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Design and Simulation of Self-Aligning Solar Panel

Kumar Shashi Ranjan[1], Vicky Gopaldas Bajaj[1],
Patil Meghraj Umesh[1], Swapnil Pramod Randive[1], A.P. Kaldate[2]
Scholars, Mechanical Engineering, Sinhgad College of Engineering, Pune, India[1]
Assistant Professor, Mechanical Engineering, Sinhgad College of Engineering, Pune, India[2]

Abstract: Non renewable energy sources like fossil fuels are soon being depleted and in future we will be faced with its extinction. Alternative energy sources which are renewable and available in abundant quantity are required. Sun's insulation fits both the criteria. Hence there are emerging technologies focused on harvesting solar power. The purpose of this projectis to make a self-aligning platform for solar panels for better utilization of the renewable solar energy source that's available. Many of the solar panels throughout the planet are positioned with the fixed angles. To maximize the utilization of the solar array we use a solar tracker which orients itself along the direction of the daylight. The solar tracker positions the panel in a hemispherical rotation to track the movement of the sun and thus increase the total electricity generation. In this project we will simulate and implement the most suitable and efficient control algorithm on the self-aligning solar tracker which can rotate in azimuth and elevation direction. PID Controller will be used to control the mechanism of solar panel. The tracking mechanism of the sun requires light dependent resistor (LDR) as a sensor to sense the maximum light availability. The software used is MATLAB Simulation.

Keywords: Solar Panel, Solar Tracker, PID Controller, LDR Sensors

I. INTRODUCTION

The daily average solar energy incident over India varies from 4 to 7 kWh/m2 with about 1500–2000 sunshine hours per year (depending upon location), which is far more than current total energy consumption. For example, assuming the efficiency of PV modules were as low as 10%, this is able to still be thousand times greater than the domestic electricity demand projected for2015. Solar energy is not being used at its full potential, mainly because present market solutions is not yet competitive with the fossil energy sources used today, in terms of efficiency. However, the usage of solar panels is increasing and therefore it is important that the solar panel efficiency increases as well. Improving the technology in the solar panel itself is one way to achieve this, but the surrounding equipment can be improved as well.
The problem with solar energy is that it's directly dependent on intensity of light. To produce the utmost amount of energy, a solar array must be perpendicular to the sunlight. Because the sun moves both throughout the day as well as throughout the year, a panel must be able to follow the sun's movement to produce the maximum possible power. The solution is to use a solar tracking system that maintains the panel's orthogonal position with the light source.

The aim of this project is to create a self-aligning platform for better utilization of a solar panel. The purpose is to compare the self-aligning platform to a stationary one and see if there are any benefits from using such a platform. If there are any improvements on the efficiency these would also be analyzed in terms of profitability in net energy. The project focuses only to make changes on the supporting structure of the solar panel, but no changes on the solar panel module itself. It follows the sun throughout the day when it's sunny enough based on the readings from photo-resistors. When this mode is inaccurate it will fall back to analyzing the voltage output from the solar panel and move accordingly.

This paper gives an overview of currently available and emerging two axis solar tracker system and Control for maximum power generation.[1] In this paper, the virtual prototype of the tracking system used for improving the energetic efficiency of a photovoltaic panel and safety of polar dual-axis system has been designed.[2]

Solar tracking is a mechanism by which we can create a system to tilt the solar panel in the direction of movement of the sun. It is essential to perform sun tracking, in order to enhance the performance of the system. It can result in the collection of more than 20 - 30% extra energy from the same collector.[3] Self-Aligning Solar trackers have two degree axis of rotation one is along vertical axis and other is along horizontal axis. It gives maximum solar exposure due to its ability to follow the sun, regardless of sun position within the sky, dual axis trackers enable the PV panel to align itself in the direction of sun. In self-aligning solar tracker vertical axis follows the angular height position of the sun in the sky and horizontal axis follows the east to west movement of the sun.[4]

The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and thus the panel. The table no. 1 shows the Direct power lost (%) due to misalignment (angle i).

Table 1 Direct power loss (%) due to misalignment (angle i)

Misalignment (angle i)	Direct power lost (%) = 1-cos(i)
00	0
10	.015
30	.14
80	1
23.40	8.3
300	13.4
450	30
750	>75

The sun travels through 360 degrees east-west each day, but from the perspective of any fixed location the visible portion is 180 degrees during a 1/2-day period. Local horizon effects reduce this somewhat, making the effective motion about 150 degrees. A solar array during a fixed orientation between the dawn and sunset extremes will see a motion of 75 degrees on either side, and thus, according to the table above, will lose 75% of the energy in the morning and evening. Rotating the solar panels to the east and west can help to recapture these losses. A tracker rotating in the east-west direction is called as a single-axis tracker. The sun also moves through 46 degrees north-south over a period of a year. The panels set at the midpoint between the two local extremes will thus see the sun move 23° on either side, causing losses of 8.3%.A tracker that accounts for both the daily and seasonal motions is known as a dual-axis tracker.[5]

There are two types of tracking system- Passive Tracking System and Active Tracking System. The Passive tracking system realizes the movement of the system by using a low boiling point liquid. This liquid is vaporized by the heat of the sun and the center of mass is shifted leading to that the system finds the new equilibrium position. The Active tracking system continuously emit signal that can be tracked anytime and the system finds the new position. As our proposed tracking system is based on an active tracking system.

