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Single Axis Solar Tracker for Maximizing Power Production and Sunlight Overlapping Removal on the Sensors of Tracker

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ABSTRACT

This paper presents the design and execution of a solar tracker system devoted to photovoltaic (PV) conversion panels. The proposed single-axis solar tracker is shifted automatically based on the sunlight detector or tracking sensor. This system also removes incident sunlight overlapping from sensors that are inside the sunlight tracking system. The Light Dependent Resistor (LDR) is used as a sensor to sense the intensity of light accurately. The sensors are placed at a certain distance from each other in the tracker system to avoid sunlight overlapping for maximum power production. The total system is designed by using a microcontroller (PIC16F877A) as a brain to control the whole system. The solar panel converts sunlight into electricity. The PV panel is fixed with a vertical axis of the tracker. This microcontroller will compare the data and rotate a solar panel via a stepper motor in the right direction to collect maximum photon energy from sunlight. From the experimental results, it can be determined that the automatic (PV solar tracker) sun tracking system is 72.45% more efficient than fixed panels, where the output power of the fixed panel and automatically adjusted panel are 8.289 watts and 14.287 watts, respectively.

1. Introduction

Renewable energy is becoming popular because its capability of producing power efficiently increasing [1]. Over the last few decades, energy consumption in the world is increasing around 56% in the developing world. About 1.6 billion people in the world are not familiar with electricity [2]. In addition, covering 0.16% of the land on earth with 10% efficient solar conversion systems would provide 20 TW of power, which is near twice the world's consumption rate of fossil energy [3]. Consuming energy, specifically electrical energy, is flourishing in the world. The people of the world are mostly dependent on electrical energy. On the other hand, according to the International Energy Agency (IEA), energy demand will be doubled during the next 40 years for progressive countries. Essentially, the prime source of energy is fossil fuels. Existing sources of energy are downsizing significantly. Environmental pollution is caused by increasing fossil fuel source [4]. Some sources in the world are fully free, unlimited, available, and pollution-free. Renewable energy is the energy that covers solar energy, wind energy, geothermal, ocean tidal wave and biofuel, etc. Solar energy is infinite energy like other renewable energy [5-7]. It is also called “alternative energy” [8]. In addition, one recent statistic says that the energy demand of humanity can be fulfilled by solar energy if it is possible to capture 1% of the sunlight coming to the earth. Solar energy has no boundaries and free of cost. It has no pollution and greenhouse emission. Photovoltaic (PV) solar cell converts the solar radiation into electricity [9]. The efficiency of the existing solar energy production system is not satisfactory due to some reasons, such as fixed solar panels, weather conditions. In the world, most of the research group is trying to invent new ways to improve the efficiency of output power through PV. PV panel’s efficiency is related to irradiance, temperature and solar incident angle, and intensity of sunlight. Those parameters are counted for the higher output of the PV panels. At present, researchers are still trying to improve efficiency with different techniques. A solar tracker is one of the latest techniques to improve the power generation of PV panel for maximum sunlight capture.

A solar tracker is a way to improve the efficiency of PV panels [10]. The power generation will also be increased when the sun position is adjusted concerning the PV panel [11, 12]. The collected solar radiation is directly proportional to the generated output power [13]. A complete solar system has several parts, including a photovoltaic (PV), battery, charge controller, and transmission line. PV panel is the most important part of the solar system because it captures sunlight from the sun to convert via different media. Single-axis and dual-axis solar tracking are the common methods to reduce the cost of power generation and maximum power production. Both tracking systems are generally tracked the sun position using sensors. Sometimes sunlight overlaps on sensors that are inside the tracking system. Neville has provided a theoretical explanation for a mid-latitude region ($\emptyset = 30^o$), compared to the fixed photovoltaic panel tilted at an angle equal weight to the local latitude with a 41% power increase [14]. They observed that about 41% power generation increment using a two-axis tracking system, whereas the increment rate was about 36% with the single-axis system. There were several approaches to apply for solar power generation, such as single-axis open loop [15], two-axis open loop [16], and dual-axis closed-loop [17] for tracking systems. Rizk et al. and Chaiko et al. presented the benefits of the tracking system using a light sensor and stepper motor [18-20]. Al-Mohamad [21] used two sensors with a single-axis solar tracker. They found about 20% daily output power of the tracking panel is more than a fixed panel. However, the existing literature indicates that research on this issue is still in its infancy.

