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ELECTRICAL CHARACTERISTICS OF THIN FILM SOLAR PANELS ON A RIVER BOAT UNDER DIFFERENT MICROCLIMATIC CONDITIONS

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Abstract. *In this paper are measured the changes in electrical output characteristics of thin film solar panels as a function of external microclimate parameters. Possible application of thin film solar panels in the production of electricity on a small river boat was analyzed. Based on the results the efficiency of thin film solar panels was determined. Also, cost benefit analysis of their use on the river boat was performed as independent and additional sources of electricity to the existing system which is based on the ship diesel engine alternator.*

Key words: *thin film solar panels, autonomous vessels, the efficiency of a thin film photovoltaic panels, economic viability of thin film solar panels*

1. INTRODUCTION

Solar energy is an important sustainable resource that can be used indefinitely. In addition to heating the fluid in solar collectors, solar energy is increasingly finding its application through technology of solar (Photovoltaic-PV) panels, which allow the conversion of light solar energy (photons) into electrical energy. The current production of solar panels in most parts of the World is based on the use of crystalline silicon. In the last ten years the average annual growth of a systems based on solar panels was about 40%, with only 0.1 GW in 1992. and 14 GW in 2008.respectively (Mišković, 2011). The main obstacle to the expansion of photovoltaic systems is their still relatively high price.

According to the data for 2004, most of its production (58%) goes to panels based on polycrystalline silicon, while 36% of the produced solar panels was related to the monocrystalline silicon. About 4% was related to the production of the thin film solar panel (amorphous silicon). These silicon panels are produced as single-junction solar panels or panels with a PN semiconductor compound with the efficiency of 10% up to

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25%. Maximum theoretical efficiency is about 38%. Solar panels based on a combination of the CdTe and CuInSe2 were represented with 2% (Poortmans and Arkhipov, 2006). Multi-junction solar panels have higher levels of efficiency, about 40%, with a maximum theoretical efficiency of 86%. They are not widely applied because the price is significantly higher than in single-junction panels.

Thin-film solar panels belong to the second generation of solar panels and they are characterized by a relatively low degree of efficiency from 10% to 15% (Green, 2006), as well as low cost of production, currently around 0.5/W (Anwell Technologies Limited). The process of manufacturing a thin film (amorphous) solar panel is based on placing a thin film of amorphous silicon on a glass or another substrate. Thickness of a layer is less than 1 μm, thus reducing production costs through lower cost of materials (Shah and Schade, 2004). As the efficiency of thin film solar panels is much lower compared with other types of panels, these solar cells are mainly used for consumers that need low electrical power (watches, calculators).

This paper analyzes the electrical characteristics of thin film solar panels in the function of changes of the microclimate conditions. Based on the results, the calculated efficiency is obtained as the ratio of the input of the sun energy and the output of electrical energy. The obtained efficiency of the thin-film solar cell is compared with the theoretical and the declared values of the efficiency for this type of a panel.

2. MATERIALS AND METHODS

This work was carried out measuring the output of the electrical power of the two thin-film solar panels (Manufacturer: Solar Cells, Croatia). Solar panels were installed on the roof of the ship. The dimensions of the ship were: length 8.5 meters, width 3.5 meters and 5 tons displacement. The ship was located in the bay of the Danube River in Novi Sad. The photovoltaic surface and the bow of the ship were directed towards the south in order to achieve the highest possible luminous flux per unit area of the panel. The panels were placed at the different angles to the horizontal surface. In this way, the goal was to determine whether any difference in the output power of the panels is by changing the angle of the illumination. In addition, the role of the water temperature on the solar panel was determined, too.

The left panel was set at the angle of 15°, while the right panel was set at the angle of 5° to the plane of water. Both panels were located at a height of 2.5 meters above the water level.

During the measurement the ship was not changing locations. By doing this the effect of changes in the ambient environment to the measurement process was eliminated. During the measurements the following parameters were recorded: date, time of measurement, weather conditions (percent cloud cover), the amount of incident light [lux], the angle of incidence of light in relation to the panel [°], the ambient air temperature [°C], the relative humidity [%], the water temperature [°C].

