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DEVELOPMENT OF A SUN-TRACKER

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DEVELOPMENT OF A SUN-TRACKER

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Final paper presented to the Department of Electrical Engineering of the Center for Science and Technology, Federal University of Viçosa, for crediting the discipline ELT 490 - Monograph and Seminary and partial fulfillment of the requirement for the degree of Bachelor in Electrical Engineering.
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"To my dear family Dida, Zene and Sâmia"

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“The good idea is not discovered or undiscovered, it comes, it happens.”
Johan Galtung

Abstract

The power generated by a solar panel is directly related to the level of solar radiation falling on it. The most advanced solar panels convert 20% to 25% of irradiance energy, besides, a steady panel has a decrease in its production and in certain moments of the day it doesn't produce. Therefore, it is necessary get more radiation to increase the generated power by the panel and a system able to follow the sun's movement could improve efficiency in this point. But the cost is an important variable to consider due to the enhancement of the final system This paper presents a study and construction of a prototype for solar tracking during the day in order to increase the power generated by the panel. The main objectives were to build a simplified, robust and low cost of production and marketing potential on a large scale. The tests showed an increase of 12 % to 18 % of the energy produced.

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SUMMARY

1. Introduction and Objective

The increase in energy demand together with the appeal for the use of less polluting sources lead research centers to seek new forms of energy production. One is the photovoltaic solar energy which appears as very promising renewable resource, it depends on the sun that is an inexhaustible resource of light.

Solar energy reaches the Earth in the thermal and lighting forms. However, it does not reach uniformly throughout its surface. It depends on the latitude, the season and weather conditions such as cloudiness and relative humidity.

In this context it is necessary to increase the power generated by the solar panel. An alternative and low cost is the use of structures that follow the sun. Thus it is possible to vary the position of the solar panel during the day and to increase the intensity of received rays on its surface. This is an alternative for projects to supply isolated locations.

One strategy is to move the structure based on the movement of the sun during the day eliminating the use of sensors. In this case, variation of the sun angles during the day is evaluated.

In order to build the solar tracker it was necessary to evaluate the kind of material structure, a motor torque and ensures precision and control system effectively. In this study, a stepper motor controlled by a PIC microcontroller was used.

The main objective of this work is to study and build a low cost sun tracker and compare the power generated with a static panel.

The development of this work provided the following publication:

1. A Low-Cost Prototype for Sun Tracking. 10^{th} IEEE/IAS International Conference on Industry Applications, 2012, Fortaleza, Brazil.

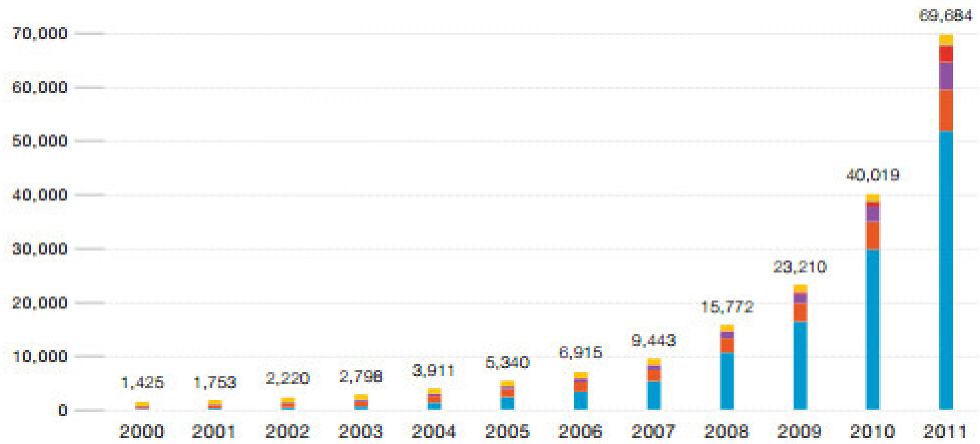
The organization of this work was done as follows: Literature Review (Chapter 2), Methodology (Chapter 3) Experimental results (Chapter 4) and Conclusion (Chapter 5).

2. Literature Review

2.1. Perspective of Solar Energy in the world

In the last years, PV technology has shown the potential to become a major source of power generation for the world with robust and continuous growth. PV is now, behind hydro and wind power, the third most important renewable energy in terms of globally installed capacity [1].

The growth rate of PV in 2011 reached almost 70% and it gained prominence among all renewable technologies. Europe still leads, with over 51 GW installed in 2011, as can be seen in Figure 1. Next in the ranking are Japan (5 GW) and the USA (4.4 GW), followed by China (3.1 GW) which reached its first GW in 2011 [1].



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
ROW	751	807	887	964	993	1,003	1,108	1,150	1,226	1,306	1,209	1,717
MEA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	21	205	336
China	19	30	45	55	64	68	80	100	145	373	893	3,093
America	146	177	222	287	379	496	645	856	1,205	1,744	2,820	5,053
APAC	355	491	677	902	1,178	1,475	1,797	2,080	2,643	3,409	5,116	7,769
Europe	154	248	389	590	1,297	2,299	3,285	5,257	10,554	16,357	29,777	51,716
Total	1,425	1,753	2,220	2,798	3,911	5,340	6,915	9,443	15,772	23,210	40,019	69,684

Figure 1 - Evolution of global cumulative installed capacity 2000-2011 (MW) [1].

In this area the development of Europe is rivaled only by the recent use of the market in Australia. The U.S. and Japan, although pioneers in the PV market, are years behind Europe. The expansion of PV has until now corresponded with economic development: after OECD countries (Europe, North America, Japan, Australia), it started to reach emerging countries. BRIC (Brazil, Russia, India, and China) have not all started to develop PV, but China and India will show the way to Brazil and possibly to Russia. The African continent is one of the last of the list of recent development, although there is some potential for short-term in South Africa [1].

2.2. Solar Energy in Brazil

As with the winds, Brazil is privileged in terms of solar radiation. The Northeast has radiation comparable to the best parts of the world as the city of Dongola, in the desert of Sudan and the region of Dagget, in the Mojave Desert, California. Figure 2 can be seen as solar radiation varies in Brazil [2].

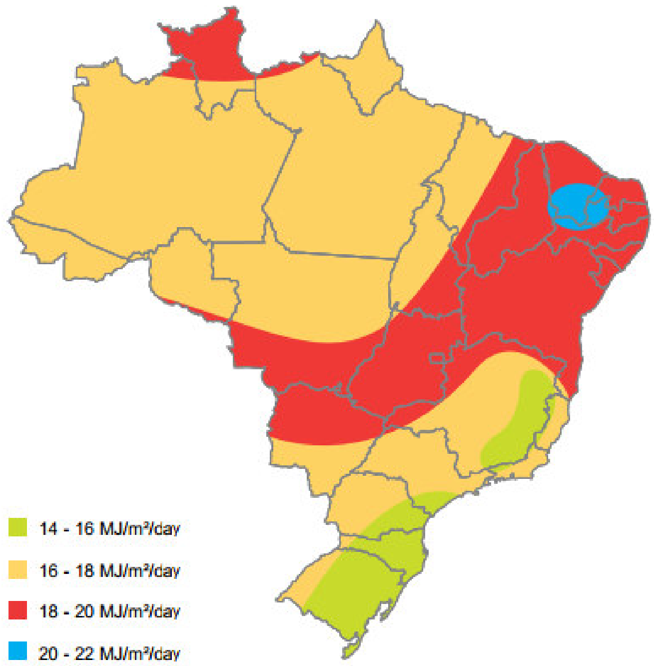


Figure 2 - Variation of solar radiation incidence in Brazil [2].