The active tracking system is designed using a closed-loop model. The microcontroller is connected with LDR sensors to receive the analog input signals. The signals are converted to digital signals, and therefore the digital signals are consecutively processed to trigger the motors via the motor drives, consistent with the tracking strategy. The axes of rotation are regulated by the motors. The movement of the mechanical system affects directly the PV module orientation. Computer simulations will be conducted using Simulink software to determine whether the control system and its algorithm is fully functional. This simulation will also help to determine the errors associated with the control system. It will also help to determine if the framework of the solar panel was stable and fully functional.

II.DESIGN AND SIMULATION

This paper presents the design of self-aligning solar system. This design makes use of the sensors as the feedback constituents as they provide signals to the control system. In this design the overall objectives were met. By making the system self-aligning, the PID is able to control the solar panel motion and increasing the amount of electricity generation as compared to static solar panel. Design and Simulation of system is presented in detail in the following sections.

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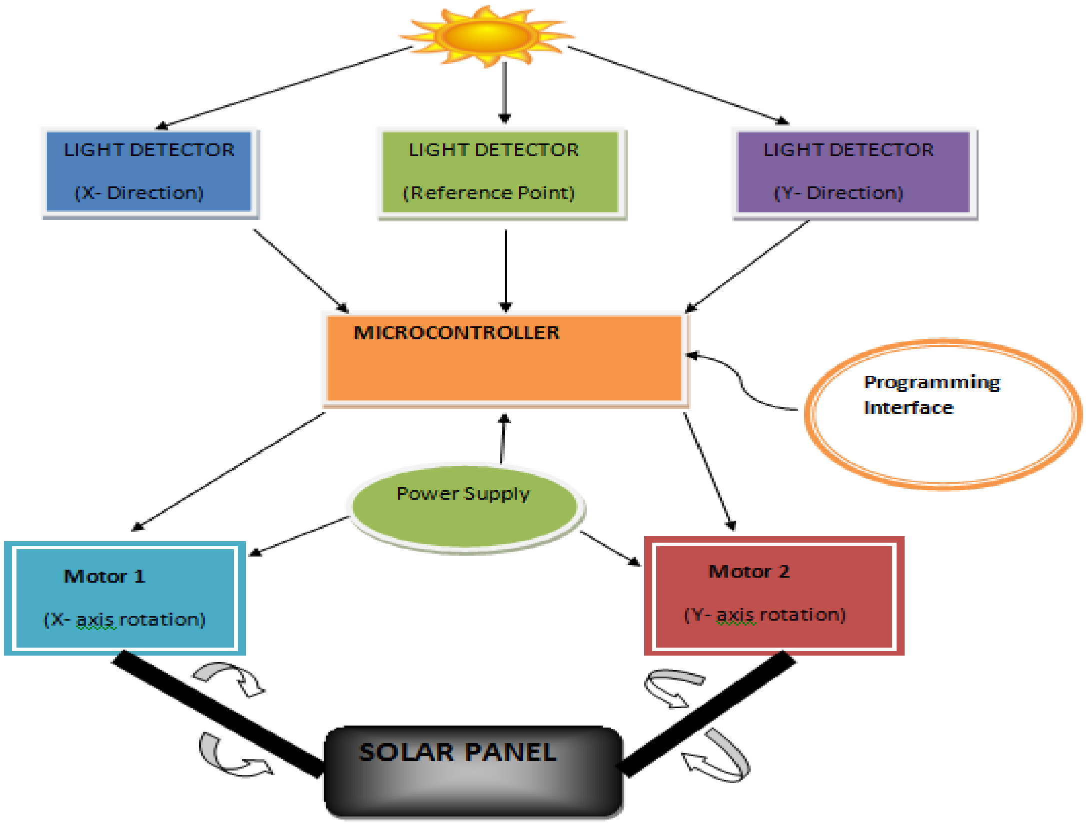
A. Block Diagram of the System



EXPLANATION OF BLOCK DIAGRAM

As we see can in the block diagram, there are three Light Dependent Resistors (LDRs) which are placed on a common plate with solar array. Light from the source strikes on them by different amounts. Due to their inherent property of decreasing resistance with increasing incident light intensity, i.e. photoconductivity, the value of resistances of all the LDRs is not always same.
Each LDR sends equivalent signal of their respective resistance value to the Microcontroller which is configured by required programming logic. The values are compared with oneanother by a specific LDR value as reference.
Both the dc servo motors is mechanically attached with the solar panel using driving axle. The axle of the servo motors is used to drive the solar panel. These two-servo motors are arranged in such a way that the solar panel can move along X-axis as well as Y-axis.
The microcontroller sends appropriate signals to the servo motors based on the input signals received from the LDRs. One servo motor is employed for tracking along x-axis and therefore the other is for y-axis tracking.
In this way the self-aligning solar tracking system is designed.

