# Design and Implementation of an Automatic Single Axis Solar Tracking System to Enhance the Performance of a Solar Photovoltaic Panel.

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***Abstract*—The power consumption rate is increasing daily, and people are greatly dependent on conventional energy sources. If it continues, the conventional energy sources will end very soon. So, it is the appropriate time to use renewable energy sources along with conventional energy sources. Solar energy is the cleanest and sustainable renewable energy source. By using a solar photovoltaic (PV) panel, solar power can be converted into electricity. The electricity production rate from a solar photovoltaic panel depends on some factors such as solar irradiance, solar cell materials, solar cell surface temperature, etc. When the solar cell captures more sunlight, the more power it produces. A fixed state solar panel can't capture maximum sunlight during the sunlight hour because the sun's position in the sky changes all day long. An automatic sunlight tracking system is required to ensure that the panel captures maximum solar irradiance. This research aims to design and implement a microcontroller-based automated single-axis solar tracking system to capture maximum sunlight and to extract maximum power from the solar PV panel in various sun positions. This system helps to face the solar panel towards the sunlight according to the sun's movement in the sky. By using the tracking system, the panel can absorb a higher amount of solar power and increase the solar panel's output power.**

***Index Terms*—Renewable Energy, Automatic Single Axis Solar Tracking System, Microcontroller, Solar Photovoltaic Panel, Solar Irradiance.**

## I. INTRODUCTION

The power demand of the world is increasing daily but our conventional energy sources are limited. Moreover, the conventional energy sources are ending very soon. So, it is the appropriate time to find an alternative source of energy. As an alternative source of energy, renewable energy sources can be considered as the best option. Solar energy, geothermal energy, tidal energy, wind energy, biomass energy, hydro energy are some popular renewable energy sources. Among them, solar energy is very eco-friendly and free of cost as the sun provides us with a massive amount of power. Solar energy is now becoming a fast-growing energy sector because of the availability of sunlight in all places and causing no harm to the environment. A sun tracking system comprises of many sensors to monitor the panel position and provide a signal to motors to position the panel properly by receiving maximum radiation. In 1962, the first solar tracker was created by Finster that was entirely mechanical. A system with an automated electronic control utilized for orienting a pyrheliometer was presented by Saavedra et all [1]. A single-axis sun tracking system utilizing an ARM processor based on the real-time clock (RTC) has been proposed by the authors [2].

In recent years, rural people of Bangladesh have already started using solar energy for electricity generation to use in their houses and for irrigation purposes. Since some factors affect the output power of the solar photovoltaic panel, some sort of system is required to control these factors. The power output of a solar photovoltaic panel is dependent on the amount of sunlight it absorbs. By facing in the south direction with an inclination of 23º, a fixed state solar panel can absorb sunlight all day long. But for capturing maximum sunlight, a tracking system is necessary. A sunlight tracking system can help the solar panel so that it can absorb maximum solar irradiance to enhance the power output. The sun rises in the East and sets on the West and it continuously changes its position in the sky all-round the day. So, for solving this problem, an automatic solar tracking system will be beneficial. An automatic solar tracking system is a system that rotates the solar panel automatically according to the changes in the sun's position in the sky. The tracking system is based on some components such as Microcontroller (Arduino Nano), DC Motor and LDR (Light Dependent Resistor). The main operating principle of the tracking system is the Microcontroller gets a reading from the sensor about the light intensity in the facing direction of the solar panel and sends an instruction to the motor to rotate the panel clockwise or anticlockwise.

Several works had been done on designing and implementing sun tracking systems by many authors. The authors had discussed about implementing a sun tracking system using a Fuzzy Logic Controller [1]. But the design and coding of the Fuzzy Logic Controller are very complex. For this reason, in this work, Arduino Nano is used as a microcontroller and offers simple coding and availability in the local market. The authors had given an idea about implementing a single axis sun tracking system using Microcontroller (ATmega328) and servo motor [3]. For rotating a solar panel of small size just like a 5W solar panel, it can be used. But while tracking a medium or larger size solar panel such as 10W, 20W, 60W and so on, it is not entirely helpful. For this reason, in this work, a 10 RPM DC Motor is used. So, this tracking system will help for facing the solar panel towards the sun position all day long to utilize the solar power at the maximum level which results in increasing the power output and efficiency of the solar photovoltaic panel.

