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Solar Tracker Using Power Feedback Mechanism

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ABSTRACT

Energy harnessing from different renewable sources like solar, wind, water and geothermal have seen constant improvement to make it more efficient. On such technology is the solar tracker. The solar tracker is a bio mimicry technology that is inspired from sunflower plant. This paper begins with a brief introduction on the topic classification of solar tracker and detailed discussion about the solar tracker design which uses ESP32 microcontroller. This paper deals with the closed loop control for an automatic solar tracker. The system is designed in a way such that it consumes less input power and tracks the solar rays based on the power feedback system and setting it at position of maximum power, thereby maximizing the efficiency of solar panel.

Keywords: Solar Energy, Solar tracker, Photovoltaic, Single Axis tracker, ESP32, Closed loop control system, INA219 sensor.

I. INTRODUCTION

The sun has proved to be the primary source of energy for all living being in planet earth since it not only helps in keeping the temperature suitable for living conditions but also helps the plants to make food by a process called photosynthesis which is the direct or indirect source of food for all living beings.

Global warming has proved to be an imperative conundrum in the recent years. The increased use of fossil fuels has not only depleted the natural resources but also led to climate change due to continuous emission of carbon di oxide. So the need of the hour is more efficacious use of technology to harness renewable source of energy.

The sun can be useful in this case since solar energy form the sun has been a proven a reliable source of renewable energy, we receive an average of 1361 W/m^2 solar radiation annually. When harnessed in efficient way we can power more homes.

There are many researches going on in the field of solar energy and many advancements have also been made in the field such as:

CSP (concentrated solar power) [1] where acres of mirrors are placed around a big pole concentrating the sun's rays are towards it and generating heat thereby evaporating water and running a turbine.

Agrivoltaics [2] where solar panels are placed over crops where the water released from the crop during transpiration keeps the solar panel cool and increases its efficiency by around 3%. This recent technology has paved way to optimize the use of land resources. Also this helps in increasing the farmer's revenue .

Floatovoltaics [3] is similar to agrivoltaics where solar panels are placed over stagnant water bodies (lakes or ponds) to increase its efficiency

Solar Thermal fuels [4] this is a type of fuel which stores energy when its exposed to sun by rearrangement of its molecules, when we need the energy from it we need to pass the fuel through a filter which changes the molecule back to its original configuration and energy is released. The energy can be stored in this fuel nearly up to two decades. And the fuel can be reused again.

PV(photovoltaic) trackers or solar trackers are structures that are attached to solar panel that move the solar panel in such a way that maximum solar rays are projected on to it. It consumes 5-10% of the energy produced by panel but its increased output energy it produces outweighs its energy consumption. This paper is about a prototype tracker which uses power feedback system to track the sun's rays and maximize the output energy produced by the solar rays.

II. CLASSIFICATION OF SOLAR TRACKERS

Solar tracking can be classified into many types such as on the basis of feedback mechanism, tracking strategy and degree of freedom of the tracker.

A. Based on Feedback Mechanism

a) Open Loop

In an open loop based design the output has no effect on the control action of the input signal. This type of system provides only the initial instruction but doesn't provide means of gathering data and comparing the output values [5].

This type of design calculates the position of the sun by using solar position equation or a table which has all the positions, with this help of predefined calculations the tracker rotates and senses the rays accordingly. This design is cost effective when compared to closed loop control system. Artificial intelligence, fuzzy control and other control inputs can be utilized to make the system more accurate.

The equation below is the sunrise direction formula [6]. It determines the sunrise direction θ,

$$\theta = -\arcsin(\sin\alpha * \cos\psi / \cos\delta)$$

where,

$\theta \in [-90°, 90°]$

α = planet axial tilt $\in [0°, 180°]$

δ = latitude $\in (-90°, 90°)$

ψ = day of year angle = orbital angle swept out from winter solstice.

b) Closed Loop

In the closed loop closed loop control system, the system continuously compares the actual value to the desired value so that the controlled output is modified and adjusted to reduce the deviation [7]. The actual value is obtained from the sensors employed to detect the rays.