Therefore, this study was initiated to design and execution a solar tracker system devoted to PV conversion panels. The novelty of this study lies in designing the tracker system. This study is structured as follows:

- A novel solar tracker system has been developed which can remove incident sunlight overlapping on sensors that are inside the sunlight tracking system (Section 2).
- A rigorous experimental study has been conducted to evaluate the performance of the developed solar tracker system (Section 3).
- Experimental results have been analyzed to demonstrate the effectiveness of the developed solar tracker system (Section 4).

2. Solar Tracker

There are various methods of sun-tracking systems used for evaluating and surveyed to stand the PV panel perpendicular to the sun. There are two main types of solar tracker exist active (electrical) and passive (mechanical) [22]. The passive solar tracker is the system in which the solar panel is fixed with a face upwards to the sky. Most of the passive solar tracker is operated manually [23]. On the other hand, an active solar tracker is an automatic solar tracking system that is based on microprocessors, computer-controlled data, and time [24, 25]. Most of the active trackers use the sensor for moving the panel with sunlight [26]. The annual power consumption of dual-axis solar tracker is 72% over single-axis solar tracker. The dual-axis solar tracker is more complicated, costly, and requires high maintenance as compared with one axis solar tracker [3]. In this proposed system, the solar tracker is used because a solar panel is not moveable, and it can improve the efficiency of power. The sun moves from east to west, but the solar panel is standing able. PV panel power output increases when solar panel moves accurately using the tracking system with the sunlight direction. The motion of the sun has a particular orientation of a plane on the earth. There are two types of angles, firstly the sun moves east to west, and it is defined by azimuthal angle. The second angle is called the zenith angle, where sun elevation or complementary angle. A solar tracker is a device that solar panels can move easily from one side to another side with moving sun. If the PV panel is installed according to the sun moving path and focuses on the sunlight all day hours, the maximum electricity will be produced from sunlight. The solar panel tracking system is the system to increase power generation and reduce the cost of power generation. In this proposed system, Light Dependent Resistor (LDR) is used for accurate sun tracking position, cost minimization, and better output power. Those LDRs are easy to collect. It is microcontroller-based and program. The Liquid-crystal-display (LCD) is used for the observation and getting signal from the sun incident. Basically, the sensor is the most important part of the tracker.

2.1. The sensor of Solar Tracker

An optical sensor that is called a photoresistor is also known as LDR. It can be used as a light-dark detector and switching circuit. A photoresistor is made of a high resistance semiconductor. The resistance of LDR varies with the intensity of light. In this investigation, LDR is used as a sensor. The diagram of LDR is shown in Fig. 1.

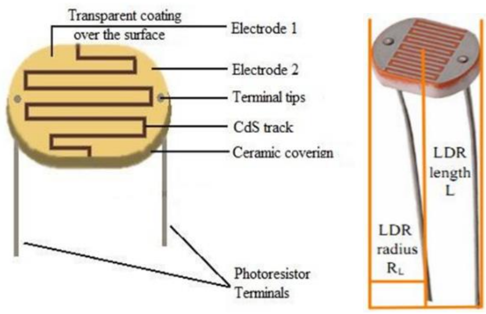


Fig. 1. (a) Light Dependent Resistor (LDR) [27]; (b) The schematic diagram of LDR.

The amount of light can be measured using an LDR. This is one kind of resistor whose value is dependent on the amount of light that hits it. The relationship between the resistance and the amount of light is expressed by

$$R = \frac{500}{L} \tag{1}$$

Where R and L are resistance and light intensity, respectively, the variable resistance can be used as a voltage divider to obtain a manually adjustable output voltage at the slider (wiper) from a fixed input voltage applied across the two ends of the potentiometer. This is the most common use of them. The LDR sensor is designed by the voltage divider circuit, as shown in Fig. 2.

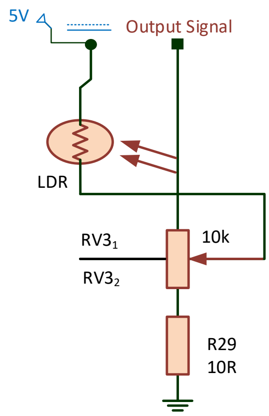


Fig. 2. The basic circuit of solar tracker sensor.

