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# ANALYSIS OF PHOTOVOLTAIC PANEL EFFICIENCY USING A SOLAR TRACKER SYSTEM

**Dr. MOHAMED AMER HASSAN ABOBMAHDI**
Faculty of natural resources.
Al.zawiya University
Mohdamerhassan19@gmail.com
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**ABSTRACT**

A solar tracker is a mechanical device that aims to ensure that the photovoltaic panels are always in the most favourable position to capture as much solar radiation as possible. Solar trackers can be used in basically all applications that use solar energy. Relatively recently, they were mainly used in the production of solar thermal energy, but in recent years, with the reduction of costs in photovoltaic technology, their use has increased, combined with photovoltaic energy. With the use of solar trackers and automated systems, photovoltaic panels can absorb more sunlight and capture it more efficiently. In this study, the efficiency of a solar tracker system is being compared with the efficiency of an older, more typical fixed solar system. Automated solar trackers and data gathering systems based on Arduino platforms were developed in order to compare the energy generated by a solar tracker photovoltaic panel to the energy generated by a standard photovoltaic panel, both of which were installed on the same roof at the same time. When tested during the initial and last hours of insolation, the prototype demonstrated considerable power improvements of up to 30 percent. The use of a solar system with a sun tracker is therefore recommended in situations where the energy collecting efficiency of the system needs to be increased.

Keywords: PV Cells, energy efficiency, solar tracker, Automation

**INTRODUCTION**

Energy is an indispensable element for the social, economic and technological evolution of humanity. In particular, electricity is the basic ingredient to connect the world through telecommunications, facilitate the provision of essential services to society, such as health, education and drinking water, move industries and promote technological development. In this way, it is essential that the means of electric energy generation are efficient, with low environmental impact and accessible to the entire population [1].

Some means of generating electricity can be obtained from virtually inexhaustible natural sources and have less negative interaction with the environment, they are the so-called renewable energy sources, or clean energy sources such as photovoltaic, wind, tidal and geothermal, among others.

According to the International Energy Agency (IEA), in 2015 renewable energy sources were the third largest contributor to global electricity production, accounting for 22.8% of world electricity generation, after coal (39.3%) and gas (22.9%) and ahead of nuclear energy (10.6%) and oil (4.1%). According to the IEA, since 1990, renewable electricity generation worldwide has grown by an average of 3.6% per year, which is slightly faster than the total growth rate of electricity generation (2.9%) [6]. Thus, while 19.4% of global electricity in 1990 was produced from renewable sources, this share increased to 22.8% in 2015. These data demonstrate the relevant importance of renewable energies.

Solar energy can be considered a clean energy source, as its generation causes little interference in the environment. The lifespan of photovoltaic modules is more than 25 years. According to Filik, et al (2017) [2], if 0.16% of the earth's surface were covered with solar panels with a conversion efficiency of 10%, an area comparable to the territory of Turkey, it would be possible to produce a power of 20 TW, which is almost twice the world consumption of energy generated through fossil fuels.

In tropical countries, such as Libya, the use of solar energy is viable in practically the entire territory. Solar radiation is higher in regions closer to the equator. However, even in more distant regions, such as the South, the radiation is higher than in many countries such as Italy and Germany, which already use solar energy on a large scale. To maximize the use of solar radiation, in these places, you can adjust the position of the collector or solar panel according to the local latitude and the period of the year when more energy is required.