The actual value is feed backed into the main controller, which then sends the appropriate actuating signal to compensate the error. When compared to open loop the design is more complex and costly.

B. Based on Degrees of freedom

(i)Single Axis

The main concept behind single axis tracking system is that it tracks the rays while keeping the solar panel perpendicular to the sun. When compared to a stationary solar panel it is more efficient. Also it has higher lifespan compared to a dual axis tracker.

There are different types of single axis system which are horizontal single axis, horizontally tilted, vertical and vertically tilted. The tilted axis solar trackers are more expensive than normal single axis tracker. Tilted axis trackers are used in high latitude regions like mountain regions. For this type of tilted design, there is a need for more complex structural design.

(ii)Dual Axis

The dual axis tracker tracks the sunlight in both east - west and north - south direction. A simple dual tracker consists of a rotating base and tilted axis which is perpendicular to the sun's movement. It can be visualized like a 2R manipulator which has two revolute joints.

The rotating base is used to control the azimuth angle while the other axis governs the tilt of the panel. The azimuth angle is the angle measured in the horizontal plane from due south for the northern hemisphere or due north for the southern hemisphere [8].

Another way is using a parallel robot manipulator. The joint for this type of manipulator are prismatic joints, universal, spherical and revolute. It can be a combination of one prismatic with two universal or one prismatic, revolute and spherical joint. This is represented in the form of 2-PUU/RS configuration. The solar panel is connected to three legs. The three legs are connected to sliding joints [9].

C. Based on Tracking System

The tracking system plays a major role in the design. It can be classified into the following categories,

(a) Photodiodes

Photodiodes are opto-electronic devices which convert light energy to electrical energy. When compared to an LDR photodiodes have fast response, when they are exposed to light. Photo diodes are used in charged couple devices.

(b) Light dependent resistors

The principle behind the working of LDR is that when exposed to light, the resistance decreases. LDR acts as a typical voltage divider bias when connected with a resistor in series when there is more light exposed it has less resistance therefore more voltage drops at the terminal of the resistor and when there is less brightness surrounding the LDR more resistance will be produced therefore less voltage drop at the resistance terminal with this mechanism we can compute the intensity of brightness surrounding the LDR.

(c) Image Processing

The sun’s image is captured using a webcam. The collected image is then processed using MATLAB program or even machine learning algorithms. The algorithm calculates the coordinates of the sun, which is then sent to microcontroller. The microcontroller sends the desired actuating signal to the motor [10].

(d) Power feedback

The solar panel is tilted to different positions and the corresponding power produced is noted and is finally set at a position where maximum power is produced. In this tracker the above method is utilized for the tracking mechanism. The solar tracker is tilted to different positions

III. EXPERIMENTAL SETUP

A. Description

Installing the solar panel as stationary is not much efficient. So here we can use a tracker to track the solar rays and simultaneously moving the solar panel. In this way we can increase the amount of solar rays and make the solar panel much more efficient [11]. Solar tracking can be classified based on the axis used and also on the base of sensors used. In this article we have designed based on single axis solar tracker that uses an INA219 power sensor for detecting the sun's rays using power feedback system. For large solar power plants, it is cost-effective to use two-axis tracking systems [12] ;because the larger the area of the solar panels, the more energy is generated, thus the energy of the rotating motors can be neglected [13] .The block diagram in Fig. 1 is the general overview of the design.