Currently, there are several projects using solar energy in Brazil, mainly for the attend isolated communities of energy networks and regional development. The main types of projects are: pumping water for domestic supply, irrigation and fish farming; lighting; institutional buildings, such as electrification of schools, health centers and community centers; dwellings [3].

The Brazilian National Electric Energy Agency was expected to introduce two regulations in 2012 designed to promote the deployment of solar power in Brazil. One of the regulations has introduced in April 2012 a net-metering system for micro generation up to 100 kW and for mini systems up to 1 MW. The other regulation should provide an 80% tax break to utilities companies that purchase electricity generated by large-scale solar parks (for systems up to 30 MW). The first 1 MW plant was commissioned in 2011 and could have been expanded if the regulation were consolidated. With a growing demand for electricity in the country and good incidence of radiation, the development of PV systems is simply a question of adequate regulation and awareness. The market can reach more than 1 GW by 2016 [1].

It can see that solar energy is not deeply explored in Brazil and according to [2] the total installed capacity in the country is still very small beside its potential. This is because to the country has enough water resources, resulting in investment in electricity generation from hydroelectric plants. But this concept is already changing mainly because the cost, time and environmental impacts on building hydroelectric power plants. And there are isolated places, far from the grid, where the photovoltaic generation becomes viable, since it does not require the implementation of transmission lines to reach these communities.

2.3. Types of PV Systems

Photovoltaic systems can be ranked into three main categories: isolated, grid connected or hybrid. Each one may have different complexity depending on the application and the specific constraints of each project.

The isolated systems are typically used in regions where the grid is not accessible. They may not use or storage of energy through batteries, feeding a DC load or AC load using an inverter [4].

In grid connect the PV array represents an additional source for a large electrical system to which it is connected. Usually, it does not use energy storage, because all the power generated is delivered to the network instantly. Installations of this type are becoming increasingly popular in many European countries, Japan, USA and more recently in Brazil. The powers range from a few kWp installed in residential facilities, until a few MWp in systems operated by large companies [4].

Hybrid systems are those where more than one way of generating energy is available, for example diesel generator, wind turbines and photovoltaic modules. These are more complex and require a type of control can integrate the various generators optimizing the operation to the user [4].

2.4. Static Converters

The output voltage generated in the panels is still, depending on the application, is required to regulate the inverter output voltage. To achieve it, it can be used DC-DC converters buck or boost. DC-DC converters are used for transferring electrical energy from a

DC source into another DC source. These converters are widely used in regulated switching power supplies and DC motor drive applications. The method used to control the output voltage is called a pulse width modulation (PWM) and changes the duty cycle D which is the ratio between the on-time key and the total period (TON + TOF) as can be seen in Figure 3 [5].

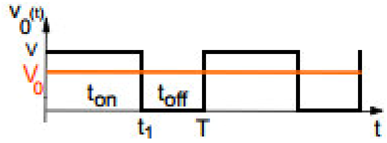


Figure 3 – Pulse width modulation [5].

The Buck converter regulates average output voltage to lower value than the input. This is possible through the controlled switching means of an IGBT, in which the DC input voltage is periodically switched on and off, resulting in a lower average output voltage [5].

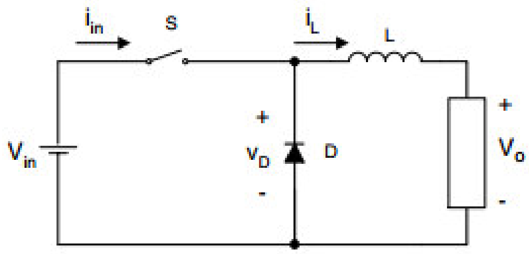


Figure 4 – Buck converter [5].

The Boost converter regulates the average output voltage to a level higher than the input voltage. The input voltage is in series with a large inductor which acts as a current source. The key in parallel with the current source and the output is turned off periodically, providing power supply and the inductor to increase the average output voltage [5].

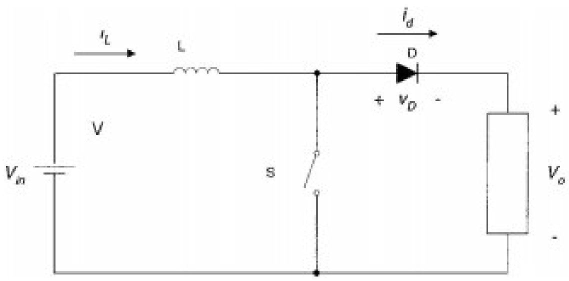


Figure 5 - Boost converter [5].

2.5. Sun Tracking

The earth revolves around the sun in an elliptical orbit with the sun as one of the focus. The relative position of the sun and earth is conveniently represented by means of the celestial sphere around the earth. The equatorial plane intersects the celestial sphere in the celestial equator, and the polar axis in the celestial poles. The earth motion round the sun is then pictured by apparent motion of the sun in the elliptic which is tilted at 23.458 from the celestial equator [6].

The regions that receive more solar radiation located between the Tropics are: Cancer in the northern hemisphere and Capricorn in the southern hemisphere. The solar radiation reaching the Earth's atmosphere is divided into direct and diffuse. The direct radiation is the portion that goes directly to the earth. The diffuse radiation is the part that suffers a scattering by clouds and particles in the atmosphere. A cloudy sky may have a greater proportion of diffuse radiation to direct, while the clear sky, no clouds, presents a greater of direct radiation [7].

Another point to be analyzed is the location of the sun at any time of day that can be described in terms of its altitude angle β and its azimuth angle $\emptyset_S$ as showns in Figure 6.

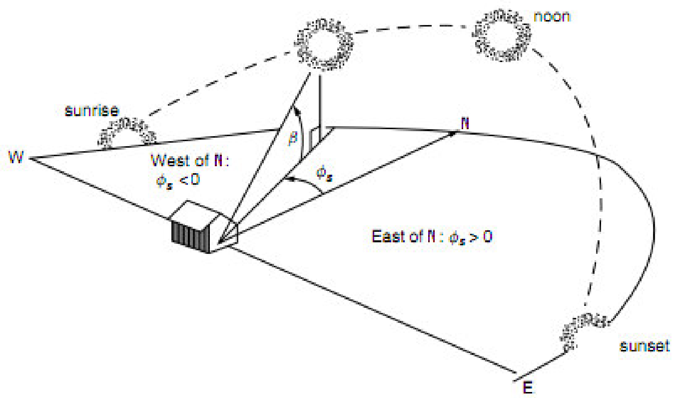


Figure 6 – The sun's position can be described by its altitude angle β and its azimuth angle $\emptyset_S$ [8].

