Acta Scientiarum
http://www.uem.br/acta
ISSN printed: 1806-2563
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v37i1.19191

Yield from photovoltaic modules under real working situations in west Paraná - Brazil

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ABSTRACT. This study analyzed the external factors that influence the yield obtained from photovoltaic modules (Solarex® - MSX 56), as solar irradiance, temperature, placement angle and dust deposition on the photovoltaic modules installed at the facilities of the Medianeira campus of the UTFPR, working under real conditions. To obtain the data it was used a datalogger from Campbell Scientific, Inc, model CR23X. It was observed that under solar irradiance below 550 W m^{-2} the panel did not convert maximum power, and above this value the panel reached saturation levels. Temperature increase led to reduced voltage, and consequently lower module output power, decreasing the efficiency value by nearly 6% at temperatures 15°C above the Standard Test Conditions (STC) temperature. These panels are usually placed at different angles according to local latitude, remaining fixed in that position. In comparison with a horizontally-placed panel, it was obtained a 4-hour increase in yield when the panel reached saturation value. Dust levels reduced electricity production levels by approximately 16%. These factors must be taken into account for placement and maintenance of photovoltaic systems, so they can function efficiently.

Keywords: solar irradiance, temperature, deposited dust, positioning.

Rendimento de módulos fotovoltáicos em situação real de trabalho no oeste do Paraná - Brasil

RESUMO. Neste trabalho foram analisados os fatores externos que influenciaram no rendimento de painéis fotovoltáicos (Solarex® - MSX 56) como irradiância solar, temperatura, ângulo de instalação e sujeira acumulada sobre os painéis fotovoltáicos, instalados nas dependências da UTFPR, Câmpus Medianeira, funcionando em condição real. Para obter os dados foi utilizado um datalogger da Campbell Scientific-Inc, modelo CR23X. Verificou-se que na irradiância abaixo de 550 W m^{-2} o painel não converteu sua potência máxima e, acima de 550 W m^{-2}, o painel atingiu o valor de saturação. O aumento da temperatura provocou redução na tensão e, portanto, na potência de saída do painel, diminuindo a eficiência cerca de 6% em temperaturas com 15°C acima da temperatura *Standard Test Conditions* (STC). É usual instalar o painel inclinado conforme a latitude do local e mantê-lo fixo nesta posição. Comparando a um painel instalado na posição horizontal, obteve-se acréscimo de 4h no rendimento em ocasiões em que o painel atingiu o valor de saturação. A geração de energia elétrica reduziu cerca de 16% o nível de sujeira. Estes fatores devem ser considerados na instalação e manutenção de sistemas fotovoltáicos para que funcionem com eficiência.

Palavras-chave: irradiância solar, temperatura, sujeira acumulada, posicionamento.

Introduction

The intensification of the environmental debate regarding Brazil's energy mix has prompted studies on new renewable and less polluting energy sources (BASSO et al., 2010). Currently, a promising renewable energy technology is solar energy, which is made available mainly by photovoltaic technology. This technology presents advantages compared to other sources: as it operates silently, is a totally clean type of energy (at least in its use), has an estimated useful lifespan of 20 to 30 years, and requires little maintenance (IBRAHIM et al., 2009).

Photovoltaic solar energy is being disseminated in several locations in Brazil and has been applied to many different ends. Since it is a versatile source, it can be used in remote locations where extension of the electrical grid is not worthwhile, representing an interesting option for small farmers (MICHELS et al., 2009). However, systems powered by solar energy still feature low efficiency. Therefore, further studies are required to investigate whether their use is feasible and will not cause disappointing results for investors.

In photovoltaic systems, light is transformed directly in electricity. However, the incident level of light on the photovoltaic panel influences performance – that is, the current generated by a module increases according to light intensity (KOLLING et al., 2004). Diffuse radiations do not provide sufficient incidence to generate significant electricity, while global radiations above saturation value do not increase panel output power. Michels et al. (2009) observed that saturation in polycrystalline photovoltaic modules occurred at about 550 Wm^{-2} of irradiance; above that value, the photovoltaic panel does not increase conversion.