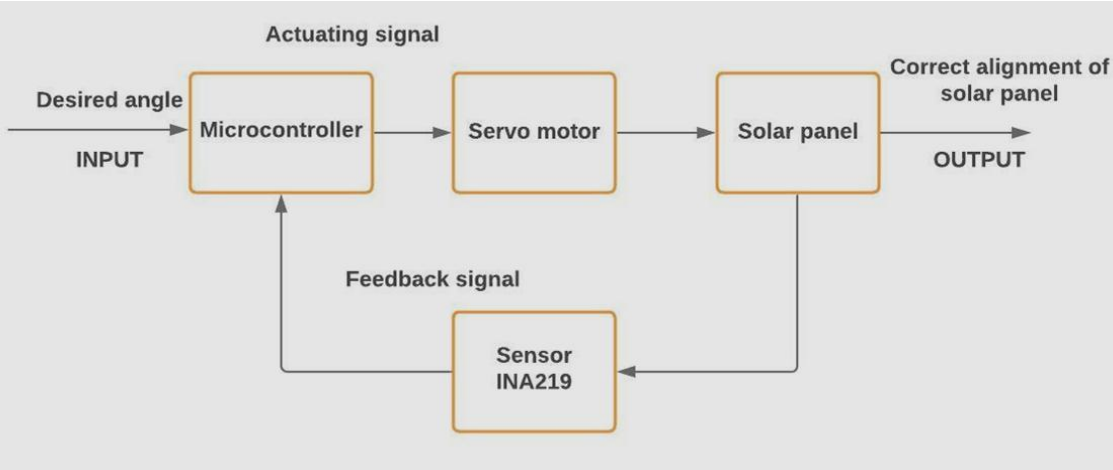

Fig.1: Block Diagram

B. Components

a) ESP32

It is a 4$ microcontroller manufactured by expressif foundation. Its features include in build Wi-Fi, Bluetooth and has deep sleep mode which is why it is preferred in this project.

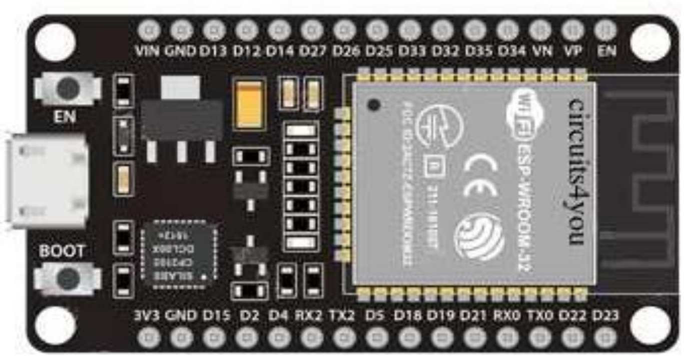

Fig.2: ESP 32

b) Worm Gear

It's a gear which is used to transmit power in perpendicular direction. It consists of a shaft with spiral thread and usually drives a toothed gear. But in this project it is used as a rope driver by pulling a string at either sides.

Fig.3: Worm Gear

c) Servo motor MG 990

It is a continuous running motor whose direction and speed of rotation can be controlled by PWM signals. It is a metal gear servo

Fig.4: Servo

d) INA219 Sensor

It is a DC power measuring sensor which is used to measure the power that is present at the resistance of 0.1 Ω. It uses I2C communication for data transfers.

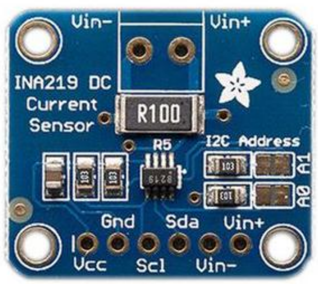

Fig.5: INA219 sensor

e) Solar Panel

A solar cell is an electrical device that converts sunlight to electrical energy. A solar panel is an arrangement of a group of photo voltaic cells arranged in a framework. A 10W solar panel has been used in this project

C. Bill of materials

S.No	***Component Name***	***Quantity***
1	ESP32	1
2	Solar panel	1
3	BC639 NPN transistor	1
4	MG90S 360 Servo	1
5	INA219 sensor	1
6	Iken joy Robotics Part	As required
7	Shaft	As required
8	Wires	As required
9	Nut and bolt	As required
10	PCB	1
11	String(with high tension)	1

IV. WORKING OF THE MODEL

The panel is tilted to various positions using the servo controlled by ESP32 and the power is noted at each of the positions and the panel is finally tilted to a position where maximum power is obtained. The working of the solar tracker depends on the feedback it gets from the INA219 sensor setup; this sensor senses the power produced and provides a feedback through which we can find the position where maximum power is produced. This setup uses only one mg90s servo motor to rotate the entire solar panel which greatly reduces the power required for rotating the panel and thereby making it efficient. This cycle is repeated every 15 minutes During the idle time the microcontroller is set into deep sleep mode at which it only consumes about 10 µA of current making it consume less power.