The solar altitude angle (β) is defined as the vertical angle between the projection of sun's rays on the horizontal plane and direction of sun's rays passing through the point [6].

Solar azimuth angle ($\emptyset_S$) is the horizontal angle measured from North (in the southern hemisphere) to the horizontal projection of the sun's rays [6].

The performance of a photovoltaic solar system is mostly dependent on climatic conditions [9]. The incident solar radiation and temperature are factors that significantly contribute to its power generated [10].

The action of shading decreases the incident radiation on a solar panel. This provides a significant decrease in power output and affects the supply at the load. These shadings can be caused by clouds, poles, trees and even a panel in front of the other panel, depending on the position of the sun [11].

In many situations, it is useful to know how to estimate where in the sky the sun will be at any time, at any location on any day of the year. In the case of solar energy, it is possible to use the knowledge about sun angles to choose the best angle of inclination to position the solar modules in order to capture the greatest insolation [8].

Figure 7 shows a south facing collector on the earth's surface that has atilt at an angle L, equal to the local latitude. This tilt angle provides that the collector is parallel to the axis of the earth. During an equinox, at solar noon, when the sun is directly over the local meridian, the sun's rays will focus the collector at the best possible angle, in other words, they are perpendicular to the collector face. At other times of the year the sun is a little high or a little low for normal incidence, but on the average it is a good tilt angle [8].

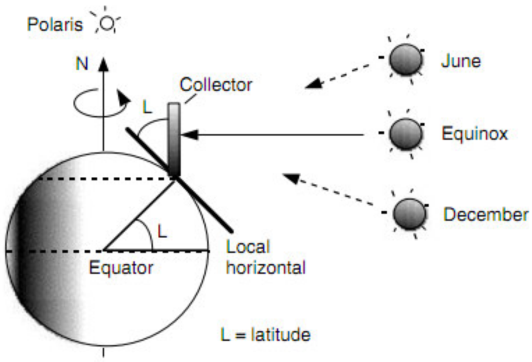


Figure 7 –A south-facing collector tipped up to an angle equal to its latitude angle [8].

More energy is collected by the end of the day if the PV module is installed on a tracker, with an actuator that follows the sun like a sunflower. The first tracker introduced by Finster in 1962, was completely mechanical. One year later, Saavedra presented a mechanism with an automatic electronic control, which was used to orient an Eppley pyrheliometer [6]. A sun tracking design can increase the energy yield up to 40 percent over the year compared to the fixed-array design. There are two types of sun trackers: one-axis tracker and two-axis tracker [12].

One-axis tracker, which follows the sun from east to west during the day, tracking the changes in azimuth angle [12]. Figure 8 shows part of the one-axis sun tracker where the tilt regulation is made and Figure 9 shows a model of sun tracker.

Figure 8 - Parts of one-axis sun tracker [12].

Figure 9 - One-axis sun tracker [13].

Two-axis tracker tracks the sun from East to West during the day, and from north to south during the seasons of the year. Figure 10 and Figure 11 show an example of two-axis tracker and Figure 12 shows parts of two-axis sun tracker. The dual-axis tracking is done by two linear actuator motors [12].

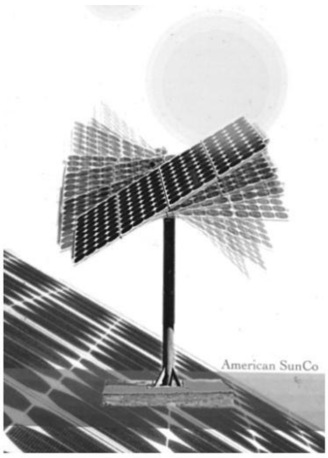


Figure 10 - Two-axis sun tracker [12].

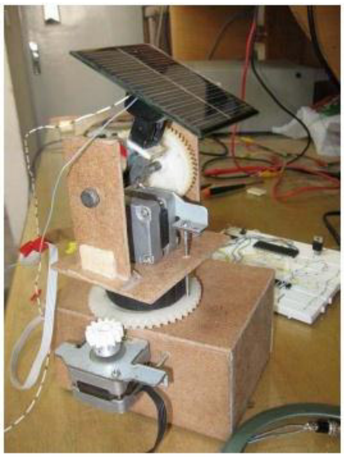


Figure 11 - Sample two-axis sun tracker [14].

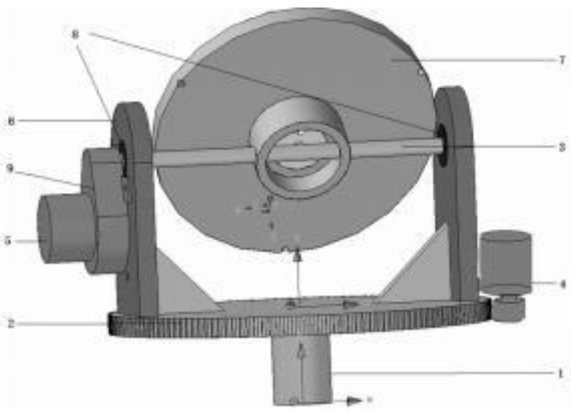


Figure 12 – Parts of two-axis sun tracker [15].

In [16] are compared results of a water pumping system driven by static, tracking and tracking with concentration PVs in Recife (PE-Brazil) for one day. The PV generator consists of four cavities and two PV modules tracking along its North–South axis, tilted at an angle of 20° towards the north. The advantage in terms of solar radiation, for tracking collectors is equal to 1.23 and for concentrating collectors, is equal to 1.74. Those values for water volume are 1.41 and 2.49 respectively.

Tomson compare the performance of PV modules with daily two-positional tracking. The symmetrical and asymmetrical positions about the North–South axis are analyzed, corresponding to the positions of sun in the morning and in the afternoon. According to this, the effect of different tilt angles, initial tilt angle, initial azimuth, and azimuth angle of the deflected plane on the daily and seasonal gain were evaluated. Results show that energy was increase by 10–20% over the yield from a fixed south-facing collector tilted at an optimal angle [17].

Michaelides studied the thermal performance and effective cost of thermosyphon solar water heaters with different solar collector tracking modes under the weather and socioeconomic conditions of Nicosia (Cyprus) and Athens (Greece). He compare the system using the TRNSYS simulation program in four ways: fixed at 40° from the horizontal, the single-axis tracking with vertical axis, fixed slope and variable azimuth and the seasonal tracking mode where the collector slope is changed twice per year. The simulation results showed that the best thermal performance was obtained with the single-axis tracking. In Nicosia, the annual solar radiation with this mode was 87.6% compared to 81.6% with the seasonal mode and to 79.7% with the fixed surface mode, while the corresponding figures for Athens were 81.4%, 76.2% and 74.4%, respectively. From the economic point of view, the fixed surface mode was found to be the most cost effective [18].

Farzin show in [14] a sample biaxial sun tracker with three algorithms of control from step motors. The first algorithm proposes moving the structure in circular coordinates in the small ranges and finding the point with the best voltage. The second algorithm finds the tilt of the voltage and use it to find its way. Third algorithm is similar to second but use it to find some appropriate points that are distinctly in different times.