The power of 12Wp (peak power in spades), and the current of 1 A respectively, with dimensions of 930 x 320 mm per solar panel, was declared by the manufacturer. The effective surface area was 905 x 295 mm per panel. Other declared features of the panels were: Voc = 22.5 V (no-load voltage), Isc = 990 mA (short circuit), Vspec = 5.14 V. The instruments used during the measurements were as follows: the digital multimeters DT9208A + (measuring range 200 mV - 1000 V and 20μA - 20 A) (2 pcs); the digital multimeter METEX M 3800 (measuring range 200 mV - 1000 V and 200 ĩa - 20 A) (1 pcs); the luxmetar MI ISKRA 7060 (measuring range of 0-50000 lux); The digital thermometer DT Dalmatia I (Thermocouple NiCr - Ni, measuring range of -65.0 ° C - 1150 ° C); sonar with temperature probe GARMIN 300C (measurement range from - 15 ° C - 55 ° C); Fischer moisture meter (measuring range 0 - 100% relative humidity). The luxmetar was not able to display the intensity of the light at the maximum insolation, due to limitations in the display options showing more than four digits. The value of the illumination (lux) was calculated by measuring the voltage of the photosensitive cells. The empirical equation which describes the dependence of a lux-cell voltage in function of the illumination is:

$$A(lux) = B(mV)\cdot 1111.1 \tag{1}$$

The solar panels were connected in a simple circuit with resistance resulting from the consumption of the electricity. The first multimeter was connected in series with the resistance as the ammeter, while the second one was connected in parallel measuring potential difference (volts). In figure 1 the simple circuit of the solar panels and instruments was depicted. The element marked with R is the electrical resistance, the elements of A and V was ammeter and voltmeter, respectively. The measurement was performed in all weather conditions, for different values of microclimate parameters and the degree of insolation.

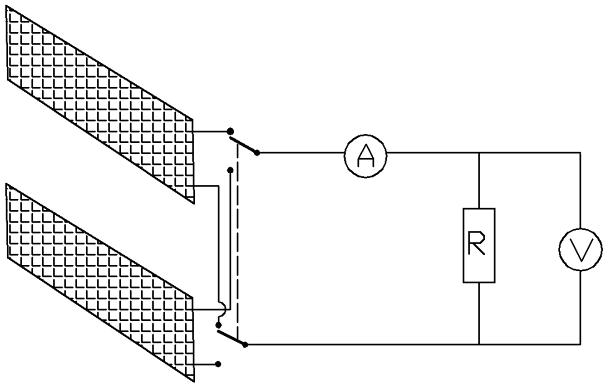

Fig. 1. The schematic of the connection of the circuit elements and the solar panels.

3. The Results and Discussion

The results of the measurements are shown in Figures 2, 3, 4, 5, 6 and 7. Based on the collected data, the correlation between the amount of the incident light [lux] and the output of the electric power [W] was obtained, as shown in Figures 2 and 3:

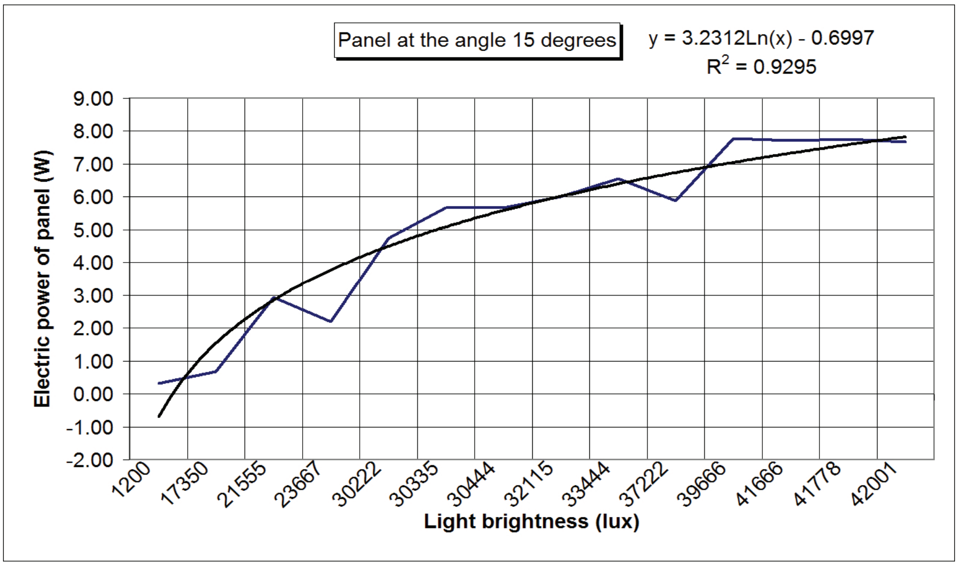

Fig. 2. Correlation between the power and insolation (panel at the angle of 15°)