## II. SOLAR PHOTOVOLTAIC SYSTEM

The solar photovoltaic system is based on solar power. Solar power can be used in many ways. According to the practices of using solar power, the components of a solar photovoltaic system may vary from one another. For electricity generation purposes, the solar PV(Photovoltaic) panel is regarded as the system's main component.

### A. PV Cell Model

The PV cell is a specially designed p-n junction. The photovoltaic systems are designed around these cells. There are different types of PV cells according to their construction materials such as monocrystalline, polycrystalline, thin-film amorphous silicon, concentrated solar PV cells, etc. The solar system's output is also dependent on these constructional materials and the efficiency varies from one type to another [4], [10]. The equivalent circuit of an ideal solar photovoltaic cell consists of a photocurrent source, a diode, a series resistance and a shunt resistance. The power output also dependent on the values of series and shunt resistance. The current source which is generated by the sunlight and the diode and the shunt resistance are connected in parallel and another resistance is connected in series. The voltage across the load is V and the current flowing through the load is I. So, the current flowing through the load can be written as,

$$I = I_L - I_0 \left[\exp\left(\frac{q(V+IR_S)}{nkT}\right) - 1\right] - \left(\frac{V+IR_S}{R_{sh}}\right) \quad (1)$$

Where,

$I_L$ = Light Generated Current (A),

$I_0$ = Reverse Saturation Current (A),

$R_S$ = Series Resistance (Ω),

$R_{sh}$ = Shunt Resistance (Ω),

q = Charge of electron (C) = $1.6*10^{-19}$ C,

n = Diode Ideality Factor,

k = Boltzmann Constant = $1.38*10^{-23}$ $JK^{-1}$,

T = Temperature (K).

In (1), the load current value is greatly dependent on the value of the photocurrent or light-generated current. The value of photocurrent changes according to the changes in solar irradiance. With the increase of solar irradiance, the photocurrent value increases and vice versa. The solar irradiance also affects some parameters of a solar cell which results in changes in output power and efficiency. $V_{OC}$ (Open-circuit voltage), $I_{SC}$ (Short-circuit current), $P_{max}$ (maximum power output), FF (fill factor) and η (efficiency) of a solar photovoltaic panel are changes according to the changing of solar irradiance.

$$\text{Fill Factor, FF} = \frac{V_{mp}*I_{mp}}{V_{OC}*I_{SC}} \quad (2)$$

$$\text{Maximum Power Output, } P_{max} = V_{OC} * I_{SC} * FF \quad (3)$$

$$\text{Efficiency, } \eta = \frac{J_{SC}*V_{OC}*FF}{I_{in}} \quad (4)$$

Here, $V_{mp}$ and $I_{mp}$ are the voltage and current at maximum power respectively. $J_{SC}$ is the short-circuit current density and $I_{in}$ is the amount of solar irradiance absorbed by the solar panel. The changes in solar irradiance change the value of $V_{OC}$ and $I_{SC}$ and thus, the value of other parameters also varies.

### B. Solar Tracking System

The solar tracking system is a type of system that tracks the sun's position all-round the day and changes the solar panel facing direction towards the sun. The solar tracking system is used to adjust the horizontal, vertical orientation of the solar panel according to the change of the sun's position in the sky. According to the adjustment in the solar panel orientation, the tracking system is categorized into different types. It is used for increasing the output of the solar panel which depends on the amount of sunlight it absorbs [5].

As seen in Fig. 1 and Fig. 2, the sunlight intensity significantly impacts the output voltage and current of the solar panel. With the increase of the solar irradiance, the output increases and decreases with the decreasing of solar irradiance. In simple words, the output of the solar panel changes at different illumination levels. So, the solar panel must be faced towards the sun to get maximum output. Due to the earth's rotation, solar panel can't always maintain their position in front of the sun [6]. For this purpose, the solar tracking system is used. Basically, there are two types of tracking system available. They are-

- Single-Axis Tracking System,
- Dual-Axis Tracking System.

