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A Comparative Study on Performance Analysis of a Single Axis Solar Tracker with a Non-Tracking System

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Abstract: This paper introduces a sun tracking solar system which is developed to compare performance with a non-tracking system. A photovoltaic (PV) panel is used to convert solar power into electricity. Solar power is chosen by us because of the availability of solar energy as a form of renewable energy on earth without any cost. The sun changes direction overall the day, it does not remain fixed so to capture maximum amount of solar energy a microcontroller based solar tracking system is developed. Here the Photovoltaic (PV) panel rotates with respect to the position of the sun, the micro servo motor is used to rotate the panel. The micro servo motor is controlled by Arduino Uno. To track the sunlight properly LDR sensors are used. This paper focuses on the design, implementation, basic mechanism, and benefits of using a single axis solar tracker. Also, this paper has shown that the comparison of output from the solar energy between tracking and non-tracking system. This developed system can be used to track maximum sunlight and thereby measure the maximum power point. This sun-tracking design can increase energy yield up to 29.30% compared to the non-tracking solar system. However, this performance can vary due to the weather condition, seasonal changes and geographical location of the solar panel.

Keywords: *PV Panel, Solar Tracker, Micro-Controller, Efficiency, Renewable Energy*

Introduction: There are several kinds of energy sources in the world. The energy sources can be categorized in two types: Renewable energy and non-renewable energy. In the recent years the uses of renewable energy already reached significant level in the perspective of electricity generation [1]. Considering, the environmental issues to reduce green-house gas emission for the generation of electricity the world has adopted with some sources of renewable energy [2], these renewable energies can be diversified as solar, wind, geothermal, hydro, ocean-wave, biomass and so on. Amongst them solar energy is the most available renewable energy sources in the world. The sun remains more or less about 8-10 hours of a day with the variation of season. The amount of the radiated energy from the sun is about 1.2 x105 TW which is good enough for the total energy consumption by the humans [3]. In the modern world the production of green and clean energy has been taken as significant concern. Therefore, the uses of solar energy for generating electricity are increasing day by day. Photovoltaic Voltaic (PV) solar panel has been extensively used for the conversion of solar energy into electrical energy. A PV solar panel is composed of an enormous number of solar cells of semiconductors like silicon. When the sunlight strikes the surface of solar panel it generates electron hole pair at the barrier junction of the solar cells. Then the electrons flow through the external circuit by electrodes and generate electric current [4]. The amount of radiation intensity received by PV panels enhances significantly in the sun tracking system than a non-tracking system which ameliorates the performance and collects the larger amount of energy. The energy efficiency of the solar tracking systems is determined by the solar radiation condition with climate changes, ambient temperature of the atmosphere, and the wind speed, and the appropriate placement of the solar panels with the position of the sun [5]. To optimize solar energy collection, it is essential to adjust the solar panel's orientation and tilt angle, and to use appropriate concentrators based on the specific geographical location to achieve the desired results [6].

Solar tracking is an electro-mechanical system where the solar panel is designed to adjust and position itself with the direction of beam radiation from the sun as it rotates from east to west every day or to the north and south as season changes so that the radiation is normal to the surface of the panel. In a typical Solar tracking system, the mechanical motor is (like servo motor in this paper) is controlled by microcontroller. Solar tracking system can be mainly two types, one is single axis solar tracking system another is dual axis solar tracking system. Single axis solar tracker: A single axis sun tracker can rotate in one direction only and in all cases, it is from east to west or north to south. Mostly, Single axis tracking system is set as a way that it can rotate from east to west. This tracking system compares the slight changes in intensity as the surface is tilted at various angles while the beam radiation moves from east to west. A dc motor is enough to change the tilt angle of the panel surface. A single axis solar tracker can be made easily with very little expense, but its efficiency is lower than that of a dual axis tracker [7]. Dual axis Solar tracker: Dual axis tracker can move in two directions and both the diurnal(east-west) and the annual(north-south) motion of the sun is taken into account for the construction of the double axis solar tracker. For accomplishing the two axial motion two dc motors are required. This tracker has higher efficiency compared to single axis tracker, but the complexity and cost of manufacture is higher [8].

