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# DESIGN AND IMPLEMENTATION OF A SOLAR TRACKER FOR THE STUDY OF THE EFFICIENT USE OF SOLAR AND ELECTRIC ENERGY

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**Abstract:** Taking advantage of renewable energies is a viable way to continue supplying electric energy without affecting our environment and avoiding the growth of the environmental impact against our planet. There are several forms of renewable energies, and solar energy is one of the most convenient to take as a solution to generate electricity in our country. Photovoltaic cells will increase their efficiency if they are included in systems with sunflower effect or also called Smartflower. The purpose of designing and implementing a solar tracker is to carry out a study to analyze the solar-electric energy efficiency of dynamic photovoltaic systems. In this article the solar tracker is presented together with the first results of the study.
**Keywords:** Alternative energy, solar tracker, photovoltaic systems, Smartflower.

## INTRODUCTION

Currently, the use of renewable energies has been increasingly used in a considerable way, seeking benefits such as economic savings in the production of electricity or as a solution to reduce pollution caused by the use of fossil fuels. Technological innovations, such as electric cars, will help reduce pollution from conventional vehicles, which generate 18% of C0 emissions$_2$ which is the cause of the greenhouse effect [1]. There are several forms of renewable energies, and solar energy is one of the most convenient to take as a solution to generate electricity in our country. It should be noted that the use of solar energy in Mexico is considered as a great option because it is one of the most potential countries in the field of solar energy applied in photovoltaic panels due to its high solar radiation (5.2 kWh / m2) in almost all its territory [2]. This paper presents the design and implementation of a photovoltaic system in solar tracker mode or Smartflower which takes full advantage of solar radiation throughout the day generating electrical energy, storing and using it at the right time. The solar tracker photovoltaic systems have a higher efficiency over photovoltaic systems in static mode.

## THEORETICAL CONTEXT

### PHOTOVOLTAIC SYSTEMS

Photovoltaic cells began with the discovery of the photoelectric effect in 1839. The Frenchman Alexandre-Edmond Becquerel put silver chloride in an acid solution, illuminated it and then connected platinum electrodes, thus generating electric current. In 1883, Charles Fritts manufactured the first solar cell, which had, in addition to the semiconductor, a thin layer of gold. This device achieved an efficiency of 1%. However, since then, experiments with different semiconductor materials began to increase the efficiency of photovoltaic cells, leading to the existence of the cells we have today [3].

The photovoltaic module, also known as a solar panel or solar plate, is the device that captures solar energy to initiate the process of transforming it into electrical energy. The semiconductor material it is coated with is sensitive to light and generates electricity when it receives solar radiation thanks to the physical phenomenon known as the photovoltaic effect. [4]. A photovoltaic system is the set of several elements that allow solar energy to be converted into electrical energy [5]. Among these elements are: the photovoltaic cell, the inverter, the charge controller, the battery bank, the bidirectional meter, mainly, as shown in Figure 1.

There are several types of structures for the placement of photovoltaic modules, among which are: solar panel structure on the ground, on a sloping roof, on a roof, on a mast or pole, on a wall, on an inclined triangle, coplanar and elevated. They have the common characteristic of being static or


Fig. 1. Elements of a photovoltaic system [6].

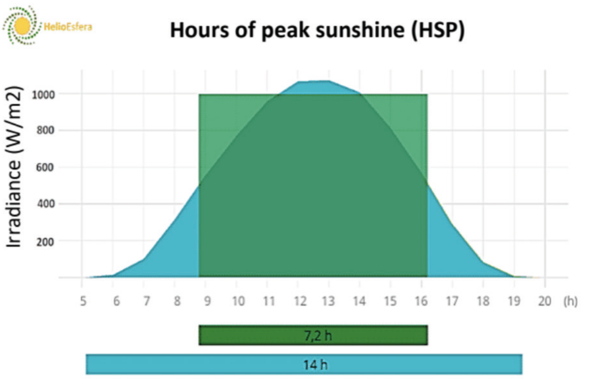


Fig. 2. Graphical representation of the solar peak hour [9].

immobile systems, inclined in the direction of the sun. This article presents the structure of a photovoltaic system in which these elements are integrated into a single module and six small photovoltaic cells are connected as petals in sunflower mode, moving as the sun moves during the day. This module will be shown in the following sections.

