VOL. 12, NO. 7, APRIL 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DESIGN AND IMPLEMENTATION OF A PHOTOVOLTAIC SOLAR TRACKER USING FUZZY CONTROL FOR SURCOLOMBIANA UNIVERSITY

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ABSTRACT

Solar tracking systems are a solution to get a higher incidence of radiation throughout the day compared a static photovoltaic system. A tracking system produces a significant improvement in energy efficiency over a fixed system. In this contribution, the design of an automated solar tracking system with diffuse control is presented. This fuzzy control presents two input variables the incidence of radiation both on the azimuth axis and on the axis of elevation. This allows developing a comparative study between a static solar system and the solar tracker that attends to evaluate produced power versus consumed power, efficiency, costs and complexity of the system through the implementation of an experimental prototype.

Keywords: fuzzy logic, photovoltaic energy, solar panel, solar tracking.

1. INTRODUCTION

Non-renewable energy sources contribute greatly to increase pollution and global warming. Little by little the alternative energy becomes a solution for the decrease of these indices. Photovoltaic solar energy from solar radiation is an inexhaustible source of energy and its capture is achieved by solar panels. The most widely used systems of electric power generation from solar radiation are static. These systems are efficient only at times where the incidence of solar radiation is direct.

Solar panels generate a prudent amount of electrical energy directly proportional to the intensity of solar radiation, so without solar radiation they will not produce electrical energy. The main disadvantage of static photovoltaic systems is that they are oriented at a particular angle and the amount of maximum solar incidence that can be reached in an instant is limited by the position of the panel and the sun. In addition, the efficiency of the solar panels is negatively affected by the temperature, decreasing the amount of electrical energy produced.

Solar tracking systems are a solution to achieve a higher incidence of solar radiation on the system, increasing the uptake compared to a static system. However, conventional solar tracking systems do not take into account the temperature, therefore very high temperatures cause very low efficiency, and affect the useful life of the solar panels. Due to this, this work proposes a solar tracker that takes into account the most influential environmental variables in the capture of solar radiation such as position and temperature and ignore others such as humidity and wind.

In all photovoltaic systems, the increase in temperature has consequences such as shortening the life of solar panels, melting of cells by high temperatures and reduction of efficiency factors. If these drawbacks are brought to solar tracking systems, it can be noted that the efficiency at certain times can be virtually zero. Due to long exposure to radiation that would have a tracking system compared to a static system, the movement of the solar tracker would be totally inefficient. When considering these factors, it is observed that it is necessary that the system designed consider the monitoring of the sun taking into account both the incidence of solar radiation and the temperature that the panel has, in order to determine the ideal position.

This work presents the design and implementation of a photovoltaic solar tracking system applying diffuse control in order to compare the efficiency of this type of technologies in static mode and in constant movement.

2. MATERIALS AND METHODS

2.1 Solar panel

A solar panel is an array of photovoltaic cells configured in such a way that they generate electricity from sunlight. These cells must be configured to provide maximum power transfer.

The electrical behavior of the solar panels is given by the current-voltage curve (I-V curve) that characterizes it. Under standard test conditions (irradiance of 1 KW/m^2 and cell temperature of 25°C), each module has a characteristic I-V curve.

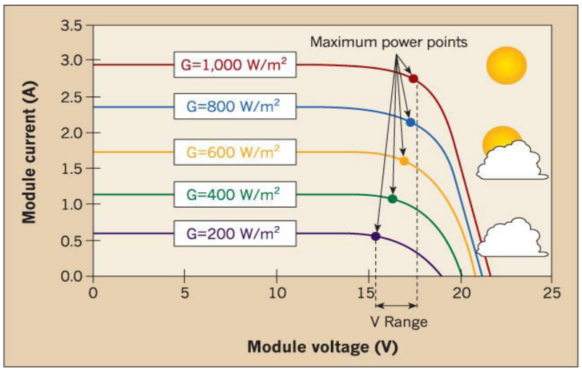

Figure-1. I-V curve.

The temperature is a variable that affects decisively in the generation of energy in a photovoltaic solar panel. From 25°C the nominal power of a photovoltaic solar panel suffers a reduction of approximately 0.5% for each °C of increase in temperature.