Temperature increase negatively influences the total efficiency of photovoltaic modules (LEUCHTER et al., 2010); conversely, temperature control contributes to higher energy production (YERLI, 2010). Gnoatto et al. (2008) studied the efficiency of a photovoltaic system under real working conditions in the region of Cascavel, Paraná State, collecting data for one year. They concluded that reducing temperature leads to increased photovoltaic panel efficiency. Open-circuit voltage decreases as temperature increases, indicating that the efficiency of a photovoltaic system decreases by about 0.03% $°C^{-1}$ (HAMROUNI et al., 2008).

Rhif (2011) affirms that photovoltaic systems present higher yield when the incidence of solar rays is perpendicular to the surface of the panel, meaning that a system for automatic positioning of photovoltaic modules can increase energy production up to 40%. However, photovoltaic modules in the southern hemisphere are placed facing the geographic north, and the angle of inclination should be the same as the local latitude, so that at critical times (winter solstice), there is perpendicular incidence of solar rays (GNOATTO et al., 2008), also contributing to reduce dust deposition on the surface of photovoltaic modules (HEGAZY, 2001). The inclined plane, depending on the angle of the irradiating face and the time of day, receives more radiation than the horizontal plane (SEME; STUMBERGER, 2011), with maximum gain of approximately 30% (SCOLAR et al., 2003).

The deposition of dust and dirt particles on the surface of photovoltaic modules negatively affects performance (BEATTIE et al., 2012). Mekhilef et al. (2012) affirmed that dirt deposited on the surface of photovoltaic modules decreases efficiency, and further described that bird droppings, pollution and dust caused by traffic or agricultural activities accumulate rapidly and can reduce the efficiency of photovoltaic cells by about 20%.

The aim of this study was to survey the effect of solar irradiance, temperature, panel placement angle and deposited dust on the protective glass cover on the yield of a photovoltaic system, operating under real conditions in West Paraná - Brazil.

Material and methods

The photovoltaic system was installed in 2004 at the facilities at the Medianeira campus of the Federal Technology University of Paraná, (25°17'43" S, 54°05'38" W, 500.7 m).

Both polycrystalline photovoltaic modules, made by Solarex®, model MSX 56 (Figure 1), standard 12 V voltage, standard 3.35 A current and 56 W of power, were placed facing the geographic north. The inclined placement of the panels (at the same angle as the local latitude) contributes to approach perpendicular incidence at the winter solstice; buildings and other obstacles were avoided in order to prevent shading onto the system.

Figure 1. Polycrystalline PV modules.

Two 12 V batteries were used for energy storage, with 350 A each, charging a motor pump, made by Shurflo® Ltd, model 2088-732-244, 12 V voltage, set in a cistern, pumping into a water tank 20 m high.

Data on voltage (V), current (A), panel temperature (°C), irradiance on the panel and horizontal planes (W m^{-2}) were collected, minute by minute, for a period of one year, beginning on February 1st, 2008. The data used in this study were extracted from clear days (without cloud cover), using a datalogger made by Campbell Scientific-INC®, model CR 23X.

Data on temperature of the photovoltaic panel were obtained using a type-K thermocouple placed in the underside of the panel, and ambient temperature was obtained from the datalogger sensor. Two Kipp & Zonen® pyranometers, model CM3, were placed next to the photovoltaic system – one at the same inclination angle as the panel, and the other in the horizontal plane – to measure irradiance in the horizontal and inclined planes.

Two voltage dividers were used to obtain voltage values (T, V) in each panel, while a shunt resistor provided current values (C, A). Each panel was analyzed separately to enable the study of the influence of dirt on them.

To assess the influence of solar irradiance on the panels, the values of solar irradiance were related to output power values. Values for power (P, W) and efficiency (η, %) were obtained through equations 1 and 2, respectively (MEKHILEF et al., 2012) :

$$P = TC \tag{1}$$

$$\eta = \frac{P}{I_S A} 100 \tag{2}$$

in which:

P – Power (W);

T – Voltage (V);

C – Current (A);

Is – Solar irradiance (W m^{-2}), and;

A – Useful area of the module (m^2).