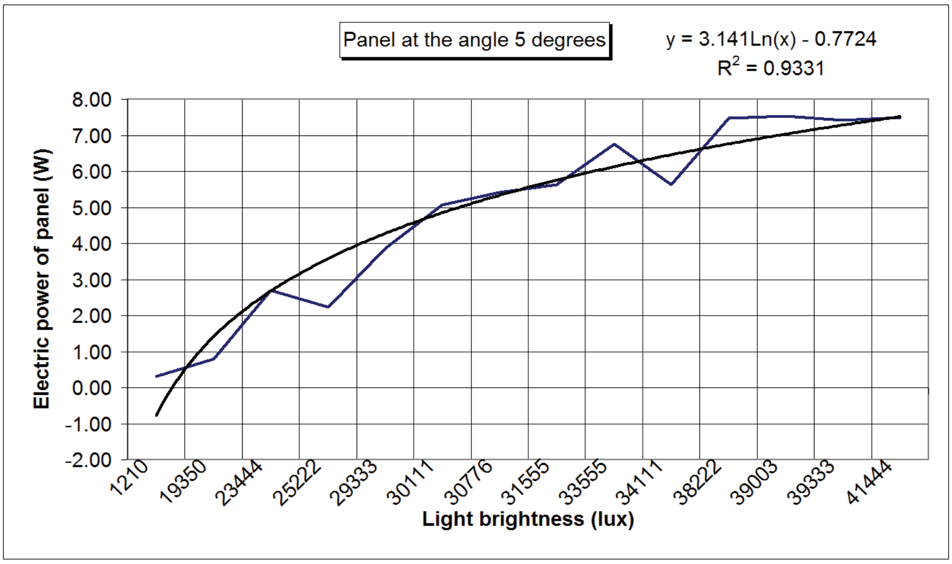

Fig. 3. Correlation between the power and insolation (panel at the angle of 5°)

Trend line shows that by the increasing of the brightness increases generated power of the solar panels as a result of increased current and voltage of the panels.

The relationships between microclimatic parameters such as relative humidity, air temperature, water temperature, and the generated power of the panel did not give a clear trend. At the same time, it was not possible to clearly define the effect of temperature, relative humidity and water temperature on the efficiency of the panel. The correlations between these quantities are shown in Figures 4 and 5.

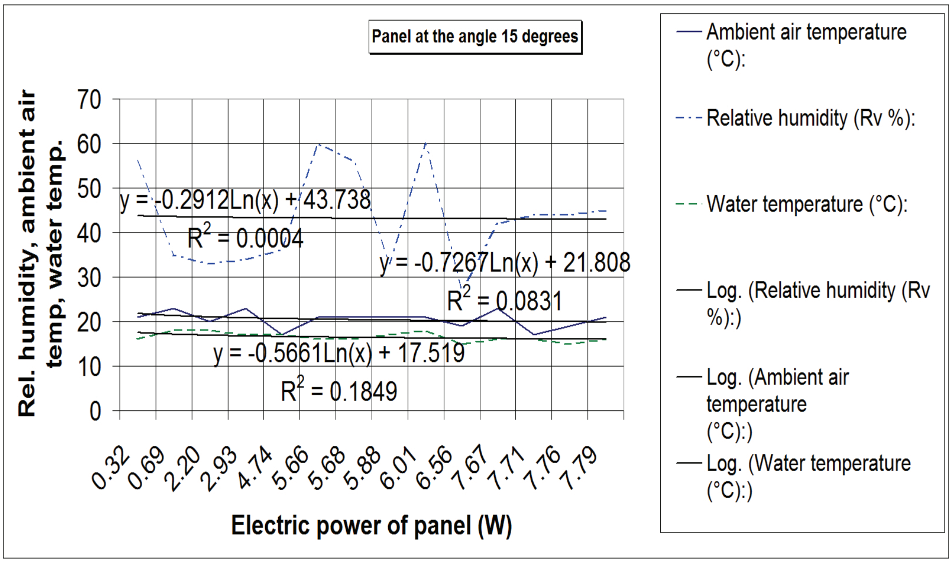

Fig. 4. Correlation between relative humidity, ambient temperature and water temperature and the power (panel at the angle of 15°)