## SOLAR RADIATION

The way to measure the solar energy potential of a territory is through solar radiation. According to the International Renewable Energy Agency [7], Mexico is located between 15° and 35° latitude, a region considered the most favored in solar resources, where an average of 5.5 $Kwh/m^2$ (the unit of measurement of solar radiation) is received daily. The northwest of the country is the area with the greatest potential, where radiation exceeds 8 $Kwh/m^2$ in spring and summer. However, the highest demand points are in the center of the country [8].

Hours of peak sunshine, or HSP, is a unit of measurement of irradiance (energy) assuming a constant radiation of 1000 $W/m^2$ . When we talk about 1 hour of peak sunshine (HSP), it refers to the energy received by a radiation of 1000 $W/m^2$ during 1 hour. This parameter allows to calculate in a simple way the energy received in a period of time. It is therefore a magnitude measured in "hours".

In Figure 2, the blue color shows the normal irradiance (power in $W/m^2$ ) over the course of a day, which increases until it reaches its maximum (1100 $W/m^2$ ), after which it begins to decrease, i.e., the irradiance varies. However, in Figure 2 in green, the irradiance is constant (1000 $W/m^2$ ) during a shorter period of time (7.2 h). The energy generated is the surface of the figure, in the case of the blue graph it is a bell shape and in the case of the green graph it is a rectangle, and in both cases it is the same, 7200 $W/m$ .$^2$

The HSP is directly related to the capacity that a solar panel will generate per day. When a panel is purchased, the power in Watt peak (also written as *Wp*) is given. With this data we can calculate the energy it will generate on any given day of the year [10]. Finally, if we want to know how much the panel generates per day, we only have to multiply the HSP by the power of the panel (in *Wp*). The hour of peak sunshine (HSP) is a parameter that depends on the location: areas closer to the equator tend to have higher HSP, on the atmosphere: the cleaner the atmosphere, the more radiation will reach the surface and on the tilt: the greater the perpendicularity of the surface being measured to the sun, the higher the radiation.

## TILT OF PHOTOVOLTAIC PANELS

Another factor that goes hand in hand with peak sun hours is the tilt of the solar panel. Solar photovoltaic panels perform best when the sunlight is perpendicular to their surface. The tilt angle for solar panels depends on the geographical latitude and the time of year when more energy needs to be captured.

The inclination of the solar panels should be more vertical, approximately 10° to 15° greater with respect to the angle of latitude, from where the solar panels are placed.

Table 1 shows the standard data for solar panel tilt angles based on the latitude of the location where the panel will be placed according to Table 1.

| Latitude of the house location | Fixed angle of inclination |
|---|---|
| 0° a 15° | 15° |
| 15° a 25° | Same latitude |
| 25° a 30° | Latitude + 5°. |
| 30° a 35° | Latitude + 10°. |
| 25° a 40° | Latitude + 15°. |
| 40° or more | Latitude + 20°. |

Table 1. Standards for solar panel tilt angles according to location [11].

## SOLAR TRACKERS

Most photovoltaic systems are static, so they can only perceive the greatest amount of solar energy for a short time, due to the fact that the sun changes its position throughout the day. If the highest possible efficiency is to be achieved, the sun must always point at the PV module. This is the principle of the solar tracker, which, as its name implies, is responsible for tracking the sun's orientation throughout the course of the day. A solar tracking system is therefore a mobile structure that connects the solar panel to the ground. Its function is to maximize the electricity production of the solar photovoltaic installation, as it optimizes the angle at which the panels receive solar radiation. [12]. There are two types of solar tracking systems: single-axis and dual-axis. The former moves the solar panel on one axis, usually aligned north-south. These systems have a lower cost, greater simplicity and the possibility of adaptation to roofs, but they perform a less accurate solar tracking, capturing less energy. The second, two-axis system moves in two directions. One is aligned north-south and the other east-west. These types of systems are designed to maximize energy production year-round. The motor systems of mechanical trackers can be electric, which are the most commonly used. Hydraulics are more appropriate for large solar trackers and gravity driven, which is a more original system that does not require electricity, but loses control of the tracker position.

