Dual Axis Solar Tracker with Multiple Tracking Strategies For Efficiency Improvement of PV Cell

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ABSTRACT: *Solar trackers are machines that track position of the sun, and can increase the receiving ability of solar panels. The incident irradiations of the sun on the panel vary with respect to time, to maximise the receiving power it is worthwhile to implement a tracking mechanism. In current work, the focused surface orientation is based on dual axis tracking using hybrid technology. For effective tracking, solar panel is bring into line where light intensity is more and the sun rays are perpendicular to the panels by using appropriate sensors and assures command from designed controllers to the two positioning motors. During initial conditions and rainy seasons, another chronological technique which is also combined and implemented. For this technique, a solar tracker is designed and implemented based on Sun earth relations, which could predict the precise the actual position of the sun, by latitude location, thereby avoiding the need to use sensors. The proposed technique reduces the cost of the tracking method and makes it cost-effective. This paper proposed a dual-axis solar tracker to improve the absorption and production of sun based power conversion and to lessen the system cost with the thought of simple assembling and collecting.*

Keywords: Dual Axis Solar Tracker, PV Cell, Solar Panel

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1. Introduction

As the electrical power is important for all kind of work, the society focuses on generation of electrical power from different modes. Power generation from non-renewable energy source is the customary innovation and it ought to be old since it has numerous detriments like more cost, carbon discharge and transport cost. Energy is basic for the monetary development and social improvement of any nation. The rapid industrialization of developed and developing countries had led to high energy utilization which has an impact on the energy sector. The energy sector tends to increase the energy generation which leads to the increase of non-conventional energy sources which thereby decrease the threat of global warming.

It is increasingly urgent to find energy alternatives that are sustainable as well as safe for environment and humanity. The solution is encouraging renewable energy [1–5]. Most of the developed countries switched over towards the employment of renewable energy sources as a major contributor in the energy sector. The wind energy and solar energy are the most popular renewable energy sources out of which solar energy outstands in merits and simplicity. It is evident the need for utilizing the available solar energy is inevitable at this stage. Hence the research moves towards tracking system for utilizing the maximum available power from solar panel. As the government additionally supports by giving sponsorship, more individuals approach to introduce solar panels for their need.

2. Solar Geometrical Data and Irradiation

Before talking about the solar tracking systems, the review of some basic concepts concerning solar radiation and mention some important values to better understand the results of this work.

The sun emits high amount of energy in the form of radiation, at temperature of 5800 K, which reaches the planets of the solar system. The direct beam and the diffuse beam are two components, of sunlight. The sum of diffuse and direct beams is considered as the global radiation on a surface. As the majority of the energy is associated with direct beam, maximizing collection requires the sun to be detectable to the panels as far as might be feasible.

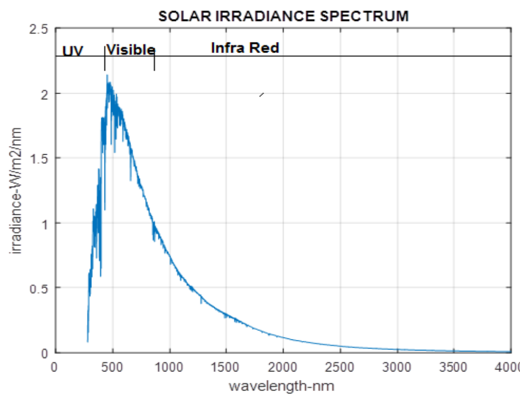

Figure 1. Solar irradiation spectrum

Figure 1 shows the solar irradiation spectrum, consists of three regions namely Ultra Violet (UV) region, visible region, Infra-Red (IR) region. Solar rays in the IR region is the widely utilised by PV panels for voltaic energy conversion.

Hour Angle (ω):
The Hour Angle is the angle through which the earth would turn to bring the meridian of the point directly under the sun. The hour angle at local solar noon is zero, with each 15°of longitude equivalent to 1 h, the morning the hour angle is negative and during afternoon hours being designated as positive. [6]

Solar Altitude (θz):
The solar altitude is the vertical angle between the horizontal and the line connecting to the sun. At sunset and sunrise, altitude is 0° and is 90° when the sun is at the zenith. The elevation (altitude) relates to the latitude of the site, the declination angle and the hour angle. [6]

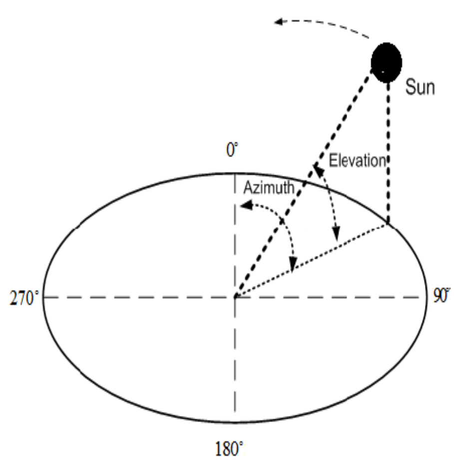

Figure 2. Representation of solar geometry

Solar Azimuth (θ_A):
The solar azimuth angle is the angle of the sun's beams estimated in the flat plane from due south for the Northern Hemisphere. [6]. At solar noon, the sun is actually on the meridian, which contains the north–south line, and therefore, the sun based azimuth is 0°.At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude, hence making the azimuth angles 90° at dawn and 270° at sunset.