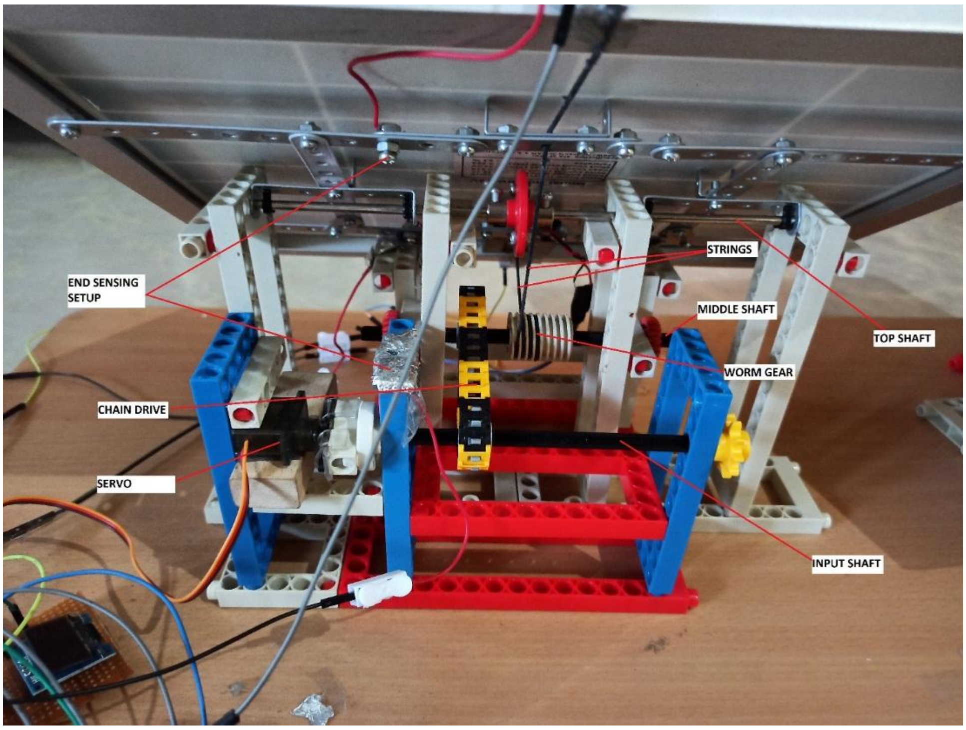

Fig.6: Solar tracker structure

The solar panel is balanced on the mechanical structure by a metal shaft which holds the entire weight. This can be termed as top shaft.

The initial torque produced by the servo motor is transmitted to the middle shaft by a chain drive in such a way that maximum torque is produced at the middle shaft. The middle shaft is parallel to the top shaft (Fig 7) which is kept down from it. Since the only purpose of the middle shaft is for rotating the solar panel (and not for balancing its weight), it is made of plastic.

At the middle shaft there is a worm gear attached to it with a string entangled to it (Fig 8) and the either ends of the string is connected to the ends of the solar panel. When the worm gear is made to rotate it pulls one end of the string thereby inducing tension at one end of the rope and releases the other end of the string thereby inducing a slack.

Subsequently a moment is created and the solar panel is rotated in a particular direction (clockwise or anti-clockwise).

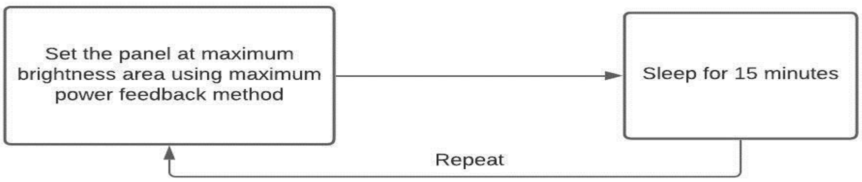

Fig.7: Solar tracker working mechanism flowchart

Due to the chain drive mechanism (between input servo shaft and middle shaft) there is no slip so it can easily maintain its position at any angle with minimal effort.