Solar trackers can have manual or automatic control. Manual control is more suitable for those who want to reduce costs. The automatic ones, on the other hand, have microprocessors that determine the position of the sun based on sensors or on a program of astronomical data on the solar position.

## SMARTFLOWER

Smartflower is an innovative "solar flower" with advanced photovoltaic solar panels. Its design resembles a flower and, like natural flowers, it follows the sun throughout the day, Smartflower's petals open and move closer to the sunlight for maximum efficiency in generating clean energy, as this equipment starts producing the electricity it needs much earlier (Figure 3).

It is an instant-start solar panel system that powers your environment with sustainable energy. This intelligent sunflower-shaped solar platform follows the path of the sun thanks to an automatic control system that allows its moving monocrystalline solar panels to always be at a 90° angle to the sun, so they can collect as much energy as possible. It consists of a set number of "petals" moving individually to maintain an optimal 90° orientation with respect to the sun throughout the day. They also move when the sun is low or during the winter. In this way, the Smartflower is more efficient in its task of producing electricity than fixed solar home panels of the same surface area.


Fig. 3. Smartflower [13].

Optionally, a battery system can be incorporated into the stem or base, which can store surplus or excess electricity produced during peak production hours.

Dynamic photovoltaic systems or solar trackers need control systems that will allow them to adjust to the best tilt angle according to the sun. The control systems that can be used to fulfill this function are the following: a microcontroller, an Arduino or ESP32 or a PLC.

## SOLAR TRACKER DESIGN

For this project we used 6 *solar cells* that provide up to 5 *VDC* with a nominal capacity of 160 *mA*, under optimal light conditions. An *LDR* (Light Dependent Resistor) or photo resistor is an electrical resistor which varies its value depending on the amount of light hitting its surface. The higher the intensity of light that strikes the surface of the LDR or photoresistor, the lower its resistance and the lower the amount of light that strikes it, the higher its resistance [14].

We also made use of an *MG996R Tower Pro servo*, which stands out for its good torque (11 *kg*), metal gears and great robustness. It is mainly used in robotics projects, such as robotic arms and biped robots. It can rotate approximately 180 degrees (90° in each direction). It has the facility to work with a variety of development platforms such as Arduino, PICs, Raspberry Pi, or any microcontroller [15].

An *ESP32*, designed to be scalable and adaptable to Wifi or Bluetooth connections, was also used. The *ACS712 current sensor* was also integrated, which supports current measurements of up to 30 *A* in AC or DC. Internally it works with a Hall effect sensor that detects the magnetic field arising from the passage of current through an internal copper wire and converting this field into a variable voltage. This means that the more current we have, the more voltage we will have on a pin [16].

It was decided to add to the base a *TP4056 lithium battery charger module with protection* which consists of a small module perfect for charging single cell LiPo or Li-ion batteries of 3.7 *V* 1 *Ah* or higher and includes its protection circuit, so that your batteries do not receive any damage.

Finally, the tracker will have a 16×2 *LCD display* which is ideal for use as an output device and user interface in projects with Arduino, Raspberry Pi and other microcontrollers. In order to assemble and integrate all these elements and form the tracker, an acrylic structure was made to give firmness to the whole prototype, in order to support the motion system and the transmission system. The design of the structure was made using SolidWorks software . R

The final result of the structure is shown in Figure 4. Among the points to highlight are: the structure must be able to respond to small and light movements. It must have real time data acquisition and a simple interface.

In relation to the materials of the structure, weather resistance, stability and rigidity were considered. The parts of the structure were elaborated in a 3D printer and CNC cutter.

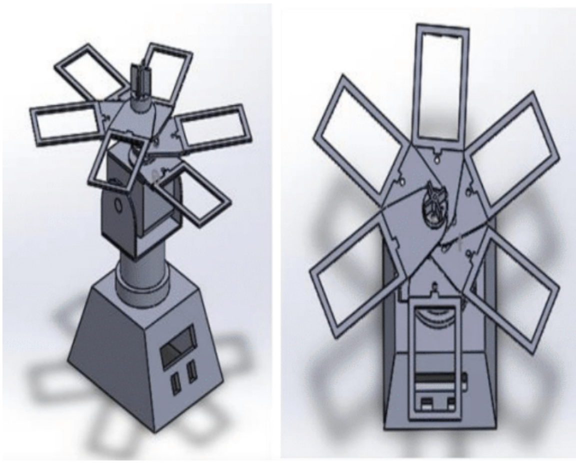

Fig. 4. Final structure of the implemented solar tracker.

