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Solar Tracking

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Abstract: ***This article is focused on the design and construction of a solar tracker, with this design is intended to make more efficient the solar collection of photovoltaic panels and thus optimize their performance. Currently, we find that the photovoltaic panels are placed in a single position, this position is determined in an empirical way since the panels are placed pointing towards the place where the sun at a certain time of day emanates a greater amount of energy, however, this is not always true, because the seasons determine the position of the sun, for that reason they cannot capture the solar energy at all times. In this way the idea arises that these panels can be optimized so that they increase their level of use of solar energy.This situation led to the construction of a solar tracker that allows to maintain the photovoltaic panels perpendicularly with the sun throughout the day and thus capture the largest possible amount of energy that radiates the main star. All this is carried out through a pair of electric motors and a microcontroller (Arduino) that make possible the movement of the structure to place the photovoltaic panels pointing towards the sun.***

Keywords: Solar tracker, Photovoltaic panels, Renewable energies, Solar energy**.**

1. Introduction

In the past, renewable energies were unimportant because at that time there was a mentality that fuels would be eternal, but as time went by, society began to realize that this was not true and in 1970 they began to consider renewable energies as an alternative to conventional energies. In recent times solar energy has been taking more importance than other clean energies because if nature uses sunlight for all its processes because humanity could not take advantage of it for their benefit [2].

Photovoltaic solar energy (ESFV) is a source of renewable energy, which can be used in the generation of electricity through the use of photovoltaic solar panels (PSFV) that convert solar radiation into electricity, making it applicable to multiple activities of life[1].

In this moment when most of us need to save and reduce fuel consumption and generate electric power, wethink of an alternative to optimize systems with solar panels, for that reason we build this solar tracker, which also allows to obtain electricity in a better way.

Solar energy is presented as an efficient and economical alternative, in comparison with other traditional forms, for the generation of electrical energy. All this has increased the need for greater use of solar energy.

To get the optimization of the amount of energy obtained from a photovoltaic installation there are two methodologies: The first consists of improving the internal components of a photovoltaic panel so that its performance increases. The second is to increase the amount of solar radiation received by the panel [2].

In photovoltaic systems there is the possibility of implementing an additional device to increase the uptake of solar radiation and therefore the energy supplied by the installation, such device is a solar tracker; with this, we sought that the area of the photovoltaic panel remains perpendicular to the light radiation of the light source.

2. Objective

To design a solar tracker with the use of a microcontroller (Arduino) to capture as much energy as possible with a solar cell.

2.1. Specific objectives

- To achieve tracking of the sun by phototransistors and digital electronic.
- To make a structure that has the ability to move in two axes.
- To capture the largest amount of solar energy by orienting the cells in a direction perpendicular to the sun.
- To test its operation in order to be implemented on a larger scale.

3. Theoretical framework

3.1. Types of solar trackers

A solar tracker is a device whose main function is to follow the path of the sun at any time of the day. They can be classified as follows [2]:

3.1.1. According to its type of movement:

- Followers to an axis: They present a degree of freedom in their movement. The rotation of the catchment surface is done on a single axis, this can be horizontal, vertical or oblique. This type of tracking represents a minimum degree of complexity. Its limitation is that it cannot follow the Sun completely since it can only follow either the azimuth or the solar height, but not both [2].
- Followers to two axes: They possess two degrees of freedom, capable of making a more precise solar tracking. This type of tracker is able to perform a total tracking of the sun, both in height and azimuth, although the performance of the installation may be higher compared to single-axis [2].

Both types of solar trackers are good according to the use they give each one, however, the two axis is better in efficiency because it can follow the trajectory of the sun with more precision reason why we decided that our robot was developed with a following in two axes.

