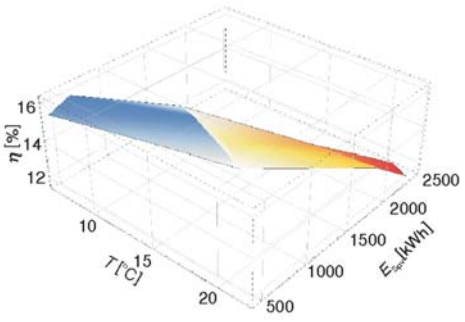

Figure 13. Energy efficiency dependence of the PV solar plant on the solar radiation incidence and the ambient temperature in the period from April 4 to November 1, 2014

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