B. Motion Mechanism

The tracker system consists of a base, north/south motion set and sensors, east/west motion set and sensors, and a photovoltaic panel. The base and the pole support the rest of the components and allow the orientation angle of the panel. The system presented in this paper can be classified as pseudo-equatorial, once daily orientation occurs relative to seasonal inclination. The engine Motor 1, from the north/south mechanism, follows the solar inclination caused by the translational north/south movement of the Sun throughout the year. This mechanism works as a response to the readings recorded by the set of light sensors of this axis, named LDR1 (north) and LDR2 (south). The engine Motor 2, from the east/west mechanism, comprises the variation of the east/west azimuth angle, such movement covers the effect of the Earth's rotation. The set of sensors that directs this axis is produced by LDR3 (east) and LDR4 (west). Finally, the photovoltaic panel was attached to the motion mechanisms.
The angular amplitude is meant to cover the majority of the possible solar positions. In the north/south direction, the variation from 0° to 60° covers the entire variation of the solar inclination throughout the year. In the east/west direction, the variation of the azimuth angle from 60° to - 60° does not cover the early-morning and late-afternoon positions. However, this variation was considered sufficient for this study, considering the geographic conditions of the

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environment, the solar intensity within the uncovered periods, and therefore the possibility of increase of motor consumption.
The signals from the sensors are a part of the stored information and are employed by the solar panel for its motion control. The activation of the motors is based on climatic conditions, such as the luminous intensity and direction, which are captured by light dependent resistors (LDRs) or photo-resistors. In this sort of component, the resistance varies consistent with the luminosity on the sensitive side. Each LDR integrated a potential divider, whose output is proportional to the variation of resistance, and therefore the output was read using the microcontroller. Two LDRs, found out on a support whose faces form an angle between them, constitute a group or modulus of sunlight sensors.
The direction of the Sun is provided by the comparison between the sunlight on the two LDRs that form a group. When one among them indicates greater luminosity, the rays of sunlight are more aligned with this sensor. Therefore, the motor should be activated for this side until there's no difference between the values from the LDRs, indicating the perpendicularity of the panel in reference to the rays of sunlight. The solar tracker is provided with two sets of sunlight sensors. The first, composed of LDR1 and LDR2, is oriented towards the north/ south axis, to follow the slow variation of the solar elevation throughout the year. Meanwhile, the set equipped with LDR3 and LDR4 reads the variations of the solar azimuth angle, i.e., they're liable for the daily motion.

C. Mathematical Equations Required

LAMBERT'S COSINE LAW

The illumination received on a surface is proportional to the cosine of the angle between the direction of the incident light rays and normal to the surface at the point of incidence. This is mainly due to the reduction of the projected area as the angle of incidence increases.

$$\boldsymbol{E_\theta = E\,cos(\theta)} \qquad (1.1)$$

Where,

E_θ = illumination on horizontal plane
E = illumination due to light normally incident
θ = the angle of incidence

SOLAR PANEL EQUATION OF MOTION

$$\frac{d^2\vartheta}{dt^2} = \frac{1}{J}\left(T - K_d\frac{d\theta}{dt}\right) \qquad (1.2)$$

Where,

$\frac{d^2\vartheta}{dt^2}$ = angular acceleration
J = polar moment of inertia
T = torque
K_d = damping constant
$\frac{d\theta}{dt}$ = angular velocity

EQUATIONOFSERVOMOTOR

$$\frac{di}{dt} = \frac{1}{L}\left(V - K_g K_f \frac{d\theta}{dt} - R\right) \qquad (1.3)$$

Where,

$\frac{di}{dt}$ = instantaneous rate of current change
L = inductance
V = velocity
K_g = gear ratio
Kf = back EMF constant
$\frac{d\theta}{dt}$ = angular velocity

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D. Simulation

We have done the simulation of Self- Aligning Solar Panel System using MATLAB Simulink Software.

In Simulink we have used the Block Model to simulate. Simulation work has been done in three phases:- Model the Physical System, Design the Controller and Test the Design.

Hence, Step- By- Step simulation process is explained below :-

Step 1 : We will start with the modelling of Solar Panel(Fig. 1). To model the equation for the solar panel we will start with the integrator block. Integrator block takes the input and integrates it over time. We will use constant block to provide torque to the panel later constant block will be replaced by the motor. For damping term we have used the gain block. For polar moment of inertia we have again used the gain block. For visualization of output of signals we have used the scope block. Using Scope block we have visualized the Position and Velocity of Panel after providing torque to the panel.

