AUTOMATION FOR SOLAR TRACKER FOR PANEL PHOTOVOLTAIC – EFFICIENCY ANALYSIS

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Abstract

This article presents the results of a prototype of electronic circuit boards for photovoltaic solar tracker based on a microcontroller circuit and sensors that has its analog voltage compared periodically. That sensor that has the highest incidence of the sun, great angle with reference to the solar panel can have the greatest absorption solar energy and consequently have the highest possible power transference that moment. Three different panoramas are studies: one panel installation on a roof random, another under the guidelines of the manufacturer and a third with the solar tracker. The results presented show a performance of automated solar panel with 27% higher than according to the manufacturer's guidelines and more than 110% of that installed on a roof arbitrary, justifying its application in relation to the costs involved, especially in small systems.

Keywords: photovoltaic panel, automation, microcontroller, efficiency

1. INTRODUCTION

Due to the economic and social development viewed mainly in the second half of the twentieth century, every country has sought constantly to improve their energy matrixes [1].

Such bottlenecks make alternative energy sources are studied. In this aspect emerges is the generation of alternative energy such as wind and photovoltaics, but the Brazilian electric energy by the year 2011 consisted of 81.9% by hydroelectric power, and the generation of electricity produced by solar panels and wind farms represent only 1.2% of all electricity generated [2].

Brazil is privileged in terms of geography (location and extent), for the use of solar power to receive an average solar 5kW.hm^2/day [3], interesting factor for the conversion of solar energy into electricity, and the fact that the country is extremely rich in raw materials used in the manufacture of solar cells, silicon. However the electricity produced by photovoltaic panels have a low income in relation to rate of solar energy converted into electricity in general that income partially depends on the semiconductor material used as a base in the manufacture of solar cell. Cells are divided into commercial manufactured monocrystalline silicon, polycrystalline and amorphous. Cells and panels using monocrystalline semiconductors are difficult to manufacture because it requires silicon in its purest form, the crystal, hence also with greater efficiency (near 16%). The polycrystalline are popular and have efficiency around 13%.

The amorphous silicon-based thin film and they are less expensive to manufacture, however its effectiveness varies from 8% to 13% [4].

So driven by this increasing demand for electricity, especially clean energy, inexhaustible and cheap, the search for better methods and application of energy obtained by solar panels is still a trend research and studies in this area.

Some mathematical models have shown the behavior of photovoltaic panels, but they have not taken into consideration factors such as, for example, the inclination of the panel in relation to the sun and air mass column [5]. The common information is only the slope fixed panel, disregarding its variation as a function of the dynamics in the solar day.

These models are intended to assist in the development of optimization techniques of maximum power supplied by the solar panel, which is not fixed and varies according to climatic characteristics.

The main studies of efficiency solar panels addressing the electronic treatment-seeking point of maximum power transfer (MPPT) [6], however do not consider the simultaneous pursuit of greater sunlight through the drive panel.

Considering that, this paper deals with the preliminary experimental proposing a system of automatic movement of a photovoltaic panel, which follow the movement of the sun seeking greater efficiency throughout the day. They are also conducted experiments to evaluate the deformation of the power curve of the panel as the slope and partial shading.

2. **BIBLIOGRAPHICAL REVIEW**

With photoelectric principle was possible the direct transformation of solar energy into electrical energy, on the form of voltage and current continues. When photons collide with atoms of certain materials end up electrons move this, so if these electrons are prevented from returning to their orbital home then these can be availed as current, being in the gaps left orbital positive charges, so we can generate difference potential and electric current [7]. Photovoltaic panels are based primarily on it, using doping materials. In solar panels for this operation uses mainly silicon, which is a critical factor in choosing this as an energy source, because silicon is the second most abundant element on earth, conveniently Brazil, owns 90% of the world's mineral silicon [8].

The solar panels or photovoltaic panels are made of solar cells which is the smallest element of the photovoltaic system, typically producing electrical power of 1.5 Watt peak (corresponding to a voltage of 0.5 V and a current of 3 A). For higher powers, the cells are connected in series and/or parallel, forming modules (typically power of the order of 50 to 100 Watt peak) [9].