Based on Fig. 2, the equation in LDR can be written as

$$\mathrm{V}_0 = \frac{RV3_1 + RV3_2}{RV3_1 + RV3_2 + \frac{500}{L} \times 1000} V_1 \tag{2}$$

Where the output signal V_0 depends on the light intensity and variable resistance RV3. So, the maximum (when direct sunlight falls into LDR and RV3 is high) and minimum (when cloudy day and RV3 is high) voltage can be calculated. LDR performance is based on the intensity of sunlight. For absolute sun tracking, the sunlight intensity is the major factor for the sensor.

Table 1 presents the sunlight intensity for the indifferent situation of sunlight. For direct sunlight, the maximum output voltage from (2) is

$V_{0(max)} = 4.99V$ and $V_{0(min)} = 0.83V$

At night, $V_{0\,(max)} = 0.098V$ and $V_{0(max)} = 9.99 \times 10^{-5}V$

Table 1. The intensity of different types of light.

Situation	Light (Lux)
Direct sunlight	100,000
In direct sunlight	20,000
Cloudy Day	10,000
Office	350
Room with candle	50

2.2. Research Design and Implementation

Sensor (LDR) is part of the parcel of the solar tracker device. PV panel is moving with the sensor path in the direction of the incident sunlight. For the accurate moving of the tracker, it is placed at a specific point in the solar tracker device. Sensor placement in the tracking system is the new model of a solar tracker device. Five or seven LDR are used in the tracking system. It is arranged in one dimensional on half of the circle body shown in Fig. 3. The sunray generally falls at a 30-degree angle on the solar panel in the morning with respect to the environment in Dhaka, Bangladesh. Therefore, 30° angle is omitted from both sides (0° to 30° and 180° to 30°), as shown in Fig. 3. The angular distance of each LDR is 17.14°. Let's consider UBV as a circle with radius r of the sensor structure.

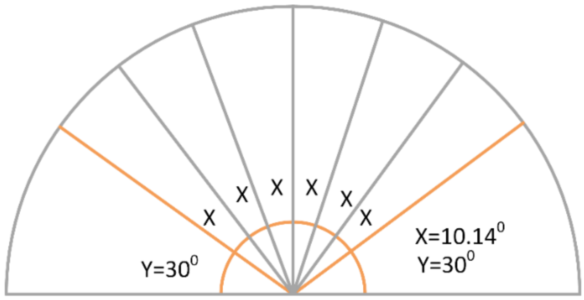


Fig. 3. Sensor Structure

The sunlight rays name as R_1, R_2 and R_3 are falling into two sensors at 90° angle according to Light law shown in Fig. 4. Now, it can be found at point Q or distance $OD = D_1$where centre lines of two LDRs at sensor body are intersected by then R_1, R_2 and R_3.

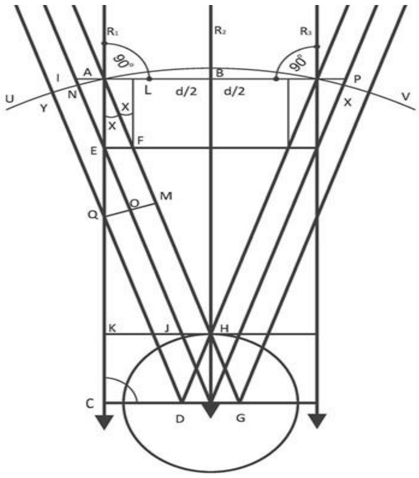


Fig. 4. Overlapping distance OD form center.

Fig. 4 represents the sensor which is placed with the accurate distance for sunlight overlapping between two sensors where $\mathrm{OD} = \mathrm{D_1}$the accurate distance between two sensors is

$$\mathrm{D_1} = \mathrm{r} - 2\frac{\mathrm{NA}}{\mathrm{COS}\angle\mathrm{EIA}} \tag{3}$$

Where, NA= LDR radius, r = Circle radius.

OD is a separate distance between two sensors (LDR) from the center of the circle, where sunlight is not overlapping on the LDR surface at a 90° angle with respect to the law of light. The length of LDR must be kept within the distance D. Otherwise, the solar tracker device does not work properly.