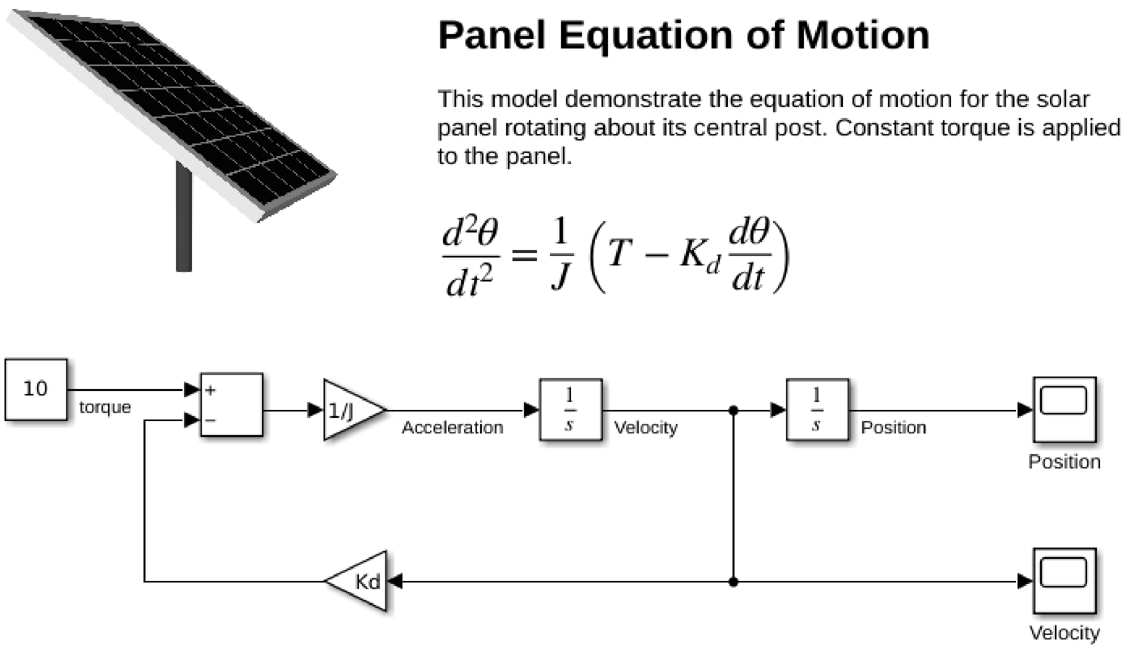

Fig. 1 Model of Solar Panel

In the position scope (Fig. 2) we see the panel's angular position is increasing with the time.

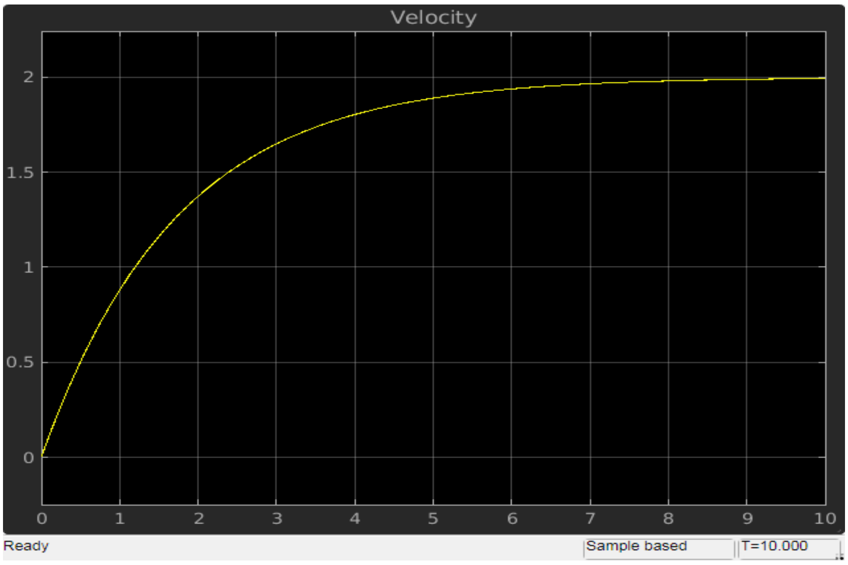

Fig. 2 Graph of Change in Position of Panel

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In the velocity scope (Fig. 3) the velocity starts from 0 and levels off, so with a constant torque the panel starts turning and settles to rotating at a fixed rate.