The use of photovoltaic systems can be considered a great option for punctual electricity generators, in homes, isolated areas, industries, hospitals, universities or any establishment that opts for a reduction, both in its dependence on the external electrical grid and in the costs of electricity consumed on site. According to Khilji et al (2021) [3], photovoltaic solar energy generation in Libya will reach a growth of 325% by the end of 2017 in relation to the capacity of 235 MW in July of the same year. According to calculations carried out by Bazyari, et al (2014) [4], the performance of solar panels with a solar tracker on one axis can be improved by 28% in areas where there is an abundance of solar resources and by 16% in areas with little solar incidence. The researcher group Samaulah, et al, (2018) [5] developed a solar tracking system of an axis in a photovoltaic module with the use of a programmable logic controller (PLC). Two light sensors separated by a barrier were used, in which a considerable angle of solar incidence would cause a shadow on one of the sensors and thus the PLC would order the motor to reposition the solar panel. The objective of this study was to find the gain provided in power due to the use of this solar tracker. A computational program was developed in Visual Basic 5 language so that it could command the PLC and also collect data. Compared with a fixed system, the photovoltaic system with developed tracking showed, at the beginning of the day, an increase of about 40% in the energy supplied, with values between 2% and 4% during the rest of the day. The average increase of this energy supplied throughout the day was more than 20% compared to a fixed photovoltaic system. In the study carried out by Ozcelik, et al. (2011) [7], two prototypes of photovoltaic panels were used, one fixed and one with a solar tracker on an axis. The design used was chosen after a research, aiming at the highest production and the lowest energy expenditure with the movement of the follower. The study was carried out for 30 days, and the experimental results indicated an increase of 12 to 20% in the energy production of the solar tracker system in relation to the fixed system. For clear sky days, the results were consistent and efficient. However, for partially clear and cloudy days, the authors indicate further studies to improve the efficiency of the solar tracker. The photovoltaic systems currently sold in Libya have variable efficiency between 10% and 16% in converting solar energy into electrical energy, according to the Portal Solar website. With the use of solar tracking equipment, which adjust the angle of the photovoltaic plates according to the position of the Sun throughout the day, it is possible to increase the total production of generated energy by an average of 25%. This equipment is known as a Tracker or solar tracker. With the help of basic electronic technology and an Arduino microcontroller, it is possible to develop an automated photovoltaic panel system capable of following the movement of the Sun during the day. Such a system can increase the efficiency of capturing solar energy. This work proposes to carry out a study to measure the energy gain of an automated system of solar tracker photovoltaic panel (Traker), comparing its capture efficiency with that of a fixed structure panel.

## 2- MATERIALS AND METHODS

In this paper, the materials used in the assembly of the solar tracker will be described, as well as the methods used to collect and analyze the data. The solar tracker prototype was developed with a PVC tube structure, supporting a photovoltaic panel on an inclined axis. Connected to the shaft is a lever arm driven by a threaded bar and an electric motor. All movement control is done by an Arduino Uno board. Data capture is done by an Arduino Mega board that transmits the data to a computer connected to the system. The batteries and the charge inverter were not connected to the solar collectors, being used exclusively to supply the motor, electrical circuits and computer. Data collection was performed by an Arduino Mega controller using electronic circuits working as voltmeters connected to the fixed panel and also to the solar tracker.

The materials used in the construction of the system are listed and detailed below:

- Two Solarex 70 W photovoltaic panels;
- Two Heliar DF2500 stationary batteries;
- A Prowatt 800 load inverter;
- An Arduino Uno R3 controller board;
- An Arduino Mega 2560 controller board;
- One L298 H Bridge integrated circuit;
- Two voltage divider circuits with resistors;
- A 12 V DC automotive electric window motor;
- Two breadboards and electronic connection wires;
- 50 mm PVC pipes and connections;
- Two bearings and housings;
- A threaded bar and ¾ nuts;
- Mains cables.

**2.1 - Photovoltaic Panels:** The photovoltaic panels used are Solarex brand with maximum power of 70 Watts each, peak voltage of 20.9 Volts and peak current of 4.8 Amps. The panels used are not new and could present differences in generation voltages. To ensure that both panels used in the work had the same characteristics and generation potential, a test was carried out. Thus, two panels were selected that, when exposed to the same lighting conditions, presented exactly the same output voltage.

**2.2 - Heliar Df2500 Stationary Batteries**: To power the motor, the electrical circuit and the charge inverter, two Heliar DR2500 stationary batteries were used, each with a capacity of 150Ah.

**2.3 - Prowatt 800 Charge Inverter:** A Prowatt 800 charge inverter was used to convert the voltage from 24 V DC of the two batteries connected in series to 110 V AC, making it possible to keep the computer on for approximately 12 hours of the test.