Finally, in Figure 5, the tracker control circuit can be seen. Based on the inputs and outputs of the system, the circuit was made using the ESP32 controller. The circuit shows the interconnection between the different elements, mainly the panels or petals.

The parts that make up the solar tracker are: the mobile structure, the transmission system, the control and power system, and finally, the data collection.

Each solar plate was fitted with the hollow shaft in the following order: one pivot base of the upper solar plate, four pivot bases of the intermediate solar plates and one pivot base of the lower solar plate.

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The Arduino IDE platform was used to create the control code (Figure 6), since it also has the option to program the ESP32 controller.

## IMPLEMENTATION OF THE SOLAR TRACKER

All parts of the tracker were carefully assembled and assembled to avoid structural and connection failures. After testing, the solar tracker was completed to start the study of the efficiency of solar and electric energy. Figures 7 and 8 show the final version of the solar tracker. The control circuit is located inside the acrylic structure. On the outside you can see the rechargeable batteries, the display and the blower panels, as well as the servomotor.

Fig. 7. Front view of the solar tracker.

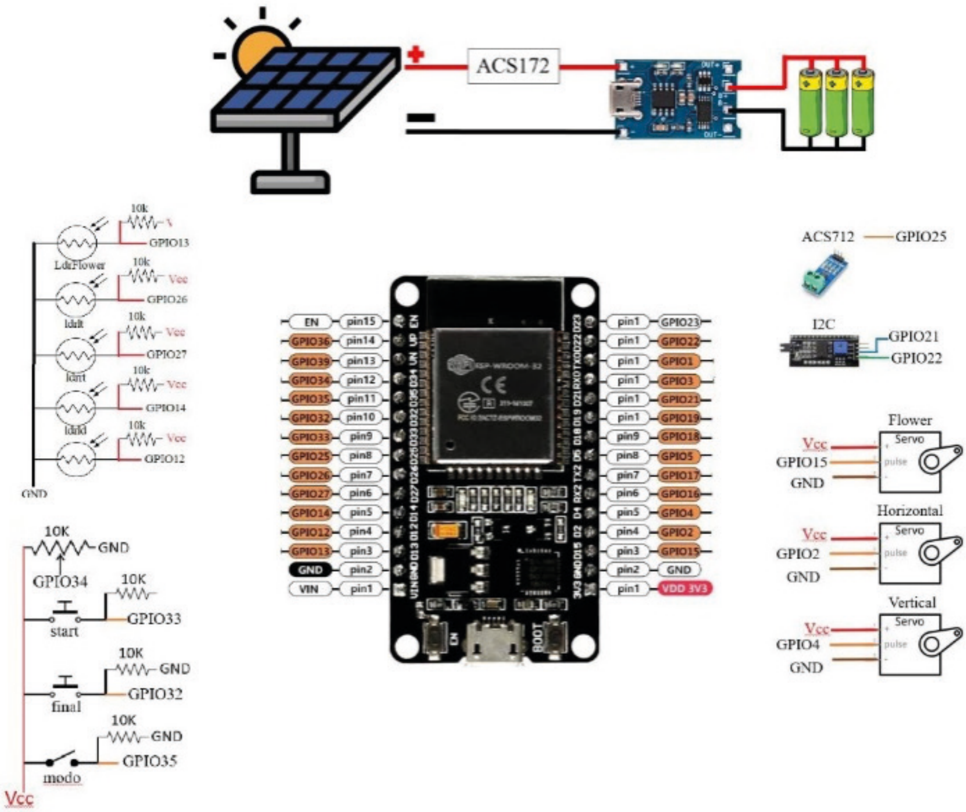


Fig. 5. Solar tracker control circuit.

solarTrackerEsp32 Arduino 1.8.19 (Windows Store 1.8.57.0)