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Bangladesh is positioned in north hemisphere of the world with latitude 23.685º N and 90.3563º E. For this global positioning in the hot summertime, the normal bright sunshine time is near to 7.6 hours in Bangladesh [9]. So, in Bangladesh vast amount of solar radiation can be captured by solar panel with the help of solar tracking system.

In paper introduces a magnificent guideline for the design, operation, and investigation of a simple single-axis sun tracking system based on electro-mechanical components which is controlled by a microcontroller. This solar tracker can rotate from east to west with the position of the sun by tracking the beam radiation of the sun. The performance comparison has been shown in this paper by real time tracking experiments under clear sunny sky with the collection of energy over a day long time. In the tracking mode the amount of energy collection is significantly more than the non-tracking mode. This system is developed with a relatively low cost and a high efficiency.

Literature Review: In the pursuit of optimizing solar energy conversion, the efficiency of solar tracking systems has become a focal point of research. Researchers has shown that the solar tracking system has more efficiency that stationery system by various methodology and control mechanism. Shang *et al*. [10] developed a dual axis solar tracking system with simple design and structure. They experimented their system under the sun with a 30º tilted fixed surface at south facing. They verified that the increased amount of energy generation was about 24.6% with the comparison of fixed system. Kuttybay *et al*. [11] developed an optimized single axis schedule solar tracker and tested it in different weather conditions. They compared the performance of single axis solar tracker based on schedule method and developed by light dependent resistor (LDR) with a non-tracking(fixed) system. They showed that this proposed method of tracking has increased efficiency of 57.4% than fixed system in sunny weather and in cloudy weather it was possible to obtain about 37.7% using the developed schedule solar tracker. Jacobson *et al*. [12] showed the calculation of optimized inclination angles of solar panel which was taken in various regions. They examined the comparison of the angles of different regions and provided a conclusion by recommending single axis solar tracker. They stated that single axis solar tracker could be used for all regions expect the regions of high latitude. Pelaez *et al*. [13] focused to find the two different ways of increasing amount of energy. They showed the output energy of bifacial photovoltaic cell which was increased about 4-15% because of having the ground reflection method. They also compared the output energy of single axis solar tracking system and a fixed system. The performance of tracking system was 15-25% higher than the fixed (stationery) system.

V. Sumathi *et al*. [14] used ARM processor based single axis tracker. He got approximately 30% increase in energy gain. Mohammed *et al*. [15] developed a rotating solar panel to harvest maximum energy from the sun. They tried to track the sun direction in 9 positions with respect to actual time and azimuth angle. They used actuator which is a device with shaft moved linearly with the rotation of stepper motor and microcontroller with real time clock (RTC). The resultant increment of energy was about 17.3% per day by the sun tracking method. They stated that the extra power that generated was over the period of solar noon times. Calderon *et al*. [16] proposed the design, construction and evaluation of a dual axis solar tracking system with high precision technology. They controlled their system by an Arduino based microcontroller with closed loop (feedback) control system. They performed Real time tracking under both clear sky and partly cloudy as well as cloudy days. They showed the increased of energy generation was up tom 37.5% for flat plate dual axis solar tracking system in comparison with fixed system.
Abdallah [17] showed the resulting effect of flat plate PV panels by using four different solar tracking systems (dual-axis system, vertical single axis system, horizontal south-north single-axis system and horizontal east-west single-axis system). He focused on the condition of current, voltage and power with different loads to compare the energy generation. He showed that volt-ampere characteristic of panel surface was apparently greater in the tracking system. Moreover, he compared the performance with fixed panel considering the tilt angle of 32º, the increased performance for dual-axis system was 43.87%, for horizontal east-west single axis system was 37.53%, for vertical single axis system was 34.53% and for horizontal south-north single axis system was 15.69%. This research clearly indicates the significance of installing solar tracking system. Muhammad *et al*. [18] compared output power of sun tracking solar system with a fixed system. They recommended to use solar tracker to increase output power from the solar system. Okoye *et al*. [19] focused on the comparison of the power generation under various tracking modes and concluded that the dual-axis tracking is more beneficial to others.