3.1.2. According to its operating algorithm:

- Followers by bright spot: They have a sensor that tells them which is the brightest point in the sky and which they should aim at. The algorithm of this type of follower bases its operation on the signal integrated by one or several sensors, depending on said signal a control command is sent to one or more motors so that they are positioned at the most appropriate point of luminosity [2].
- Followers with astronomical programming: These through a program know at what point the sun should be at every hour and they point to that position. It presents a total independence of the climatic conditions since its algorithm does not require sensors that indicate which is the most luminous point. The follow-up in this case depends solely on a series of equations that predict the location of the sun at any time [2].

Although the algorithm of operation with greater degree of efficiency is the one of astronomical programming because it is independent to the climatic conditions, its price is higher than the one of luminous point which is affected by the climatic conditions reason why sometimes its performance is not very good.

3.2. Solar energy

Now that we already know a little about the types of solar tracker, we are going to talk about the solar energy and the applications that the human being is giving.

Mexico has an average global solar irradiation of 5 kWh/day/m², although in some regions it reaches values of 6 kWh/day/m². On one hand, the main application of solar energy has been for photothermal applications, specifically for heating water, where the economic benefit lies in the saving of gas in its majority and its application is feasible to the whole country for the levels of solar radiation that they have[3].

On another hand, the main purpose of solar energy for photovoltaic applications is rural electrification, water pumping and refrigeration in rural communities isolated from the electricity grid. Although the costs of photovoltaic technology are high, the cost of developing extensions of the electric grid in remote communities is even greater, so in these cases it is economically viable for the government to use photovoltaic technology, although most of the photovoltaic installations that exist in the country are located in remote communities and most of them have been installed through governmental programs of rural electrification. It is estimated that the total capacity of photovoltaic installations in 2010 was 28.6 MW. As regards the generation of electricity with connection to the electricity grid using the solar resource, there are financially viable market niches for residential electricity consumers with a capacity of at least 700 MW [3].

3.2.1. Photovoltaic panels

Previously, we sawthat one of the applications of the solar energy is on the photovoltaic technology and for that reason below it is shown what a cell is and what its operation is.

Photovoltaic cells are devices formed by metals sensitive to light that release electrons when light rays hit them, generating electrical energy. They consist of cells made of pure silicon with addition of impurities of certain chemical elements, being able to generate each of 2 to 4 Amperes, at a voltage of 0.46 to 0.48 Volts. The panels are placed in series to achieve a voltage appropriate to the electrical application in question or demanded; then the panels capture the solar energy transforming it directly into electricity in the form of direct current, which is stored in accumulators, so that it can be used outside the hours of light. The photovoltaic modules admit both direct and diffuse radiation, being able to generate electric power even on cloudy days [1].

3.2.2. The Stations, Equinoxes and Solstices

The seasons of the year are another factor that affects the level of energy capture of a photovoltaic panel and that is why now we will talk about this topic.

The change of seasons throughout the year occurs when there is the peculiarity that the axis of rotation of the Earth is inclined with respect to the plane of the orbit, this causes the Sun's rays to affect differently along the year in each hemisphere [2].

Figure 1: Rotation of the Earth

Summer Solstice: It starts on June 21, the northern hemisphere is tilted towards the Sun. The days are longer than the nights and the Sun's rays strike more perpendicularly, as the Sun rises vertically in the Tropic of Cancer, beginning in this hemisphere the warmest season, summer. However, in the southern hemisphere the opposite situation occurs, then winter begins.

Autumn Equinox: Starts on September 22, the days and nights have the same duration on the whole planet, as the sun is placed in the vertical of the equator, beginning the autumn in the northern hemisphere and the spring in the south.

Spring Equinox: Starts on March 21, the days and nights have the same duration on the entire planet, as the sun rises

again in the vertical of the equator, beginning spring in the northern hemisphere and autumn in the southern hemisphere.
In the Winter Solstice, December 22nd, it is the northern hemisphere that has the days shorter than the nights, while the sun's rays strike in a more oblique way, when the Sun is placed in the vertical of the Tropic of Capricorn, beginning in this hemisphere the coldest season, winter. In the southern hemisphere the opposite situation occurs, then the summer begins [2].

