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THE STUDY OF ENERGY EFFICIENCY OF MONOCRYSTALLINE SILICON MODULES

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Abstract: This paper presents the effect of temperature and wind speed on physical characteristics of monocrystalline silicon solar modules, which are placed on the building of the Academy of Sciences and Arts of the Republic of Srpska in Banja Luka. Measurements of the solar modules were carried out by UI analyzer for photovoltaic PV-KLA and Mini PV-KLA. Meteorological parameters (temperature, wind speed and intensity of solar radiation) were measured using the automatic meteorological station Davis Vantage Pro-USA. This paper gives the results of comparisons between theoretically obtained energy efficiency and experimentally obtained energy efficiency of the monocrystalline silicon modules in relation to their characteristics.
Keywords: Photovoltaic, solar energy, efficiency, Monocrystalline Silicon Modules.

1. INTRODUCTION

Energy efficiency of photovoltaic modules depends on the ambient operating conditions such as temperature, intensity of solar irradiation, tilt angle, and type of solar modules. Since other parameters such as tilt angle, type of modules are mainly known, parameters which are of vital importance for the working efficiency of the module include temperature and wind speed. This paper will especially deal with the investigation of the influence of temperature and wind speed on physical characteristics of monocrystalline silicon modules.

2. EXPERIMENT

Determination of the physical characteristics of solar modules depending on the ambient temperature and wind speed was performed on the system comprising photovoltaic solar modules made of monocrystalline silicon HYM-260W (Seasun, China). Solar modules were installed at an angle of 32° (Figure 1.) and oriented at 23°09" towards the southeast [1-5].

Physical characteristics of solar module HYM-260W (Seasun, China) with dimensions of 1575 mm × 1082 mm and surface of 1.70415 m2 in standard conditions (T = 25°C, I = 1000W/m2 and AM 1,5) are given in Table 1.

Figure 1. Solar system made of monocrystalline photovoltaic solar modules

For recording the current-voltage characteristics of solar irradiation intensity and the temperature of solar modules PV-KLA device (Ingenieurbüro, Germany) was used. Automatic meteorological station DAVIS Vantage Pro (USA) was used to measure solar irradiation intensity and energy and the ambient temperature (Figure 2.) Recording of the current-voltage characteristics of solar modules was performed by connecting PV-KLA device, Figure 3,

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on one of the solar modules, where by the same device, solar irradiation intensity under the mentioned inclination and the temperature of solar modules (by means of temperature sensor and sensor of solar irradiation) Figures 4 and 5, were measured. Generated energy of solar modules was measured by adequate software while the energy transmitted to the distribution grid was measured by a single phase electrical meter (manufactured by the company Mikroelektronika, Republic of Srpska).

Table 1. Physical characteristics of solar module Seasun HYM-260W in standard conditions

Title	Marking	Value	Measuring unit
Voltage at maximum power point	V_{mp}	48.8	V
Current at maximum power point	I_{mp}	5.43	A
Open circuit voltage	V_{oc}	58.4	V
Open circuit current	I_{sc}	5.96	A
Maximal power	P_{max}	260	W_p
Module efficiency		15.3	%
Working temperature		-40 do +85	ºC
Maximal voltage of system (DC)		1000	V
Power tolerance		0/+5	W
Temperature coefficient of the open circuit voltage		– 0,34	% / °C
Temperature coefficient of the short circuit current		0,037	% / °C
Temperature coefficient of the maximal power		– 0,48	% / °C