For 5 LDR sensors that are shown in Fig. 5(a), LDR distance L is equal to $\mathrm{D_1}$ and the radius of the sensor is $\mathrm{R_L}$. In practice, L is 2cm, the dedicated angle ∠IDP of 5 LDRs is 24°, and the radius of LDR is 0.25 cm. It can determine the radius r of the body sensor. So,

$$\mathrm{r} = \mathrm{D_1} + 2\frac{\mathrm{NA}}{\mathrm{COS}\angle\mathrm{EIA}} \tag{4}$$

Therefore, $\mathrm{r} = 4.405$ cm.

Now, assume D_1 is equal to L at the initial level. The radius r must be greater than this value, or the length of LDR must be less than D_1.

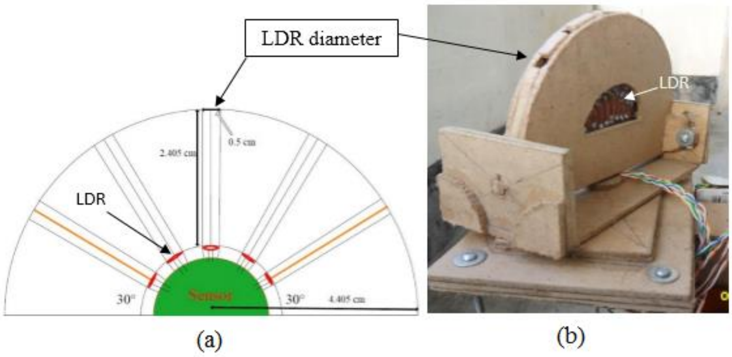
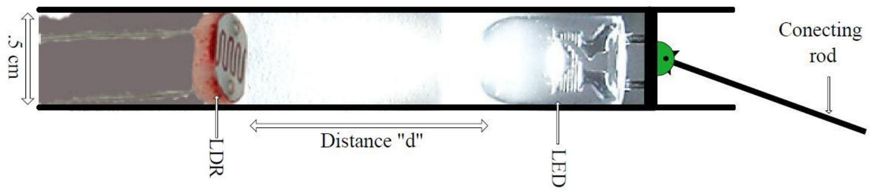


Fig. 5. (a) Sensor with 5 LDRs; (b) Sensor with 7 LDRs in the real world.

2.3. Feedback of Solar Tracker Device

The feedback of the solar tracker device measures the angular distance of the solar panel to improve the exact position, as shown in Fig. 6 (a). The feedback sensor is designed with LDR and LED according to (2). LDRs or Light Dependent Resistors are very useful, especially in light/dark sensor circuits. Normally the resistance of an LDR is very high, sometimes as high as 1000000Ω. It can be measured by the voltage drop across the LDR with a microcontroller DC port which can be changed depends on the light intensity of the LED, sunlight and others.



(a)

(b)

Fig. 6. (a) Inner position of feedback device of solar tracker; (b): Feedback device of solar tracker full.

3. Experimental Setup

In this proposed system (see Fig. 7), the solar panel collects electrons (charge) from the sunray and provides input power to the charge controller. The charge controller is one of the important sections of this circuit. It has multifunction such as load voltage controlling, battery monitoring, power control, battery (rechargeable 12v, 7A) charge control. In the daytime, the battery is recharged via a charge controller from solar output voltage, and its voltage is used at load. When a load voltage is below 11.6V or equal to 11.6 volts of battery, the charge controller sends cut-off the signal to the microcontroller, and it detects the signal.

The power driving circuit supplies 5 volts to the microcontroller for driving it. The microcontroller is the main part of this diagram because it controls a total circuit. The input sensor tracks the sun position, then sends the signal to the microcontroller. The microcontroller detects it and sends the desired signal to the amplifier circuit, then amplifies the input signal up to 12 volts for the driving stepper motor. The stepper motor drives the gear to the desired position of the solar panel. The feedback sensor sends a signal to the microcontroller for the exact position of the solar panel. If the panel stays in the desired position, the microcontroller does not send signals. Otherwise, it sends signals to the driver circuit of the motor to rotate for the exact positioning of the solar panel.