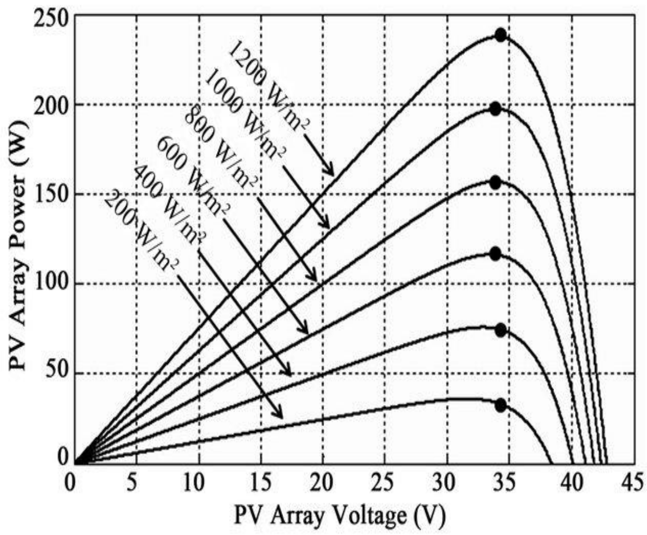


Fig. 1. P-V Curve of a Solar Photovoltaic Panel at Different Illumination Level.

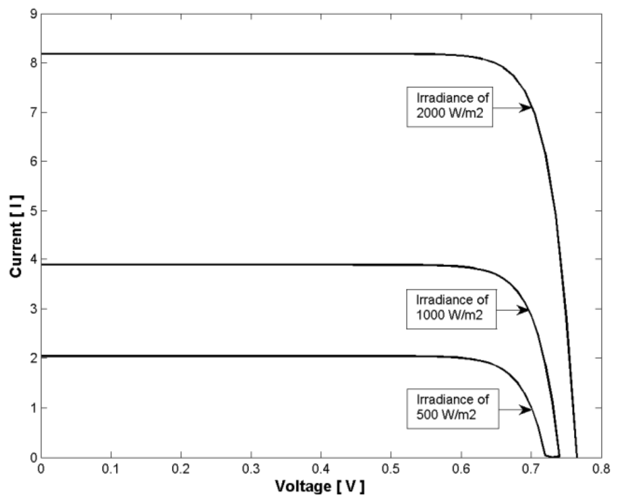


Fig. 2. I-V Curve of a Solar Photovoltaic Cell at Different Solar Irradiance [7].

A Single-axis tracking system changes the solar photovoltaic panel's position over a single axis like a vertical or horizontal axis. On the other hand, a dual-axis tracking system tracks the sun's position in both horizontal direction and vertical direction. The primary function of a solar tracking system is to orient the solar photovoltaic panel's position to the direction of the sun. While orienting the solar photovoltaic panel, it needs to maintain some solar angles such as azimuth angle, zenith angle and solar incidence angle.

Single-axis tracking system rotates the solar photovoltaic panel along one fixed axis. This system is used in several modes, like horizontal axis tracking, vertical axis tracking, polar alignment tracking, tilted single-axis tracking, etc. According to requirements, any of these trackings can be done using a single-axis tracking system. A Dual-axis tracking system has two degrees of rotation such as azimuth rotation and horizontal rotation. The azimuth rotation allows the panel to move in a circular path parallel to the surface. The horizontal orientation, also called elevation angle rotation, allows the panel to move up and down [8].

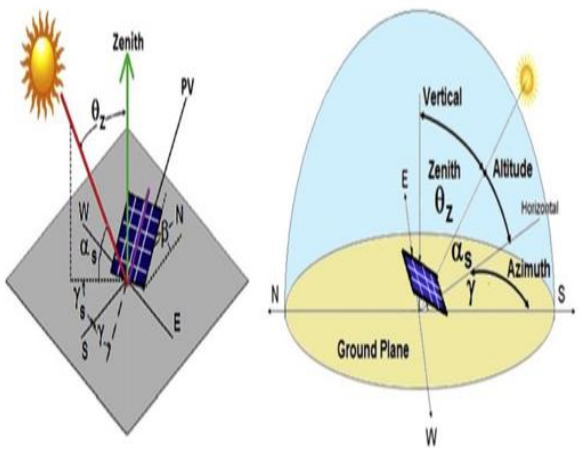


Fig. 3. Different Solar Angles for Tracking Sun's Position [9].