The change in the relative humidity during the measurements was significant. Despite of that, it can be noted that relative humidity changes in the measured range did not have a greater impact on the output power of the panel. It is assumed that in the case of higher humidity, more than 90%, the reduced insolation would have a stronger negative effect on the electric power of the solar panels.

The obtained correlation factors of the generated trend lines (R^2) were very low. The logarithmic equations, the models, for each of the correlated parameters shown in Figures 4 and 5 poorly represent measurement's values. In other words, there is not a clear correlation between changes in relative humidity, air temperature and water temperature with generated electric power of the panels. These results could be explained by the fact that the air and the water temperature changed at the low range during the measurements.

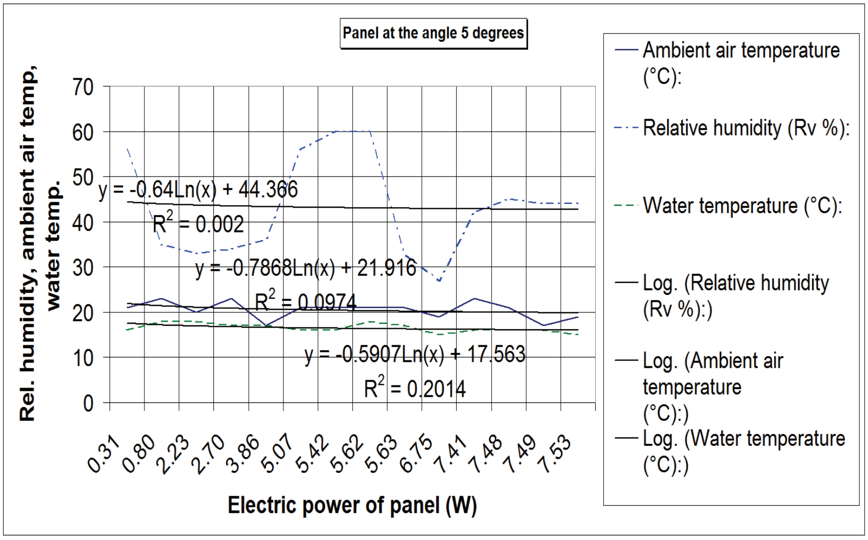

Fig. 5. Correlation between relative humidity, ambient temperature and water temperature and the power (panel at the angle of 5º)

It is possible to notice that the generated power at the angle of 15° is greater than at the angle of 5° (figures 6 and 7). This was a consequence of the increased incidence angle of light on the panel. Some variation in the trend growth of the output power of the panels is result of changeable weather and cloud cover during the period of measurement. This caused reduction in the power of the panels despite of the increase of the angle of the light. The influence is most evident for the values of the power that is not defined by the angle of illumination (first two values of the incident light angle in figures 6 and 7).