**2.4 - Arduino Uno R3 and Arduino Mega 2560: In** the study, two controller boards were used. Arduino UNO controls the motor and, consequently, the rotation of the movable panel on the inclined axis. The Arduino Mega 2560 is used to read and store voltage data from both photovoltaic panels during the day. Arduino is a tool that enables direct interaction between the physical and cybernetic environment, through sensors that capture physical phenomena and equipment such as motors, pumps and lights, which respond to the stimuli of the sensors, obeying a pre-programmed logic in its CPU. Arduino is an open source electronics prototyping platform based on the flexibility and ease of use of hardware and software. Therefore, it is intended for anyone who is interested in creating ways of interacting with objects or the environment.

In practical terms, an Arduino is a small computer that can be programmed to process inputs and outputs between the device and the components that are connected to it externally. Therefore, it can be used to develop interactive objects independently or can be connected to a computer, a local network or even the Internet [6]. The platform can interact with the environment through hardware and software, as it allows the connection with devices that capture data from the environment or that can be controlled, such as temperature, brightness, distance, pressure, humidity sensors, among others, motors, GPS receivers. , LEDs, buttons, switches, Ethernet modules and displays. Since Arduino is open source, anyone can use the schematics or the project. The software used to write the code, the IDE, is made available by the Arduino project development team, available at its electronic address. Arduino programming is done using the IDE (Integrated Development Environment), in which the user writes code in the language that Arduino understands based on the C/C++ language [6].

**2.5 - H Bridge Integrated Circuit L298:** The integrated circuit Ponte H L298 was used to make it possible to invert the rotation side of the electric glass motor, allowing the control of the photovoltaic panel rotation both clockwise and counterclockwise.

**2.6 - Voltage Divider Circuit, Breadboards and Connection Cables:** Voltage divider circuits can be considered a key piece to obtain data from this study. Such circuits were used to reduce the voltage of the photovoltaic panels from 20.9 V to 5 V, which is the maximum working voltage of the Arduino controller. They also provide a fixed resistance between the positive and negative poles of the photovoltaic panels, thus providing a parameter for calculating the powers of each system, since there is a direct relationship between voltage (V), resistance (R), current (I) and electrical power (P), expressed in equations 1 and 2.

$$V = IR \ldots (Eq\ 1)$$

$$P = V \times I \ldots. (Eq\ 2)$$

Figure 1 contains the electronic system assembled to perform the data collection. It is possible to visualize the voltage divider circuit, the Arduino Mega board, a battery, a breadboard and electronic connection cables. Figure 1 contains the electronics mounted to control the motor of the mobile photovoltaic panel. In it you can see the Arduino Uno, a breadboard with power circuit and connection cables.

**2.7 - Automotive Electric Glass Motor 12 V DC:** To control the rotation of the photovoltaic panel, a 12 V direct current motor with a power of 17 W was used. Figure 1 shows the motor used to move the solar tracker.

**2.8 - Solar Tracker Structure:** In assembling the structure of the solar tracker panel, 50 mm PVC pipes and connections, metal parts, wood and bearings, among other materials, were used. The structure was developed to keep the photovoltaic panel at a 34° angle to the surface. This angle was preset according to the solar declination for the month of October at this location. The structure allows the face of the photovoltaic panel to always remain directed towards the position of the Sun. The structure can be seen in Figure 1. To perform the rotation of the structure, a system was developed with a lever arm coupled to the axis of rotation located in the longitudinal center of the panel. This lever arm is guided by a threaded bar coupled to the 12V motor. When the engine is running, the system produces a panel rotation of 1° every 5 seconds, i.e 0.033 revolutions per minute (RPM). In this way, it was possible to achieve a good accuracy in the rotational angle of the panel, and also a locking of the structure when the engine is off.

The structure to support the photovoltaic panel was assembled with an aluminum frame and iron shaft ends connected to two wooden bearings and bearings coupled to a PVC connection. This assembly provided a relatively strong structure for carrying out the tests and with little friction.The structure's movement system can be seen in figure 1.

