# Economical Photovoltaic Tree with Improved Angle of Movement Based Sun Tracking System

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**Abstract:** *In this paper we propose a renewable energy storing system in order to harness optimal solar radiation. In consideration of photosynthesis process of a tree, photovoltaic cells of this artificial tree are arranged by Fibonacci pattern instead of leaves. This design will increase efficiency of storing energy compare to flat structure. To solve the problem of low efficiency of a solar system, it is necessary to orient photovoltaic cells with varying direction of periodic sun irradiation. Taking this into account, a tracking system based on one-degree angle of movement maintaining small angle of tolerance, is implemented with a specific movement flexibility for any promising fluctuation of sunlight. A incomplex techniqe and low cost design makes it economical and easy implementable.*

**Keywords:** *renewable energy, low cost photovoltaic tree, sun tracking system*

## 1. Introduction

A solar tree is a structure fusing sun oriented vitality innovation on a solitary column, similar to a tree trunk. These days, with the development of population in the present world and energy demand; a renewable source that does not cause contamination and other characteristic turnover must be taken over. For this situation, the solar energy is the best alternative for this world. A solar panel or photovoltaic cell consumes plenty space and Bangladesh is a densely populated country which needs much power, so the advantage of such energy should be taken which requires a very less space to generate power efficiently. Solar tree is one of those which do not need much space but produce sufficient energy.

"TREE" acronym stands for: T=Tree generating, R=Renewable, E=Energy, E=Electricity.

The importance of a solar tracking is to figure out the exact position of the sun. This will provide PV plates those consists of a tracking system, to store maximum energy from the sun all the time. Solar panels can be highly efficient when they are directly faced towards to the sun. The nature of the PV cells is to provide highest power when the angle between them and sun is nearly zero. The study shows that, the panel absorbed less energy compared to the one that can move along with the direction of sunlight. [1]. For the collection of efficient solar energy, a solar panel have to be within 20 degrees from normal or perpendicular to the sun [2]. To know the precise location of the sun, a tracking system consisting of mathematical relations is needed. It been calculated that a solar system which use a tracking unit can produce 13%-20% (single axis) and around 30 % (dual axis) more power that the conventional ones [3].

Jay Taneja et. al. introduced a process of building micro-solar power subsystems for wireless sensor network nodes. They also evaluate the deployment by analyzing the effects of the range of solar profiles experienced across the network [4]. Whereas A. Kavaz et. al. describes the whole system with necessary calculations, technical specifications, basic characteristics, working principle and 3D rendering of the chosen design in [5]. Dr. Suwarna Torgal proposed to mount Silicon-crystalline Photo-Voltaic (SPV) on some tall poles which can directly provide electrical energy from solar energy [6]. C. Bhuvaneswari proposed a new idea to design a solar tree using nanowire solar cell [7]. In [8] S.N. Maity also introduced a SPV system which will occupy a very less space. However, Jay Taneja et. al. introduced a process of building micro-solar power subsystems for wireless sensor network nodes. They also evaluate the deployment by analyzing the effects of the range of solar profiles experienced across the network in [9].

## 2. Methodology

The apprehend starts from the photo sensor, as an input device for the microcontroller. Depending on four LDR (Light dependent resistor), the microprocessor received several data from the sensor, and then provides two signals to servo motors for the specified movement. There are two set of sensors for each tracking mechanism. Comparing between two LDR, the microcontroller processes the input data and generates signals for two servo motors for their movements. This method will cause multiple or single shafts that performs as a torque transmitter to create rotations for the solar panels to change their positions. The movement of the motors will halt its current position at the very moment it received same amount of sunlight to each sensor. In addition to this, when the water sensor gets a few drops of rain, it will generate a signal for the microcontroller which leads canopy system cover the top of the tree in order to protect the solar panels. The following system calculate voltage differences using voltage divider rule to figure out light intensity for the LDRs. With this concept, a set of values of Light dependent resistor can be obtained due to the voltage difference of the LDR in both light and shade cases. This data can prove general characterizes of photo sensor as for highest amount of voltage make the sensor more sensitive.

## 3. Proposed Prototype

### 3.1. System Construction

To simplify the design, calculation, maintenance a two axis symmetric design have been constructed. The main body is a simple 4 feet aluminum squire tube attached with a squire base made of aluminum which should carry the upper panels and servos. One of three panel is placed high above the other panels at a 90-degree vertical angle. The angle provides a constant area for the sunlight of the sun trajectory. The other two panels are attached with two separately controlled servos. Two 1 feet limbs are connected with the main body at the height of 2.7 feet to hold the servos. If needed, additional limbs can be added to increase to total amount of tracking panels which increase power to the consumer end. However, this limb shouldn't be too long because of a possibly high bending moment and can create vibration during the tracking process. Additionally, a display and a battery level indicator is added in order to observe the voltage and current drawn by the panels and the charging level of the battery which is used to store the energy. Moreover, a voltage booster module was needed to meet the rating which is needed to charge the battery.