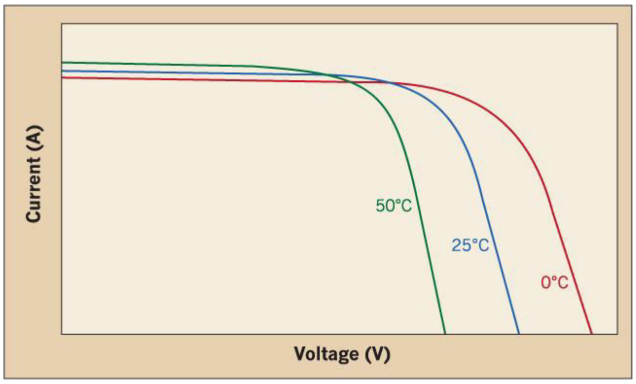

Figure-2. Influence of temperature on I-V curve.

Electricity generation systems based on solar panels need to obtain the maximum use of solar radiation that impinges on it, for this reason it is sought that the solar rays strike the most perpendicular possible on the surface of the panel. For this, it is necessary to take into account the angle of elevation that the sun has throughout the year, and based on this, to determine the inclination that this arrangement must have. The angle of inclination of the globe on its polar axis is 23.45 ° and declination (δ) is the angle of deviation of the sun from the equatorial plane of the earth and is defined as:

$$\delta = 23.45 \sin\left(\frac{360(n-80)}{365}\right)$$

where n is the day of the year.The optimal inclination with which the system should be chosen is reflected in the following equation:

$$\phi_z = \phi - \delta$$

Where ϕ is the latitude of the zone (10° for Colombia), in most cases ϕ_z is defined only by latitude, so that for local designs, an inclination between 5° and 15° is chosen.

2.2 Fuzzy logic

Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1. By contrast, in Boolean logic, the truth values of variables may only be the "crisp" values 0 or 1. Fuzzy logic has been employed to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific (membership) functions.

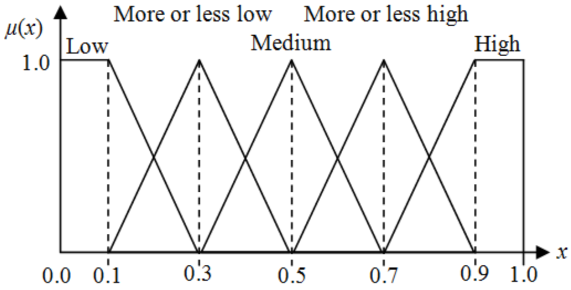

Figure-3. Example of a membership function.

Diffuse controllers use expressions based on fuzzy logic to formulate rules that control a system. Diffuse controllers need a knowledge base provided by the experience of one or more experts to make decision-making.

Fuzzification: It is a process that converts real values to diffuse values. In this, degrees of membership are assigned to each of the entries in relation to the previously defined fuzzy sets using the membership functions associated with fuzzy sets (Cahuantzi Diaz, 2013).

Knowledge base: Here is the information associated with the domain of the application and the objectives of the control. In this process the linguistic rules of control in charge of the decision making for a correct functioning of the system must be defined (Cahuantzi Diaz, 2013).

Inference: Relates the fuzzy input and output sets to represent the rules that will define the system. In the inference, knowledge base information is used to generate rules by using heuristic rules of the form IF (antecedent) THEN (consequent), where the antecedent and consequent are the input and output sets respectively (Cahuantzi Diaz, 2013).

Defuzzification: The defuzzification is the inverse process to the Fuzzification, that is to say, in this stage the fuzzy values are adjusted to real values that will later be used in the control process. In the defuzzificacion usually simple mathematical methods like the Method of the centroid and the method of Weighted Average are used

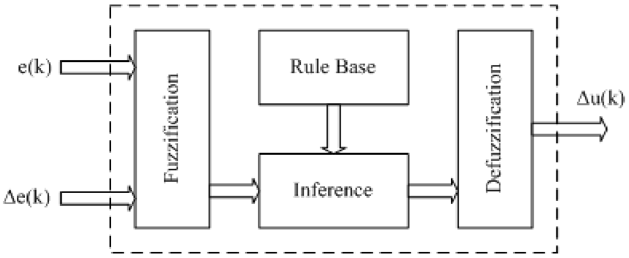

Figure-4. Structure of a fuzzy model.