On commercial solar cells there are three main technologies which were compared in Table 1. These being: mono-crystalline cells, which are higher yielding, but are expensive and difficult to manufacture because they require silicon in the form of pure crystal; poly-crystal cells, which have lower production cost, with a lower yield the mono-crystal because of imperfections in the crystal due to the manufacturing system; and amorphous silicon cells, yielding even smaller than the previous ones, but also the reduced price [10].

Table 1 – Conversion efficiency and cost of solar cells

Cell Type	Theoretical Efficiency (%)	Experimental Efficiency (%)	Cost (US$/Wpico)
Mono-crystalline	27	28,2	5 a8
Poly-crystalline	25	19,8	4 a7
Amorphous Silicon	13	4 a7	-

Source: Adapted of GREEN, M. A. et Al. Solar cell efficiency tables: version 16. Progress in Photovoltaics: Research and Aplications, Sydney, v.8, p. 377-384, 2000.

In practical experiments carried out were used panels MSX-70, already old, produced by Solarex [11], consisting of 36 cells of poly-crystalline silicon, these modules are well suited for virtually all applications where photovoltaic panels are viable sources of energy, such as telecommunications , pumping irrigation, remote villages and also for a hybrid system with the electrical grid to homes. The features MSX-70 panels are presented in Table 2, and these values, according to the manufacturer, valid for 20°C ambient temperature, solar radiation of 0.8kW/m².

Table 2 – Electrical Characteristics of MSX – 70

Maximum Power (P_{max})	70.1W
Voltage for P_{max} (V_{mp})	16.4V
Current for P_{max} (I_{mp})	4.28A
Open Circuit Voltage (V_{oc})	20.5V
Short Circuit Current (Isc)	4.73A

Source: Adapted of SOLAREX, Msx- 70 datasheet, 1997 [12] .

To calculate and determine the theoretical efficiency of the plates was used compared (1) [13]:

$$\eta = \frac{Imp \ x \ Vmp}{S \ x \ Ic} \tag{1}$$

Where: "I_{mp}" is the maximum surge current (A); "V_{mp}" is the maximum peak voltage (V), "S" is the floor area of the solar module (m^2), and "Ic" is the rate of solar radiation (W/m^2). The value of solar irradiation used as a reference for typical days of winter and is about 350 W/m^2 for the region of Ponta Grossa [14].

To understand the behavior of solar panels, it uses the electrical model [15] shown in Figure 01, where I_{ph}, I_0, R_s and R_p are the photocurrent, the reverse saturation or flow current diode series resistance and the parallel resistance, respectively.

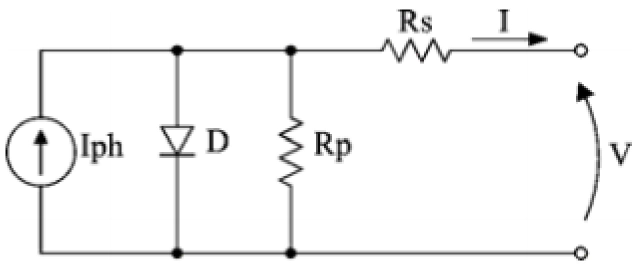


Figure 01– Electrical model of a solar panel.

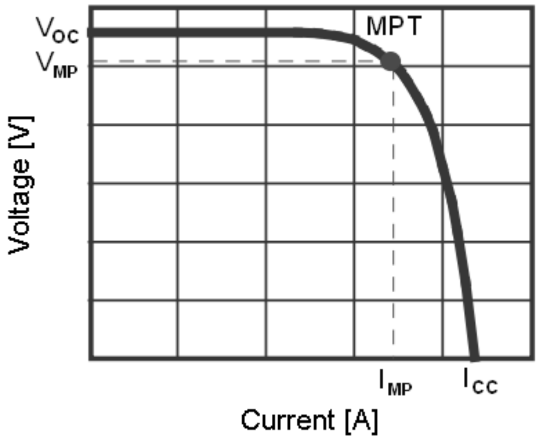
The analysis of this circuit results in equation (2) that represents the voltage-current behavior of an electrical panel.