Chen compares the solar irradiation for fixed bracket and uniaxial automatic solar tracking. The system was produced by Kunming green electrical science and technology Ltd, its name is Rack Sun. There were made three days of test with good weather conditions to show that the system proposed can improve electricity quantity of solar PV system to 25~28% [19].

Ponniran designed the single axis sun tracking system for residential usage and compared it to static solar panel. It was used the microcontroller PIC16F877A and the control is based in signals from the two different Light Dependent Resistor (LDR). The results show that the system allows a considerable gain of energy during the day mainly in the morning [20].

3. Metodology

The purpose of this study was to build a solar tracker easily controlled, low cost, capable of tracking the sun and increase the power available in the system. Based on this, it was decided to study how the sun focus on the earth during each month of the year. Build a simple prototype with resistant materials able to give support to the solar panel. In the end it was define the drive and the control strategy based on studies of movement of the sun.

3.1. Study of the Sun

The main objective was to interpret the variations of the azimuth and altitude angle during the day. It was used the software Satellite Antenna Alignment that provides the value of altitude and azimuth every minute. The data plots of the sun per month were constructed using the information for the city of Viçosa-MG. Figure 13 shows the solar altitude and azimuth angles for -20° 45’ latitude and which helped to build an intuition into where the sun is at any time.

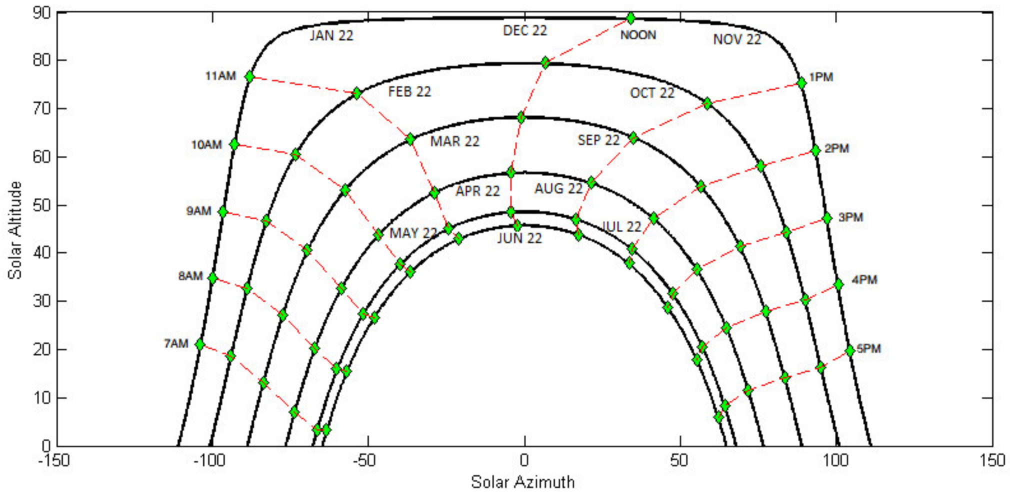


Figure 13 - Variation of solar angles during the year for Viçosa-MG.

Since the behavior of the sun is well defined throughout the year, it is possible through preliminary studies define the positions of the sun throughout the year, which is the technique used in this work. Can be seen in Figure 13 that the azimuth angle has larger variation between 11:00 and 13:00 hours, mainly in the summer season.

The months with the highest incidence of rays are November, December and January. However, in this period there is a great could concentration in the atmosphere, resulting in a diffuse radiation component greater than direct radiation.

3.2. Building the prototype

The initial idea was to build a simple prototype using a few resistant materials. So, it was decided that a first design would be built with one-axis sun tracker. But the structure was designed with a manual inclination.

The base was made of iron because it is heavier and helps lifting. Next, a bearing for the motor force was added, which required to move the structure. Just above the bearing, a gear similar to the ones found in a washing machine was installed as seen in Figure 14. This gear is connected to the motor through a smaller attached to a belt. The rest of structure was made of aluminum, lightweight and sturdy material able to withstand the solar panel and to suffer less damage over time. Figure 15 shows the location of the inclination adjustment which is made manually and the Figure 16 the complete structure fixed to a wood support by means of screws.

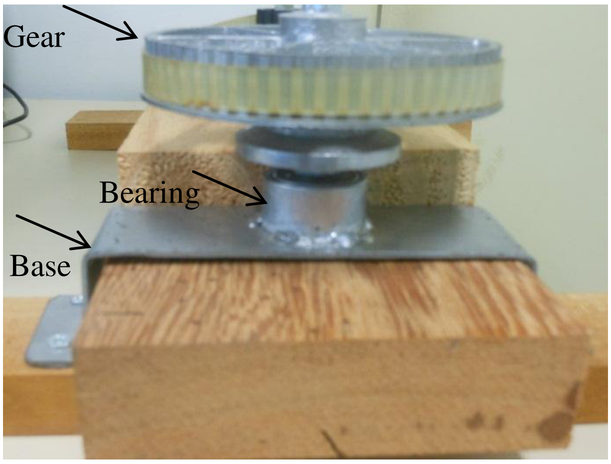


Figure 14 – Parts of prototype.

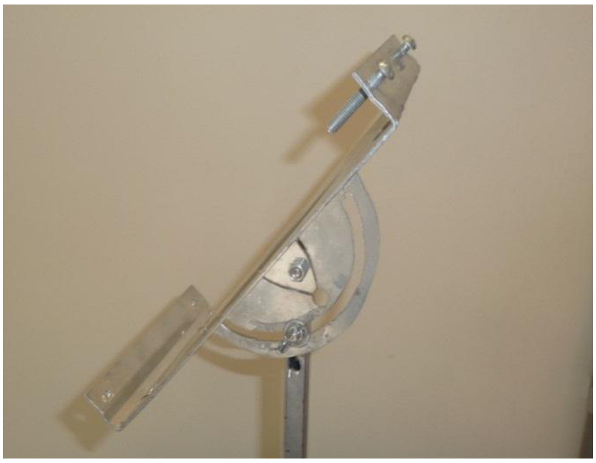


Figure 15 - Tilt adjustment.

Figure 16 – Prototype with the motor and fixed on wood support.

3.3. Motor

It was used a step motor instead of other motors because it needs a stable torque to keep fixed the prototype when there is no voltage supply. It is accurate and it moves with well-defined angles, besides it can be used in open loop control position. It helps in the control and positioning of the panel because it gradually moves during the day.

The step motor and gear used are shown in Figure 17. There are two connectors per phase and none are in common. The supply voltage is 12V, the resistance of each coil is 36 ohms and the step angle is 15°.