Also there are end sensing setup at either ends of the solar stands which senses the maximum reach of the solar panel at either ends (beyond which it cannot move) and sends a signal to make the motor stop moving the panel in the particular direction since it would be touching the stand and it cannot be tilted further.

The end sensing setup is such that one end of the wire is connected to a metal foil and placed at the stand and the other end is connected to an input in ESP32. And at the panel a wire from the positive terminal of the ESP32 is connected at either ends, such that when the solar panel reaches the maximum reach point its body touches the stand and the wires are kept connected with each other. Therefore, there will be a positive signal received at either input terminal when the solar panel touches the stand sensing that it cannot tilt further and rotation is stopped.

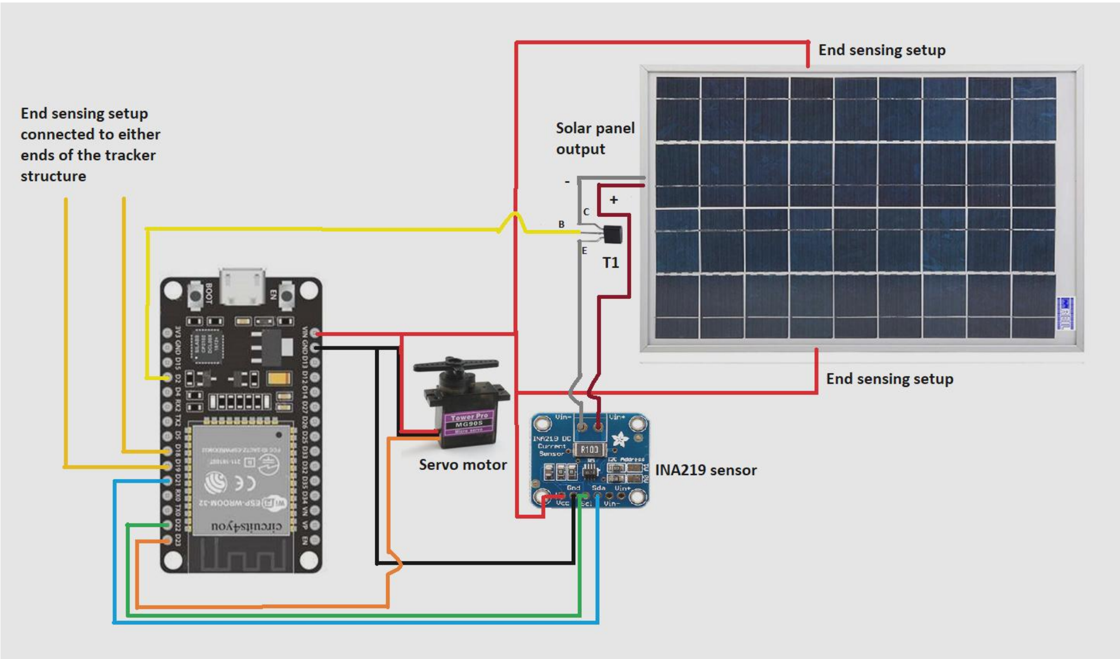

Fig. 8: Solar tracker circuit diagram

A transistor T1 is also connected is also connected at the negative input of the measuring voltage port in INA219 sensor its purpose is to allow current flow to the shunt resistance only when the power measuring is required and at other times to prevent current flow. It acts as switch which is controlled by ESP32. A BC639 NPN transistor could be used for this operation. This is an optional attachment which can be used if the power dissipated at the 0.1 Ω resistor is to be saved.

The ESP32 is coded in micro python for this project and the code is uploaded to it using a thonny ide.