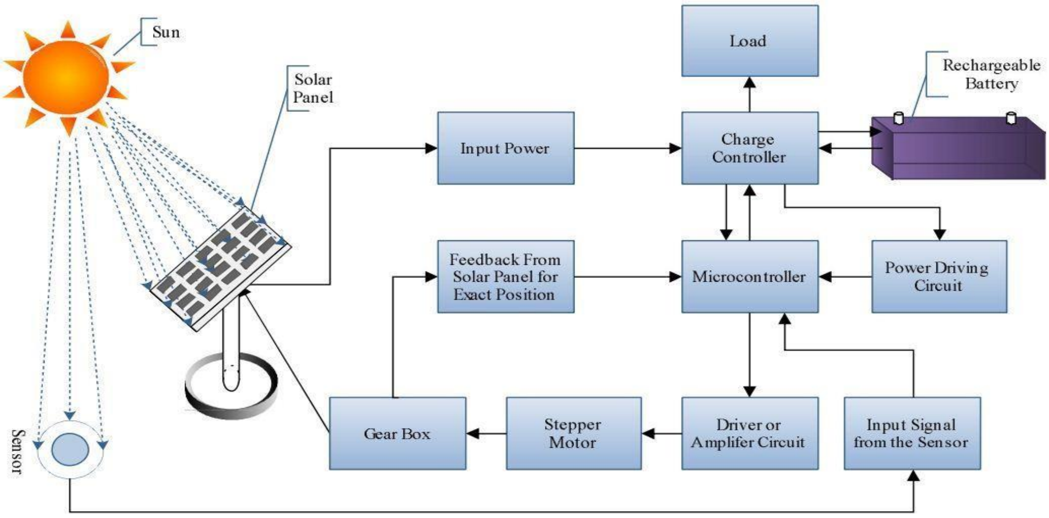


Fig. 7. Block diagram of the solar system.

The experimental setup is shown in Fig. 8. According to design, the solar panel is kept at 90^0 angles with respect to sunray for maximum energy conversion where the sun position detector (tracking sensor) detects the position of the sun and sends a signal to the mainboard. The mainboard processes the signal and takes the decision either it rotates or not by the stepper motor. The solar panel position detector (feedback device) always measures the angle of the solar panel with respect to the panel stand and sends a feedback signal to the mainboard to keep it in the appropriate position. Its rotation continues on the left or right side until it keeps at a 90-degree angle with respect to the sunray. The mainboard has a built-in charge controller that charges the battery and controls the load. The experimental setup has been installed on the building rooftop. The height of the rooftop is around 20 meters. During the experiment, the temperature, open voltage, and current for power measuring have been recorded. The experimental data have been collected in normal conditions with an average temperature of around 40^0C.

Fig. 8. The experimental architecture of solar tracker device.

4. Result and Discussion

The voltage and current readings from the solar panel were taken at three-position (static, manual, and automatic). The sun tracking mechanism can improve efficiency by manually moving the panels to face the sun and also took the data for fixed positions of the panels. Data has been taken from at the beginning of the day. The effect of solar tracking on the PV performance can be measured by the efficiency, which is defined as [28, 29].

$$\eta = \frac{(E_T - (E_F + E_c)}{E_F} \tag{5}$$

where, E_T is the energy produced by the tracking PV, E_F and E_c is the energy-producing by the fixed PV and energy consumption by the tracking, respectively. Table 2 shows the experimental results of the gain percentage of tracking PV according to the fixed panel. The power gain of a power tracker is increased with Bakos and George C.'s [30] experimental investigation.

Table 2. PV Performance by Tacking System.

Panel Position	Power (W)	Gain (%)
Fixed Panel	8.289	
Adjusted Panel	14.234	71.72
Tracker Panel (Automatic)	14.287	72.45

Fig. 9 shows the output power of the static and automatic solar panels. At the beginning of the day, it marked a spot that was considered to be the fixed position of the panels. A static PV panel power curve is lower than the static panel power curve. From the start to the next 45 minutes, a panel was placed in the correct position to obtain the current and voltage that were taken through the 5 watts' panel. For the 5-watts panel, the load was 112-Ohm resistors (from the PV panel gives maximum power output at a load around 120 ohms), and the 12V battery was connected to it. These experimental results were collected from 8.45 am to 5 pm. From Fig. 10, it can be observed that the output power of the manual PV panel is near the automatic PV panel. In contrast, the static PV panel power is very low.