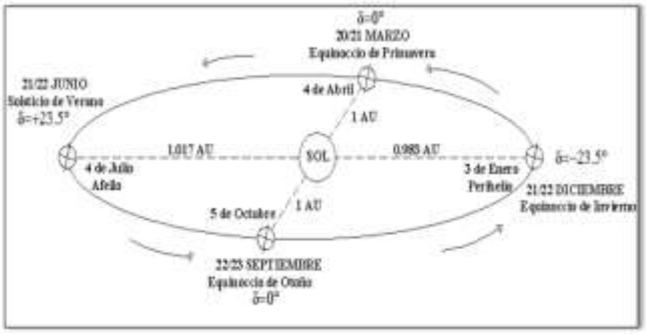

Figure 2: Seasons of the year

3.2.3. World map of solar radiation

Now it is presented a little about the solar radiation in the whole world.

The mapping of the average solar radiation in the world, gives us an idea of which zones are the ones that receive more solar radiation. These are found mainly in the area of the equator, diffusing towards the poles, although different factors such as cloudiness or geological characteristics of the soil come into play, refracting this greater or lesser radiation, contributing to the greenhouse effect and the increase in temperature [2].

The map in the image below is very important for two things. First, because it shows us in which part of the world solar energy can be better used. And second, because if we study it a little more in detail we can see that solar energy has a bigger potential than we imagine [2].

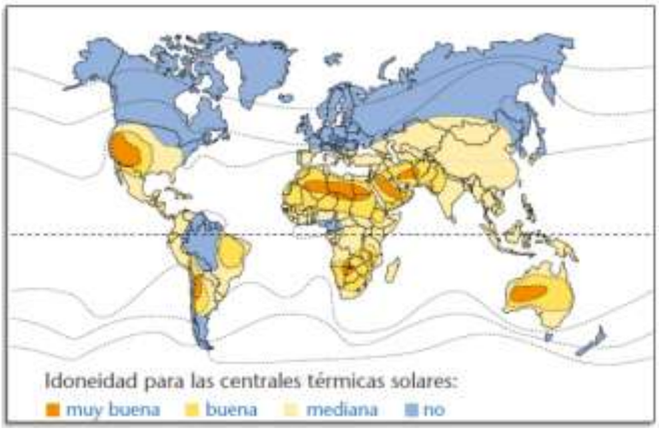

Figure 3: World map of solar radiation

4. Developing

4.1. Characteristics of the solar tracker

4.1.1. Mechanical design

Previously it has been explained the differences between the different types of solar trackers and based on that it was decided that it was two axes since it is the one that offers the best results. Before being physically constructed you have to design the structure of it, fortunately at present there are several 3D drawing software such as SolidWorks and Inventor, the latter has stood out for its friendly interface and the various tools it contains. Due to the mentioned characteristics, Inventor was chosen to design the structure.

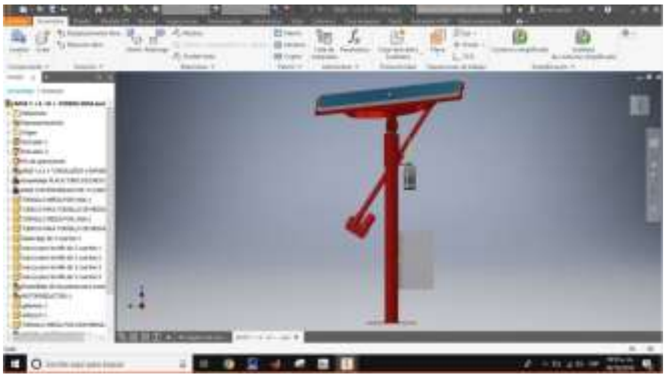

Figure 4: Design in inventor

The solar tracker designed is two-axis one of them is inspired by the operation of a satellite dish and the other is to improve the solar tracking process as it is known the year is divided into 4 seasons and in each of them the sun change position.
Once the number of axes tothe robot has been decided, it is necessary to choose the material with which it will be built and for economic convenience it will be metallic profiles. The design of the structure of the solar tracker will be of the mono-pole type and consists of a base, a pole, toothed pulleys coupled to a gearmotor, standard type screws, AR type metallic profiles among others.