Initially it was observed the influence of solar irradiance in increasing temperatures, in order to, in a further moment, to isolate at 1,000 W m^{-2} of solar irradiance, the temperature values, and to calculate the efficiency of the photovoltaic system.

To assess the importance of placing photovoltaic modules at a determined angle and its relation with efficiency, pyranometers were installed horizontally and at the angle of inclination of the panels, in order to verify any difference in the values. The results for solar irradiance were analyzed on a clear day, when data were collected every two hours and averages were calculated to detect any decrease in efficiency caused by the inclination factor (Table 1).

To establish if deposited dust on the photovoltaic modules alters efficiency, the panels were not cleaned for approximately six months. Since data on voltage and current were collected from each photovoltaic module separately, one of the panels was cleaned and power values were compared between them (Table 1).

Table 1. Schedule for data collection in relation to position and dust accumulation of the photovoltaic panels.

Photovoltaic Panels	Photovoltaic Panels Positioning	Inclined pyranometer	Clean Day with efficiency compared every 2 hours	
		Horizontal pyranometer	Clean Day with efficiency compared every 2 hours	
	Dust accumulation on the Photovoltaic Panels	Clean panel	After 6 months	Check the Power with the clean panel
		Unclean panel	After 6 months	Check the Power with the dirty panel

Results and discussion

Solar irradiance

Low solar irradiance values generated electricity in the photovoltaic modules, but with non-significant levels of power. For the charge in question, the initial value for significant generation was 300 W m^{-2}. Current increased with irradiance between the values of 300 and 550 W m^{-2} (Figure 2).

Solar irradiance values near 1,000 W m^{-2} are common; however, the photovoltaic panel in this study showed saturation at 550 W m^{-2}, meaning that higher values showed negligible increase in the results. Since it is a meteorological factor, there is no way to compensate the possible unavailability of solar rays.

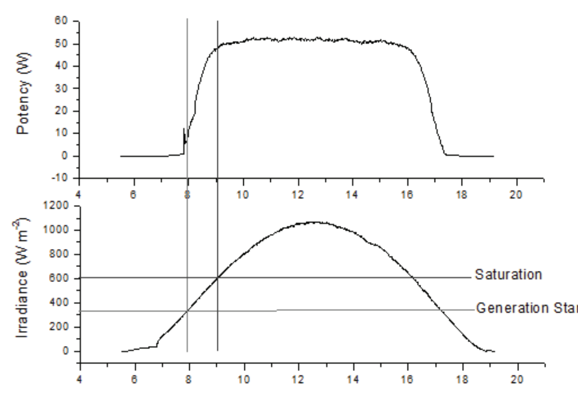

Figure 2. Power and solar irradiance over the course of a clear day.

Temperature

Increasing solar irradiance resulted in higher temperature on the panels and consequently decreased efficiency, which corroborates the findings of Yerli (2010). To confirm these results, the efficiency for irradiance of 1,000 W m^{-2} was isolated and the temperature was measured (Figure 3). It was noticed that for a difference in temperature between 42 and 58ºC, efficiency decreased an average of 5.45 to 5.9% – values that corroborate Hamrouni et al. (2008).

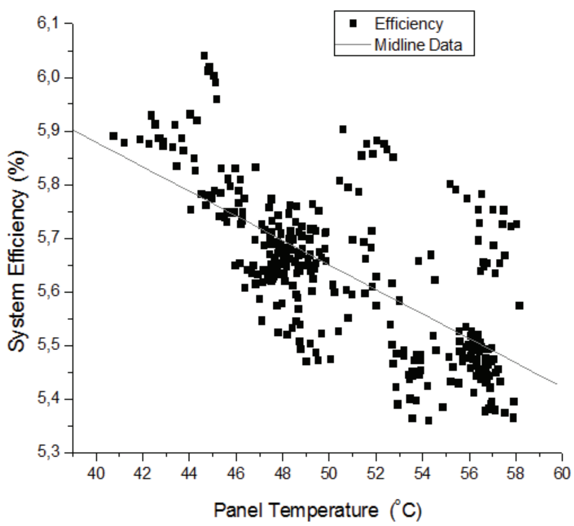

Figure 3. Relationship between system efficiency and temperature for 1,000 W m^{-2} irradiance.