$$I = I_{ph} - I_0\left[\exp\left(\frac{V + I \cdot R_s}{V_t}\right) - 1\right] - \frac{V + I \cdot R_s}{R_p} \tag{2}$$

However, the physical variables and I_{ph} I_o are not informed by the manufacturers, which normally provide the values of short-circuit current I_{sc}, the open circuit voltage V_{oc}. Neglecting the effect of the resistance in parallel and since the photocurrent and the short-circuit current are equal simplifies the equation resulting (3) [15].

$$I = I_{SC}\left[1 - \exp\left(\frac{V - V_{OC} + I \cdot R_s}{V_t}\right)\right] \tag{3}$$

The typical characteristic curves of a photovoltaic module are presented in Figure 02, for a determined solar irradiation and temperature. The power increases as the supplied current increases. This characteristic is maintained up to the point where the output voltage starts to decrease. This point is called the point of Maximum Power Transfer (MPP). From this point, the output power starts to decay until the next zero at short circuit condition. The maximum power point is not fixed. It varies with weather conditions such as the level of solar radiation and temperature of operation, and other factors such as partial shading of the panel.



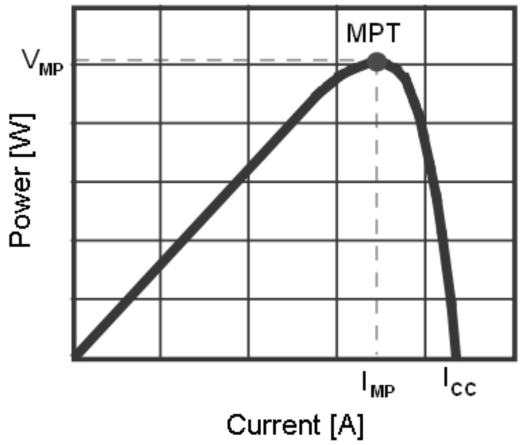


Figure 02. Characteristic curves of photovoltaic panels (voltage versus current and power versus current)

Where V_{oc} is the open circuit voltage, V_{mp} is the voltage at the point of maximum power, I_{mp} is the current at maximum power point, I_{sc} is the short circuit current and MPT indicates the point of maximum power transfer (Maximum Power Point transfer).

To obtain practical point of maximum power transfer was used Ohm's law. Using the maximum values for voltage (V_{mp}) and current (I_{mp}), is obtained the value of the resistance which dissipate the most power for this panel. However, due to the intrinsic characteristics of the photovoltaic panel used (longstanding) this load value is different of theoretical and the point of maximum power transfer is obtained empirically, by adjusting the value of the load through variable resistance.

The cost of the system is still not cheap; studies appointing that for a residence with four residents, the total load average is 10238.5 Wh/day, which would require a generation by photovoltaic panels 4567.256 W and also an inverter compatible with this load [16]. Considering the use of panels MSX-70, for the hypothetical energy indicated it would take 24 panels, resulting in a total approximate cost of installing this system moving over R$ 64000,00, as detailed in Table 3.

Table 3 – Installation price mobile system (base 2011).

Item	Unit Price (R$)	Total (R$)
24 Panels MSX-70	711.44	1,7074.56
1 inverter 12 Vcc – 20000 W	25,000.00	25,000.00
24 Batteries 240 Ah	929.00	22,296.00
Step Motor - torque 24N	44.61	44.61
PIC 16F877A	15.00	15.00
Metal support	100.00	100.00
	Total:	64,530.17

Source: Adapted and supplemented from:: TEIXEIRA, A. A. et al. Analysis of feasibility for implementation of residential solar power system. [16].