Figure 2. Automatic meteorological station DAvis

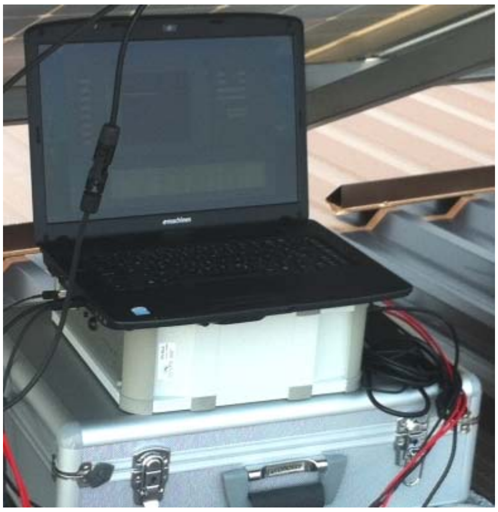

Figure 3. PV-KLA UI analyzer

Figure 4. Sensor of solar irradiation

Figure 5.Temperature sensor

Measurements were performed during three days in weather conditions described as clear-sky in the period from 19 June 2013 to 21 June 2013, from 08.00 am to 17.00 pm. During this period, each day, each half an hour, current-voltage characteristics of solar modules, irradiation intensity and the temperature of solar modules were recorded by PV-KLA device. The example of the cited characteristics of a solar module which is oriented at 23°09" towards southeast at an angle of 32° (21 June.2013 at 13.30 pm) is given in Figure 6.

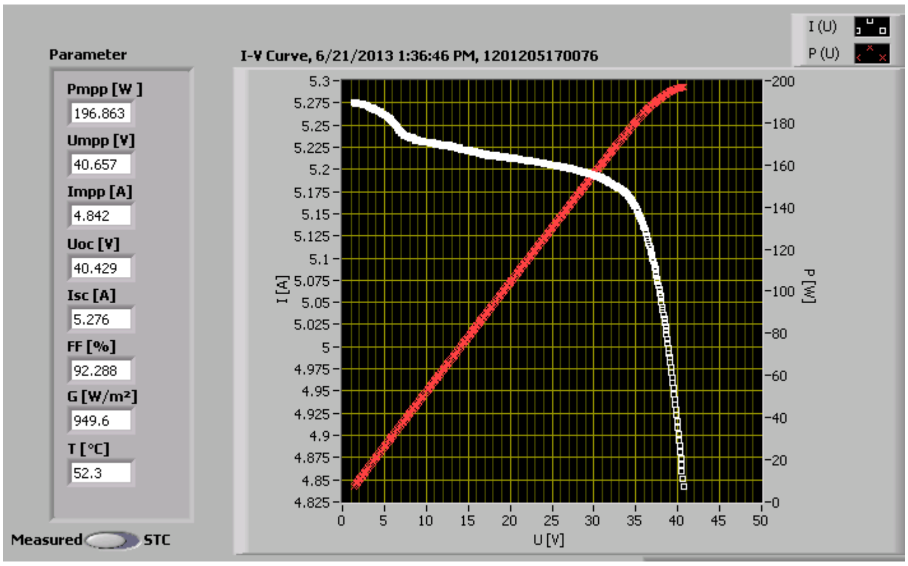

Figure 6. Current-voltage characteristics of monocrystalline solar module, oriented 23°09" towards southeast at the angle of 32° (21.06.2013 at 13.30pm)

Energy efficiency

Energy efficiency of the solar module represents a relation of electrical energy generated during a certain time interval by the solar module and the energy of the solar irradiation incident on solar module during the same time interval. Having this in mind, one can talk about hourly, daily, monthly and annual energy efficiency of the PV module.

The energy efficiency of a PV solar module, during a single time interval measurement, is calculated by the following expression:

$$\eta_{\exp} = \frac{\sum_{i=1}^{n} (E_S)_i}{S \cdot \sum_{i=1}^{n} (E_G)_i} \qquad (1)$$

where

- n is – a number of measurement hours,
- E_S – is the total amount of electrical energy generated in one hour by PV module (Wh),
- E_G – is the total amount of global solar irradiation energy reaching during one hour the solar module (Wh/m^2) and
- S – is the total surface of the solar module (m^2) [1].

Experimental determination of the energy efficiency of solar module

Experimental determination of the energy efficiency of solar module is performed by including in the expression (1) the measured data of hourly amounts of electrical energy generated by solar module and the value of solar irradiation energy reaching the solar module.