As shown in Fig. 3, the values of different solar angles concerning a solar panel change continuously all day long. For a fixed state solar panel, it is impossible to maintain a constant value of these solar angles and that's why a tracking system is required. The solar tracking system changes the solar panel position so that the values of these solar angles remain constant. That's how the tracking system helps the solar panel system face towards the sun and so the output power gets increased and the solar panel's performance improves.

## III. Methodology

In this work, the solar tracking system is microcontroller-based. Arduino Nano is used as a microcontroller here. The other major components for this work are DC Motor, Motor Driver Module and LDR Sensor Module. The block diagram for the single-axis solar tracking system is given in Fig. 4.

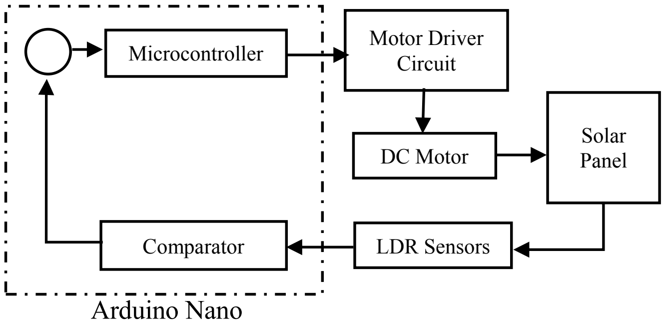


Fig. 4. Block Diagram for Automatic Single-Axis Solar Tracking System.

Here, LDR Sensors are attached to the solar panel to detect solar intensity in the facing direction of the solar photovoltaic panel. Then it sends a signal to the Arduino Nano or the microcontroller unit. According to the set program, the microcontroller unit sends a signal to the Motor Driver Circuit. According to the signal, it helps the DC Motor rotate clockwise or anticlockwise or doesn't rotate at all. So, at last, when the DC Motor rotates, the solar panel also rotates and stops when it faces towards the sun. For this purpose, a DC Motor of 10 rpm is used. It is used because the motor with lower rotation per minute will rotate the solar panel very slowly. As a result, the tracking will be smooth and more accurate. When the panel is faced towards the sun, both LDR sensors will capture the same amount of sunlight, So, the value of internal resistance will same and then the motor will not rotate.

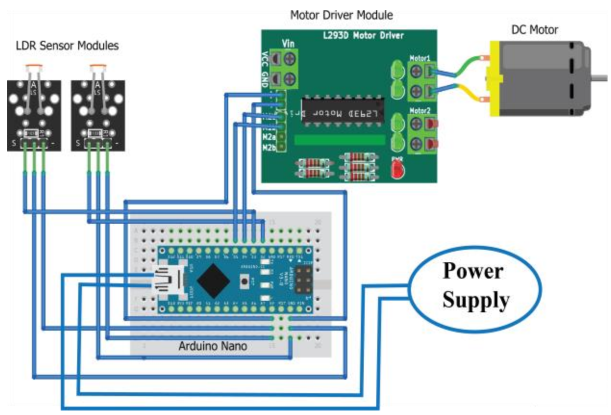


Fig. 5. Component Setup for Automatic Single-Axis Solar Tracking System.

In Fig. 5, the connection between all the components is shown. Here, for experimental purposes, the power is provided by an external source. But in real life, the power supply required for the Arduino or the microcontroller unit will be provided by the power produced by the solar panel and then no external power supply will be required for tracking purposes. The flowchart of the entire system is shown below.