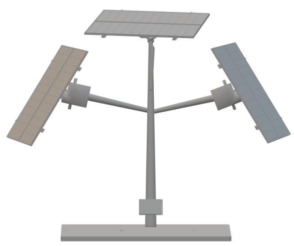

**Fig. 1.** 3D model

### 3.2. Operation Strategy

Once the system sets it initial position, it shows a tendency to seek an optimal position and start sending signals to operating motor for the correction of the orientation and keep tracking the sun. The panels change its position from angular value α to –α as shown in figure 2. Therefore, two scenarios will be obtained. First one is the sensor oscillates between either sides of the sun position and the second one is the sun being virtually sliding westward, so that the panel and the LDR are at angle θ. So, a specified torque calculation is required for a precise movement.

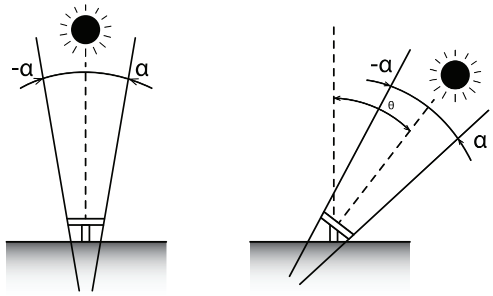


**Fig. 2.** Panel orientation according to the position of sun

**Calculation of torque required for the rotation.**

Length of the solar panel a = 12.5 cm, width of the solar panel b = 9.8 cm, mass of the solar panel m = 50 g, length of the shaft L= 13 cm.

We know, moment of inertia of a rectangular body,

$$I = \frac{m\left(a^2 + b^2\right)}{12} \tag{1}$$

$$I_{\text{rectangular}} = 1.05 \times 10^{-4}\ \text{Kgm}^{-2}$$

where α is angular acceleration and ω is angular speed. *I* = moment of inertia.

$$\alpha = \frac{\nabla\omega}{t} \tag{2}$$

where, $\nabla\omega = \omega_1 - \omega_o$ and

$\omega_o$ = initial angular velocity

$\omega_1$ = final angular velocity

For a design speed of 500 rpm (52.35 rads$^{-1}$) Time (t) = 10 sec from potentiometer value 10 k ohms (i.e. 1000 is 1 sec)

Therefore Angular acceleration α = 5.235 rads$^{-1}$

$$T = I \times \alpha = 5.497 \times 10^{4}\ \text{Nm}$$

for shaft $I = \frac{mL^2}{12}$, where L is the length of the shaft and M is its mass

$$I_{\text{shaft}} = 1.4 \times 10^{-5}\ \text{kgm}^2$$

$$\text{Torque} = I \times \alpha = 7.37 \times 10^{-5}\ \text{Nm}$$

$$\text{Hence total torque} = 6.23 \times 10^{-4}\ \text{Nm}$$

### 3.3. System Operation

Here we have used two sets of photo resistor each consists of two LDR. Light dependent resistor is working as input devices for the Arduino. In the prototype, two of the solar plates have the tracking mechanism which allows them to follow sunlight by measuring the light intensity. As the basic nature for a photo sensor is to decrease resistance with the increment of light intensity. So following this law, the microprocessor compare data for both LDR and provide signals to the respective servo to move as show in figure 3 and figure 4. Therefore, servo start its movement maintaining $1^o$ angle of tolerance towards the LDR which have the maximum amount of light intensity. Whereas photo sensor does its tracking, water sensor detects rain drops and send signals to microcontroller. Then microcontroller provide command to the servo motor installed on the top of the tree hence the motor rotate anti clockwise with canopy to protect the plates being wet. The motherboard which is controlling the whole system, gets its power from the same battery that have been charged by the solar panels.

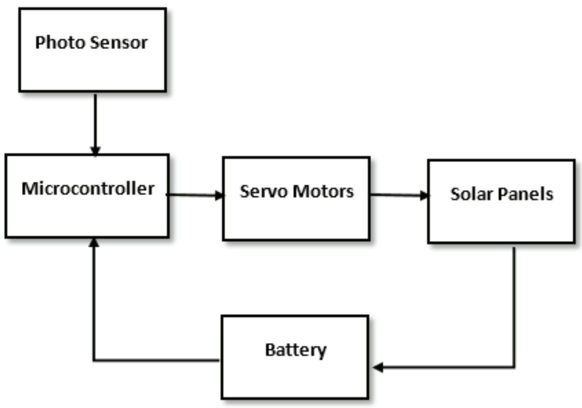


**Fig. 3.** Block Diagram for the control system

### 3.4. Flow Chart

### 3.5. Sensor Calculation

Improving upon the sensitivity of the system, comparison between LDR values and initial tolerance value was extremely needed. So we have to assign a small initial tolerance value. As a set of tracking system consists two LDR.