2.3 Project development

The block diagram of the proposed system is presented below:

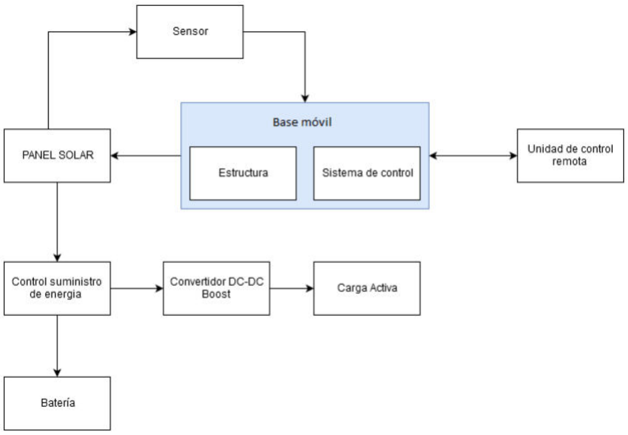

Figure-5. Designed system.

The structure where this implementation was made consists of the rotor Yaesu G5500 which makes the movement of the solar panel, in such a way that there is always the highest solar incidence with the conditions raised in the control. This motor is coupled with a structure that holds the photovoltaic solar panel, together with a base that rests on the ground.

The G5500 rotor has a manual control unit for handling and positioning, which is responsible for feeding the structure with 24 VAC, also makes a reading of the positioning sensors located in the motors in order to display the values through an interface. This interface consists of two meters: one for the elevation angle with a scale of 0° to 180° and one for the azimuth with a scale of 0° to 450°.

The system has the ability to measure voltage, current in the panel, voltage and current in the active load, ambient temperature and temperature on the surface of the photovoltaic solar panel, orientation and elevation angles of the photovoltaic solar panel, given by the rotor controller.

The control and instrumentation unit was designed as a printed circuit; the distribution of elements makes it very accessible. It also has ports for possible expansion and a port for LCD display if required. The figure shows the 3D model of the card.

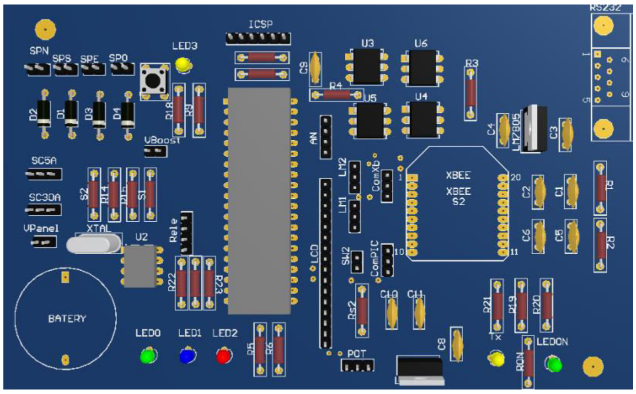

Figure-6. Control and instrumentation board.

One of the great challenges of photovoltaic systems is the handling of inductive loads such as motors. Electric motor needs a current, greater than the steady state current to start. This starting current can easily be from two to eight times higher than the steady state current (nominal). This value is instantaneous or very small with respect to time; however these large currents can cause damage to the circuit. For this reason a soft starter is required. The load coupling circuit is given by the block diagram of figure.

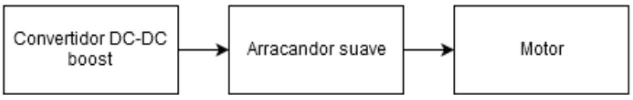

Figure-7. Block diagram for the load coupling.

The soft starter uses a pulse width modulation (PWM) control, using an interface with an IRFZ44N. In this way the goal is to reduce that amount of current that the motor needs to break the inertia. Below is the graph of current versus time of the motor to be controlled.

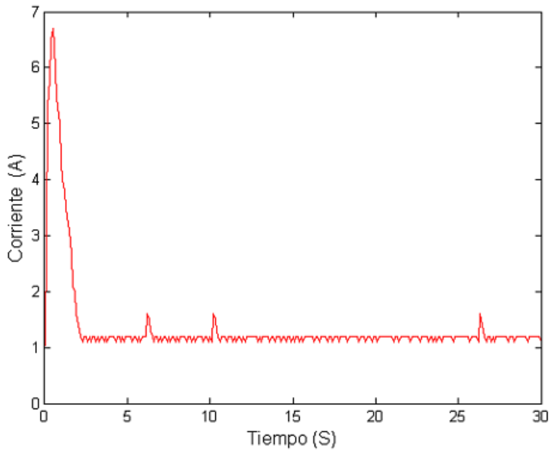

Figure-8. Motor current without soft starter.