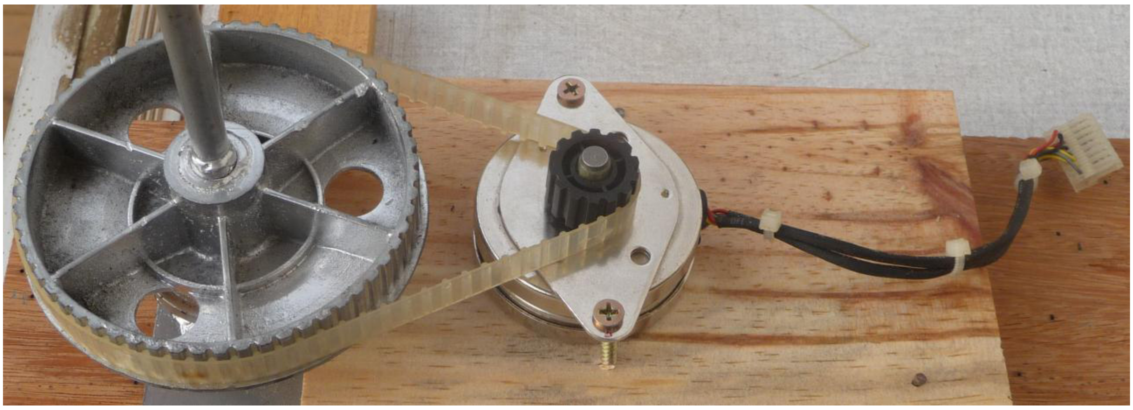


Figure 17 – Motor and gear system.

3.4. Drive and control strategy

A Microchip PIC 16F877 was used to control the solar tracker. A Integrated Circuit (IC) ULN2004 was used to drain the current required for operation of the engine and a LCD display shows the timing. The control system is based on time of day, in each hour the prototype movement 15°.

3.4.1. Drive control

The control system and the drive are shown in simplified form in Figure 18. In the PIC 16F877 is stored all the information and adjustment commands.

The IC ULN2004 is a set of Darlington transistors which allows a gain of the current signal sent by the microcontroller. Each coil of the stepper motor has two connections. The first one is connected to 12V and the other one another to IC output. Its control circuit is shown in Figure 19. To protect the drive circuit was built a box as shown in Figure 20.

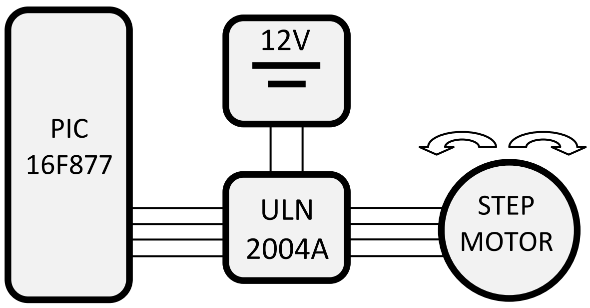


Figure 18 – Drive control.

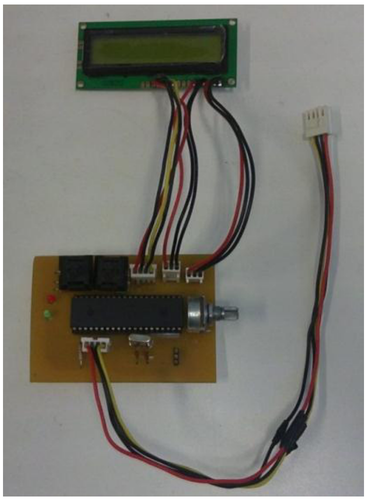


Figure 19 – Built control circuit.

Figure 20 – Box built.

3.4.2. Control strategy

Once the system is started a welcome message request that the timer is set, Figure 21. There is a button for set each minute and another for set each hour. When adjusted, the clock operates normally and it is displayed on a 16x2 LCD display, Figure 22.

Figure 21 – Initial message.

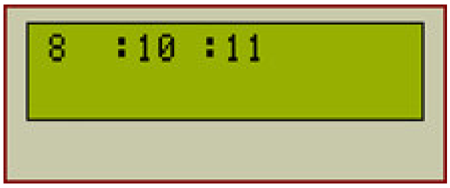


Figure 22 – Timer.

After set the clock the algorithm makes the decision according to time-of-day. The initial position is at 7 A.M. and the final position is at 6 P.M. Decisions are made as follows:

1- If the system is started between 7 A.M. and 6 P.M. the program calculates how much the engine must act. If it is at 7 A.M., the structure keep in original position, otherwise goes to the position corresponding to the time-of-day. Thereafter the panel begins to follow the sun moving 15° every hour.

2- At 6:10 P.M. the microcontroller sends a command to the engine to return the panel to the starting position.

3- If the clock is set to any range of different time from 7 A.M to 6 P.M the panel keeps in the initial position until 8 A.M when it moves for the first time.

3.5. System data acquisition

The Figure 23 show the acquisition system (SPIDER 8) used to allows measuring the current and voltage in the experiment. The Spider 8 is an electronic measuring system for PCs and is intended for measurement as voltage, power, pressure, acceleration and temperature. The equipment has eight analog channels for data acquisition, a printer port, a PC/Master connection, a socket with 25 pins (8 digital inputs and 8 digital inputs/outputs), a RS-232 port and a connection to external power [21].

To measure the current generated by solar panel it was used a Honeywell CSLA1CF current sensor, Figure 24. It is capable of measuring AC and DC current, it has a fast response time, wide current range for operation and voltage output [22]. Some specifications of this sensor are shown in Table 1.

Figure 23 – Data acquisition.

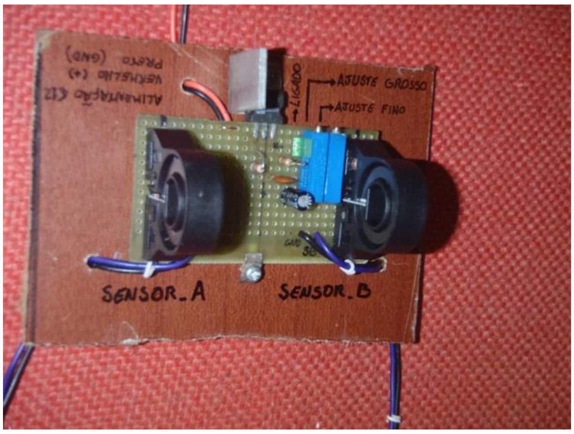


Figure 24 – Current sensor circuit.

Table 1 – Current Sensor Specifications [22]

Honeywell CSLA1CF	
Sensor Type	Open Loop Linear
Sensed Current Type	ac or dc
Sensed Current Range	0 A to 100 A
Output Type	Voltage
Sensitivity	29.7 mV N* ± 2.7 @ 12 Vdc
Supply Current	19 mA max.
Offset Voltage	Vcc/2 ± 10 %
Supply Voltage	8.0 Vdc to 16.0 Vdc
Response Time	3 µs
Operating Temperature Range	-25 °C to 85 °C [-13 °F to 185 °F]
Storage Temperature Range	-40 °C to 100°C [-40 °F to 212 °F]
Pinout Style	3 pin

3.6. Complete system

For analysis of the prototype constructed were used two panels, 5 watts each. First, it was tested whether the panels would generate the same amount of energy by placing them alongside in the same conditions of radiation, Figure 25. In another test they were placed in the same direction at an inclination of 25°, Figure 26.

Figure 25 – Panels under the same conditions.

Figure 26 – Panels with same tilt.

Before to start the collection data, the fixed panel was set to inclination of 25° towards the geographical north and the other one was put in the prototype with the same tilt. The panels with the data acquisition system are represented in simplified form in Figure 27.