Panel Placement Angle

Considering irradiance averages for the days near the winter solstice – that is, the critical period for operation of the photovoltaic system – a higher reading was obtained in the pyranometer installed next to the inclined panel, compared to the device placed horizontally (Figure 4), corroborating Souza et al. (2011). Overcast days resulted in similar low irradiance levels in both pyranometers compared, because in this case only diffuse radiation occurs. The significant difference between each pyranometer, with higher values for the pyranometer inclined one, was observed on clear or partially cloudy days.

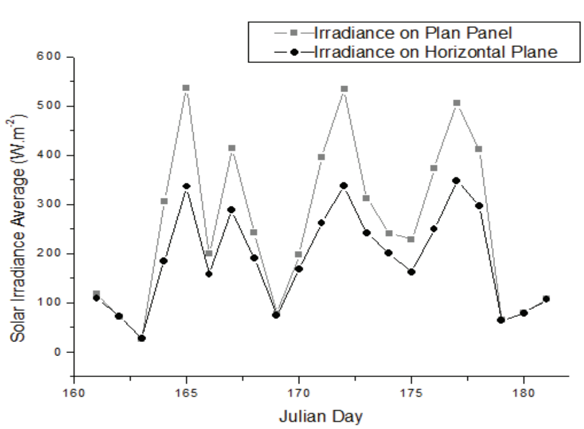

Figure 4. Mean solar irradiation for days near the winter solstice in the pyranometers installed horizontally and at the same angle as the panel.

To better visualize the effect of panel placement position, Julian day 199 (July 19th) was chosen, regarded as a clear day (Figure 5). It was observed that from 8 to 10 a.m., the irradiance recorded by the pyranometer placed in the inclined plane was, on average, 129.56 W m^{-2} higher than the reading obtained by the other device, placed horizontally. In the time interval between 10 a.m. and 12 p.m., the difference was of 248.31 W m^{-2}; from 12 p.m. to 2 p.m. it was of 309.69 W m^{-2}; from 2 p.m. to 4 p.m., 313.39 W m^{-2}; and finally, for the interval between 4 p.m. and 6 p.m., the average difference was of 190.40 W m^{-2}. The greatest difference occurred when the sun was at its zenith, with the inclined plane showing values 32% higher compared to the horizontal plane, in agreement with the results found by Scolar et al. (2003).

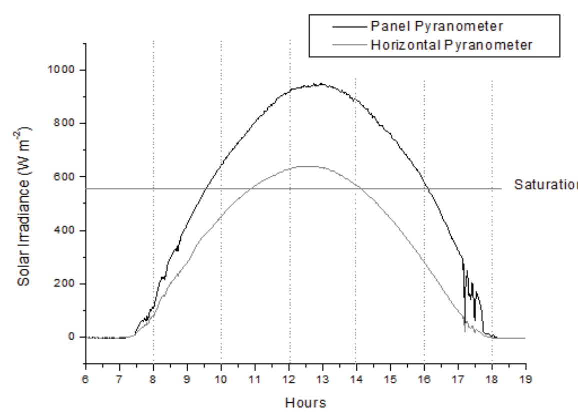

Figure 5. Incidence of solar rays on the plane of the panel compared to the horizontally placed pyranometer (July 19th).

In Figure 5, a straight line was drawn at the point of saturation of the photovoltaic panel, showing that if the photovoltaic system had been installed horizontally, the exposure time to the saturation irradiance level in winter would be approximately 3 hours shorter; in the inclined plane, the panel worked for approximately 7 hours under saturation conditions. In other words, the inclined panel achieved a more favorable period of approximately 4 hours compared to the horizontal configuration.