4.2. Electrical control design

Today, we have a wide variety of microcontrollers with a free and open platform, one of them is Arduino, which is an open-source electronic prototype platform based on flexible and easy-to-use hardware and software.

That is why Arduino represents the best option to be the brain of the robot, it works with a system called "by bright spot" because its programming is easier. The electrical set of the solar tracker consists of Arduinos one, LDR's, motors, contactors, relays among others. Next, the electrical control is shown:

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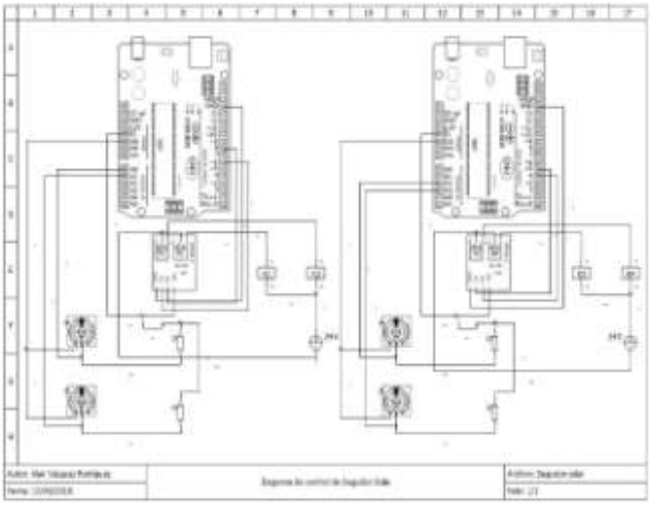

Figure 5: Circuit of the Arduino

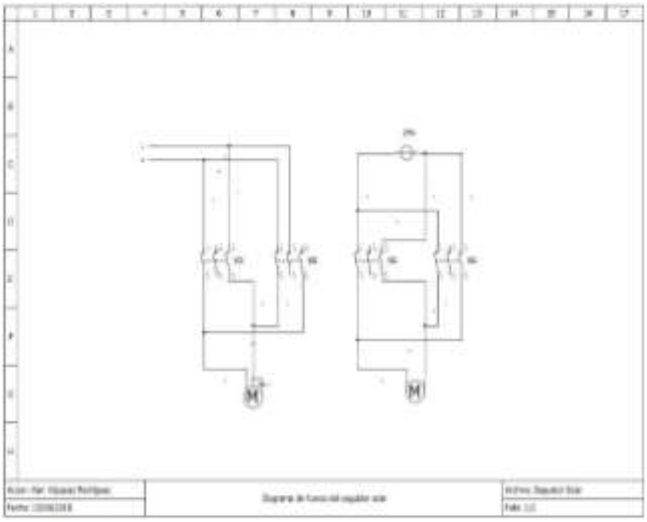

Figure 6: Circuit of the motors

The way in which these circuits work is the following: when sunlight hits a couple of photoresistors the Arduino will read and compare the results obtained by the LDR'S, if the sunlight affects most to any of them, the Arduino will activate a relay and this will turn to a contactor to activate the sense of the corresponding motor, this will stop when the values of the LDR'S are similar. It is true that electrical control is not shown at 100%, but the most import thing is shown.