Materials & Methodology: This paper for the solar tracking system is hardware based. To rotate the solar panel according to the position of sun servomotor is used which is driven by microcontroller Arduino Uno. For sensing the light rays from the sun Light Dependent Resistor (LDR) is used.

Requirement for Hardware implementation:

i. Solar Photo Voltaic Panel (8 V): Solar PV panel has been used to convert the solar energy to electrical energy by means of photo voltaic effect.
ii. Micro servo motor (SG-90): Micro servo motor has been used to rotate the solar panel with the position of the sun.
iii. Light Dependent Resistor LDR (2): LDR senses the sunlight and gives feedback to the servo motor through Arduino UNO.
iv. Arduino UNO: It is a microcontroller. The Arduino uno was used in digital control to generate PWM pluses in terms of duty cycles to deliver more precise control signals.
v. Resistors (100kΩ)

vi. Connector and connecting wires.
vii. Cardboard: Cardboard was need to make the hardware stand to set the panel with the motor and to form the base structure.
viii. Super glue and hot glue gun: To join the panel with servo motor properly.
ix. Screw and nut: To join the panel with cardboard stand.

Circuit Diagram:

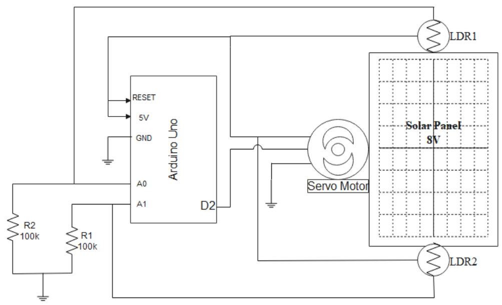

Fig. 1: Circuit diagram for Arduino based solar tracking system.

Steps for Hardware Implementation:

i. Take some cardboard and cut them into suitable sizes to make the stand and rotating axis for the solar panel,
ii. Connect the solar panel with the cardboard stand with the help of screw nut and be careful about its rotational movement,
iii. Make an empty slot in the cardboard stand to place the micro servo motor, setup a connection between solar panel and the servo motor also,
iv. Connect Two LDRs between two sides of panel as shown in the circuit diagram,
v. Make the code to operate the Arduino uno microcontroller,
vi. Upload the code to Arduino UNO,
vii. Connect all the wires according to the connection shown in the circuit diagram with resistors and connectors properly.
viii. Take data under the bright sunny day to get maximum output from the solar panel.

Data Collection & Analysis: To observe the output voltage(V) and current(mA) of the solar panel, Multimeter is used to take the voltmeter readings for voltage(V), and ammeter readings for current(mA). Data was taken at 15 minutes interval to see how the current and voltage changes due to the radiation intensity of the sunlight.

Fig. 2.a: Voltage (V). **Fig. 2.b:** Current(mA) reading at tracking mode.

Fig. 3.a: Voltage(V). **Fig. 3.b:** Current(mA) reading at non-tracking mode.

Table 1. Observation of solar panel at tracking mode.

PV output	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00
Output Voltage (v)	6.71	6.7	6.78	7.2	7.27	7.31	7.31	7.3	7.28	7.1	6.91	6.8	6.77
Output Current(mA)	89.3	90.1	90.5	91.3	93.7	95.7	96	96.1	95.7	95.8	95.2	90.1	86.2
Output Power (mW)	599	603	613	657	681	699	701	701	696	680	657	612	583

Table 2. Observation of solar panel at non-tracking mode.