As noted, it produces a considerable starting current and clearly detrimental to any regulator. In the same way the soft starter also provides a small impulse to break the inertia and also has to regulate its cycle so as not to exceed the peak current that it generated before, that is to say that it regulates and only handles a small overshoot. With these conditions the following results were obtained.

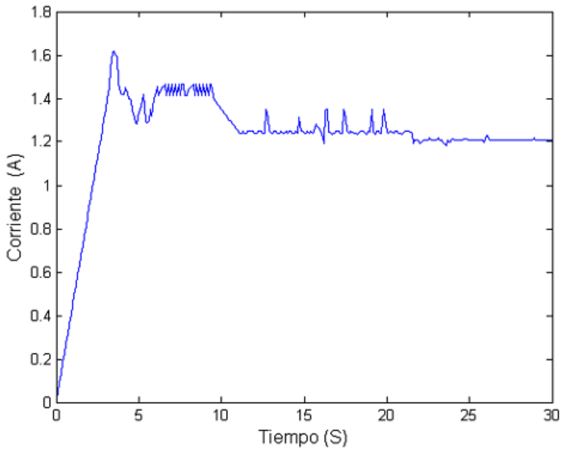

Figure-9. Motor current with soft starter.

The fuzzy controller must find the ideal position in order to guarantee perpendicularity between the solar panel and the Sun. Therefore, it is necessary to find a logical way that determines the best procedure to perform this task. The incidence of direct light on the surface of some type of sensor can determine the exact position of the Sun.

In order to determine the perpendicular position between the solar panel and the Sun, a device consisting of 4 Light Dependent Resistors (LDR) is provided. Here, 2 LDR are distributed for monitoring the position in Azimuth and the other 2 LDR provide the Elevation value. In this way an accurate measurement of the position of the sun is obtained.In order to measure the incidence of radiation on the panels, an arrangement of LDR is used, which has the characteristic of diminishing its resistivity when the incidence of light on them increases.

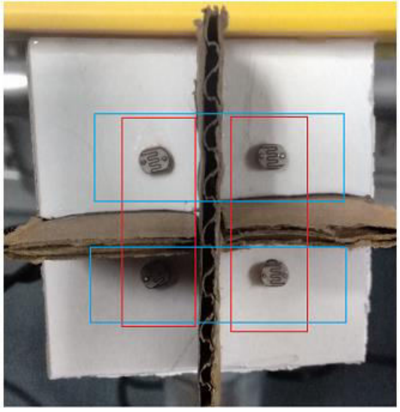

Figure-10. LDR configuration.

The two lateral sensors are labeled A1 and A2, among them there is a difference that can be positive or negative depending on which LDR receives a greater amount of light. Similarly the upper and lower sensors are labeled as E1 and E2 and their difference can be negative or positive. These differences take the name Az and El. Depending on the incidence of light on the sensors these variables will take a positive value if the incidence of light is greater in A1, an OK if the difference is very close to 0 and a negative value if A2 is greater. Likewise El will take a positive value if E1 is greater, an OK value if the difference is very close to 0 and a negative value if E2 is greater.

These variables Az and El are the input variables of the fuzzy control, which delivers at its output two states of position one for the control of the Azimuth angle and the other for the Elevation value, ie if the value of El is negative the Elevation motor rotates in a direction that takes the name of Ele1, if Ok keeps its current position taking a value of NoEle and if it is positive it turns in the opposite direction Ele2. A similar operation has the Azimut engine, if Az is negative the motor rotates clockwise called Rotar2, if it is Ok it maintains its NoRotar position and if it is positive it rotates in the opposite direction Rotar1. In this way it is possible that according to the states of these input variables the position of the rotors is controlled and thus the equilibrium point is present when the values of Az and El are Ok. At this point it can be said that the panel is located perpendicular to the position of the sun.

To build the membership functions the Mamdani-type rules were used. This type of rules allows presenting the inputs and outputs in a logical way unlike other types of rules that propose a mathematical function at their output, or even some values that are not necessary for this design. The Mamdani type rules are defined as:

IF ($\mathbf{x1}$ is $\mathbf{A}$ AND $\mathbf{x2}$ is $\mathbf{B}$) THEN ($\mathbf{u1}$ is $\mathbf{D}, \mathbf{u2}$ is $\mathbf{E}$)

Where $\boldsymbol{x1}$, $\boldsymbol{x2}$ are input variables. $\boldsymbol{A}$, $\boldsymbol{B}$ are membership functions and can adopt linguistic values such as High, Low, Hot, Cold, among others. $\boldsymbol{u1}$, $\boldsymbol{u2}$ are the actions to be controlled.Finally $\boldsymbol{D}$ and $\boldsymbol{E}$ are the output membership functions. Based on this, a series of rules were designed for the proposed control.