Theoretical determination of energy efficiency of solar module

The amount of the energy of the global solar irradiation reaching, during a time interval, one square meter of the solar module, oriented at an optimal angle in relation to the horizontal plane, is calculated by means of the following expression:

$$G_{teo}(\beta) = \frac{G(0^{\circ})}{1 - 4{,}46 \cdot 10^{-4} \cdot \beta - 1{,}19 \cdot 10^{-4} \cdot \beta^2} \qquad (2)$$

where

- β is the optimal angle of solar module installation (°),
- G_{teo} (β) is the amount of the energy of global solar irradiation reaching, during a time interval, one square meter of the solar module

$G(0°)$ – is the amount of energy of global solar irradiation reaching, during a time interval, one square meter of the horizontal plane.

Theoretical value of the solar module power (P_{teo}) is obtained by means of the following expressions (Sarhaddi et al., 2010; Burger, and Ruther, 2006; Skoplaki and Palyvos, 2009; Ross, 1980) [5]:

$$P_{teo} = P_m \cdot \frac{G_{teo}}{1000} \cdot \left[1 - \lambda \cdot \left(T_{cell} - 25\right)\right] \quad (3)$$

$$T_{cell} = T_{amb} + \frac{G_{teo}}{800} \cdot \left(T_{NOCT} - 20\right) \quad (4)$$

where P_m = 260W is the maximum power of the solar module, G_{teo} – is measured value of the solar irradiation intensity, Tamb – is ambient temperature, λ – is temperature coefficient and T_{NOCT} – is a nominal working temperature of solar cells. Temperature coefficient and nominal working temperature of solar cells are given by the module manufacturers.

Theoretically calculated value of electrical energy of solar module is obtained by multiplying theoretically calculated power with the time interval of 30 minutes and by adding the values obtained for the measurement time period.

The values of the energy of global solar irradiation, reaching a solar module, are obtained by means of the expression (2), whereby the values of the energy of global solar irradiation G (0°) reaching one square meter of the horizontal plane and the ambient temperature Tamb are obtained by continuous measurements performed by Davis Meteos Vantage Pro meteorological station.

Theoretical value of the solar module efficiency ηteo is obtained, on the basis of the previously calculated values of power and solar irradiation intensity, by means of the expression [1].

Determination of energy efficiency of solar module by PVGIS software

Determination of energy efficiency of solar module by PVGIS software is performed by including in the expression (1) the mean values of electrical energy generated by solar module and solar irradiation energy reaching the total surface of solar module in one hour, which were obtained by means of PVGIS-CMSAF software for the month of June, on the basis of thirty-year-long climate measurements [1].

3. MEASUREMENT RESULTS AND DISCUSSION

A comparative overview of the changes of mean values of the obtained power of solar module, based on measured solar irradiation intensity reaching the solar module for the period (19 June 2013 to 21 June 2013) depending on the measured temperature of module, is given in Figure 7.

Figures 8 and 9, respectively, show the average values of the power and energy efficiency of the solar modules obtained experimentally, theoretically and by PVGIS software, depending on the measuring period.

We can notice in Figure 8 that only during the time interval from 13:00 to 15:30h the experimentally obtained power on a solar module is higher than the power obtained by PVGIS software. Nominal power of the solar module obtained by experiment reaches the value of theoretically approximated power with a 2 hour delay.

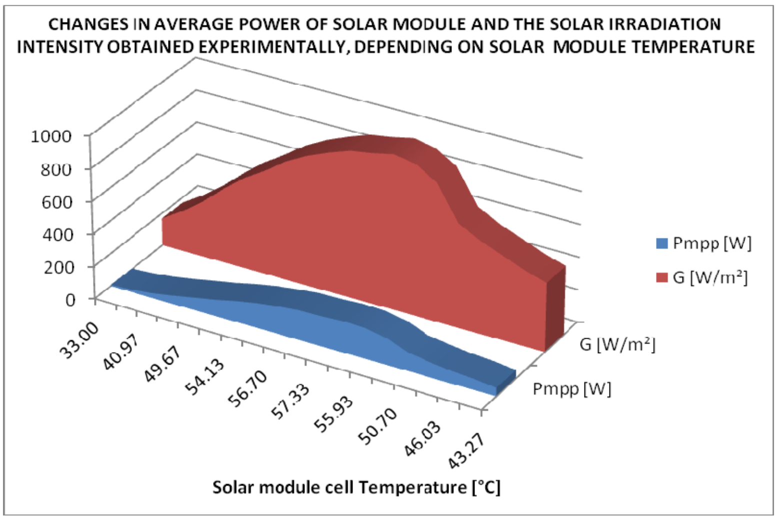

Figure 7. Comparative overview of the changes in average power of solar module and the solar irradiation intensity obtained experimentally, depending on solar module temperature.