Equation of time (ET):
It is an empirical equation that corrects the local standard time (LST) to apparent solar time (AST). [6]

$$ET = 9.87 \sin(2B) - 7.53 \cos B - 1.5 \sin B \text{ (minutes)}$$

Where,
$B = 360*(N-81)/364$;
N = day of the year.

Based on the above relations and empirical formulae one can calculate the position and path of sun. This method of tracking sun is called chronological method. Figure 2 shows the sun path at latitude 13.03° where the experiment is conducted to study the performance of designed tracker mechanism.

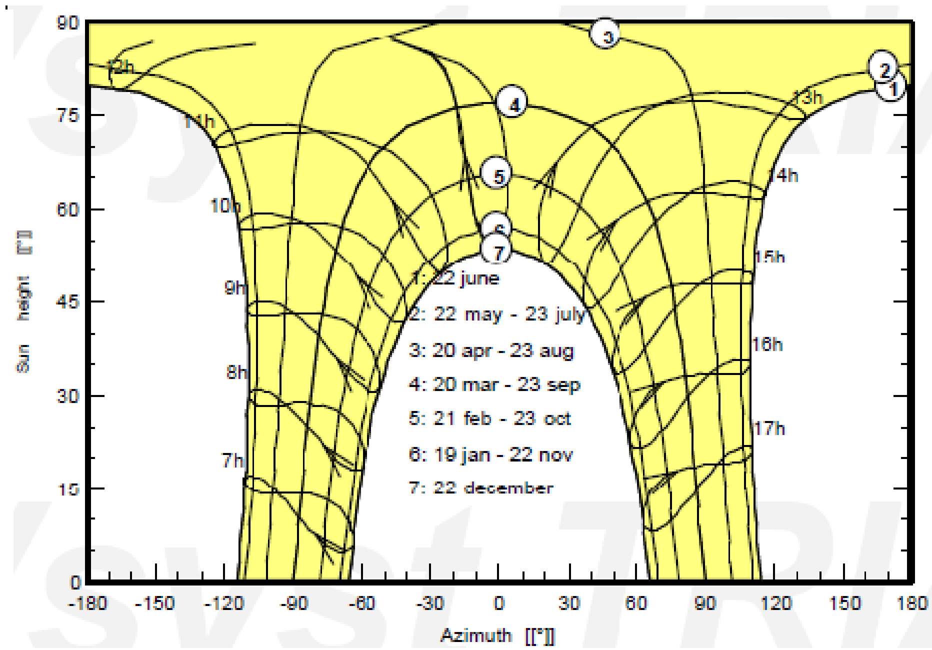

Figure 3. Solar Path at lattitude13.03°(Saveetha Engineering College)

3. Tracking System and Theoretical Approach

The solar panels are made of photovoltaic cells which convert solar radiations directly into electricity. The solar panels are mostly deployed in fixed positions (i.e.) oriented in the maximum direction of solar radiation. The tracker system tends to orient the solar panel always in the geometry of the rotating sun angle to receive maximum solar irradiance, so as to operate the panel in the maximum operating voltage and increases the effectiveness of the PV panel. There are different methodologies employed in solar tracking out of which active tracking, passive tracking and chronological methodologies are popular. Active tracking method involves photo sensors which orient the panels in accordance with the difference in the radiation level. Chronological method uses calculation to determine the sun angle of a particular location; hence the use of sensor can be avoided. This also involves motors and gear setups to orient the panel according to the calculated sun angle. Two types of trackers are commonly used based on their degrees of freedom (DOF). Single-axis tracking (DOF = 1) uses elevation angle for orienting the panel whereas Dual axis trackers (DOF = 2) relies on both Azimuth and elevation angles in the orientation.

In this current work, a single-axis sun tracking system with three sensors is compared with the designed dual axis tracker system combines active and chronological method of tracking which utilise the Internet for weather updates so as to improve energy efficiency which is implemented by Cayenne IOT platform. The structural stability of the Dual Axis system is ensured by positioning the main rotational axis in the horizontal position, which tracks the azimuthal change in the solar radiation and the vertical elevation changes.

The tracking mechanism of the photovoltaic module and its control circuits were implemented based on Arduino Uno which makes the operating condition stable and easily controllable. The data is read from the weather forecast application and the weather that prevails subjects the tracking method. To achieve this Arduino Ethernet Shield V1 and Arduino Uno is used. The Arduino Uno is a single board computer which supports internet applications. The Arduino Uno has a good speed of response with 5V to 12V; 1A is enough to power it. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