- If **Az** is **Negative** Then **Azimuth** is **Rotar2**
- If **Az** is **OK**Then **Azimuth** is **NoRotar**
- If **Az** is **Positive** Then **Azimuth** is **Rotar1**

For the control of the lifting rotor the following rules were proposed:

- If El is Negative Then Elevation is Ele1
- If El is OK Then Elevation is NoEle
- If El is Positive Then Elevation is Ele2

The fuzzification process is performed at all times of time. That is, this process evaluates whether the difference belongs to the membership functions Negative, OK or Positive.

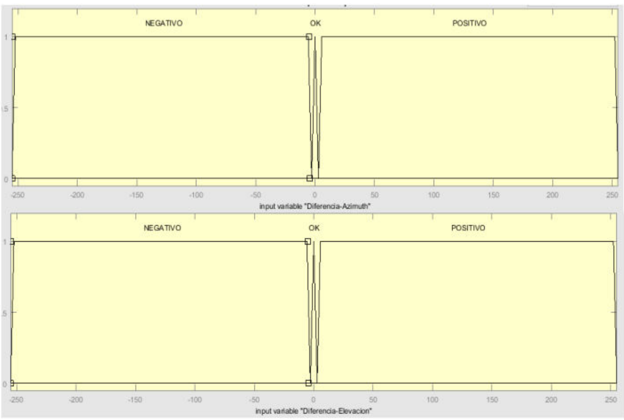

Figure-11. Input membership functions.

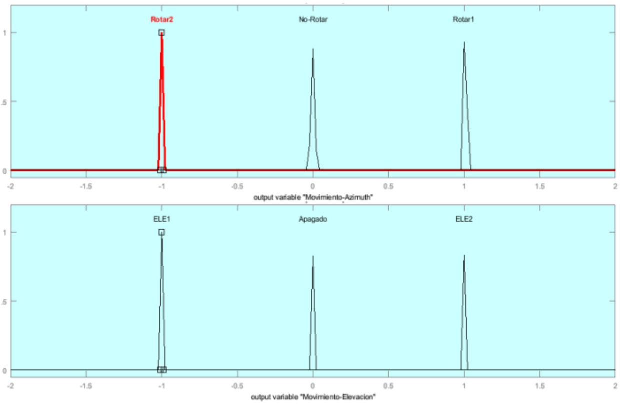

Figure-12. Output membership functions.

Once the rules are implemented and the membership functions determined, it can be seen that the two inputs and the two outputs behave independently.

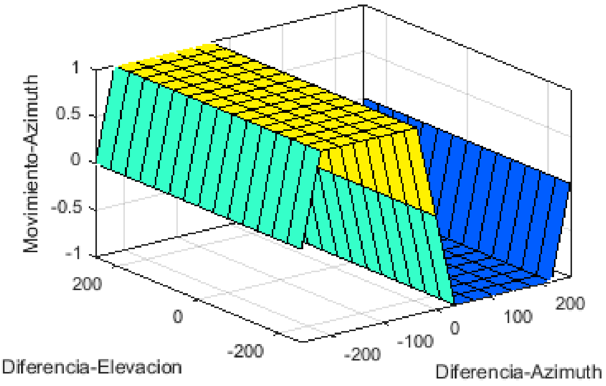

Figure-13. Fuzzy inference system.

3. RESULTS AND DISCUSSIONS

The comparative study is performed by experimentation. For this, two identical solar panels were used. The test was performed the same days and in this way a comparison was made, which gave a strong response of the designed control.