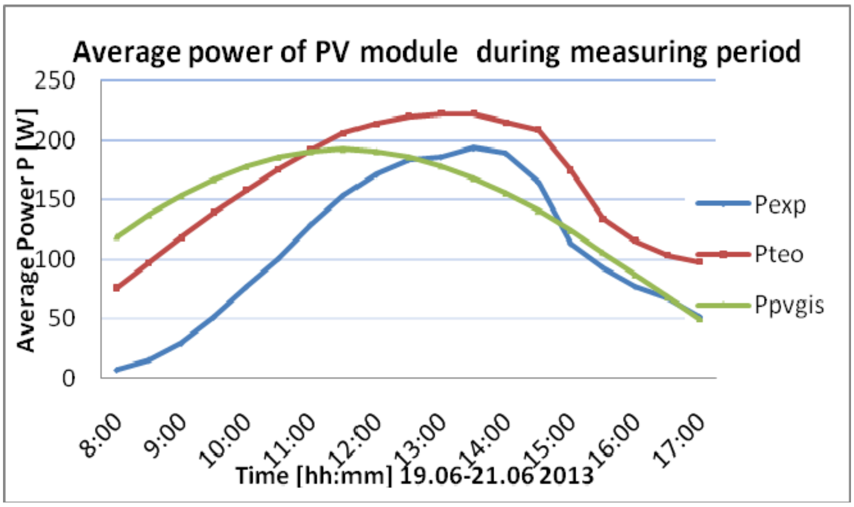

Figure 8. Comparative overview of the changes in average power of PV modules obtained experimentally, theoretically and by PVGIS software, during measuring period.

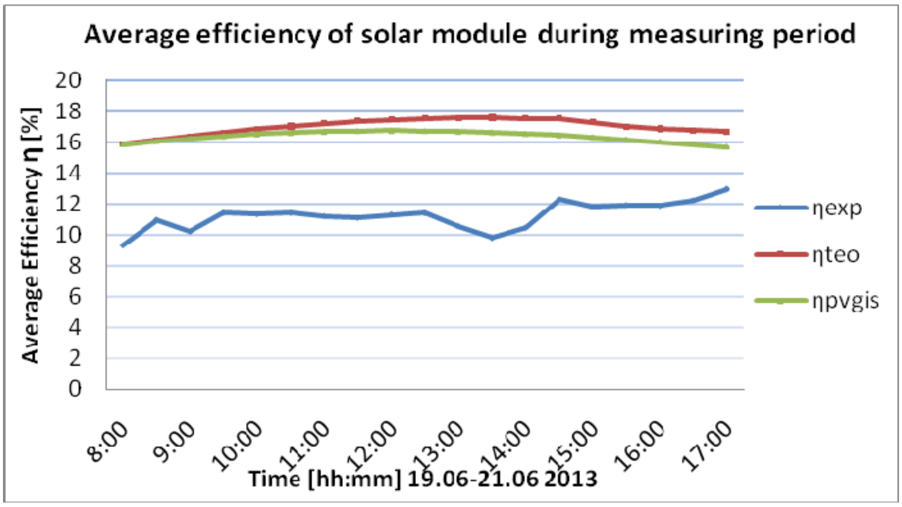

Figure 9. Comparative overview of the changes in average energy efficiency of solar modules obtained experimentally, theoretically and by PVGIS software, during measuring period.