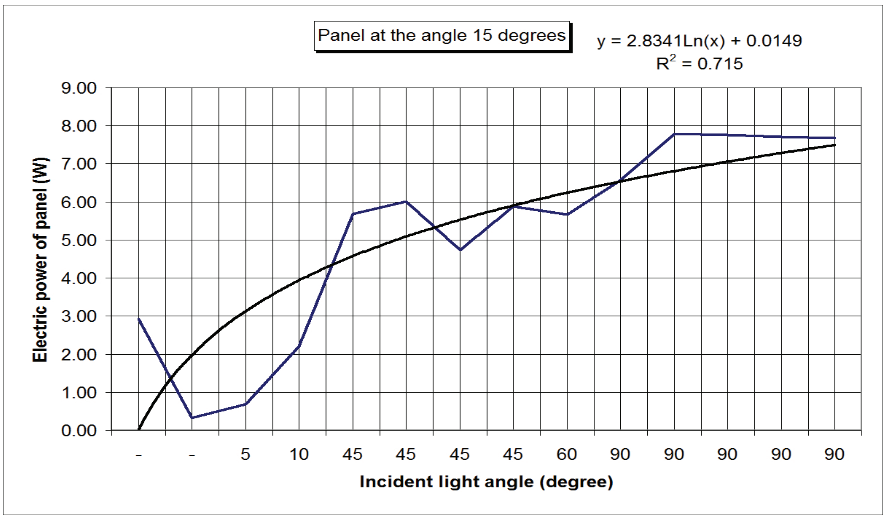

Fig. 6. Correlation between the power and incident light angle(panel at the angle of 15º)

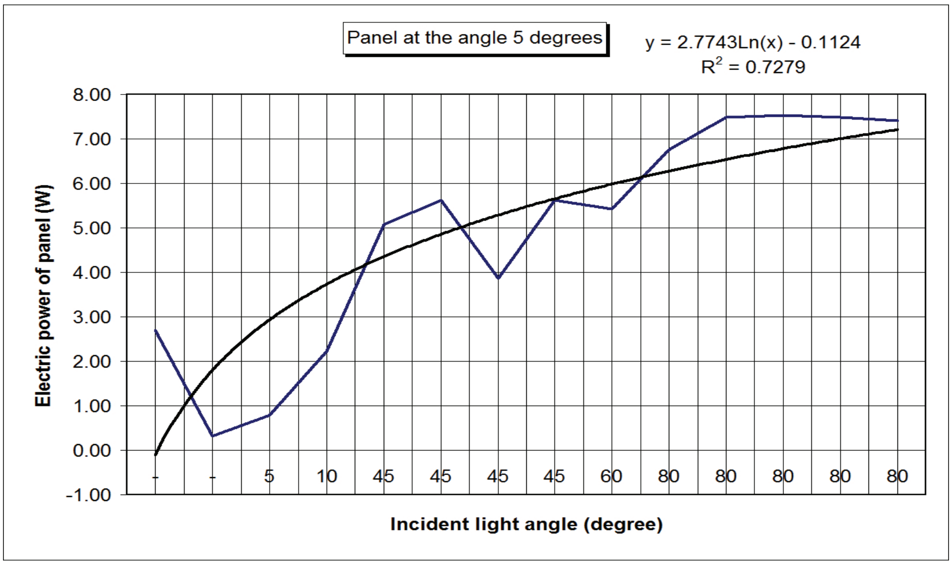

Fig. 7. Correlation between the power and incident light angle (panel at the angle of 5°)

The influence of the weather conditions reduced the correlation factor of the logarithmic trend line (R^2) at the range of low incident light angle.

Generally, based on the presented results it can be stated that the power output of solar panels is significantly affected by the amount of the light, as well as the angle of the illumination. The correlation between the powers of the panels, the measured values of microclimate and the water temperature have shown stochastic manifestation.

The efficiency of solar panels can be defined as the ratio of electric power generated by photovoltaic panels (power output) and the power to be transferred into the photovoltaic panel through insolation (power input). This relationship is calculated as follows:

$$\eta = \frac{P_{output}}{P_{input}} \cdot 100 . \tag{2}$$

In this research for the input power a universally accepted fact that the average insolation is 1 kW per m^2 of illuminated surface was taken. For the analysis of the output power generated by the panels, a data provided by the manufacturer was taken. The declared output power of 12 Wp (peak power in spades), was determined as the maximum efficiency of a thin film solar panel. For the calculation of the efficiency of the panel effective surface area was determined. The effective surface area per panel used in this work is:

$$P_{panel} = 0.905[m] \cdot 0.295[m] = 0.267[m^2] . \tag{3}$$

The connection between the light radiated solar energy per square meter and panel surface gives the relation:

$$\alpha = \frac{1[m^2]}{0.267[m^2]} = 3.74 . \tag{4}$$

This indicates that the total radiated sunlight per m^2 on the surface of the panel gives about 27% of energy. Based on the above, the declared efficiency is calculated as follows:

$$\eta_d = \frac{12[W] \cdot 3.74}{1000[W]} \cdot 100 = 4.48\% . \tag{5}$$

The theoretical efficiency of today's thin film panels is around 10% to 15%, depending on the technology and materials used in a production. The equation (5) shows that the maximum efficiency of the panels used in this research is about 4.5%. It is about 70% less efficiency compared to the current theoretical efficiency.