Variable 1 = 1st LDR value
Variable 2 = 2nd LDR value

For the first case when sun is almost on 0 deviation (θ) from α to –α shown in figure 5, the values of both LDR should be equal to tolerance or less that the initial value.

Variable 1 – Variable 2 <= tolerance
Variable 2 – Variable 1 <= tolerance

Now when the sun has a deviation angle from 0 degree to toward α degree, there should be difference between sensor values.

Variable 1 < Variable 2

When the scenario is opposite that is sun moves form 0 degree to backwards –α,

Variable 1 > Variable 2

At this moment it is very important to look upon maximum angle of tolerance at which the sun goes away from sensors. It's been learned that the smaller the angle is, the more the sensitivity is. So following this study, we have used 1 degree movements concept for the trackers. With this small angle deviation will make the system more sensitive.

### 3.6. Observed Voltage

The experiment conducted on solar panels that are used on solar tree, showed various voltages in different weather before adding voltage booster. The data are as follows-

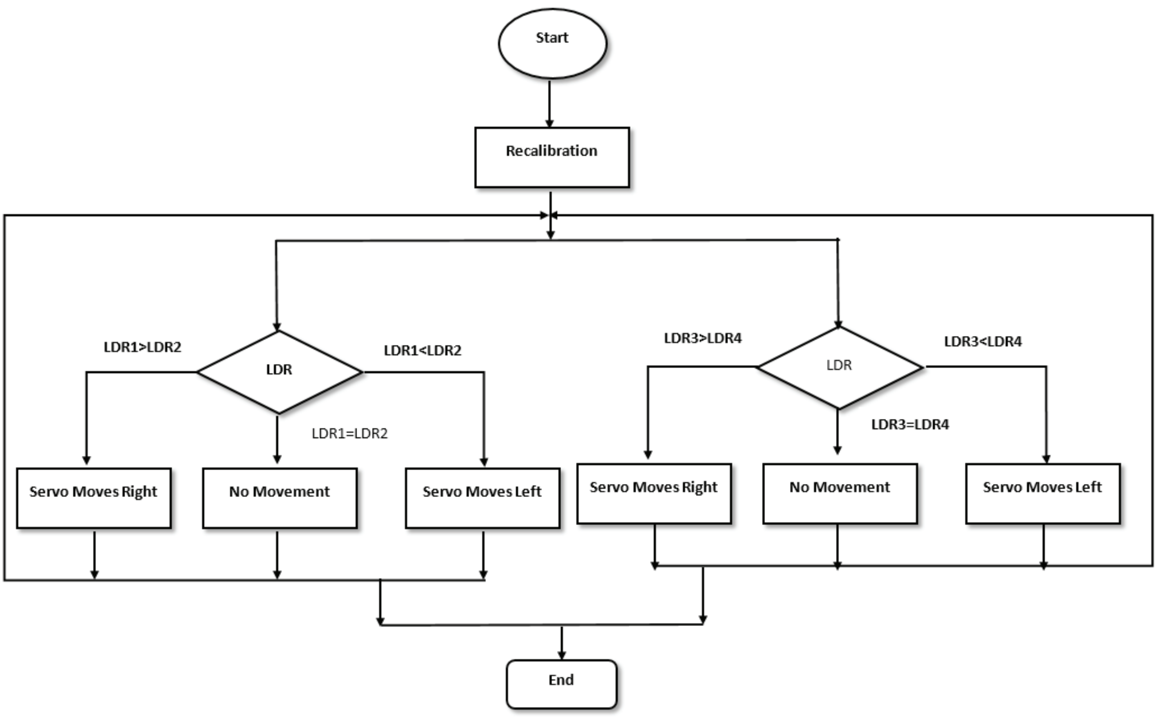


**Fig. 4.** Software Flow diagram

**Tab. 1.** Observed Voltages in normal day

| No of sample | Time | Voltage [V] |
|---|---|---|
| 1 | 5am–7am | approx. 2.1 |
| 2 | 7am–9am | approx. 3.5 |
| 3 | 9am–11am | approx. 3.7 |
| 4 | 11am–1pm | approx. 4.5 |
| 5 | 1pm–3pm | approx. 4.3 |
| 6 | 3pm–5pm | approx. 3.6 |