Archivo Editar Programa Herramientas Ayuda

solarTrackerEsp32

```
#include <ESP32Servo.h>
#include <LiquidCrystal_I2C.h>
#include<Wire.h>


//declaracion de ldrs-señal analogica
const int ldrFlor = 13;
const int ldrlt = 26; //LDR top left - BOTTOM LEFT <--- BDG
const int ldrrt = 27; //LDR top rigt - BOTTOM RIGHT
const int ldrld = 14; //LDR down left - TOP LEFT
const int ldrrd = 12;

//declaracion de botones--señal digital
int inicio = 33;
int fin = 32;
int modo = 35;

int modo_estatico_dinamico;
int estadoBotonInicio = 0;
int estadoBotonFinal = 0;
int pos = 0;
int pos2 = 0;
```

Fig. 6. Arduino IDE interface.

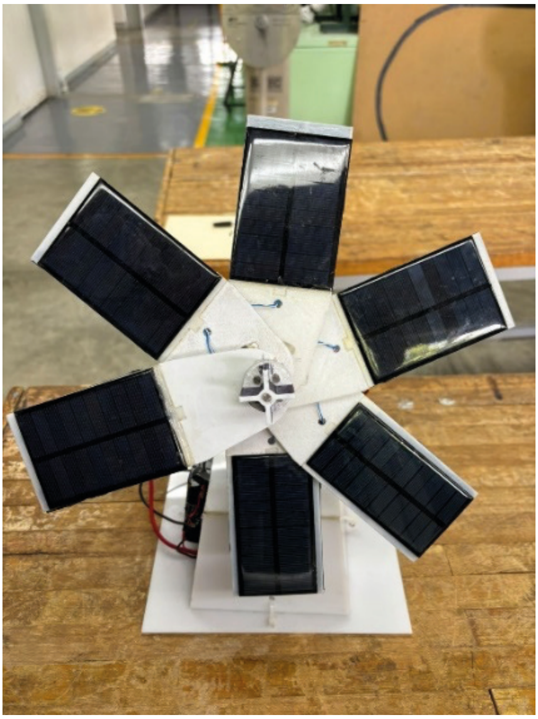

Fig. 8. Rear view of the solar tracker.

## RESULTS

First, tests were performed in a dark environment and using a lamp to simulate the movement of the sun. Figure 9 shows the tracker in darkness illuminated by a lamp.

Figure 9. Functional tests of the solar tracker in the dark and illuminated by a lamp.

This allowed to verify that all components of the tracker responded to the incidence of light before exposing it to sunlight, particularly the light sensors and the motor.

Subsequently, by adjusting the appropriate light sensitivity, the solar tracker was tested outdoors, in these tests the data of the current generated by the solar panels, either in static mode or in solar tracker mode, were taken for analysis. Several tests were performed in cloudy weather and in clear weather. This allowed observing the behavior of the solar tracker and its response to solar radiation.

The results obtained in sunny weather and in the two modes, static and dynamic, are shown in Table 2. The last column shows the percentage difference between the dynamic mode compared to the static mode. It can be seen the advantages of the solar tracker as a dynamic system in contrast to the static mode.

| Time | In Static | In Dynamic | Difference |
|---|---|---|---|
| 07:00 | 0.11 | 0.34 | 209% |
| 08:00 | 0.17 | 0.37 | 118% |
| 09:00 | 0.34 | 0.49 | 44% |
| 10:00 | 0.76 | 0.82 | 8% |
| 11:00 | 0.82 | 1 | 22% |
| 12:00 | 1.11 | 1.11 | 0% |
| 13:00 | 1.07 | 1.25 | 17% |
| 14:00 | 1.07 | 1.17 | 9% |
| 15:00 | 0.76 | 1.13 | 49% |
| 16:00 | 0.43 | 0.58 | 35% |
| 17:00 | 0.32 | 0.47 | 47% |
| 18:00 | 0.11 | 0.34 | 209% |

Sunny day current values of the solar tracker.

## CONCLUSION

Finally, and based on the development of the project, it can be concluded that the implementation of dynamic photovoltaic systems generates higher efficiency than fixed photovoltaic systems. The project opens the door to a possible implementation with large solar panels, since the idea to follow does not vary too much, it is only a matter of finding equivalent materials for its implementation.

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