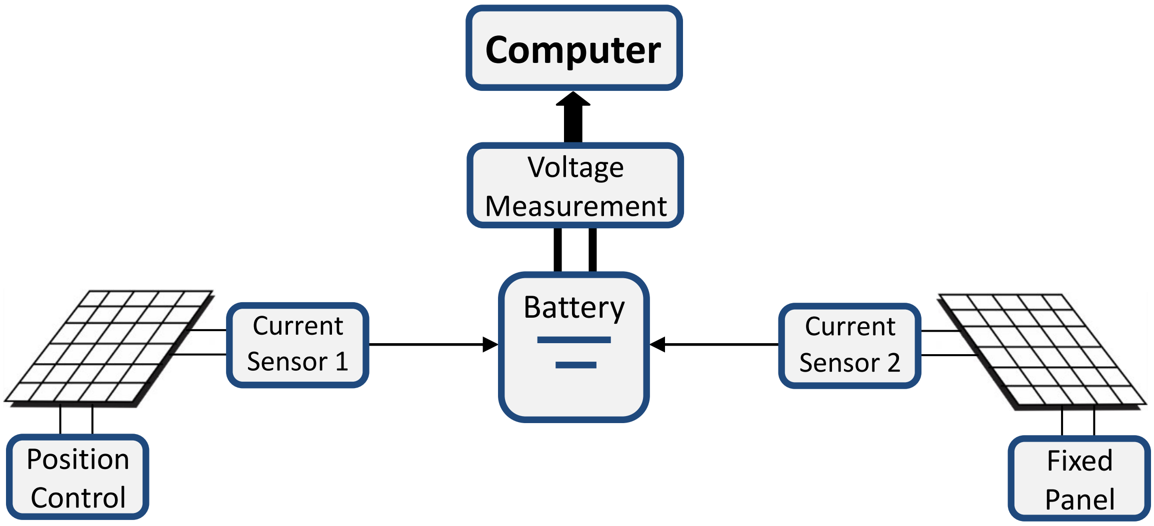


Figure 27 – Build System.

The panels are connected in series with current sensors and then connect to a 12V battery. The battery receives all generated energy in the process and a voltage divisor circuit, connected in parallel, measures the voltage sending to the data acquisition system. The characteristics of the solar panel used are shown in Table 2.

Table 2 – Panel Technical Features

Kyocera Multicrystal Photovoltaic Module – KS5	
Maximum Power	5 Watts
Maximum Power Voltage	16.9 Volts

Maximum Power Current	0.29 Amps
Open Circuit Voltage	21.5 Volts
Open Circuit Current	0.31 Amps
Type	Multicrystalline
Dimension (cm)	20.5 x 35.2 x 2.2
Area (cm²)	580.8
Weight (kg)	1.2

In the next chapter will be present the results for the calibration of the panel and a day of tests to compare the fixed panel with another sun tracking. In the appendix will be show the invalidated results with errors that not are do during the test.

3.7. Weather conditions

The collected data for comparison between the fixed panel and tracking system were made on days 20, 21 and 22 August 2012. In this period of the year it is winter in Brazil. The sun rises around 6:20 A.M. and sets around 5:40 P.M. Table 3 shows the weather conditions for the test days.

Table 3 – Experimental conditions

Day	Temperature	Weather
August 20, 2012	24°C	partly cloudy
August 21, 2012	21°C	cloudy
August 22, 2012	25°C	sunny

4. Results

As mentioned in the methodology, for the validation of the electrical characteristics of the two panels used under the same irradiation conditions can be seen the graph in Figure 28. It is possible to observe that the panels have the same power output. Therefore, the differences observed are due to the solar tracker.

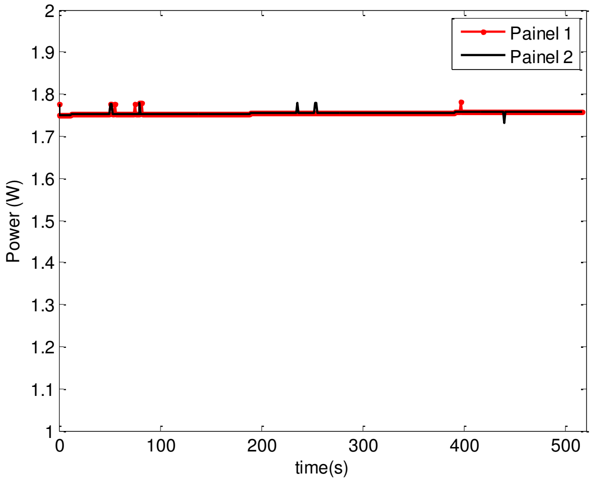


Figure 28 – Panel in same conditions.

Now analyzing the system with a stationary panel and the proposed follower it can see in Figure 29 and Figure 30 the battery voltage, current and power generated in the panels on the 20th of August. It can be seen that the tracing system is capable of increasing the energy produced during the morning and afternoon, since the stationary panel was positioned to take maximum of radiation in midday.

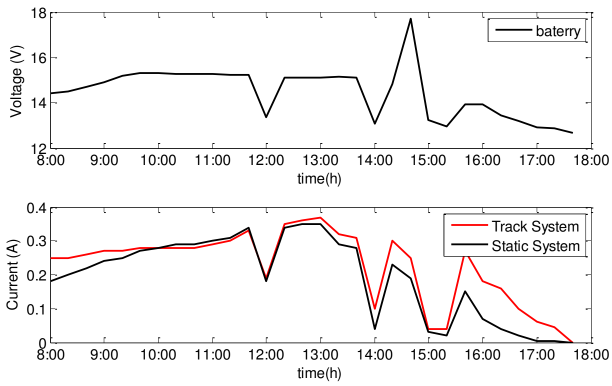


Figure 29 – Voltage and current in August 20.

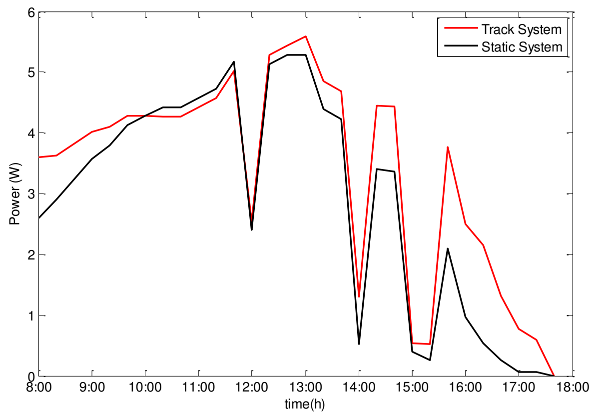


Figure 30 – Power Track x Static System in August 20.

A second test was performed for a cloudy day, since under these conditions the system efficiency drops dramatically. Figure 31 and Figure 32 show the results for August 21. Despite being a cloudy day the proposed system was able to increase the energy produced.

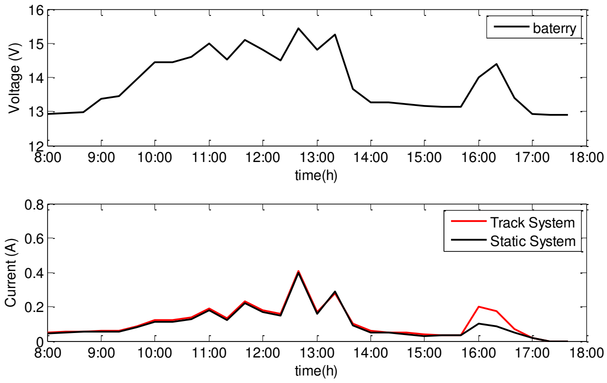


Figure 31 – Voltage and current in August 21.