Electrical energy generated by one solar module during the measurement period is obtained by multiplying the measured power with a 30 minute time interval and by adding the values obtained for the entire measuring period. A comparative overview of the average electrical energy and efficiency generated in one day by solar module experimentally, theoretically and by PVGIS software, is given in Figures 10 and 11, respectively.

The average daily energy efficiency of solar modules obtained experimentally is 1.0291kWh, and is by 33.43% lower than the average energy obtained theoretically (1,5462 kWh) and by 26.00% lower than the energy obtained by PVGIS software (1,390 kWh).

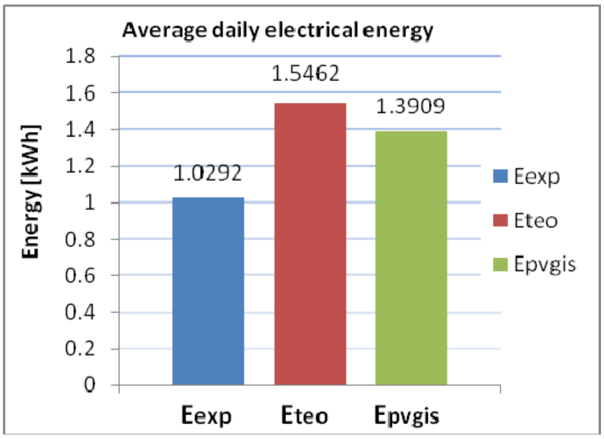

Figure 10. Comparative overview of the average daily electrical energy of solar modules obtained experimentally, theoretically and by PVGIS software

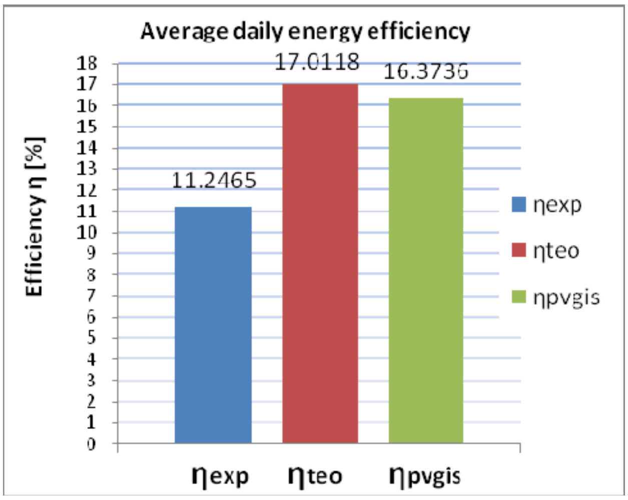

Figure 11. Comparative overview of the average energy efficiency of solar modules obtained experimentally, theoretically and by PVGIS software

Tthere was an average incidence of 5.99 kWh of solar energy on the area of one square metere during the measurement period. The efficiency of the applied solar modules according to the manufacturers' specifications is 15.3%, while the calculated average daily efficiency of the given solar module for the period 19 June 2013 – 21 June 2013 is 11.246%.

Figures 12 and 13, respectively, show the influence of the ambient temperature on the efficiency and nominal power of solar module.

Figures 14 and 15, respectively, show changes in energy efficiency and nominal power of the solar module depending on the changes in the wind speed.