PV output	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00
Output Voltage (v)	6.35	6.71	6.75	6.78	6.73	6.7	6.69	6.64	6.43	6.21	5.97	5.61	5.37
Output Current(mA)	86.9	85.9	90.1	91.9	94.3	93.4	91.2	88.8	84	73.3	55.8	42.3	34.2
Output Power (mW)	552	576	608	623	634	626	610	589	540	455	333	237	183

Results and discussion:

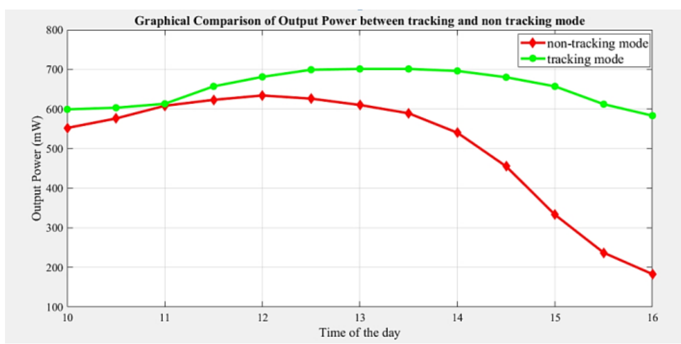

Fig. 4: Comparison between output Power(mW) at tracking and non-tracking mode.

Here the pictorial representation is showing a comparison of output power between tracking and non-tracking mode of solar panel. In the X-axis the data is showing the time of the day that was taken from morning time 10.00 hrs. to afternoon at 16.00 hrs. and in Y-axis the data represents the Output Power (mW). When the sun crosses mid of the day or solar noon time the output power of the non-tracking mode decreases as at non-tracking mode the panel remains fixed. At the time of 11.00 hrs. the values of both curves are very close because that time the fixed and tracking panel remains very similar. At the tracking mode the value of output power is higher.

Calculation:

Total power at Tracking mode $P_{tracking} = 8482\,mW = 8.482\,W$
Total no. of observations $= 13$
Average power at tracking mode $P_{average\_tracking} = 8.482 \div 13 = 0.653\,W$
Total hours of data collection $= 6.00\,h$
Total energy from the solar panel $E_{tracking} = 0.653 \times 6.00\,Wh = 3.918\,Wh$

Total power at non-tracking mode $P_{non-tracking} = 6566\, mW = 6.566\, W$
Total no. of observations $= 13$
Average power at non-tracking mode $P_{average\_nontracking} = 6.566 \div 13 = 0.505\, W$
Total hours of data collection $= 6.00\, h$
Total energy from the solar panel $E_{non-tracking} = 0.505 \times 6.00\, Wh = 3.03\, Wh$
Increase energy at tracking mode:
$\Delta E = E_{tracking} - E_{non-tracking}$
$= 3.918\, Wh - 3.03\, Wh = 0.888\, Wh$

Increased Performance:

$$\eta = \frac{\Delta E}{E_{non-tracking}} \times 100\%$$
$$= \frac{0.888}{3.03} \times 100\,\%$$
$$= 29.30\,\%$$

Table 3. Summary of Results.

Sl. No.	Output	Tracking mode	Non-tracking mode
1.	Average power (Watt)	$0.653\, W$	$0.505\, W$
2.	Total Energy (Watt-hour)	$3.918\, Wh$	$3.03\, Wh$
3.	Increased Performance	$29.30\,\%$	Reference Value

The value from non-tracking mode has been taken as reference value to compare the increased performance at the tracking mode.

Conclusions: An automatic solar tracking system is designed for harvesting sun energy with solar panel which is able to track the sun in one axis. When the sun is positioned at the east the panel rotate itself towards itself by sensing the sunlight with the help of Light Dependent Resistor. As the sun changes position at different time of the day the tracker rotates according to the sun and gives electric power by means of photo voltaic effect. But in static or non-tracking mode panels are kept fixed and they get direct sunlight only at a small portion of the day. That's why the tracking system provides more electric energy than the static solar system. Here in this project the increased efficiency in the tracking system is about 29.30%. If we look back on Figure No.-4 it is seen that, from 10:00 AM to 12:00 PM the output values of tracking and non-tracking system are very close because during this time the sun hits the solar panel surface directly in both two modes. After 12:00 PM the sun goes towards the west, but the static panel remains fixed at its old position, so it can't get the sun light properly and as a result produces less voltage and current. Hence provides less power output than tracking system. The result of this paper clearly indicates the significance of installing solar tracking system to capture maximum amount of energy.

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