3. AUTOMATION

In an attempt to achieve greater efficiency in the use of photovoltaic panels has been proposed an electronic circuit microcontroller that makes the orientation of the panel due to higher solar radiation. This circuit periodically compares the incidence of solar light at certain angles by light sensors of the type LDR coupled to the plate, moving it with the aid of a stepper motor to position the solar higher reception as shown in the simplified diagram of Figure 3.

From a prototype of this system was evaluated experimentally with periodic sampling voltage and current; also are used an oscilloscope where we evaluated the influence of slope on the formation of the characteristic curve of photovoltaic panel.

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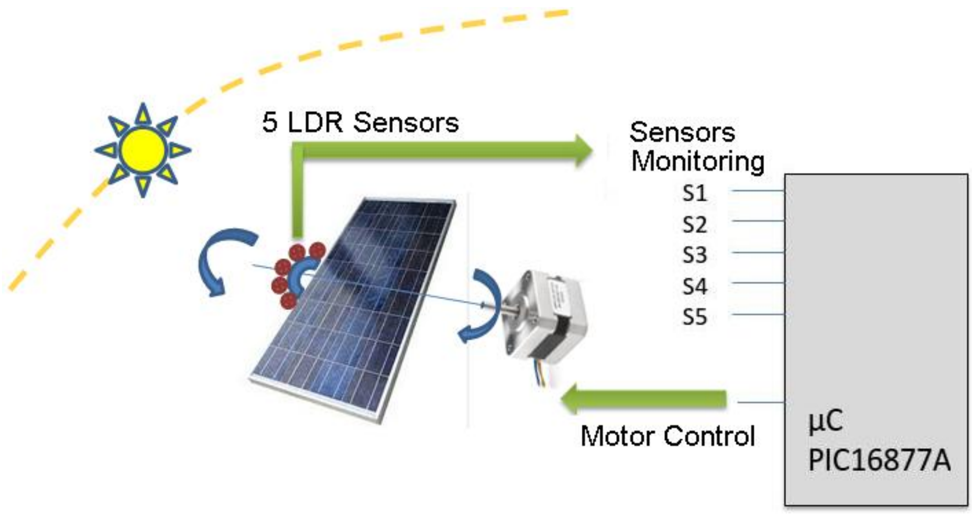

Figure 3. Simple diagram of operation of the automation system proposed.

The project establishes five angular positions of the solar panel, configurable for five equidistant LDR sensors, 30° apart. To control the position of the photovoltaic panel was used a PIC16F877A microcontroller which compares the analog voltage inputs provided by sensors and acts on the stepper motor. This microcontroller has 40 pins of which 33 are input or output ports. These, eight can be configured as analog inputs, which would allow expansion up to eight analog sensors position. This PIC was chosen because it is easily accessible in the market and have sufficient analog ports, and also present peripheral power control (PWM), and three timers and serial communication, A / D converters up to 10 bits available, among other peripherals [17]. A stepper motor of 39 mm with 28N of radial force and 10N of axial force moves the panel [18]. Using the maximum torque, it uses a voltage of 12 V and a current of 0.3A.

Periodically, the microcontroller conducted a sweep of voltages provided by five LDR sensors. The microcontroller converts the five analog signals into digital signals s of 10 bits resolution, then comparing them. The LDR sensor that is receiving more light than others has a lowest value in digital microcontroller, which indicates whether or not the displacement of the panel. Once the microcontroller checks a sensor that has a lower voltage than the others do, it operates the motor and moves the panel to the position referenced by the sensor. This routine is performed every time from a minimum amount of solar radiation. At intervals, the microcontroller is put into sleep mode (sleep) that keeps only its basic functions, aiming at energy saving. Figure 4 presents a simplified flowchart depicting the routine for tracking the sun, where S1, S2, S3, S4 and S5 represent the five LDR sensors.