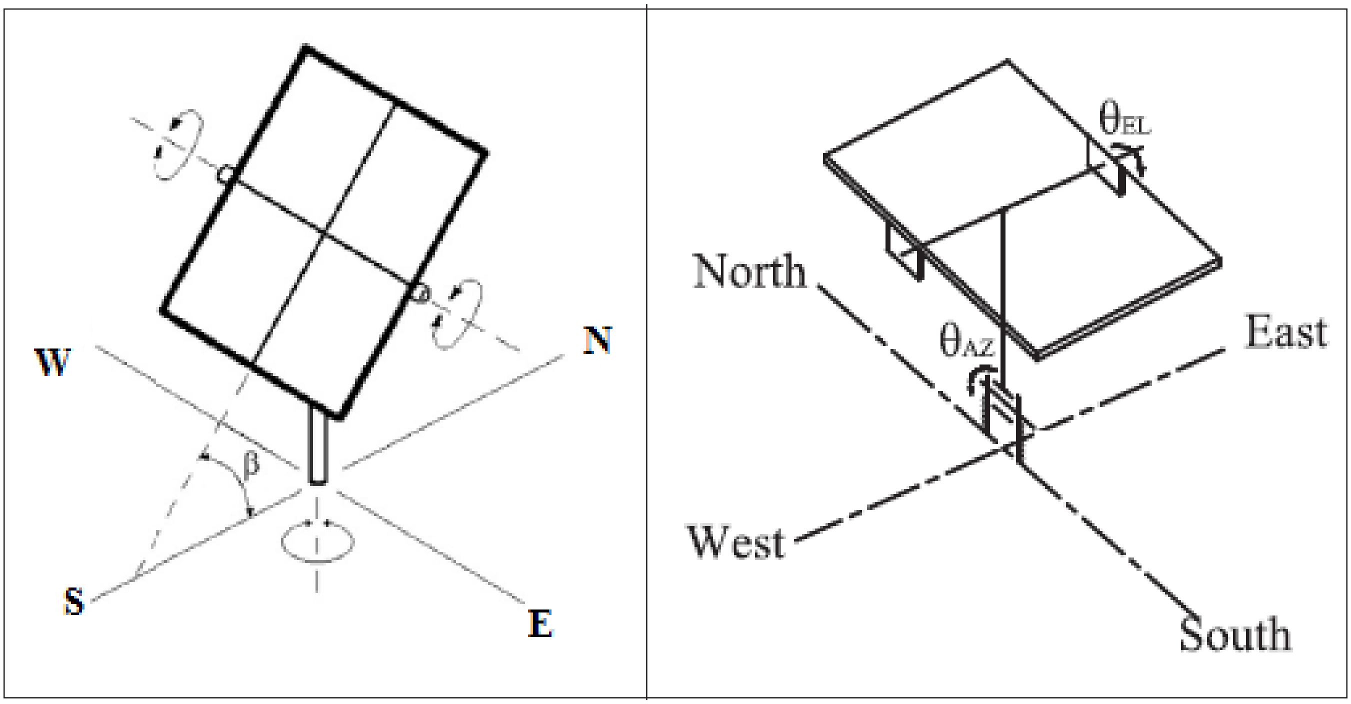

Figure 4. Illustration of Dual Axis Mechanism

The active tracking method uses four LDR's (light dependent resistor) as sensors and they are connected to the analog inputs pins of the Arduino controller. The difference in the light radiations will make the corresponding digital output pins go to high and the servo motor is programmed to rotate in the direction of the maximum radiation. The motor will be in stable position when the light sensors receive equal light radiation. Only when there is difference in the intensity of radiation levels the motor rotates. The LDRs are utilized to segregate the sun's position and to send electrical signals corresponding to the error of the controller, which incites the motors to follow the sun. Customary system has 180° horizontal and 90° vertical moving ability. For the horizontal axis, a motor with 180° moving ability was used. Higher difference values of the light intensity that the LDRs estimated than the reference value initiate the movement of the motor in both directions.

During partial shading conditions and cloudy weather, the ineffectiveness of the Active Tracking system using LDRs, is overcome by utilizing the chronological method where calculated values are used to track the position of the sun. In this project the previous sunshine records of that particular location are taken into account and the tracker is set to rotate accordingly. The motor is made to rotate every half an hour (i.e.) 7.5 degree rotation every half an hour. This is put forth from the fact that earth rotates for an hour 15° which is 1° for every 4 minutes. Instead of moving in steps the panel is oriented for every 7.5 degree variation from the values. The flow chart below explains the procedure followed.