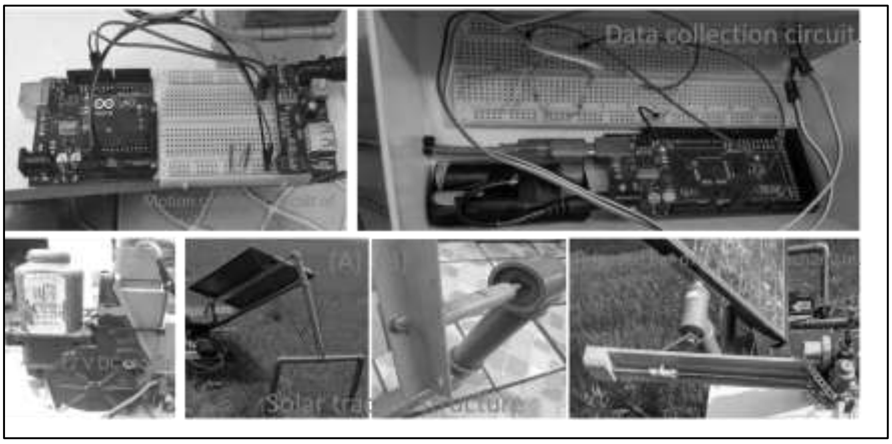


Figure 1: Schematic representation of Components, structure and mechanism of developed tracker

**2.9 - Experiment**

To control the positioning of the solar tracker panel on the day of the tests, it was decided to use a timing command. The timer was created using the Arduino Uno controller (programming in attachments), taking into account the time of rotation of the earth and the angle of solar incidence. With these parameters, it was possible to determine the exact time the engine would need to be on and the interval time for each rotation. With that, the system was programmed to perform a 5° turn in the structure every 20 minutes, thus performing 18 movements during the day. The first movement of the system took place at 10 am and the last at 4:30 pm. In this way, the face of the photovoltaic panel remained at an orthogonal angle to the sun's rays during most of the day. The test was carried out on October 10, 2017. Daylight saving time prevailed on the day of the test, so solar noon occurred around 1 pm. In the following Figure 2 it is possible to visualize the movement of the solar tracker during the testing period. Figure 2 (a) is a image taken around 11:00 am, the Figure 2 (b) was taken at 1:00 pm at solar noon, and the photograph on the right, Figure 2 (c) was taken at 4:00 pm. The fixed panel was always kept in the same position.

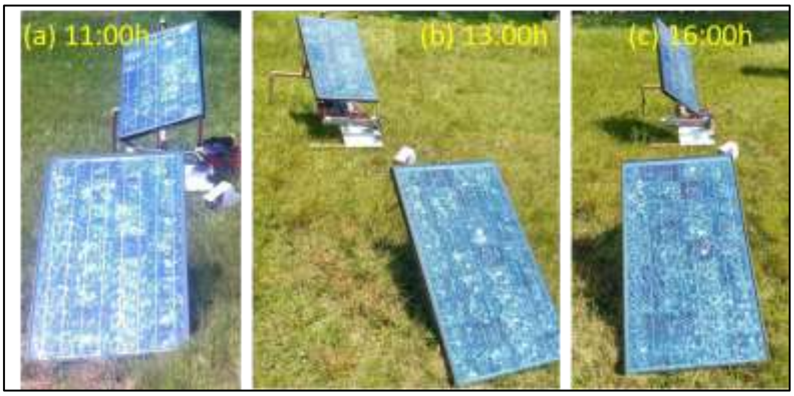


Figure 2:(a) (b) and (c) – Test photographs at different times of the day.

The data for the analysis of the variation of power by the time of solar exposure for the systems of fixed photovoltaic panels and with solar tracker, were obtained through the interaction between the photovoltaic panels, an electronic circuit, an Arduino Mega controller and a computer (schedule in attachments).