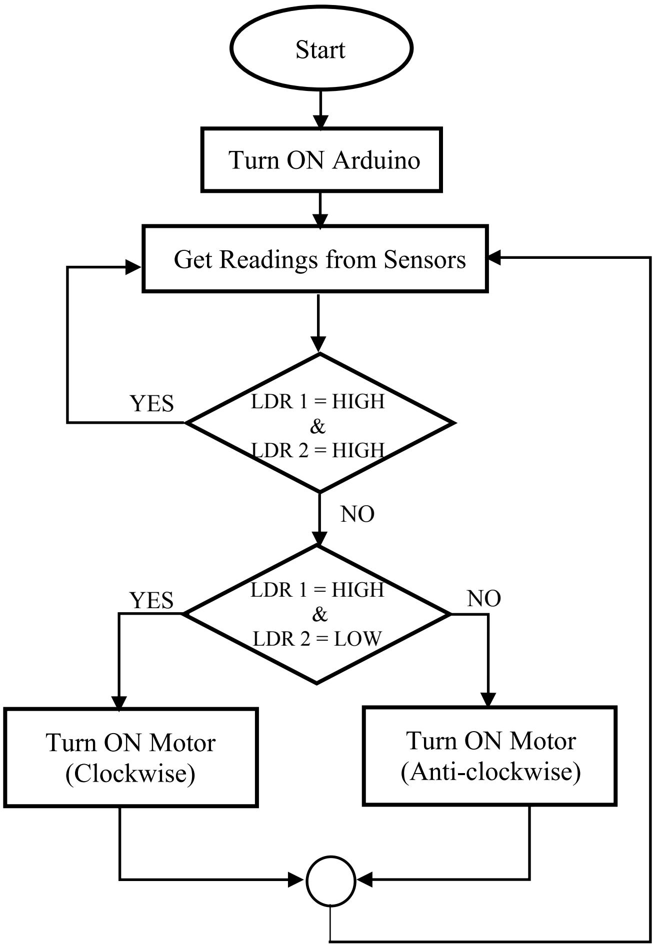


Fig. 6. Flowchart of Single-Axis Solar Tracking System.

## IV. Experimental Setup

In this work, a single-axis tracking system is implemented and used on a 10W solar panel. The specification of the solar photovoltaic panel is given below.

TABLE I. Specification of the Solar Photovoltaic Panel

| | |
|---|---|
| Peak Power, $P_{max}$ (W) | 10 |
| Short Circuit Current, $I_{sc}$ (A) | 0.58 |
| Open Circuit Voltage, $V_{oc}$ (V) | 22.00 |
| Current at Maximum Power, $I_{mp}$ (A) | 0.54 |
| Voltage at Maximum Power, $V_{mp}$ (V) | 18.36 |
| Dimensions (mm) | 355*300*18 |
| Cell Type | Polycrystalline |

The experimental setup for the single-axis solar tracking system is shown in Fig. 7, where all the components are connected with the Microcontroller unit as discussed in methodology.

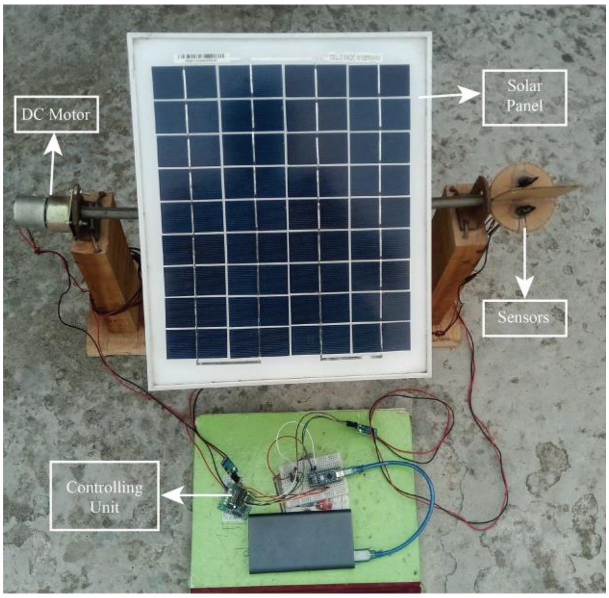


Fig. 7. Experimental Setup for an Automatic Single-Axis Solar Tracking System for Solar PV Panel.

In this work, the tracking is developed for a 10W solar photovoltaic panel. The LDR sensors are attached to the solar panel in a parallel position with an ordinary circular rod between them. When the motor rotates, it rotates both the solar panel and the LDR sensors unit. Though the setup is done for a 10W solar panel, it can also be used for a larger solar panel after making some modifications like adding some gear setup. The schematic diagram of the complete system is shown in below.