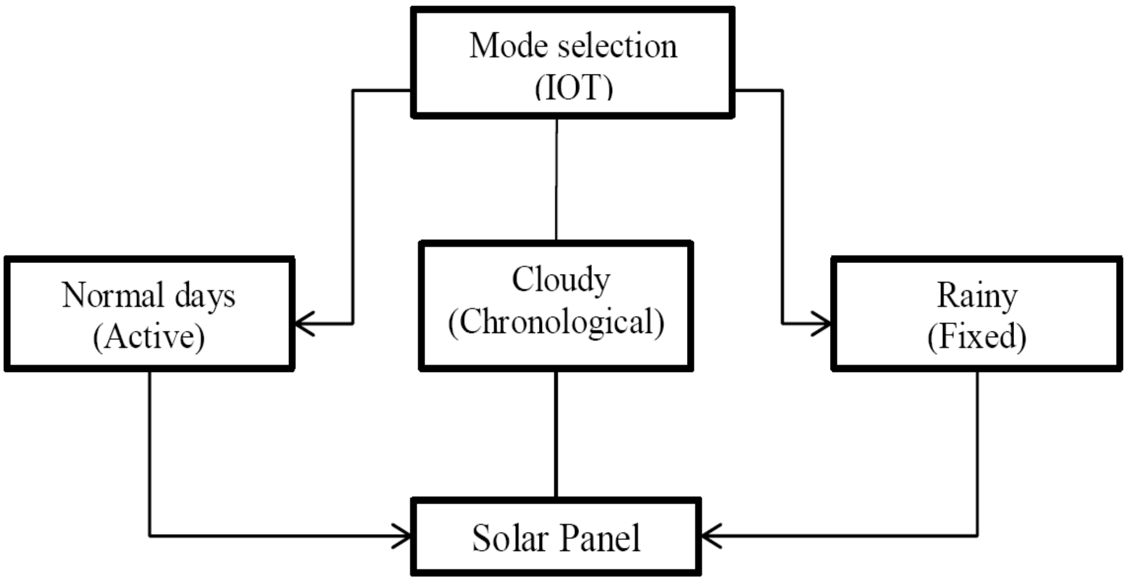

Figure 5. Flow-chart of proposed method

Under prevailing rainy weather in that particular location then there will be least amount of solar radiation and more energy is spent on tracking than on energy obtained hence at that times the panel will be in fixed position. If a tracking system is not used, the solar panel should still be situated in the ideal position. The best tilt angle ought to be resolved dependent on the geographical location of the panel. As a general guideline for the northern hemisphere, the PV panel should be placed at a tilt angle equal to the latitude of the site and facing south [7]. However, for a progressively exact position and tilt angle a hypothetical model of the sun's irradiance for the duration of a year is made and the angle and position is coordinated to the model.

The weather forecast technique in solar tracker system improves the control and also reduces energy expenditure by the tracker. The usage of chronological tracking on cloudy and partially cloudy weather improves the stability of the system and does not waste energy like conventional solar tracker system during cloudy days. During rainy weather the panels are kept in fixed orientation and thereby saving energy. In case if the internet connection fails then the tracker follows chronological tracking method. It does not employ any extra hardware components like voltage and current sensors. Thus this type of tracking gives superiority over other conventional methods.

4. Design and Implementation of Proposed Solar Tracker Prototype for PV Module Positioning

To analyse the impact of the proposed Dual axis tracking mechanisms, an assessment of performance of a PV crystalline module is being carried out in Saveetha Engineering College, Chennai (Tamil Nadu). This section contains description of this system and a detailed explanation of how the individual components of the system are a part of design, implementation, and testing. The design and building of the solar tracker can be solved into two sections.

(i) The electronic section deals with the programming and circuitry units.

(ii) The second section constitutes the framework of the tracker and the mechanical section which deals with the frame setup, the gear and their ratios, supporting structures etc.

5. Electronic Section

The **Electronic Section** of solar tracker consists of the following:

• Arduino Uno microcontroller

• Servo motor

• Servo Motor drive circuit

• LDR Sensors

The circuit scheme designed in PROTEUS 7.1 PROFESSIONAL software explains the working of the solar tracker circuit for horizontal axis. Once LDR east is irradiated the motor rotates in the right-hand direction and when LDR west goes high the motor rotates in the left hand direction. When the panel is connected to the motor via gears the corresponding orientation changes occur.

The panel can rotate from east to west with 180° rotation on the horizontal axis. At point X, two light sensors are connected in series. The direction of rotation of the motor is controlled by using two differential amplifiers. Same procedure likewise happens when the sun goes toward the east. If the potential difference across the motor terminals is zero, then the panel does not rotate.

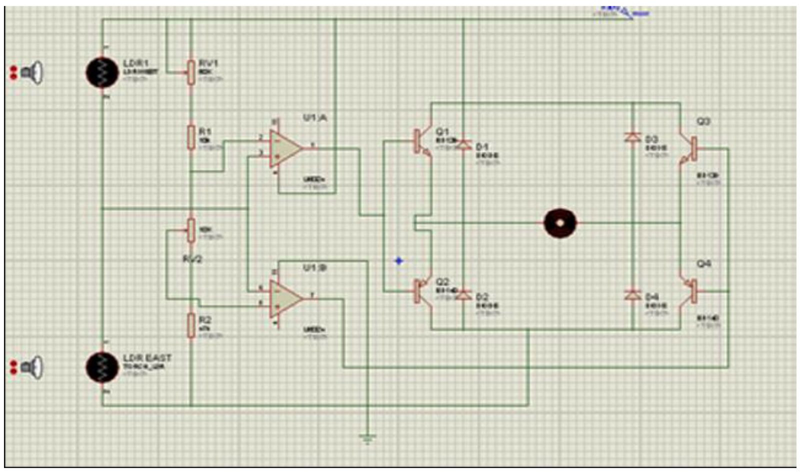

Figure 6. Circuit scheme for horizontal axis tracking

For vertical axis, a motor with 0° to 90° moving ability was used. Different values which are higher than the reference value of the light measured by the LDRs starts the motor to rotate in both directions.

The Arduino is programmed to produce the elevation angle when the LDRs identify the changes in the radiation received. The servo motor is varied correspondingly and the adjustment in the elevation of associated panel occurs.

6. Mechanical Section

The mechanical design considerations including the capability of the system to hold and secure the PV panel, ability to rotate the PV panel, ability to change the tilt angle of the PV panel, ease of manufacture assembly, and the ability to withstand wind, based on above consideration the type of material, the gear system, bearing system etc. are being dealt below. While selecting the material, materials with minimum weight and maximum strength should be preferred so that load on the motor can be reduced. Thereby the torque required is reduced which in turns makes the tracker cost effective. Carbon steel is a preferred material.

The height and the size of the structure which decide the system stability for that short column design is used. Initially the total load is calculated. The area of the circular supporting structure is calculated using the formula,

Area = $\pi*(\Phi^2 \text{ outer} - \Phi^2 \text{inner})$

Then the stress factor is found as (*load/area*)*g in N/m^2 or *MP*a based on which the yield stress value of the support is found. This is compared with the calculated stress factor and if the stress factor is less than the yield stress value then the system structure is stable and if the value is more the system will collapse.