First, the electronic circuit mounted on the basis of a voltage divider transforms the voltage values generated by the photovoltaic panels into values that can be processed by the Arduino Mega controller. Through the PLX-DAQ software, the controller transmits the information in real time to a computer connected to the system. Finally, the data is stored in spreadsheets, thus providing a graphical analysis of the results. Voltage values were collected from sunrise to sunset, on October 10, 2017, adding up to a total of 13 hours and 15 minutes, with a collection frequency of 2 seconds, thus generating about 22,000 voltage values for each one of the systems, being able to be considered a significant number of data for the analysis.

**3. RESULTS AND DISCUSSION**

The results of each of the photovoltaic panels are presented below. Figure 3 presents the voltage variation curve over time in the fixed panel. We noticed that in this system the voltage rises slowly until reaching the maximum level of energy generation around 9 am. The voltage remains practically constant, until it starts to decrease around 5:45 pm, continuing to fall until power generation stops at 7:45 pm. The maximum generation duration is approximately 8 hours and 45 minutes.

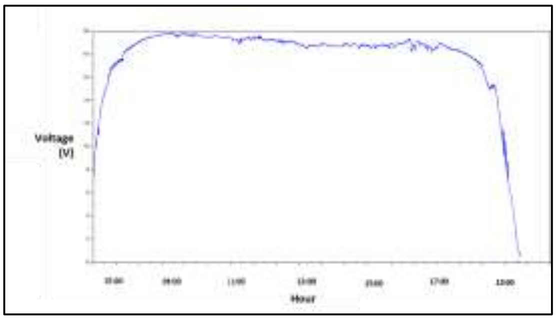


Figure 3: Voltage variation in the fixed panel throughout the day.

Figure 3 shows the voltage variation curve over time on the solar tracker plate. In this system, it is possible to notice that the maximum energy generation of the panel occurs earlier, around 07:00, right after sunrise. The voltage remains practically constant, until around 19:15, the decrease in energy generation begins. It is noticed both an increase and a more abrupt generation decay when compared to the fixed panel. With this system, a maximum generation duration of approximately 12 hours and 15 minutes was reached.

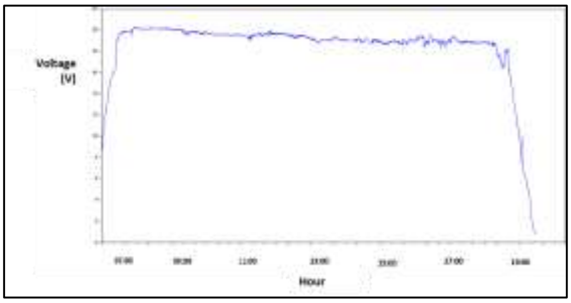


Figure 4- Voltage variation in the solar tracker panel during the day.

From the voltage values for each collection interval, it was possible to identify the variation of the electric current and, consequently, the variation of the power generated in each of the photovoltaic systems, in units of Watts. To determine the power, the voltage obtained in the panels was multiplied by the current that passed through the voltage divider circuit. The total resistance in each of the voltage divider circuits was defined as 1310 Ohms. This high resistance value was chosen to guarantee the integrity of the Arduino Mega, thus avoiding the passage of a high current through the controller.

The current is directly dependent on voltage and resistance, and as the resistance in the circuits is high, the power scale was reduced, limiting the current that passes through the developed circuit, but being representative for any load value used in photovoltaic systems [9].

In Figure 5 it is possible to verify the comparison of the obtained results. In the red line, it is possible to verify the variation of the power during the period of insolation for the fixed system. In the blue line, you can see the power variation in the mobile system. It is possible to identify that the mobile system had greater energy generation efficiency, compared to the fixed system, especially at the extremes of the graph 5, in the first and last hours of daily insolation. There is also a slight increase in efficiency around solar noon.

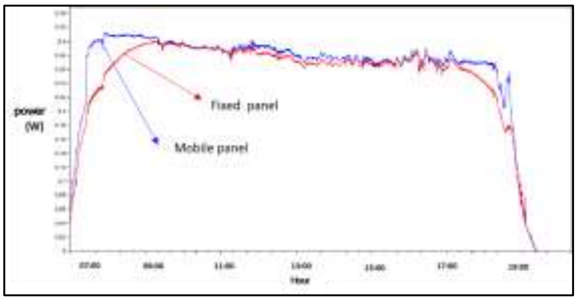


Figure 5: Power generated by the panels during the day.