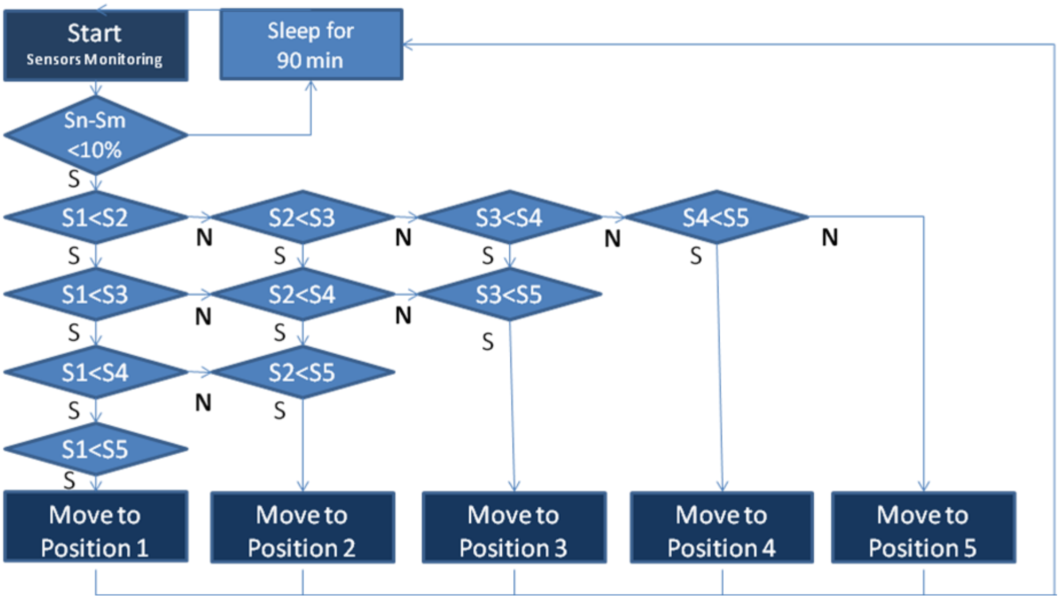

Fig.4 – Flowchart comparing sensors, where S_n are the n LDR sensors.

Figure 5 shows the electronic circuit of the control system proposed positioning of the Photovoltaic panel. On the left side are the five LDR sensors, the microcontroller PIC16F877A the center and the right side are the transistors Q1, Q2, Q3 and Q4 power of the stepper motor M1.