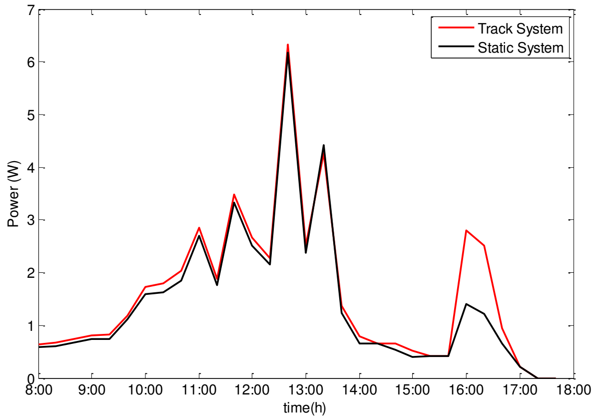


Figure 32 – Power Track x Static System in August 21.

A third test for a day with few clouds was done in August 22. Figure 33 and Figure 34 show the results where similar characteristics, such as increased power in the morning and afternoon, were observed.

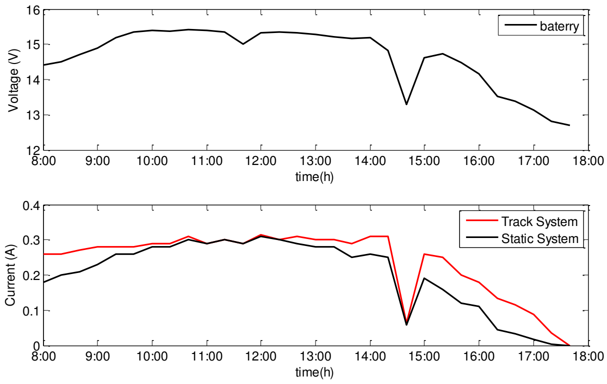


Figure 33 – Voltage and current in August 22.

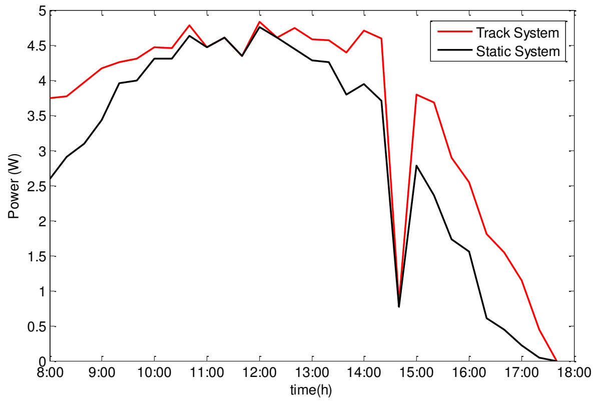


Figure 34 – Power Track x Static System in August 22.

Table 4 shows the result of average power during one day of measurement. Even on a cloudy day the tracking system showed a power increase of 12.67% compared to the stationary model. The best yield was obtained on the third day of testing, close to 18%.

Table 4 – Average Power During conditions

Day	Average power of Static System (Watts)	Average power of Track System (Watts)	Percent gain (%)
August 20, 2012	2.88	3.36	16.67
August 21, 2012	1.42	1.60	12.67
August 22, 2012	3.03	3.57	17.82

To analyze the gain in efficiency over days a comparative analysis was performed. Figure 35, Figure 36 and Figure 37 show the results power gain percentage in comparison to the panel nominal power for August 20th, August 21st and August 22nd, respectively.

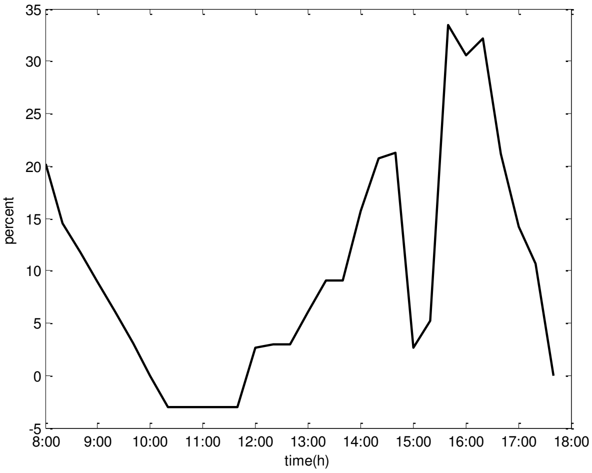


Figure 35 – Power gain percentage in comparison to the panel nominal power for August 20th.

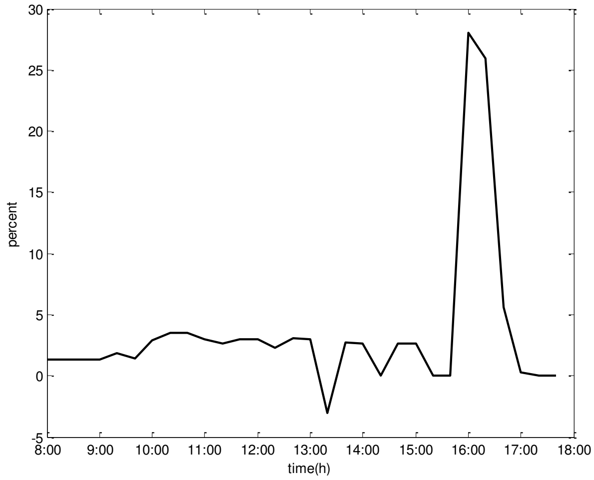


Figure 36 – Power gain percentage in comparison to the panel nominal power for August 21st.

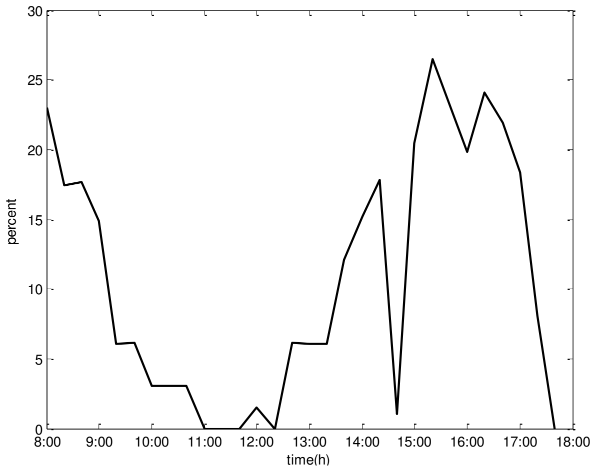


Figure 37 – Power gain percentage in comparison to the panel nominal power for August 22nd.

It was possible to see that largest increases in yield occur in the morning and afternoon, when the stationary panel is no longer in its optimal position relative to the sun. The construction’s price of the structure was approximately $20.00 and the drivers and components $10.00.