Fig. 9 a) Top view

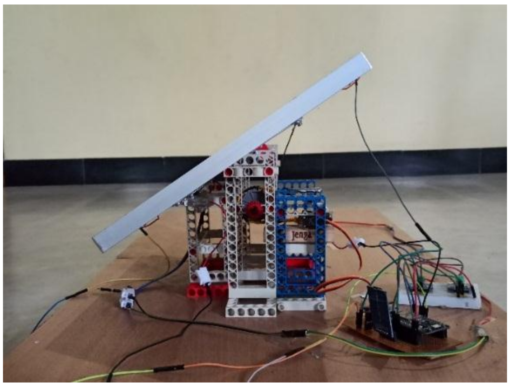

Fig. 9 b) Side view

Fig. 9 c) Internal view

Fig. 9: Views of Solar tracker

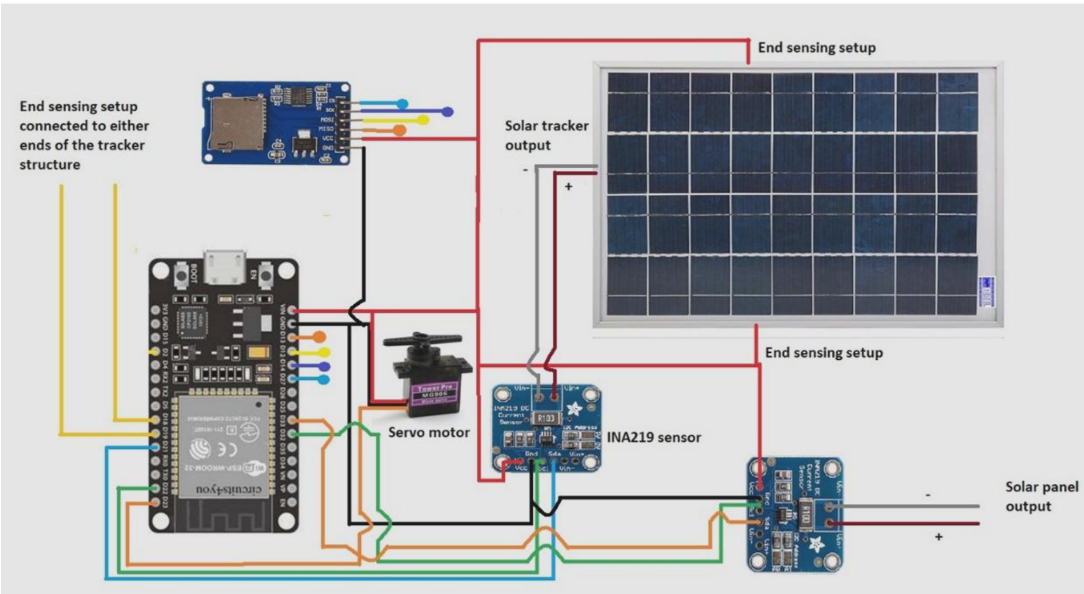

Fig. 10: Power measurement circuit diagram

V. EXPERIMENTAL RESULTS

The solar tracker model is compared with a normal stationary solar panel and both their powers are measured every second for a total of 6 hours and a graph is plotted as shown in fig. 13. The panels used are 10W 12V panels and their dimensions are of 13.26×8.03×0.7 $inch^3$ as shown in fig.11. For measuring the power between normal solar panel and solar tracker slight modifications are added to the original tracker circuit shown in fig. 8 and made into a circuit as shown in fig. 9 and also slight modifications is done to the code and ESP32 is not made to sleep instead it's made to continuously note the power produced by the solar tracker and normal solar panel every 1 sec for 6 hours. As a modification transistor T1 is removed since the power is measured continuously and also another INA219 sensor is added to measure the power produced by the normal solar panel. The measured powers are stored into an SD card using a SD card module which uses SPI communication.