Considering that the saturation value for the panel in question is 550 W m^{-2}, the sooner this value is reached, the longer the time the photovoltaic system will work under maximum conversion power. In Figure 6, the difference was plotted between both irradiances, showing an increase between value differences until 12 p.m., remaining practically unchanged until 4 p.m.; from then on, the difference decreased again.

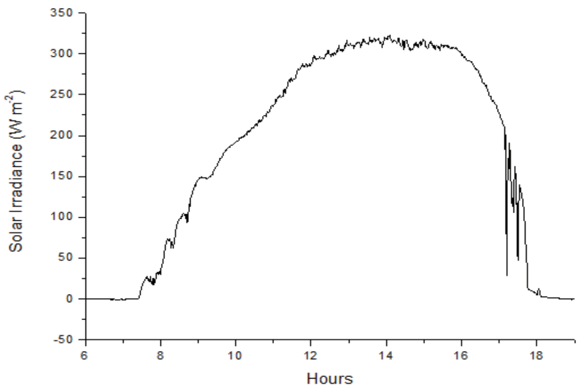

Figure 6. Difference in solar irradiance between the pyranometers placed horizontally and on the plane of the panel.

Dust Deposited on the Photovoltaic Modules

The variation in power between the two photovoltaic modules with deposited dust, which were not cleaned for a period of six months, was identical (Figure 7).

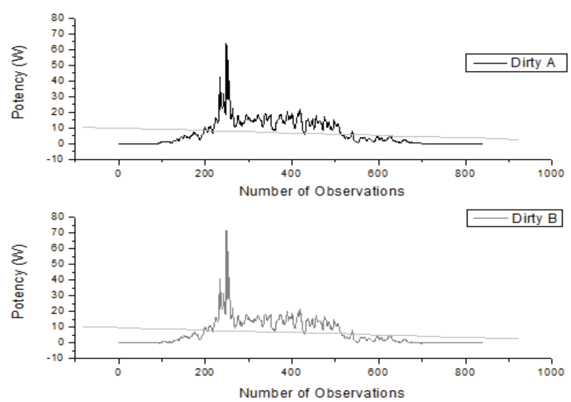

Figure 7. Power values for both dirty panels prior to cleaning.

After one of the panels was cleaned, it was possible to observe greater power output in that clean module (Figure 8), corroborating Mekhilef et al. (2012) and Jiang et al. (2011).

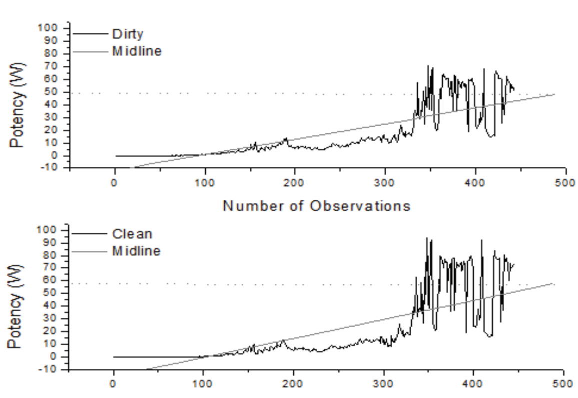

Figure 8. Power comparison between the dirty and clean panels.

The dirty panel showed a power deficit of 16.3% compared to the cleaned panel, close to the value found by Mekhilef et al. (2012).

Conclusion

With this study, it was concluded that: *i)* the level of solar irradiance influenced output power as the panel has reached its saturation value; *ii)* temperature increase in the photovoltaic modules leads to reduced efficiency values of the photovoltaic panels; *iii)* placement of the photovoltaic module at an inclined plane led to increased efficiency during the critical period (winter); *iv)* dust deposition on the photovoltaic modules reduced the electricity production.

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Received on November 19, 2012.
Accepted on April 14, 2014.