In some periods of the day, the tracker panel had an efficiency gain that resulted in up to 30% more energy generated than the fixed panel. This maximum can be observed just after 07:00h and also just before 19:00h. During the period from 11:30 am to approximately 2:30 pm, the efficiency gain was around 3%. It is noticed that, in some periods of the day, the generation was practically the same in both photovoltaic panels, as can be observed around 10 am and also at 4 pm.

It can be identified that the generation of both panels is maximum during the morning and tends to decrease gradually over time. This fact can be explained by the increase in temperature of two panels. According to Verma et al (2020) [10] there is a direct relationship between the increase in temperature of the photovoltaic panels with the reduction of the current respectively. Consequently, the longer the time of solar exposure, the higher the temperature of the panels and the lower their generation efficiency.

It is possible to identify a large variation in power generation at approximately 18:50, with a voltage drop in both systems, but more pronounced in the solar tracker [10]. This power discontinuation happened as a result of a shading in the panels caused by a tree located to the west of the study site, affecting mainly the mobile panel.

Through a differentiation between the powers of the two systems, it is possible to identify more clearly the increase in power of the solar tracker panel system, especially during sunrise and sunset periods, that is, at times when the system angle fixed is more out of phase with the solar angle.

Figure 6 shows the difference in power generated between the two systems during the period of insolation.

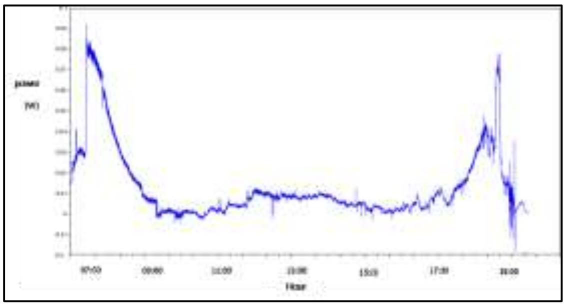

Figure 6: Difference in power generated between the fixed system and the solar tracker.

The automation system developed to move the panel was programmed to move the structure every 20 minutes, keeping the motor on for 6 seconds at each interval. In this way, the mechanism was turned on during the day for a total period of approximately 2 minutes. Since the motor has a power of 17 Watts and the rest of the electrical circuit consumes 3 Watts, the entire movement mechanism consumes a total of 20 Watts. Taking into account the time it remains on during the day and assuming it works for 30 days, the total energy expenditure during a month to carry out the movement keeping the panel always facing the Sun is 0.02 kWh/month.

Each panel used in the test has a power of 70 Watts, assuming that the panel supplies this energy during a period of 10 hours a day, for 30 days, in a month it supplies 21 kWh/month. In this way it is possible to quantify the amount of energy spent to move the panel compared to the energy produced. The tested drive system consumes 0.095% of the total theoretical energy produced by a 70 watt photovoltaic panel during a month.

**4 CONCLUSIONS**

With the results obtained, it is possible to conclude that a tracker tracker solar panel system can be a good option in cases where system optimization is necessary. The increase in efficiency will be more significant in locations where the sun shines on the panels throughout the day, from dawn to dusk, as the greatest gains in capturing solar energy occur at these extremes of the day. It may not be viable in places where there is shading of the panels. Efficiency gains can be considered significant, reaching up to 30% at certain times of the day. It is extremely important in this type of system the energy consumption ratio for moving the panel with the increase in efficiency generated by the mechanism. In this study it was found that the application of a solar tracker system can be viable because the energy consumption for movement is low, with 0.095% of the total energy generated by a 70 Watt photovoltaic panel, in this type of solar tracker.

In future studies, the relationship between the heating of the solar panels and the variation of the electric current generated by the Tracker systems can be further analyzed. As well as a quantitative analysis of the relationship between energy consumption and power increase of this type of solar tracker.

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