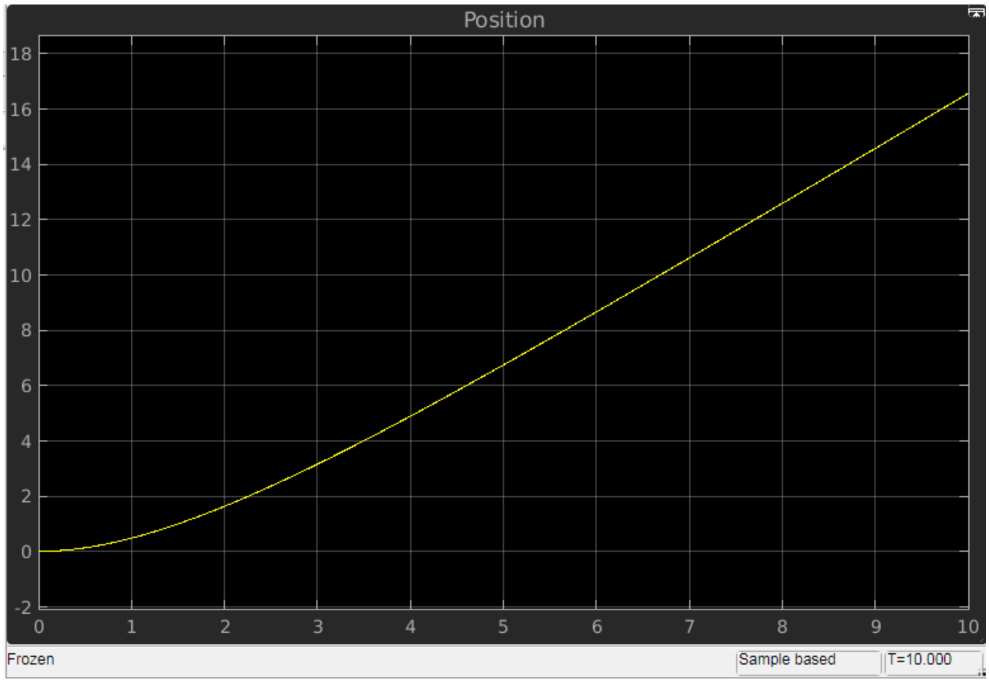

Fig. 3 Graph of change of velocity of panel

Step 2 : Now, we will model the motor (Fig. 4). We will use the equation of motor to model the motor. Similarly, like the solar panel equation we will model it.

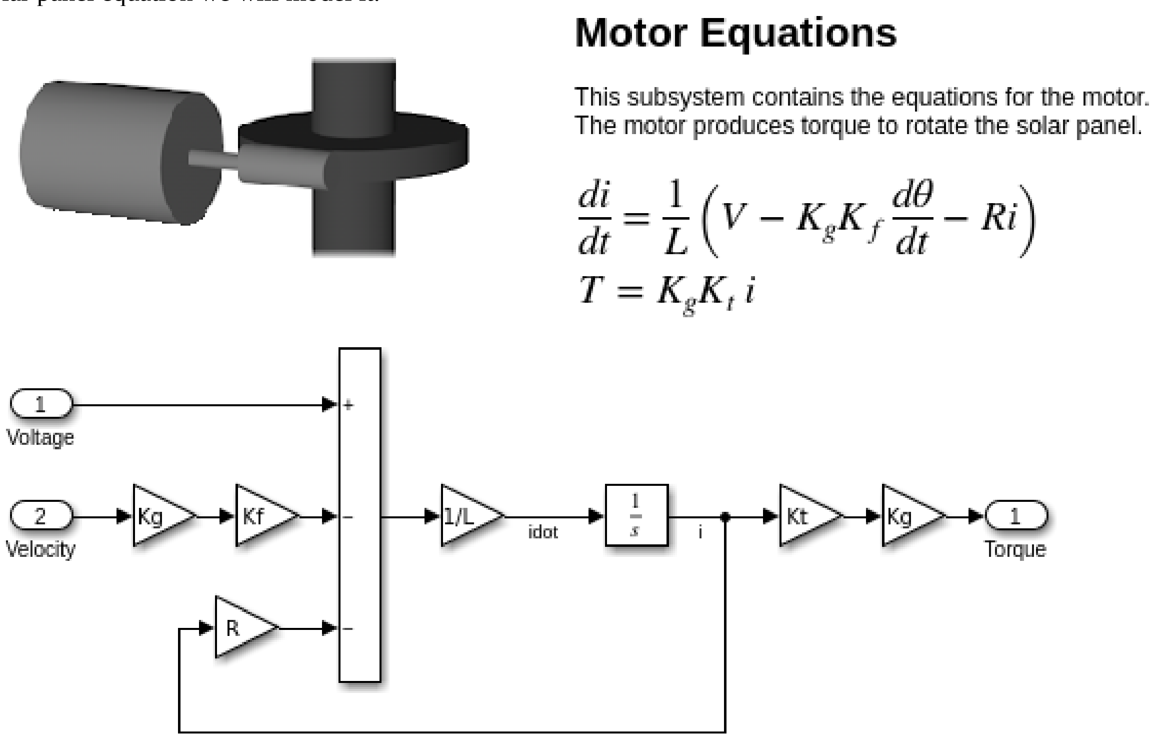

Fig. 4 Model of Motor

Step 3 : Now, we have assembled the both panel and motor model (Fig. 5). We have supplied the voltage to the motor to generate a torque and move the panel.