Under the real conditions, the panel at the angle of 15° by the maximum insolation gave the 7.7 W of a power. The calculation of efficiency for the real conditions gives the following result:

$$\eta(15^\circ) = \frac{7.7[W] \cdot 3.74}{1000[W]} \cdot 100 = 2.87\% . \tag{6}$$

Panel at the angle of 5° at the maximum brightness generated slightly less power of 7.5 W. Calculation of the efficiency gave the following result:

$$\eta(5^\circ) = \frac{7.5[W] \cdot 3.74}{1000[W]} \cdot 100 = 2.8\% . \tag{7}$$

The difference in the calculated real efficiency between the panels is insignificant. According to the equation (6) it can be concluded that the panel at the angle of 15° had an efficiency of 64% compared to the declared efficiency. The equation (7) has shown that the panel at the angle of 5° had the efficiency of 62% of the declared value.

4. COST-BENEFIT ANALYSIS

River vessels for the most part use electricity generated by an alternator, charging a battery by the work of marine internal combustion engines. The most common marine combustion engines are diesel engines. In this case internal combustion engine can be seen as a converter of mechanical work generated by burning diesel fuel into electrical energy generated by an alternator.

One kilogram of diesel fuel contains 47 MJ of energy, which is 13.05 kWh. If we take into account that about 0.85 kg of diesel fuel occupies a volume of 1 liter, it is possible to derive the following relationship of the kWh per liter of fuel:

$$E_{diesel\_fuel} = 13.05[kWh/kg] \cdot 0.85[kg/l] = 11.09[kWh/l] \approx 11.1[kWh/l] . \tag{8}$$

The efficiency of a diesel engine is around 20%, while at the same time an alternator's efficiency reaches about 95%. Based on these data and the relation (8), the electric power generated by the alternator during combustion of diesel fuel in the engine can be expressed as follows:

$$P_{alternator} = 11.1[kWh/l] \cdot 0.2 \cdot 0.95 = 2.1[kWh/l]. \tag{9}$$

Assuming that the total needs of a small river boat for electricity is about 1 kWh, leads into the daily basis amount of the 0.47 liters of a diesel fuel to power up a ship's electrical systems. Further, assuming that the production of electricity is constant, the annual amount of diesel fuel is about 174 liters.

Based on the measurements performed for the solar panels, it can be assumed that the average power that a panel generates is 5 W. Assuming that the average brightness of the solar panels during the year is 10 hours per day, and there are 30% of cloudy days per year, the following calculation gives the electric power generated by a panel per year:

$$P_{panel} = 5W \cdot 10 hours \cdot 365 year \cdot 0.7 \approx 12.8 kWh / year. \tag{10}$$

According to the previous analysis, the required number of thin-film solar panels is 28.5 that would generate an adequate amount of electricity per year. This is equivalent to the 174 liters of diesel fuel.

5. CONCLUSION

Based on the measured values of electrical and physical parameters monitored for the thin film photovoltaic panels installed on the river boat, it is possible to conclude as follows.

Electrical power output of the solar panels increases with increasing of a brightness of the panels and with increasing of the angle of an incidence of a light on the panels.

There is no effect of humidity, air temperature, or water temperature on the panel's power output.

The obtained efficiency of the thin film solar panels was about 70% lower than the theoretical one, while 40% lower than the declared one.

Under the assumption that most of the smaller river vessels possess internal combustion engine, generating electricity through the alternators by burning diesel fuel is imposed as a logical solution. However, as shown in this paper, internal combustion engine consumes half a liter of diesel fuel per day to power electrical devices on the ship. It was calculated that the 28.5 thin film solar panels would provide the same amount of electricity per year.

Taking in account all above, it is possible to point out that solar panels are an acceptable addition in generating the electricity on the ship, while protecting the environment and saving energy consumption.

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