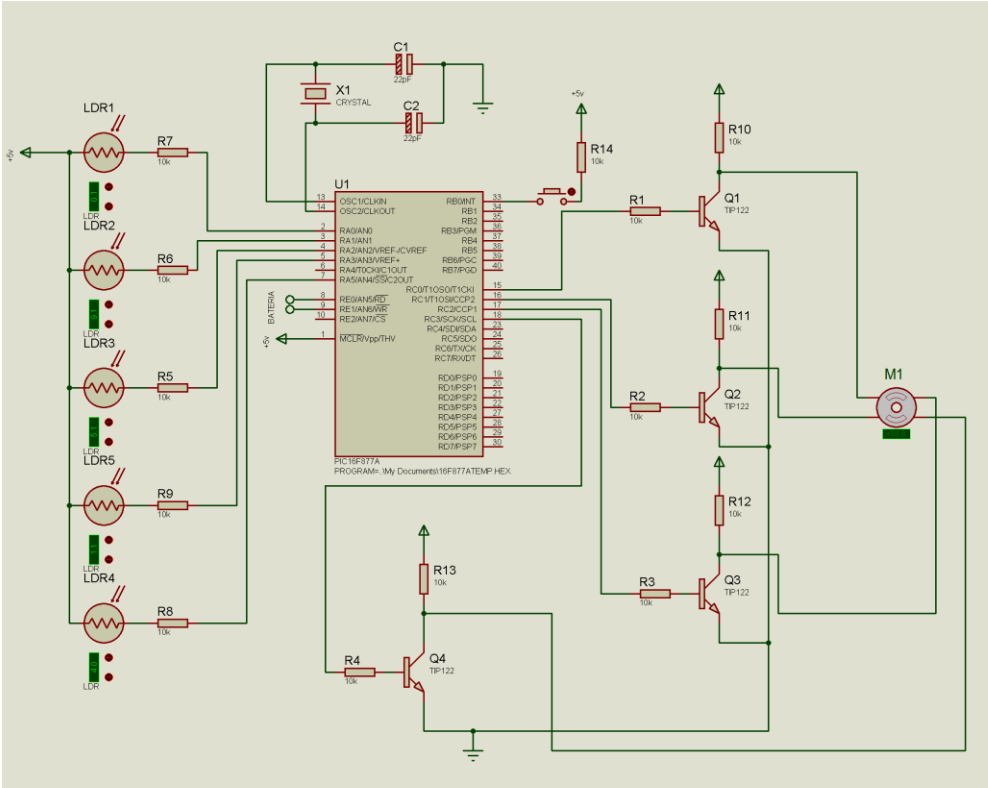

Figure 5 – Circuit electronic control sensors and stepper motor.

4. EXPERIMENTAL ANALYSIS

We used three experimental panoramas function of fixing the photovoltaic panel for comparative analysis.

The first case consisted of a panel that was installed on a roof sloped at 30° from a block of UTFPR campus Ponta Grossa – Paraná (25°03'06" S - 50°07'52" W) built the face southwest, considering this a residential common, which often uses the tilt and orientation of the existing roof, without modification, to secure more easily photovoltaics.

The second case uses a panel installed according to manufacturer's guidelines, which recommends 15 ° to the path of the sun and tilted 45 ° from the floor.

The third case was based on a panel installed at 15 degrees from the sun way, secured in a structure, which enables automatic movement of the panel relative to the support shaft by changing its shape according to the intensity of the sun. Five are possible inclination (30 °, 60 °, 90 °, 120 ° and 150 ° relative to the horizontal axis - soil) seeking the highest power transfer to the load.

For all three cases measurements were performed with a time interval of one hour during the 10 hours up to 17 hours in the spring site.

The impedance would allow maximum transfer of power was analyzed. According to manufacturer's recommended impedance is obtained by the ratio of the open circuit voltage and short circuit current of the photovoltaic panel, this panel to which the value is 3.8 Ω. However, due to inherent characteristics of the semiconductor material, over time the efficiency of these panels is changed. Thus, by using a variable resistor of 10Ω - 100W, which has been empirically determined to be greater load impedance for power transfer, who is obtained value of 3.3 Ω .This charge is employed for the three experimental cases.

Figure 6 shows the behavior of the product of open circuit voltage (V_{oc}) and short circuit current (I_{sc}) versus time for the three cases in question. It is found that the power transferred to the load on a roof with random characteristics tend to have lower values when compared with the characteristics of inclination directed by the manufacturer. However, it can be seen that the deployment direction of the panel involves a greater than 10W at different times for better guidance of the fixed panel, which occurred in the experiments, to 14h.

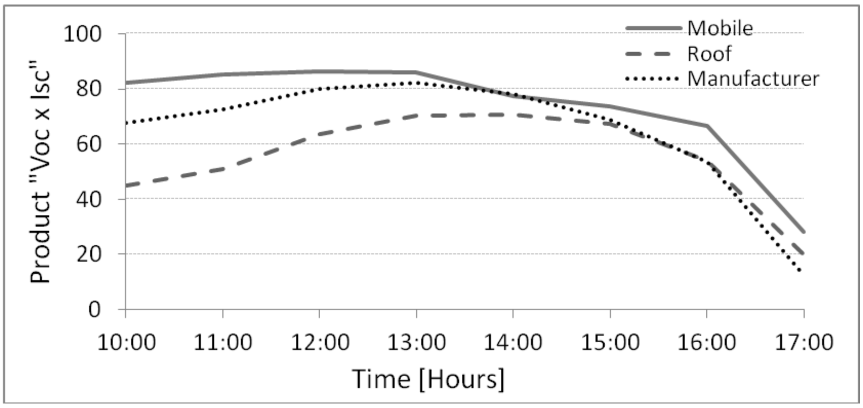

Figure 6 – Variation of product "V_{oc} x I_{sc}" versus time.