For the selection of gear system, consider the power to be transmitted, the centre distance between two gears, ratio of the speed of the driving gear and driven gear or the velocity ratio.

Let

Tp = Number of teeth on the pinion

Dp = Pitch circle diameter of the pinion

Dg = Pitch circle diameter of the gear

Tg = Number of teeth on the gear

m = Required module

ϕ = Pressure angle

The minimum number of teeth on the pinion in order to avoid the interference is given by

$$Tp = 2\,Aw/\,(G\,[\,\surd(1+1/G * (1/G+2)* \sin^2\phi - 1)]$$

$$TG = G * TP$$

Then the centre distance (L) between two gears is assumed according to the design made. It is known that

$$L = DG/2 + DP/2$$

On solving this equation the diameter of the pinion is found. From the diameter of the pinion the module value is calculated using the equation below

$Dp = m.\,Tp$ which implies $m = DP/TP$

After calculating the *module* (m) value the number of teeth on each wheel is found using the formula below

$$TP = DP/m$$

$$TG = G*TG$$

The calculated gear values are then simulated to get the complete gear structure to understand their meshing etc. The simulated gear wheels for the tracker system are shown below.

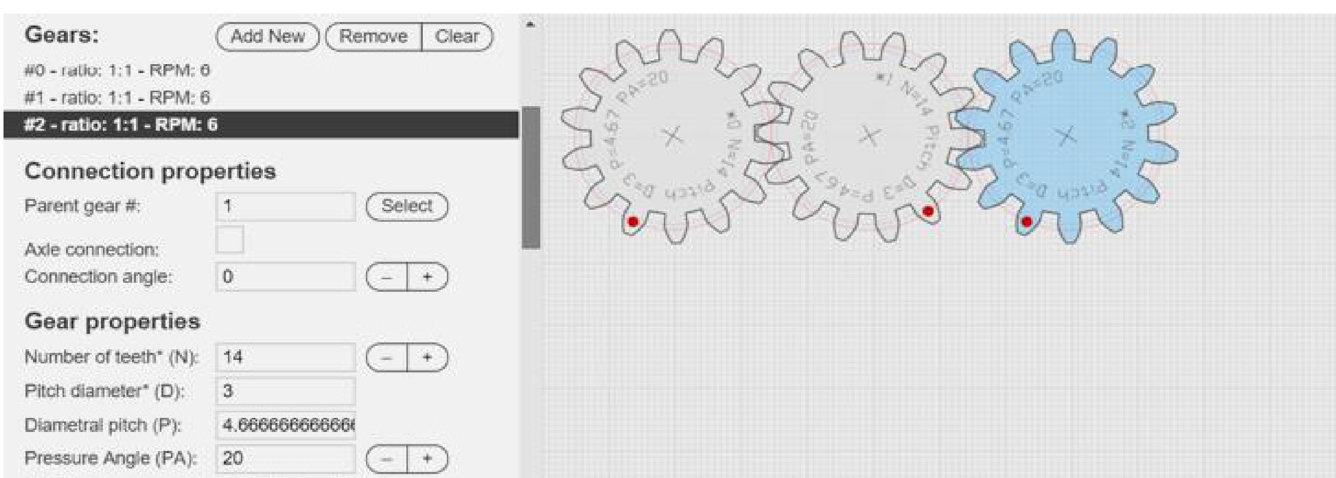

Figure 7. The simulated gear wheels for the tracker system

The two gear system makes the driven to rotate in the direction opposite to the driver. In order for the driver to rotate in the same direction as the driven an intermediate gear called the idler is used.

The tracker consists of rotating mechanism; the bearing plays the important role. The most suitable ball bearing is selected by considering the following parameters such as Life hours of bearing (LH), basic dynamic radial load and dynamic load rating.

*LH = years * working days *hours*

Based on the above consideration the final assembly of the solar tracker system has been designed and shown in the below figure. Thus by utilizing proper amount of energy the overall efficiency of the tracker is improved.