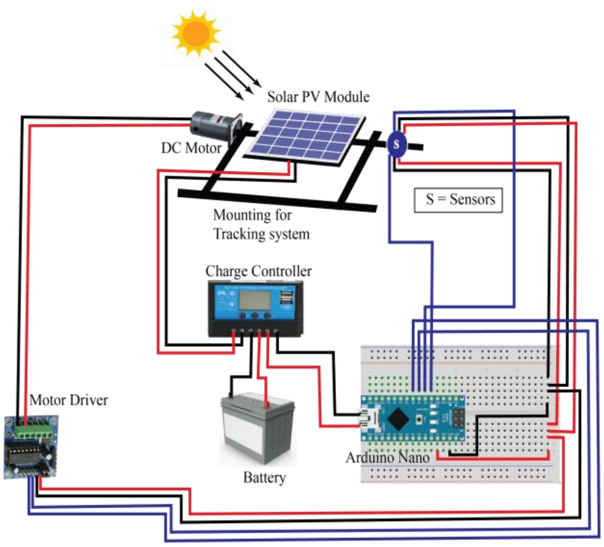


Fig. 8. Schematic Diagram of a Solar PV System with an Automatic Single-Axis Solar Tracking System.

## V. RESULT

For the single-axis tracking system, several experimental measurements have been observed from April to May 2021. The data for a single day of observation is shown below.

TABLE II. OUTPUT VOLTAGE AND CURRENT OF THE SOLAR PHOTOVOLTAIC PANEL WITH AND WITHOUT SOLAR TRACKING SYSTEM.

| Time of Day | Without Tracking System | | With Tracking System | |
|---|---|---|---|---|
| | *Voc (V)* | *Isc (A)* | *Voc (V)* | *Isc (A)* |
| 10:00 AM | 17.1 | 0.36 | 18.2 | 0.39 |
| 10:30 AM | 17.6 | 0.37 | 18.7 | 0.4 |
| 11:00 AM | 18.4 | 0.39 | 19.1 | 0.44 |
| 11:30 AM | 18.9 | 0.41 | 19.7 | 0.46 |
| 12:00 PM | 19.9 | 0.44 | 20.6 | 0.49 |
| 12:30 PM | 21.1 | 0.52 | 21.4 | 0.54 |
| 1:00 PM | 20.8 | 0.49 | 21.3 | 0.52 |
| 1:30 PM | 20.6 | 0.47 | 21 | 0.51 |
| 2:00 PM | 20.2 | 0.45 | 20.9 | 0.5 |
| 2:30 PM | 19.9 | 0.44 | 20.7 | 0.48 |
| 3:00 PM | 19.5 | 0.43 | 20.6 | 0.47 |
| 3:30 PM | 19.1 | 0.4 | 20.2 | 0.45 |
| 4:00 PM | 18.6 | 0.39 | 19.7 | 0.43 |

From the data, it is observed that the output of the solar photovoltaic panel was increased after using the sun tracking system. The maximum output was obtained at 12:30 PM for both panels. due to higher solar irradiance. The data are presented in Fig. 9, Fig. 10 and Fig. 11, respectively.

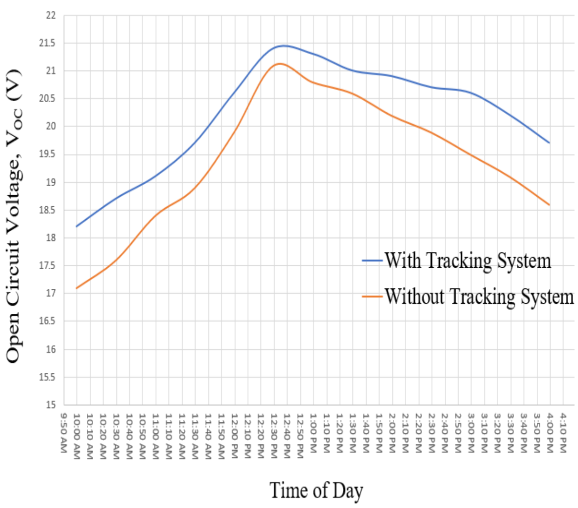


Fig. 9. Open-Circuit Voltage of Solar Photovoltaic Panel with and without Solar Tracking System.