Figure 7 shows the behavior of the power as a function of applied load of 3.3 Ω as a function of time for three types of installation.

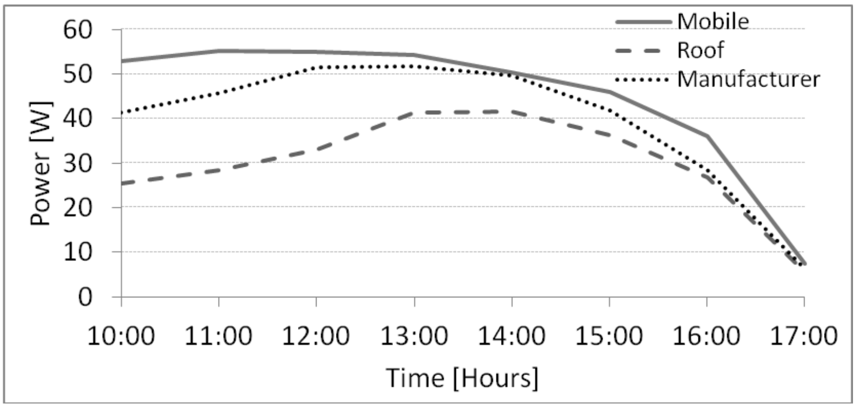

Figure 7 - Power versus time.

The Figure 6, as in Figure 5, shows a coincidence of the maximum power transferred to the load 14h for the case of installation in accordance with guidelines of the manufacturer and the case of mobile installation and power increase are more evident in the hours before. As seen in the case of roof random, it has less efficiency.

Figure 8 shows the percentage of power attained in relation to the theoretical maximum power of 70.1 W, analyzing it is evident that the movable panel has much better performance than the others presented.

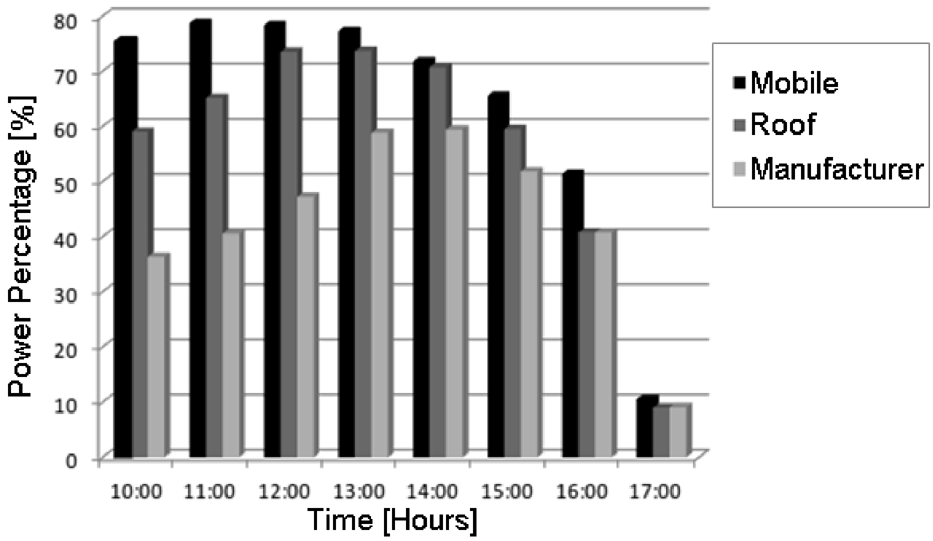

Figure. 8 – Percentage of dissipated power in relation to the maximum for the three experimental cases.

Considering the amount of solar irradiation used as a reference in typical winter day approximately 350 W/m^2 for the region of Ponta Grossa (Prates, 2012), we calculated the conversion efficiencies of the panel considering the experimental results. Table 4 presents the efficiency values for the three comparative overviews of panel installation, obtained at 13h.