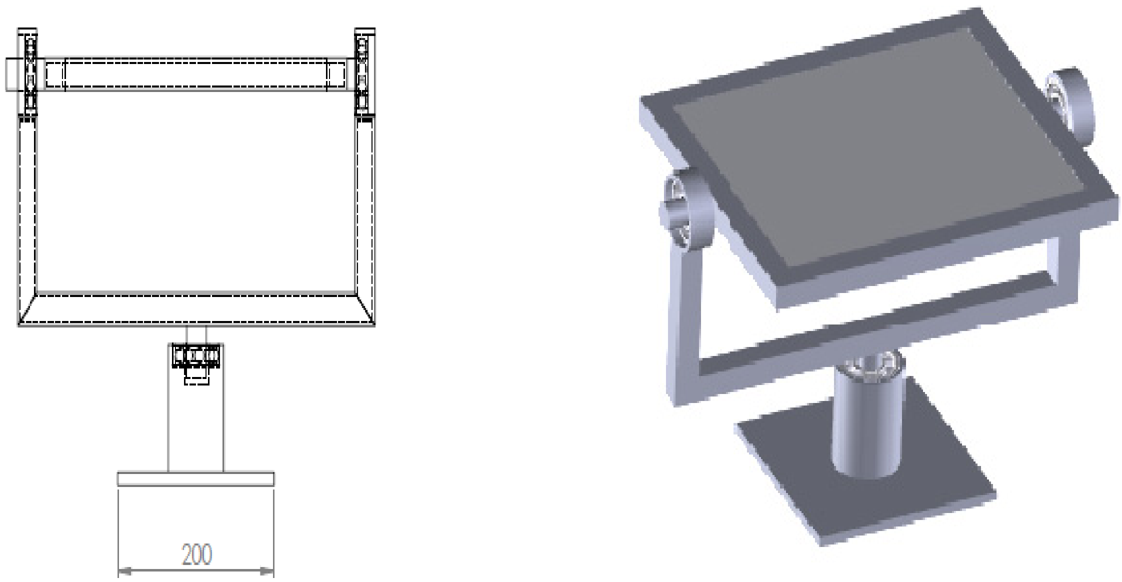

Figure 8. Final assembly of the mechanical system

Advantages of the Proposed Design are Listed below

The structure will be stable and also allows for customizing the system depending on the type and size of the solar panel. The mechanical system, on a structural basis is quite simple and this enables an ease in the manufacturing process and also a high dependability. The system is cost effective and uses readily available components. The Dual Axis nature of the system allows for energy efficiency even during cloudy and rainy weather conditions. The system can be modelled and simulated to realistic conditions. This enables a simple way to analyse the performance of the panels under different conditions.

7. Real Time Implemention and Experimentation

Two identical PV panels as shown in Figures 8 and 9 were used in this experiment. One panel was placed on the dual axis mechanical system while the other was placed on the single axis mechanical tracking system. The rheostat loads that were used in the electrical system were identical. The irradiance of the PV panel was measured through the use of an irradiance sensor placed beside the PV panel. In dual axis tracker, the sensor was recording the irradiance due to the changes in the tilt angles and the azimuth angles whereas the sensor used in single axis tracker records the irradiance due to the changes in the tilt angles.

The experiment starts in the morning at 6 am and continues till the evening 6 pm for two consecutive days; the system is automatically tracked by using Arduino UNO microcontroller. The dual axis tracker, tracks in such a way that the axis of the panel will be always perpendicular to the incoming rays. For this prototype model, 10W PV panel is fitted on the assembly and tested .The motor was driven by 12V regulated power supply. Solar radiation data obtained by tracker mechanism is given below and, the yield response of the process was determined to be the power differences between the two PV panels.

Figure 9. Dual Axis Tracker

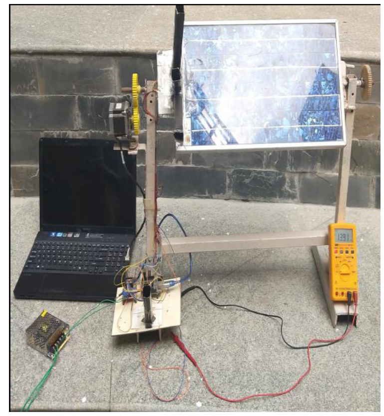

Figure 10. Single Axis Tracker

8. Result and Analysis

Sl.No	Time(hrs)	Module Temp	Radiation(W/m2)		PV Output Power(w)		Yield power (W)
			Single Axis tracker	Proposed Dual Axis tracker	Single Axis tracker	Proposed Dual Axis tracker	
1.	6.20 AM	23.6	20.5333	21.06668	0.96	1.1	0.14
2.	7.00 AM	25.5	90.24	109.23	1.59	1.845	0.255
3.	7.20 AM	27.6	149.76	186.0266	2.065	2.28	0.215
4.	7.55 AM	32.9	274.93	324.96	2.93	3.36	0.43
5.	8.15 AM	37.1	348.21	395.73	4.12	4.32	0.2
6.	8.32 AM	37.3	415.73	465.33	4.555	4.93	0.375
7.	9.00 AM	40.3	525.49	551.57	5.96	6.8	0.84
8.	9.25 AM	43.6	321.12	619.91	3.37	8.4	5.03
9.	10.00 AM	48.4	210.93	733.87	2.7	8.76	6.06
10.	10.25 AM	51.2	270.93	802.08	3.14	9.095	5.955
11.	11.00 AM	55.1	900.53	938.51	9.485	9.66	0.175
12.	11.30 AM	53.6	950.99	984.31	9.81	10	0.19
13.	12.00	56.9	978.51	1003.73	9.865	10	0.135
14.	12.40PM	58	978.45	988.8	9.88	9.94	0.06
15.	1.10 PM	57.4	919.8	920.53	9.5	9.515	0.015
16.	1.40 PM	59.3	846.35	850.19	9.23	9.29	0.06
17.	2.20 PM	56.9	784.53	797.97	8.765	8.97	0.205
18.	3.00 PM	53.8	333.17	646.67	3.77	7.66	3.89
19.	3.40 PM	49.4	524.91	535.95	5.93	6.225	0.295
20.	4.10 PM	41.1	329.65	335.79	3.42	3.625	0.205
21.	5.05 PM	41.8	207.15	205.97	2.6	2.4	-0.2
22.	5.30 PM	41.8	190.08	201.07	1.96	2.215	0.255
23.	6.05 PM	35.4	54.99	52.43	1.425	1.335	-0.09