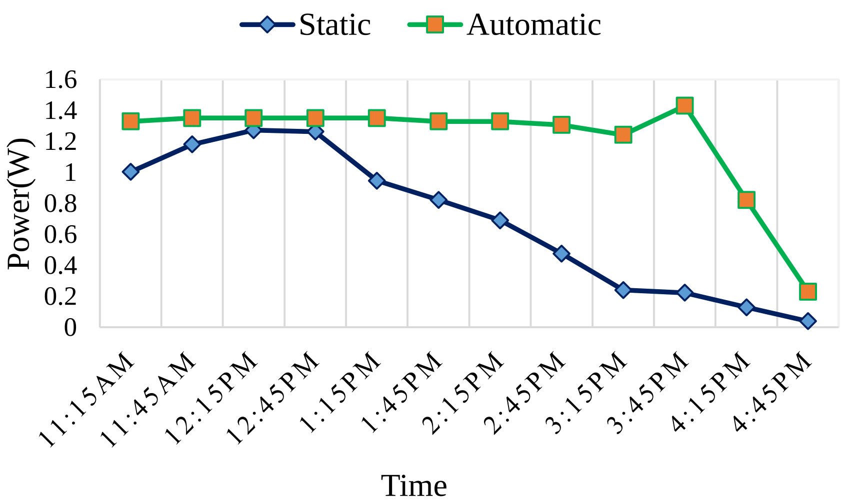


Fig. 9. Output Power of 5-Watt PV Panel (Static Vs Automatic).

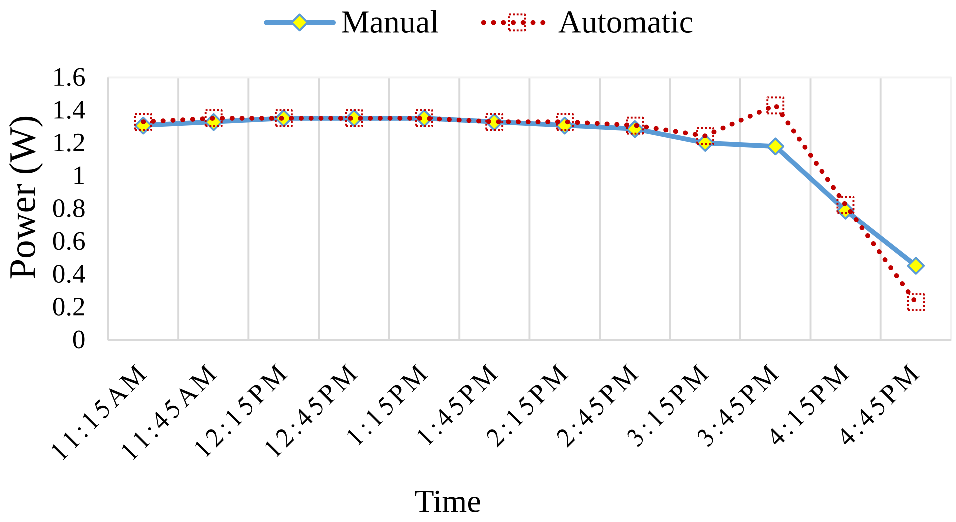


Fig. 10. Output Power of 5-Watt PV Panel (Manual Vs. Automatic).

Fig. 11 displays three different output power of different solar panel positions. Here, the Fig. 11, the automatic panel output has a significant contribution to the solar system because the power curve of automatic PV panels is higher than static and manual PV panels. For the static PV panel at the starting of the day (8.45 am), the power was increased until 10.15 am before power dramatically decreased in the afternoon at 5 pm. The automatic PV panel output was approximately stable until at 4.15 pm then suddenly decreased to 5 pm. Therefore, the power output for PV automatic panel was 72.45% to more than a static PV panel. It is occurred by the proposed solar tracker (automatic PV) system. For this solar tracker, the power has increased dramatically. The maximum sunlight captured is possible due to the solar tracker in each solar system.