Table 4 – Conversion efficiency (%)

Installation Type	**Theoretical Efficiency (%)**
Mobile (Automated)	22,09
Fixed as suggested by the manufacturer	20,67
Arbitrary fixed roof	16,57

Figure 9 shows how the movable panel is more efficient in relation to the roof and directed by the manufacturer in terms of percentage. The solid line shows that the movable panel can be up to 110% more effective than a fixed system on a rooftop while the dotted line shows that the panel can be up to 27% more effective than when installed according to manufacturer's recommendations (in the early hours day).

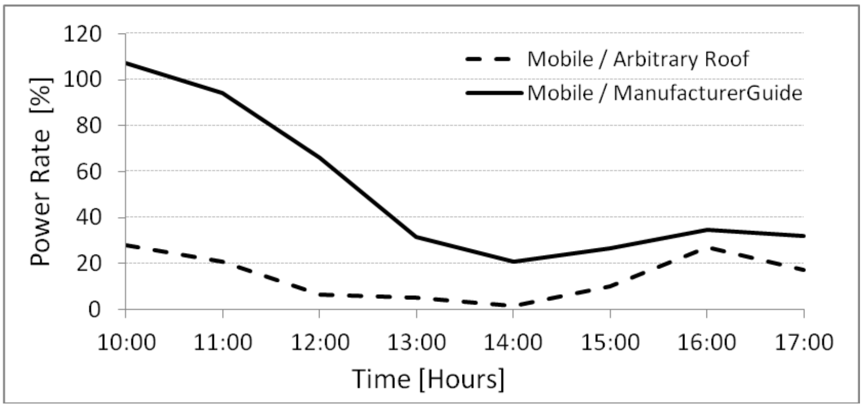

Figure 9 – Percentage power panel movable relative to the other methods.

It is noticed that the movable panel scores a performance during the day 14.5% higher than the panel mounted according to the manufacturer, and 51.4% better than the one installed on the roof.

5. CONCLUSIONS

The use of photovoltaic panels is still a little energy solution used in Brazil (around 1%), which is a form of clean energy that is spreading, especially for small residential applications. Considering this, we proposed an electro-mechanical technique that utilizes a resource handling of the panels due to the solar position. For such a circuit based on LDR sensor and a stepper motor controlled by a microcontroller PIC16F877A been proposed

This technique was isolated to analyze exclusively the efficiency as a function of the direction of the panel to the sun instead of electronic techniques more advanced maximum power point tracking (MPPT).

Three methods were suggested for obtaining comparative data yield. The first, a panel installed on a roof random; the second one, according to manufacturer's guidelines and, the last one, a mobile panel automated. The movable panel scores a performance during the day 14.5% higher than the panel mounted according to the manufacturer, and 51.4% better than the roof arbitrary, justifying the costs involved for the implementation of the proposal.

Once realized the efficiency of the method, it is suggested interlacing method electro-mechanical with electronic methods of maximum power transfer tracker in order to reduce the complexity of the latter, aided by solar orientation control. This technique was isolated to analyze exclusively the efficiency as a function of the direction of the panel to the sun instead of electronic techniques more advanced techniques of MPPT.

Were suggested three methods for obtaining comparative data yield. A panel installed on a roof random one according to manufacturer's guidelines and a third, mobile, automated proposed by us. The movable panel scores a performance during the day 14.5% higher than the panel mounted according to the manufacturer, and 51.4%

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Once realized the efficiency of the method, it is suggested interlacing method electro-mechanical with electronic methods of search MPPT in order to reduce the complexity of the latter, aided by solar orientation control.

This study also aimed to collect data on the behavior of solar panels as a function of position, for further improvement proposal in equations describing their behavior, since the same, in general, do not consider in their design data such as slope , partial shading, air column (geographic location), these data efficiency data considered for the installation of solar panels.

It s also the electro-mechanical technical proposal, may have great immediate interest to improve efficiency in small installations, which typically has been applied for residential purposes with specific goals, such as the maintenance of closed circuits, water heating and/or charging battery banks of small, but can be a solution for more isolated rural areas, for irradiation systems or signaling.

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