For this study, two panels of 300W were used, one was anchored to the experimental tracker and the other oriented south with an elevation of 11°. The study was carried out obtaining the following graph:

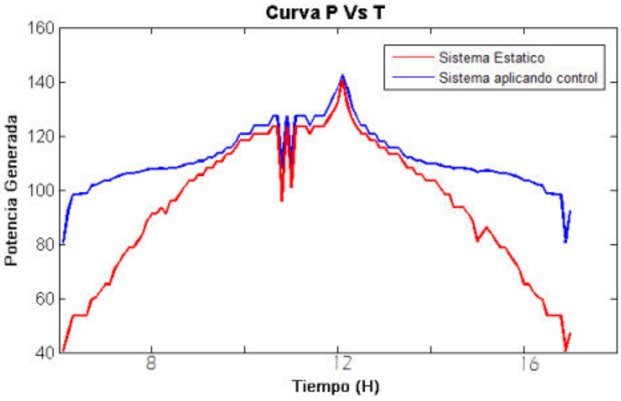

Figure-14. Power produced by the static (red) and the tracker (blue) systems.

To know the amount of power generated by each system during a solar day, the area under the power curve was found. The result was 1.03 KW/day with the designed controller and 866W/day with the fixed panel.

The average temperature of the days with follow-up is shown below. At no time did the temperature exceed 70°C; however, when the static panel exhibited a peak temperature.

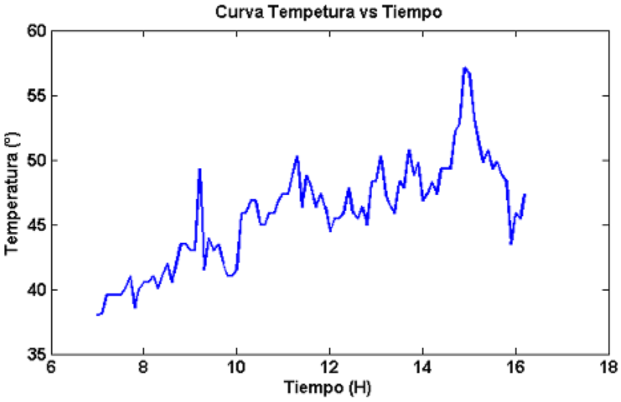

Figure-15. Solar panel temperature.

For this reason, a tracking algorithm was designed that covers the path of the sun during the 12 hours of irradiation to observe the influence of the temperature on the maximum power of the panel, obtaining the following result.

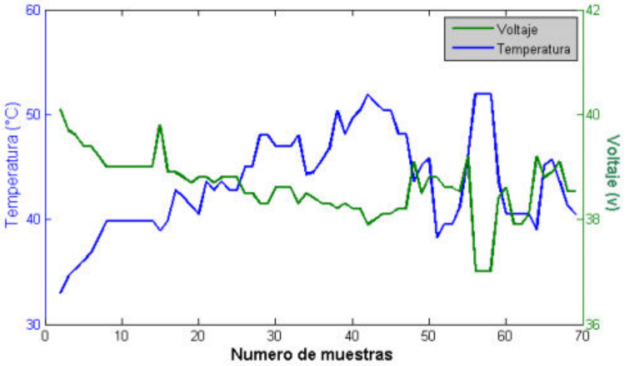

Figure-16. Voltage and temperature in open loop.

It can be observed that although the temperature present on the surface of the panel affects the open circuit voltage, there was a strong voltage drop. Only a loss of 9VDC was present at a peak temperature of 52°C.

The energy captured by the solar tracking was 1.03 KW/day, to this data is subtracted the consumption per day of the energy used in the tracking resulting in 972 W/day. In this way, compared to the power produced by the fixed panel 866W/day, there is an increase in the uptake of 12.45%.

Although the solar tracker produces more energy compared to static system, the cost of the equipment used for tracking is the weak point of the system. Since the price of 3 solar panels of 300W equals the cost of the rotor Yaesu G5500.

Based on the results obtained, at present it is not advisable to carry out solar tracking to increase the energy collection of the same, at least in this area of the world. Since the SurcolombianaUniversity is located very near the line of the Ecuador does not present many changes in the azimut movement. However, this technology must be very viable in those regions where there are movements of greater magnitude both elevation and azimuth.

The weak point of the solar tracking is the investment that has to be made in the electromechanical elements, since for the situation that evaluated the project it is much more convenient to buy more photovoltaic solar panels, than to invest in the Yaesu G5500 rotor used for solar tracking.

The temperature on the surface of the solar panels is not the same as in the photovoltaic solar cell due to the fact that between the cell and the protective glass there is an encapsulation of Ethyl Vinyl Acetate (EVA), a protection filter for humidity, abrasion and UV rays. Because of this the open circuit voltage is not drastically affected.

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