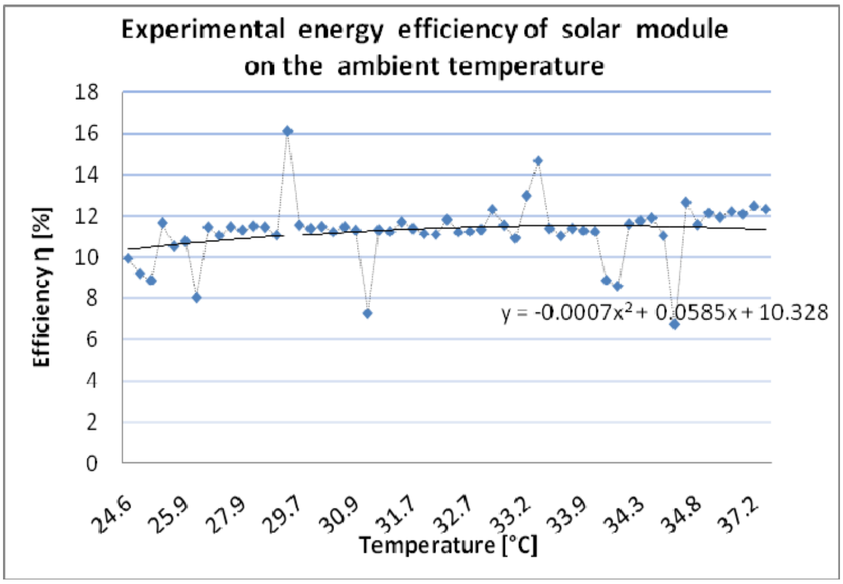

Figure 12. Graphic presentation of the dependence of experimental energy efficiency of solar module on the ambient temperature

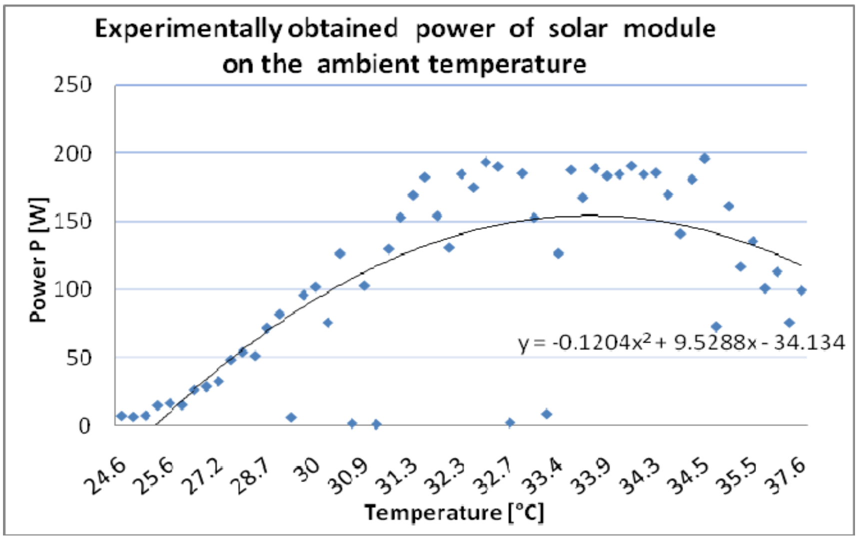

Figure 13. Graphic presentation of the dependence of experimentally obtained power of solar module on the ambient temperature

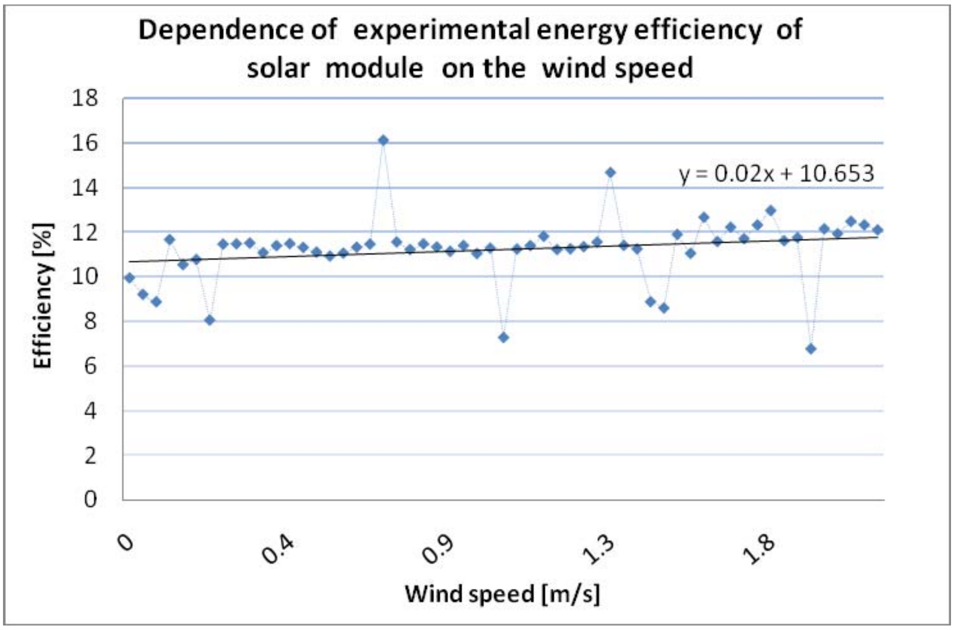

Figure 14. Graphic presentation of the dependence of experimental energy efficiency of solar module on the wind speed