In summary, this is the way in which the circuit works, which gives the positioning to the photovoltaic panel whit respect to the sun:

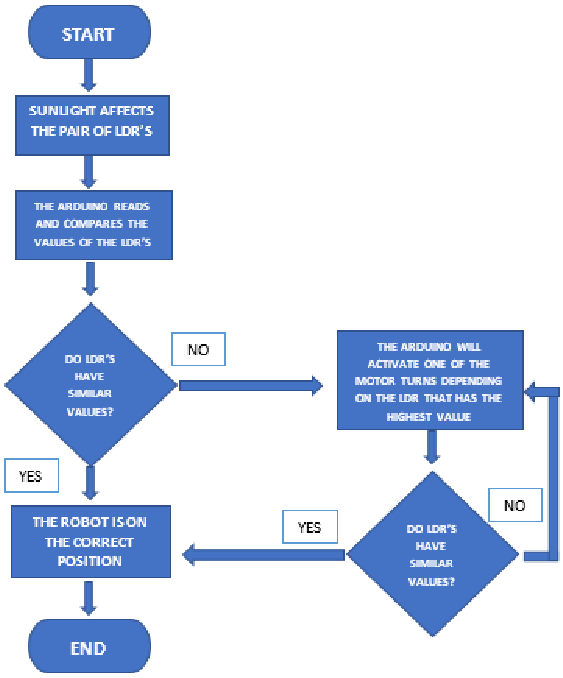

Figure 7: Operation flowchart

4.3. Checking the main objective of the solar tracker

For the verification of the main objective, we will work with a photovoltaic panel of the polycrystal type model LA361J48 and of the Condumex brand. The way in which the tests will be done will be as follows: with the help of a voltmeter built with Arduino, the voltage of the photovoltaic panel will be measured, which will be in a specific position throughout the day.

4.4. Operating the voltmeter

The voltmeter is a device that allows the measurement of the potential difference or voltage that exists between two points belonging to an electrical circuit. Unfortunately, we do not have a device capable of measuring the voltage and recording the results that is why we decided to create one with the help of Arduino because with this we can create a history of the measured results with the help of auxiliary modules.

The way in which this device works is when the Arduino reads a value from 0 to 1024 with the help of a voltage divider, after being read this data will be introduced in some equations and finally it will show us the value in volts, this same result will be printed in a file type txt together with the date and time in which the reading was taken, in order to obtain the exact date and time a module called RTC will be used and to record the history of readings an SD module will be needed.

4.5. Data collection of the photovoltaic panel

Now that there is a device capable of taking and recording the voltage readings it is time to do the tests with the photovoltaic panel the positions in which the readings are taken are 0 °, 30 ° and mounted on the follower. All these positions are to compare the different voltages obtained by the panel and check whether the solar tracker optimizes the process performed by the photovoltaic module.

4.5.1. Data at a 0° angle

When the installation of photovoltaic modules is done, they do not normally tilt at 0°, so with this test we try to see the impact that the inclination of the panel has to generate tension. Normally the manufacturer does not support 100% inclination at 0 ° as it is obvious that there will be large losses of tension caused by the conditions and characteristics of the place. The results obtained were the following:

Table 1: 0° Inclination

0° INCLINATION

HOUR	AVERAGE VOLTAGE
6	1.279333333
7	10.56
8	14.335
10	18.1
11	18.1
12	18.1
13	18.1
14	18.1
15	18.1
16	17.2
17	17.2
18	17.2
19	7.218
20	0

Based on the results we can see that, if voltage is generated, but it is the minimum plus it takes too long to generate the highest voltage value, this behavior has only one explanation, the angle.

Figure 8: 0° Inclination

4.5.2. Data at a 30 ° angle

Conermex one of the most important manufacturers and distributors of photovoltaic panels in Mexico recognizes that it is important to consider the following concepts: "Solar panels are oriented to the South" and "The panels must be inclined according to the latitude of the site" [5]. This with the objective of obtaining the maximum tension of the photovoltaic panels, including the same manufacturer provides us tables to determine the inclination that our solar panel must have in order to fix it, these tables depend on the latitude of the place, on the surface where it will be installed the panel and the address where it will be installed.

In this case, the surface is flat, the direction is towards the south and the latitude of the place where the tests were performed is 19,416 (Tlaxcala, Mexico).