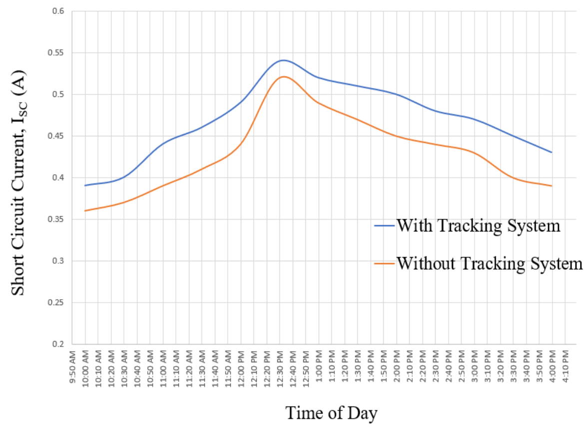


Fig. 10. Short-Circuit Current of Solar Photovoltaic Panel with and without Solar Tracking System.

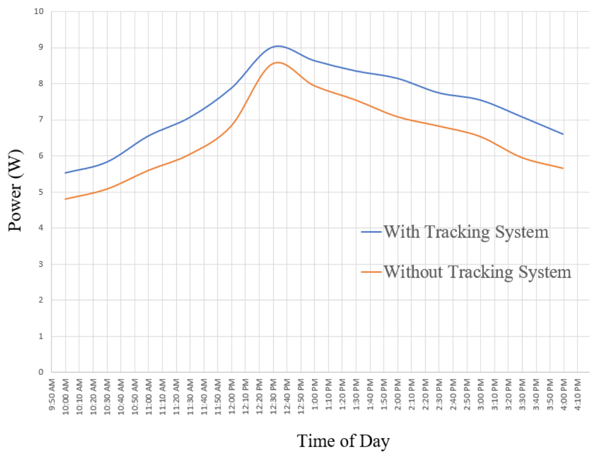


Fig. 11. Solar Photovoltaic Panel Power Output with and without Solar Tracking System.

As shown in Fig. 9 and Fig. 10, after using the tracking system, the solar photovoltaic panel's $V_{OC}$ and $I_{SC}$ were higher than that of the fixed state solar panel. During the noon session, the output voltage and current for both with and without the tracking system are nearly the same. So, at that time, the tracking system is not required. With the increase of output voltage and current, the output power was also increased.

## VI. COST ANALYSIS

A single-axis sun tracking system was implemented and used on a 10W solar panel in this work. By doing so, the average power output of the solar panel was increased about 1W per hour. If the system is used on a 100W panel, the value becomes 80W per day for 8-hour sunlight. By converting it to KWh in a year, the value becomes 29.2 KWh. For 7 BDT per unit electricity price, the price for 29.2 KWh electricity is 204.4 BDT. For an automatic single-axis sun tracking system, the values of all components are- Arduino Nano – 280 BDT, 10 RPM DC Motor – 350 BDT, Motor Driver Module – 300 BDT, LDR Sensor Modules – 130 BDT. So, the total cost for the single-axis solar tracking system is 1060 BDT. In this case, the payback period is 5-6 years. As the solar panel has a lifetime of 15 years, the owner gets benefitted from the system rest of the time.

## VII. CONCLUSION

The primary objective of this article to develop an automatic single-axis sun tracking system to extract maximum power from the solar PV panel. In this work, an automatic microcontroller-based single-axis solar tracking system was designed and implemented. The proposed system can rotate the solar panel according to the sun's movement in the sky. A low rpm motor is used here for making the tracking smooth. The system was tested on a 10W solar panel and it was observed that the output power was higher than the conventional solar PV system. Hence it can be said that the tracking system fulfills that target. The tracking system can be built very easily because all the components used in this work are available in the local market and their prices are not so high. This system can be used for larger size solar panels or large-scale PV systems by making some modifications. So, it can be said that this type of tracking system is beneficial to bring significant changes in the output of the solar photovoltaic panel and increase efficiency. In the future, this type of tracking system can be used in solar panels in residential use or solar powerplant to increase the output.

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