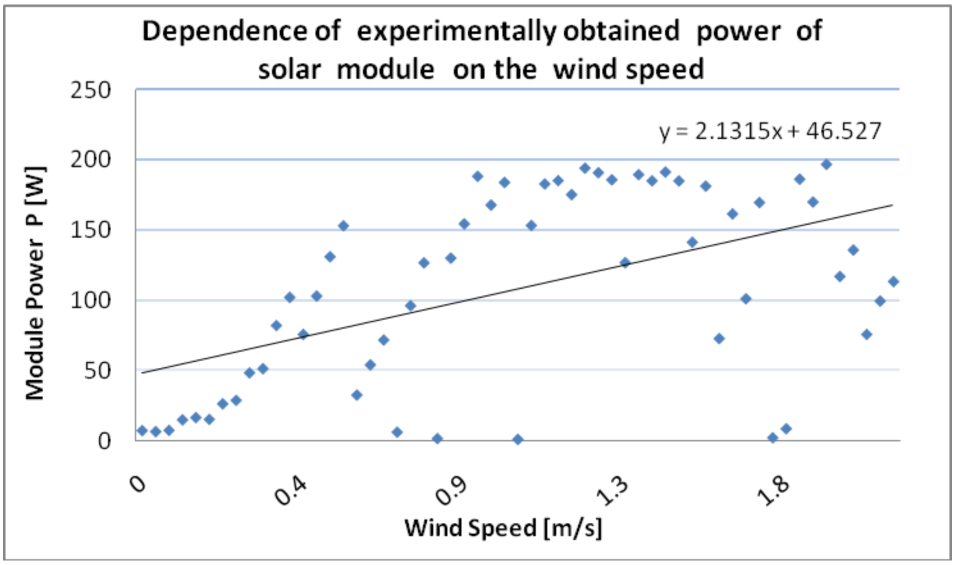

Figure 15. Graphic presenation of the dependence of experimentally obtained power of solar module on the wind speed

4. CONCLUSION

In the light of all above mentioned it can be concluded that by solar module oriented at 23.09º towards the east and tilted at 32º during the measured period lower values of electrical energy are obtained compared to the electrical energy generated by theoretically calculated values and values obtained by PVGIS software. Likewise, the experimentally obtained energy efficiency of the same module is lower, which is also lower than the efficiency of the module declared by the manufacturer. Energy efficiency of the solar modules decreases with an increase of the ambient temperature and increases with the wind speed increase.

5. ACKNOWLEDGEMENT

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ПРОУЧАВАЊЕ ЕНЕРГЕТСКЕ ЕФИКАСНОСТИ МОДУЛА
ОД МОНОКРИСТАЛНОГ СИЛИЦИЈУМА

Апстракт: У раду је приказан утицај температуре и брзине вјетра на физичке карактеристике соларних модула од монокристалног силицијума, који су постављени на зграду Академије наука и умјетности Републике Српске у Бањој Луци. Помоћу U-I анализатора за фотоволтаике PV-KLA и мини PV-KLA вршена су мјерења карактеристика соларних модула. Метеролошки параметри (температура, брзина вјетра и интензитет сунчевог зрачења) мјерени су помоћу аутоматске метеролошке станице Davis Vantage Pro-USA. Приказани су резултати упоређивања теоријских и експериментално добијених енергетских ефикасности соларних модула у односу на њихове карактеристике.

Кључне ријечи: фотоволтаици, соларна енергија, ефикасност, монокристални силицијумски модули.