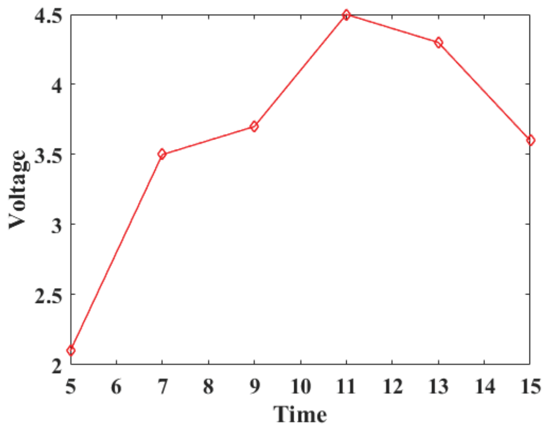


**Fig. 5.** Voltage Response on Normal day

**Tab. 2.** Observe voltages in cloudy day

| No of sample | Time | Voltage [V] |
|---|---|---|
| 1 | 5am–7am | approx. 1.3 |
| 2 | 7am–9am | approx. 2.5 |
| 3 | 9am–11am | approx. 3.2 |
| 4 | 11am–1pm | approx. 3.47 |
| 5 | 1pm–3pm | approx. 3.1 |
| 6 | 3pm–5pm | approx. 2.2 |

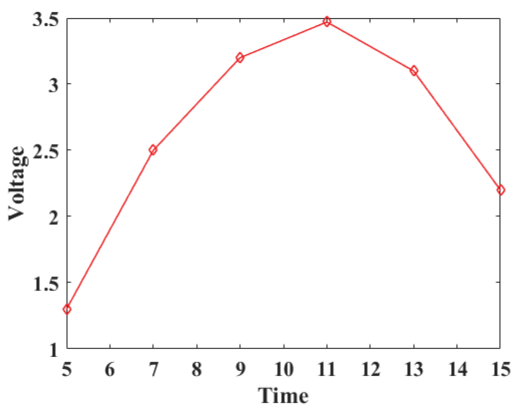


**Fig. 6.** Voltage Response on Cloudy day

### 3.7. Result and Analysis

As sunlight consists of two factors, one is direct beam that carries almost about 90% of the solar energy and another is the diffuse beam which import rest of the materials. The diffuse part can be denoted as blue sky on a normal day that gets a raise proportionally on cloudy days. So for the maximum amount of energy, it is necessary for the panel visible towards sun directly for the most possible times. But due to cosine angle between direct beam and the panel, efficiency will be dropped. For the experiment, three solar plates having maximum 21-watt rating have been used. We have analyzed some of the results of our two single axis rotating and one fixed solar panels with all three solar panels being fixed. A major power values shows that the rotating panels provides more energy than fixed mount. It can be said that, around 15% efficiency is increased due to one-degree angle of tolerance based movable panels than the fixed ones.

**Tab. 3.** Analyzed data

| Time | Power obtained when all panels are fixed (W) | Power obtained when panels have single axis movement (W) |
|---|---|---|
| 8 am | 3 | 3.45 |
| 9 am | 4.5 | 5.0 |
| 10 am | 4.8 | 5.7 |
| 11 am | 6.88 | 8.1 |
| 12 pm | 8.7 | 10 |
| 13 pm | 15.55 | 18.9 |
| 14 pm | 10.3 | 12.0 |
| 15 pm | 9.1 | 10.4 |
| 16 pm | 7.33 | 8.3 |

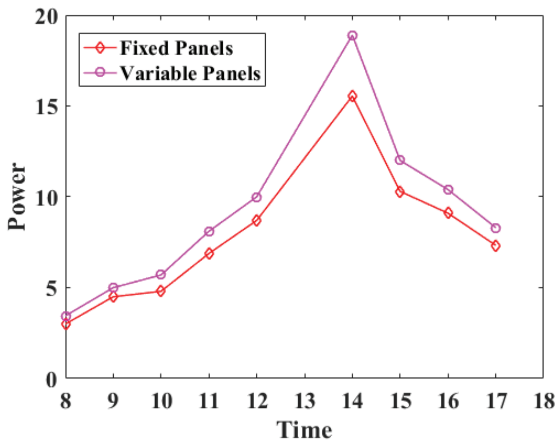


**Fig. 7.** Power Response for Fixed panel over the panels having Tracking system

Fluctuation between steady state and movable solar panels has been investigated through MATLAB platform. Figure 10 shows the deflection between various times with power generation in watt. For constant panels, the lowest watt rating is 3 which gradually increases up to 15.55 watt and then it shows its continuous decrease characteristics with the decrement of sunlight intensity. Whereas for the tracking system the graph founds more convenient. Its minimal power is 3.45 that goes up to 18.9 watt and then goes down with light intensity.

## 4. Conclusion

We suggested more efficient ecopowered solar tree with very small angle of tolerance dependent sun tracking system to store more energy. It can state easily that with rotating solar plates absorbed more power than fixed panels. Not only the efficiency analysis for solar have been done but also a calculation for maximum torque needed for any tracking system have been shown here.


## AUTHORS

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