Latitud 18-19°	E						Pérdidas con respecto a la inclinación óptima						O
Orientación/Inclinación	-90	-75	-60	-45	-30	-15	0	15	30	45	60	75	90
0	-5.7	-5.7	-5.7	-5.7	-5.7	-5.7	-5.7	-5.7	-5.7	-5.7	-5.7	-5.7	-5.7
5	-5.6	-4.9	-4.3	-3.8	-3.4	-3.1	-3.0	-3.1	-3.4	-3.8	-4.3	-4.9	-5.5
10	-6.0	-4.8	-3.6	-2.6	-1.7	-1.2	-1.0	-1.2	-1.7	-2.5	-3.5	-4.7	-5.9
15	-6.7	-4.8	-3.2	-1.8	-0.7	0.0	0.0	0.0	-0.6	-1.7	-3.0	-4.6	-6.5
20	-7.8	-5.4	-3.3	-1.5	-0.2	0.0	0.0	0.0	0.0	-1.4	-3.1	-5.2	-7.6
25	-8.9	-6.1	-3.7	-1.8	-0.2	0.0	0.0	0.0	-0.1	-1.6	-3.5	-5.8	-8.7
30	-10.7	-7.3	-4.6	-2.5	-0.9	0.0	0.0	0.0	-0.7	-2.3	-4.4	-7.1	-10.4
35	-12.3	-8.8	-6.0	-3.8	-2.1	-1.1	-0.7	-1.0	-1.9	-3.5	-5.7	-8.5	-12.0
40	-14.5	-10.6	-7.7	-5.5	-3.9	-2.8	-2.5	-2.7	-3.7	-5.2	-7.3	-10.3	-14.2
45	-16.7	-12.9	-9.9	-7.7	-6.1	-5.2	-4.9	-5.1	-5.9	-7.4	-9.7	-12.5	-16.5

Figure 9: Latitude from Tlaxcala, Mexico

For this case, an inclination of 30 ° oriented to the south was used because it reflects less stress losses. The results obtained from the test were the following:

Table 2: 30° Inclination

30° INCLINATION

HOUR	AVERAGE VOLTAGE
6	1.798
7	12.61974026
8	18.82706897
10	19.30918033
11	19.2
12	19.2
13	19.2
14	19.2
15	19.2
16	19.2
17	19.2
18	19.2
19	8.063
20	0

Now that the correct angle has been considered, it can be seen that the use of voltage is better, besides that it takes less time to generate an acceptable voltage.

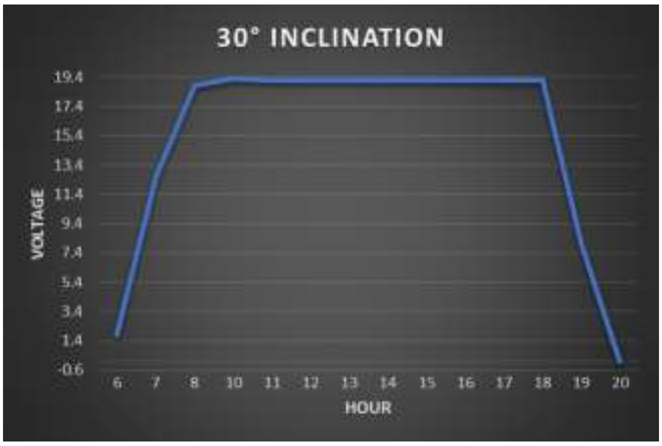

Figure 10: 30° Inclination

4.5.3. Data of the photovoltaic panel in the solar tracker

This is the most important test of the 3, because this is where the effects of a solar tracker for the generation of electricity are checked, what must be done is to fix the photovoltaic panel to the solar tracker.