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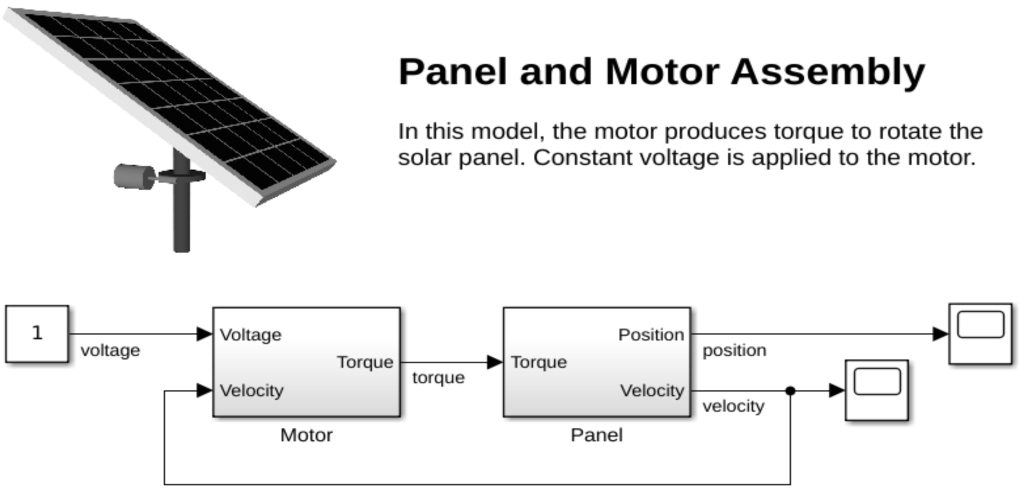

Fig. 5 Panel and Motor Assembly

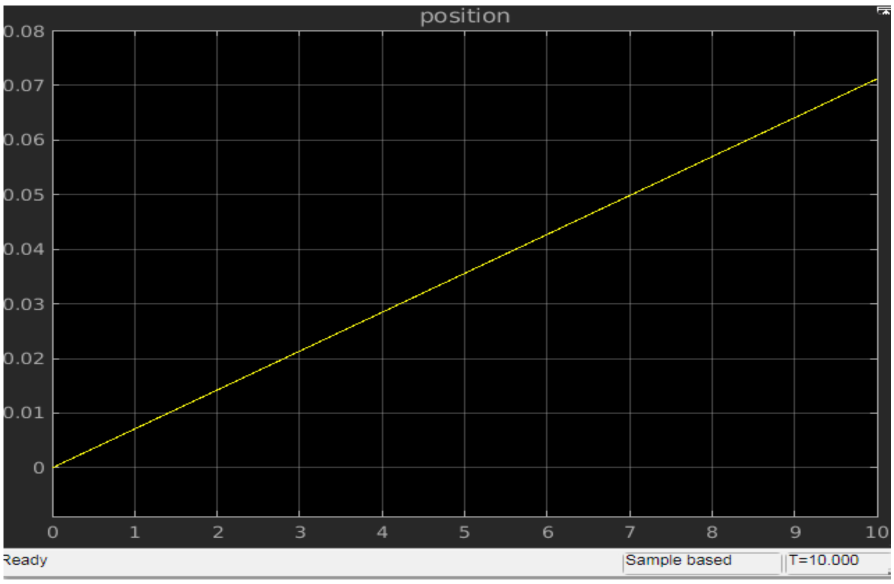

Fig. 6 Graph of Panel changing its position after voltage supplied

After checking the scope model for position we can see that panel spins when a voltage is applied to the motor (Fig. 6).