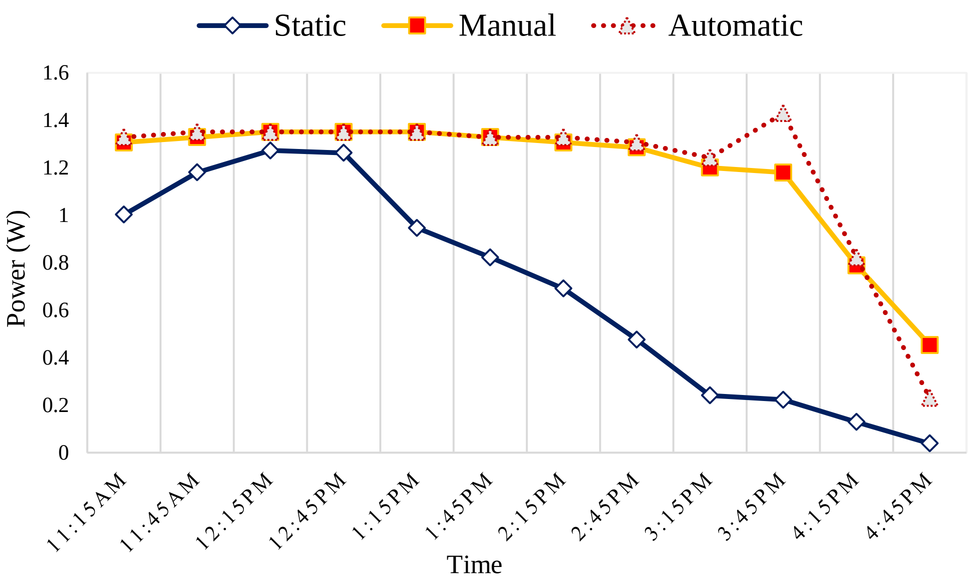


Fig. 11. Output Power of 5-Watt PV Panel (Automatic, Manual, Static).

Error bar has been calculated for each parametric investigation to express the variability values that are used in the graph to point out the error or uncertainly in a reported measurement. Fig. 12 shows the error bars of the experimental values of the output power of three different places solar panels. The minimum and maximum errors have at time 12.15 pm and 3.45 pm respectively. It refers that the minimum and maximum deflections of output powers are observed at 12.15 pm and 3.45 pm, respectively.

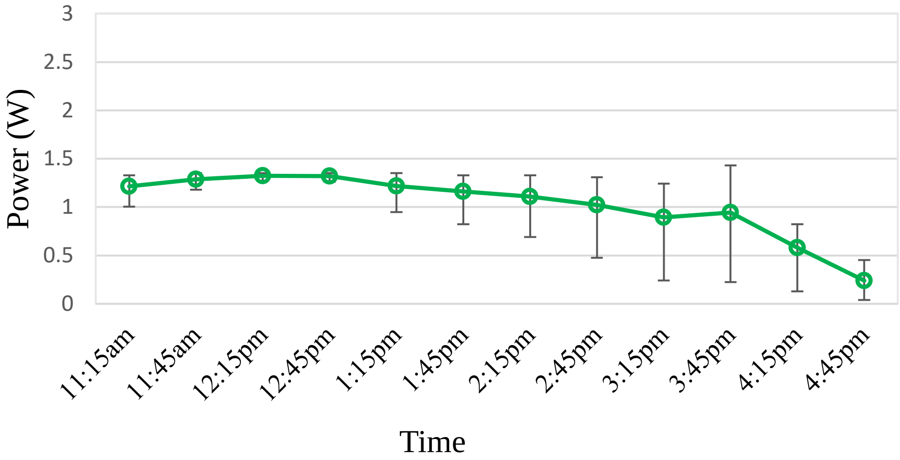


Fig. 12. Error Bar of Output Power.

5. Conclusion

In this paper, the design, modeling, and experiment of a single-angle solar tracker are presented. The tracker depends on the sunlight. If the sunlight intensity is very low, the tracking system is not able to move the PV panel. This happens because the tracking system depends on the sensors that depend on sunlight. It can clearly be determined from the results that the moveable PV panel by the tracker can improve the power efficiency significantly. The control of the tracker is flexible.

Thus, it is feasible and practical to make the solar panel move to make it more efficient because of the current moment of the world, even a 1% improvement would be worth it, and the automatic sun tracking system has shown to be 72.45% more efficient than fixed panels; an appropriate way to harvest more solar energy. This solar system can be used domestically to provide highly efficient solar energy. For commercial purposes, it can be manufactured in the industry because the components of the solar tracker are recoverable and at low prices. In the future, it will cover large-scale smart grid solar energy with high efficiency.

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