Figure 11: Photovoltaic panel on the solar tracker

When the photovoltaic panel is fixed in the solar tracker, it will have to follow the sunlight so that the panel receives all the possible sun irradiation, this will increase the voltage production of the panel, these were the results obtained:

Table 3: Solar panel in solar tracker

Solar panel in solar tracker

HOUR	AVERAGE VOLTAGE
6	1.279333333
7	20.8
8	20.8
10	20.8
11	20.8
12	20.8
13	20.8
14	20.8
15	20.8
16	20.8
17	20.8
18	20.8
19	16.5
20	0.456

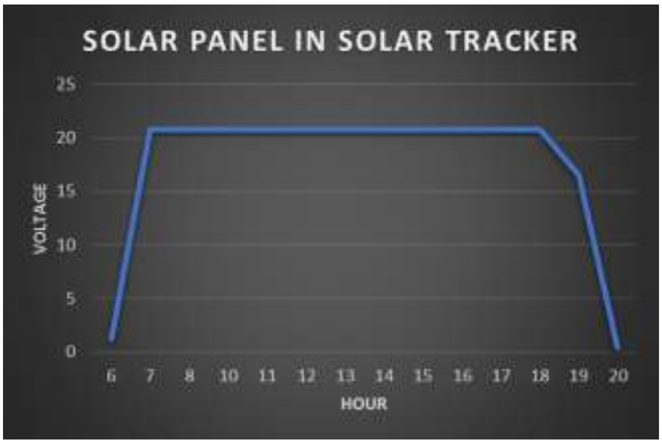

Figure 12: Solar panel in solar tracker

5. Conclusions

Once the results of all the positions have been obtained it is time to compare them to see if in truth a solar tracker improves the generation of electricity.

Table 4: Comparison of the 3 types of results obtained

COMPARISON OF THE 3 TYPES OF RESULTS OBTAINED

HOUR	**Voltage**		
	30° inclination	**0° Inclination**	**Solar panel in solar tracker**
6	1.798	1.279333333	1.279333333
7	12.61974026	10.56	20.8
8	18.82706897	14.335	20.8
10	19.30918033	18.1	20.8
11	19.2	18.1	20.8
12	19.2	18.1	20.8
13	19.2	18.1	20.8
14	19.2	18.1	20.8
15	19.2	18.1	20.8
16	19.2	17.2	20.8
17	19.2	17.2	20.8
18	19.2	17.2	20.8
19	8.063	7.218	16.5
20	0	0	0.456

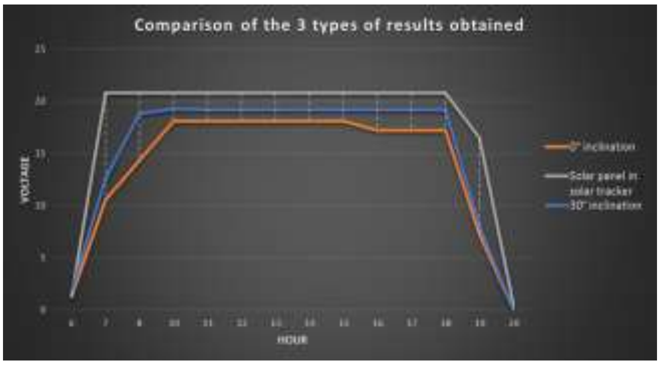

Figure 13: Comparison of the 3 types of results obtained

As you can see the electricity generation of the photovoltaic panel is better in a solar tracker because it improves by 35% with respect to the two inclinations, although it must be considered that this improvement can be increased by the simple fact that the inclinations can receive less irradiation in the other seasons of the year.

The energy losses caused by shading in solar panels are always greater than intuition tells us. Therefore, it is advisable to try to minimize the presence of shadows in our arrangements. You should always look at the hours of maximum solar radiation (three hours before and after meditation) the arrangement is completely free of shadows throughout the year. If there is a shadow somewhere that we cannot avoid, it is advisable to use a FV shadow simulation software that allows us to determine if the system is viable even with the shading effect [4].

In conclusion, the solar tracker fulfilled its main objective which was the optimization of power generation.

Figure 14: Solar tracker ended

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