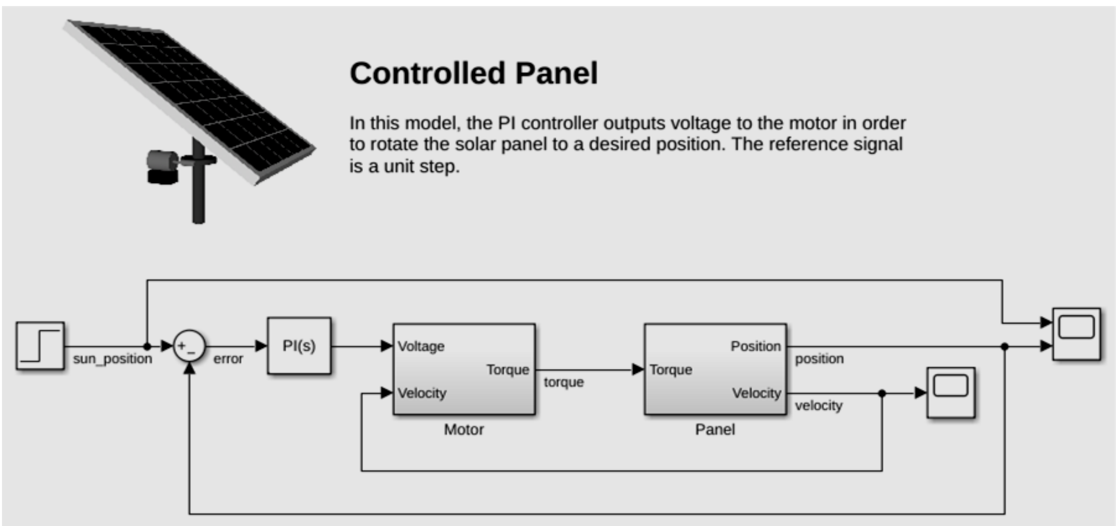

Fig. 7 Model of Controlled Panel

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Step 4: Now, we need to model a controller to set the correct voltage so that the panel tracks the sun. In model of controller (Fig. 7) we have used the PID controller which is already available in Simulink Workspace. As the sun moves the controller will react accordingly to keep the panel pointing at the Sun. While we are designing the controller we will use a unit step input. Now, to calculate the error we will use the sum block and we need to change the second port of sum block to be minus instead of a plus.

Now by checking the scope block for position (Fig. 8) we can see that the controller overshoots a little then settles for the reference value of 1.

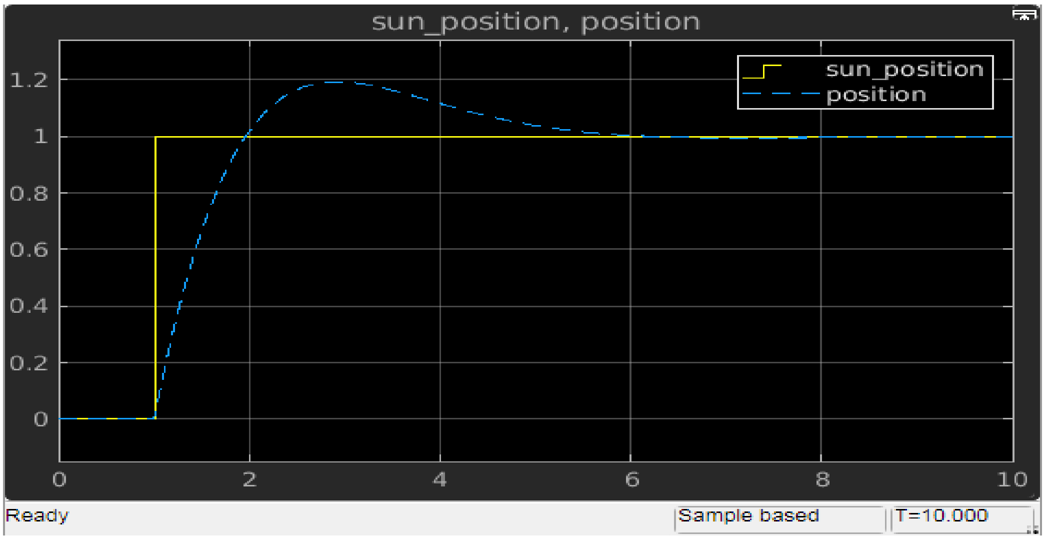

Fig. 8 Graph of Controller regulating panel motion

Step 5 :Now, first replace the step block with the import block to provide the sun position data, we have provide it with some real time data for 10 hours. And System model is complete(Fig. 9).