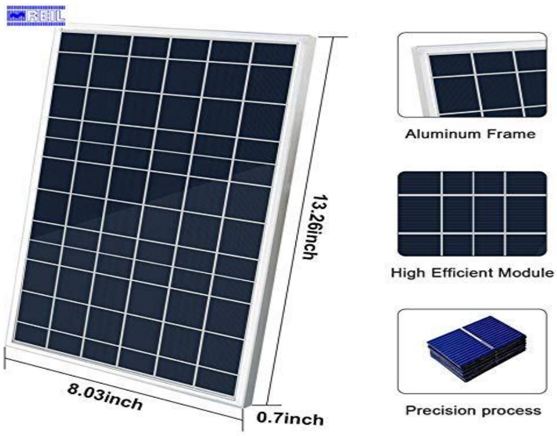

Fig. 11: Solar panel dimensions

The table below shows the power at different times

TIME	POWER at Solar tracker (mW)	POWER at normal Solar panel (mW)
10:00 am	481.951	469.268
11:00 am	561.951	557.073
12:00 pm	585.854	538.537
1:00 pm	580	468.293
2:00 pm	623.415	346.098
3:00 pm	500.976	177.317

Mean power produced by solar tracker = 532.998 mW

Mean power produced by solar panel = 428.458 mW

Fig. 12: Solar tracker power comparison with stationary solar panel

Left - Solar tracker

Right - Normal solar panel

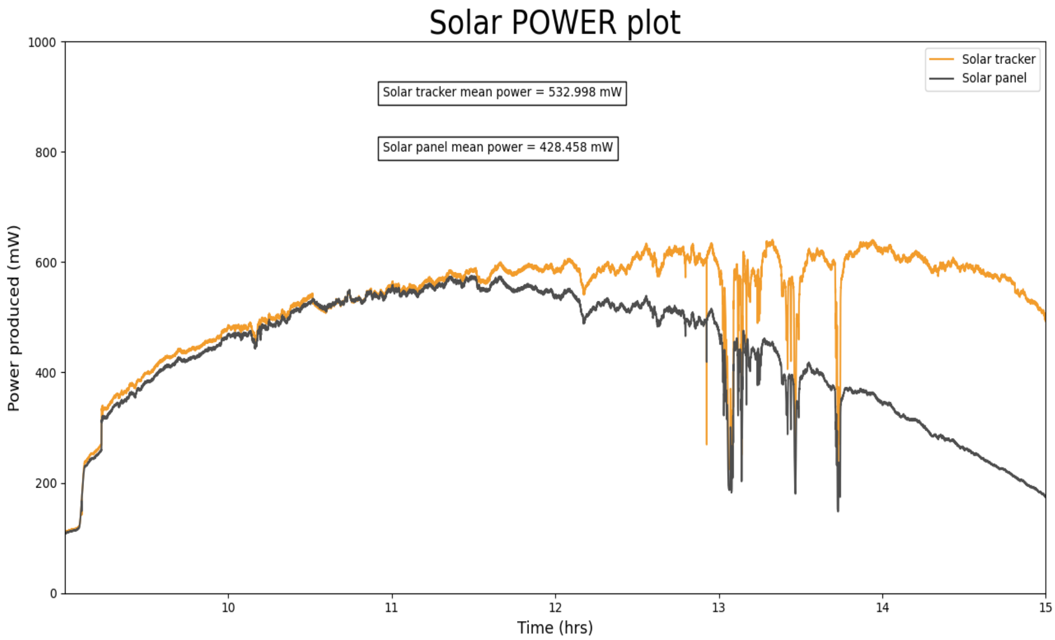

Fig. 13: Solar power production plot between solar tracker and normal solar panel

The power produced before noon is more of the same since the normal solar panel is tilted in that direction by default. Gradually the solar tracker's power increases between 11 to 12 as it tilts itself accordingly using maximum power feedback mechanism and produces more power than the stationary solar panel.

VI. CONCLUSION

This paper proposed a novel and simple single axis solar tracker which maximizes the efficiency of the solar panel by tilting itself accordingly with respect to the surrounding brightness. The model also used only one 360 micro servo motor for tilting the solar panel which is quite

cheap compared to other motors and does not need an external motor driver which greatly reduces the initial costs.

The model is designed in such a way that with minimum initial torque a maximum output torque is achieved. In most cases a closed loop solar tracker shows more efficient than an open loop solar tracker. A single axis solar tracker is more reliable than a dual axis solar panel since the mechanical system is more complex in a dual axis solar tracker also proper maintenance is required. The further

design updation will be focused more on including dual axis motion in the tracker and also for a bigger solar panel model.

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