Table 1. Experimental data of Single Axis tracker and Dual Axis tracker

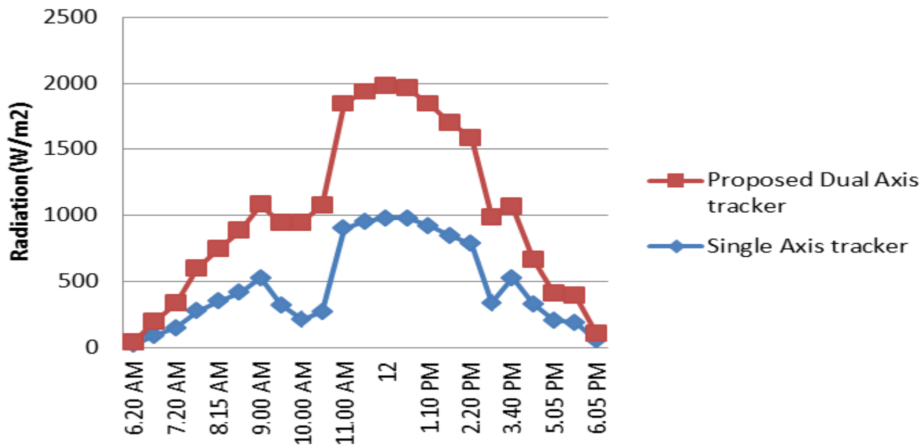

Figure 11. The Incident Radiation In Different Tracking Methods

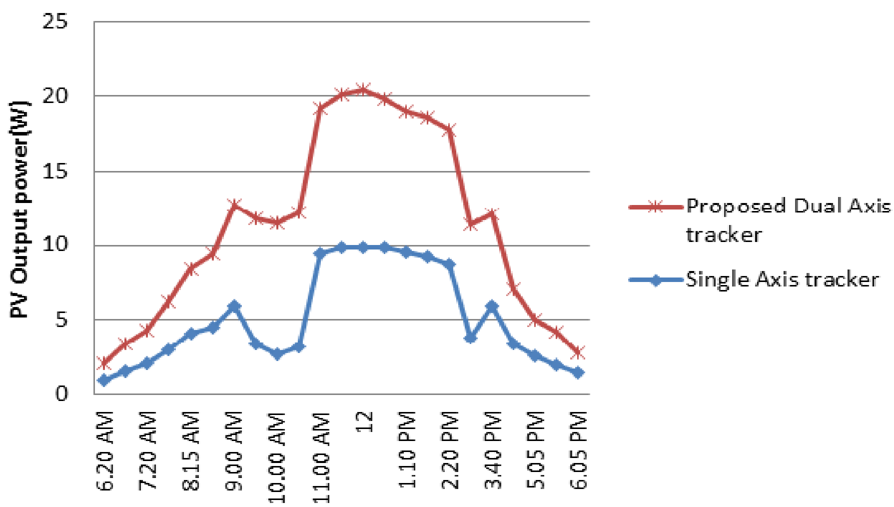

Figure 12. The electric power generated with different tracking methods

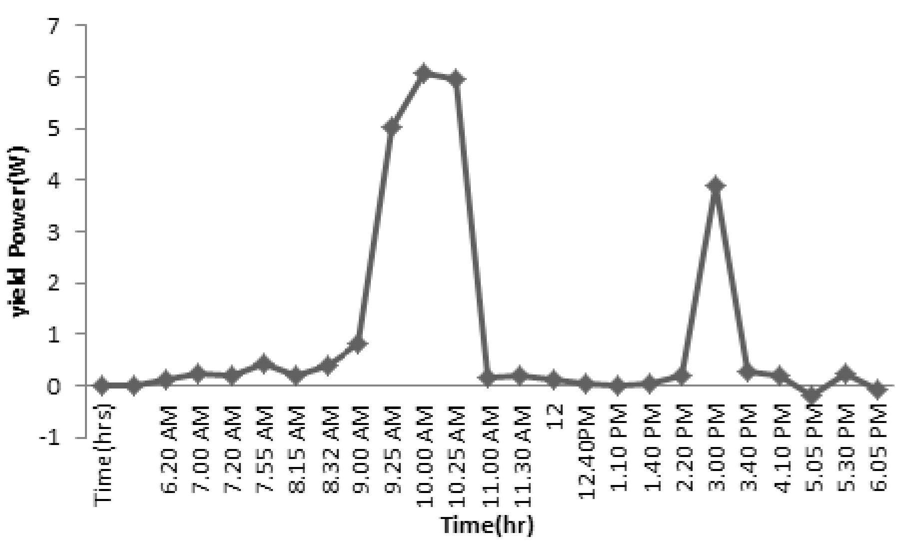

Figure 13. Yield power of dual axis tracking

The proposed Dual Axis tracker receives more radiation and generates more power which is evident through the yield power response. To validate the proposed model, the experiment was designed using Response Surface Methodology (RSM), a combination of mathematical and statistical techniques effective for establishing, refining, and optimizing processes usually used for product design and development [8]. The selection of the method was based on both the objective of the experiment and the number of factors and levels. The observed curvature response indicates that the quadratic second order model is suitable for analysis.

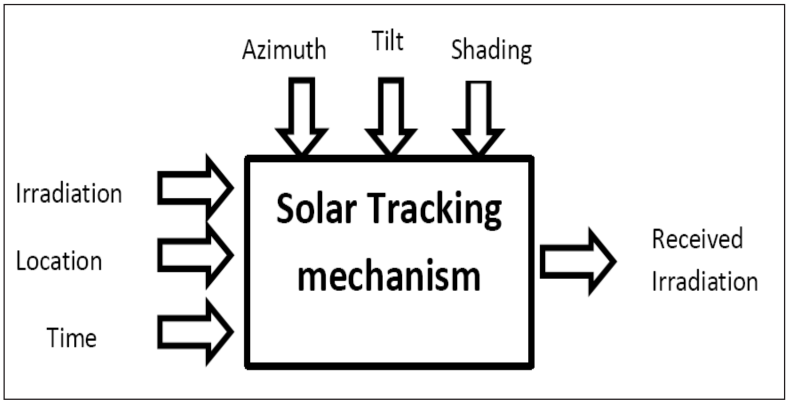

Figure 14. Functional block diagram

The input factors namely irradiation, location and time for the RSM design based on the controllable factors namely the azimuth angle, tilt angle and shading, the single and dual axis solar tracking mechanisms are designed and analysed based on the experimentation.