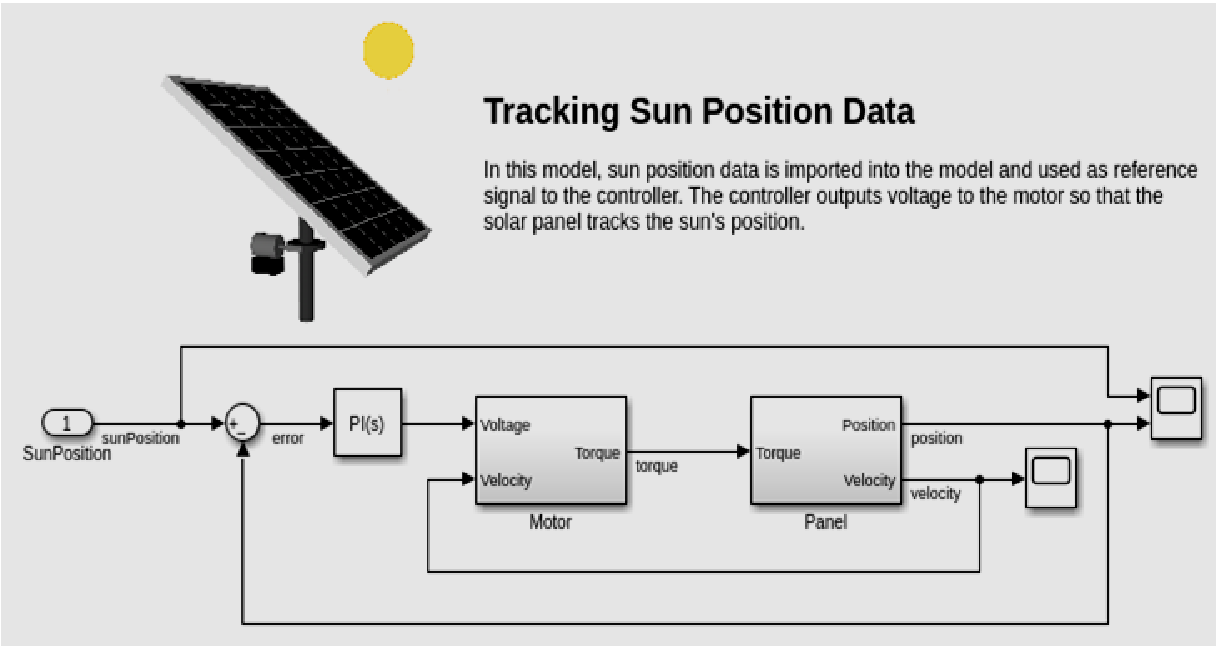

Fig. 9 Model of Self-Aligning Solar Tracker

Now, Run the final model and let’s analyze the position of solar panel motion and sun motion with respect to time using the scope block for Position (Fig. 10). We can see that it’s tracking the sun’s position quite well.

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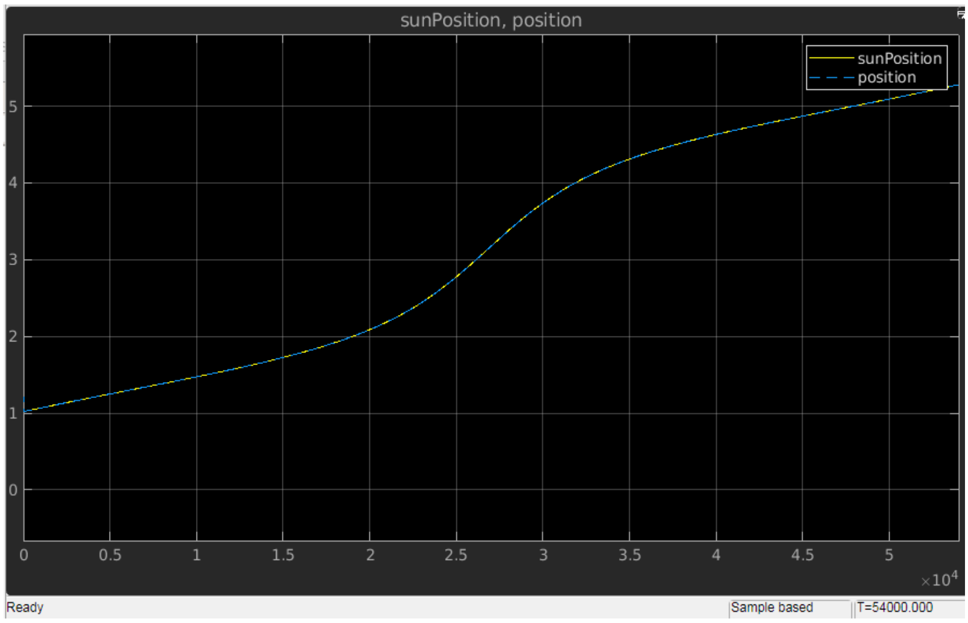

Fig. 10 Graph of Solar Panel and Sun position overlapping

III. CONCLUSION

The project work was carried out for making the tracking automatic by incorporating Solar Panel, PID, sensors and servomotor to work as effectively as posssible. This project makes an optimization strategy of the motion law, which is based on the determination of the optimum angular field of the daily motion, the number of actuating operations and the actuating time in the step-by-step tracking leads to an efficient PV system, without developing expensive hardware prototypes. The virtual system was successfully designed and automated. Also, we found that the self-aligning solar panel is 30 - 40% more energy efficient as compared to static solar panel. In the final position graph we can see that the position of panel and sun is overlapping during the period of time, so the simulation has shown the desired result. The Self-Aligning Solar Panel works in all the weather conditions. It moves the solar panel according to the movement of sun to get the maximum intensity of sunlight. This mechanism through the microcontroller as compared to the static solar panel, increases the share of the solar power in the total power production from the non-conventional energy resources and thus tends to make our environment pollution free and thus development is sustainable.

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