5. Conclusion

This work shows the design, construction and validation of a one-axis Sun tracker. The focus of the study was to develop a differentiated product of low cost, robust, able of tracking the sun during the day and in the future could be easily earn different dimensions. These characteristics provide conditions for it to be used in different types of environments and applications.

The main difference of this work is the non-use of sensor. The use of this enhances the equipment cost, in addition to increasing vulnerability due to some defect. Since the behavior of the sun is well defined throughout the year, it is possible through preliminary studies define the positions of the sun throughout the year, which is the technique used in this work. In turn, the results showed that the model is effective even on a cloudy day of winter and the best result was close to 18% on a sunny day.

More studies are needed mainly for large-scale construction.

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Appendix A

The appendix A shows the invalidated results with errors that happened during the tests. Figure 38 shows the power generated in the panels in July 29. It seen that the tracking system is capable of increasing the energy produced during all the day but, close to noon the power should be equal for both panels, despite being in the same position. The powers were different because the panels were not in the same inclination.

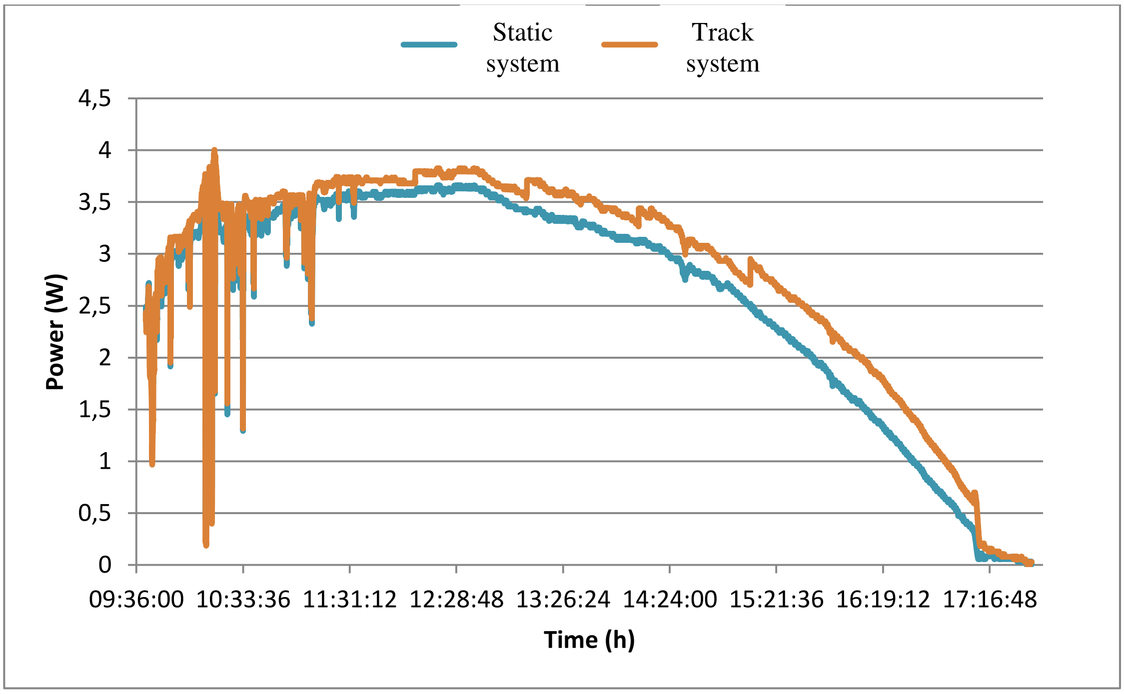

Figure 38 – Power Track x Static System in July 29.

In the end of the day August 19 there was also a problem with the current sensor, which was deregulated and lost calibration. Figure 39 shows the power generated when it was evening and there was no presence of the Sun. This fact it is still being studied and are seeking alternatives to solve the problem.

In these results, it can be concluded that it is not so simple to do experiments with solar panels. So it was necessary to planning it carefully to have reliable results, mainly because we do not have an appropriate structure.

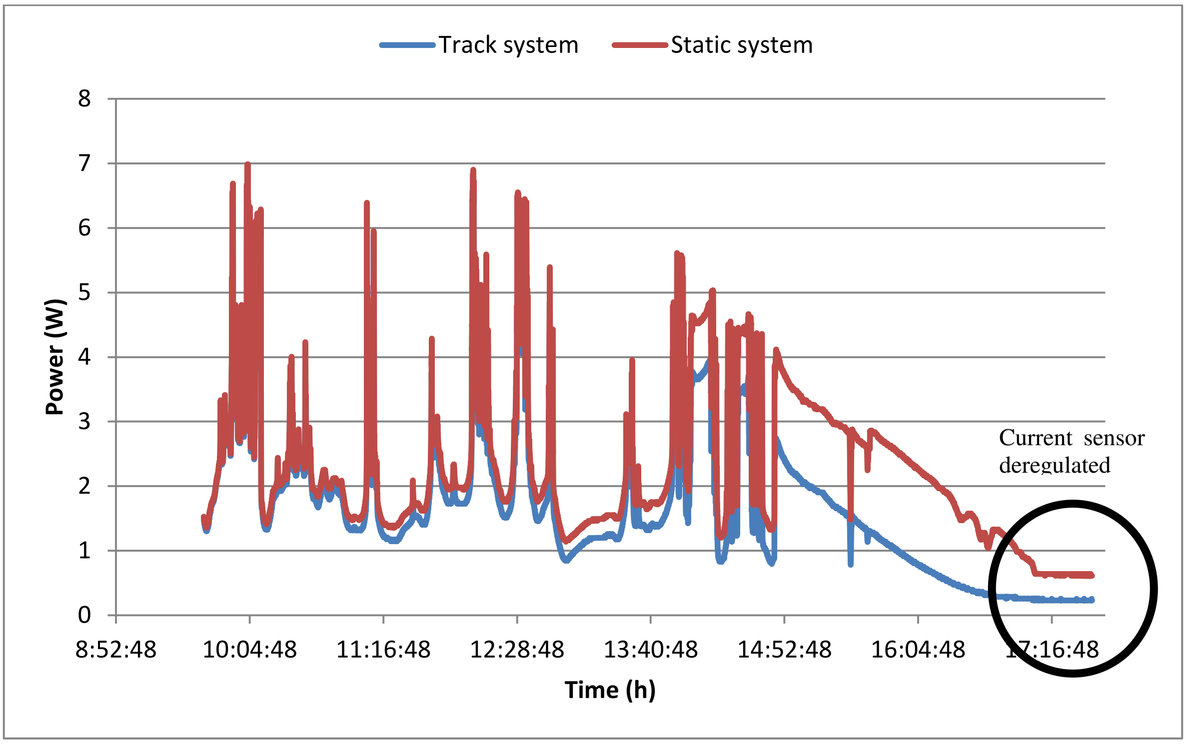

Figure 39 – Power Track x Static System at the night in August 19.

Appendix B

In this appendix is shown the paper, “A Low-Cost Prototype for Sun Tracking”, based on this work that was published in 10th IEEE/IAS International Conference on Industry Applications, 2012, Fortaleza, Brazil.