Using Minitab, the data is analysed for 95% confidence level and two-sided. The residual plots for the observed difference in irradiation of the proposed Dual-axis solar tracker are shown, in which a valid model is evident.

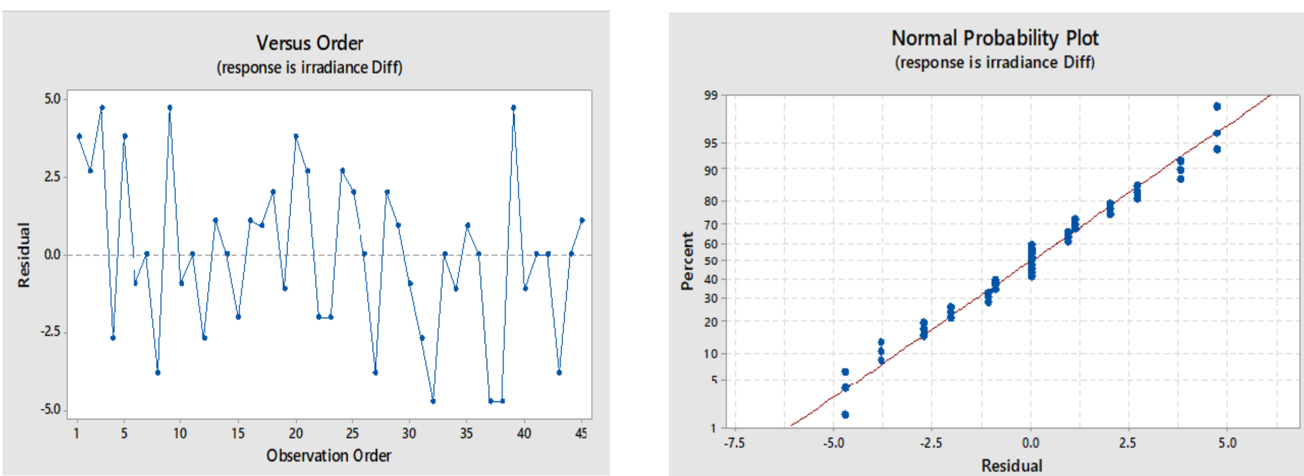

Figure 15. Regression plots

The regression equation for the change in irradiation of the two mechanisms and their pareto plots show that, in comparison with the single axis tracking which only takes into account the tilt angle, the azimuth angle which is considered in the Dual axis tracking system has a predominant role in the irradiation received. Shading also has an impact on receiving capacity of the PV panel. The regression equation developed by Minitab in uncoded units is

Irradiance Difference = -24.78 - 0.233 θ_z + 0.0304 θ_A + 3.338 Shading + 0.00485 θ_z x θ_z - 0.001979 θ_A x θ_A - 0.05772 Shading x Shading- 0.000475 θ_z x θ_A + 0.00224 θ_z x Shading - 0.000025 θ_A x Shading

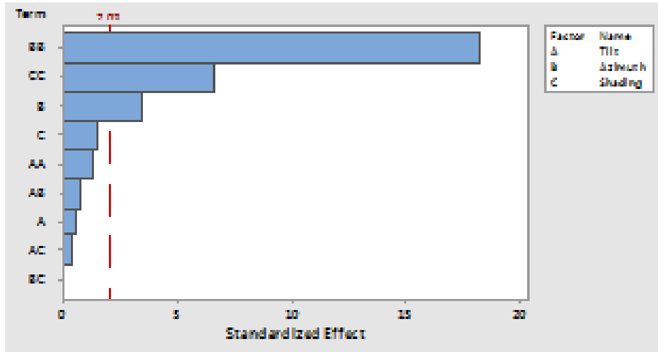

Figure 16. Parado chart of standardised effect of irradiance

9. Conclusions

Conventionally, the simple fixed angle systems were preferred, however an increase in the market exposure is boosting the confidence in the reliability of solar tracking technology among developers. Research in this area revolves around the need for minimal energy consumption and maximization of overall efficiency. The dependability of the system under various weather conditions, and the simplicity of the mechanical setup allows for optimal cost-performance ratio. The arduino microprocessor makes the monitoring and control of the system simplistic.

A web based dual-axis solar tracker has been presented in this paper. The important challenge associated with solar power panels are increased efficiency under cloudy and rainy weather which is overcome by the dual axis system. The solar tracking system allows maximum irradiance and during shading, the chronological tracker rotates while the solar tracker remains idle. The simple motor and gear system rotates the panel at 7.5 degrees for every 30 minutes and ensures high tracking efficiency. The reduced power consumption, high efficiency, ease of control and the low cost systems prove the superiority of the dual axis system. A significant energy gain of around (16-21) % has been noted in the proposed Dual Axis tracking system when compared to the single axis method.

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