J. Adv. Res. in Alternative Energy, Environment and Ecology
Volume 9, Issue 1&2 - 2022, Pg. No. 1-10
Peer Reviewed Journal

Research Article

Performance Evaluation of 50 W PV Panel Mounted at Single Axis Sun Tracker and Fixed Structure Facing Due South

Dhruv Berwal[1], Ritik Attri[1], Ritesh Pratap[1], Sahil Chandra[1], Monika Kaushik[2]

[1]UG Students, [2]Assistant Professor, Department of Electronics and Communication Engineering, Bhagwan Parshuram Institute of Technology, Delhi, India.

INFO

Corresponding Author:
Dhruv Berwal, Department of Electronics and Communication Engineering, Bhagwan Parshuram Institute of Technology, Delhi, India.
E-mail Id:
dhruvberwal93@mail.com
How to cite this article:
Berwal D, Attri R, Pratap R et al. Performance Evaluation of 50 W PV Panel Mounted at Single Axis Sun Tracker and Fixed Structure Facing Due South. *J Adv Res Alt Energ Env Eco* 2022; 9(1&2): 1-10.

Date of Submission: 2022-02-15
Date of Acceptance: 2022-03-04

ABSTRACT

Sun changes its position along the day from east to west and continuously keep reposition between 23.5^0 N and 23.5^0 S latitudes around the year. To track the sun position along the day and year are defined by horizontal axis and vertical axis monitoring. In this paper a single axis tracker mounted with 50 W photovoltaic panel was designed and developed to track the sun with horizontal axis. Sun's tracking was defined by the azimuth angle. Performance of 50 W PV panel mounted on the single axis tracker was compared with the PV panel of identical capacity and specification mounted on the fixed structure facing due south. Data was recorded to analyze the outcome in solar radiations received of the suggested single axis sun tracker system over the 50 W solar panel placed on fixed structure and the slope (tilt angle) of a panels mounted on the fixed structure oriented due south as well as on sun tracker is varied manually for 25^0, 30^0, 35^0 and 40^0 and observe that during any time of the day the tilted solar panels receives above 50% of radiations to that of horizontal surface. Study reveals that surfaces at this latitude (29.05^0) can be sloped at 30^0 to receive optimum radiations during the year.

Keywords: Solar Tracker, Solar Panel, Zenith, Azimuth, Angle, Microcontroller, Linear Actuator

Introduction

With the rise of the industrial revolution, the world is shifting from conventional to non-conventional resources of energy. In the 19th century, coal, petroleum etc. were utilized for power generation and transportation purposes but they also led to an increase in greenhouse gas emissions. The rise in greenhouse gases in the atmosphere led to an imbalance in nature leading to several adverse climatic conditions like global warming, ozone layer depletion. At the same time, the fast-growing industry observed a fast depletion of conventional sources as well. Therefore, a need for alternative, non-conventional, clean and green sources of energy were researched by various scientists. Some of the alternative sources of energy are solar, wind, tidal, geothermal etc. Solar energy is preferred more as it is available in abundance.

The improvement of solar electricity conversion techniques necessarily ends in the improvement of independent systems based totally on photovoltaic panels, which include portable and occasional-power solar power flora, streetlights systems, delivery, Smart Grid structures, etc. But with the rapid rise of solar energy as a prospective source of energy in the distant future, also raised a need to maximize the potential of the technology. This means a dire need to optimize energy conversion of every single solar panel as each solar panel takes a significant amount of space and land which is no longer in abundance.

The solar tracking method is used to maximize efficiency of solar PV panels in the given space. Solar trackers achieve this by rotating the solar panels to face the sun at an angle that always ensures maximum solar radiations to be received by the surface and consequently generate more power during the day. To maximize energy output from the PV panel the zenith angle and azimuth angle plays vital role. The zenith angle and azimuth angle determine the position of solar panels at which they must face the sun at any time of the year and day, respectively. As sun rises from east and sets in west the azimuth angle changes throughout the day, similarly sun changes its position between 23.5^0 N and 23.5^0 S latitudes, zenith angle changes throughout the year. So, solar trackers rotate the solar panel to follow the sun from its risings to setting throughout the day are called single axis tracker. However, this only consists of horizontal tracking of the sun. But in regions between the 23.5^0 N and 23.5^0 S latitudes, the sun's vertical position is also constantly changing throughout the year. Trackers that rotate on both vertical and horizontal axes are called double axis solar trackers.

In the beginning it was customary to fix the inclination of PV panels were fixed at an angle ± 20 to the location and facing the sun to address the zenith angle requirement and periodically according to angle of declination some people try and alter the solar panels' inclination manually in the direction of the sun, Serhan et al.,[1] compared the fixed solar panels inclined at fixed angle and oriented in one direction with another system whose orientation was changed twice a season according to winter and summer sun arch and reported that change in orientation twice a year has generated more energy comparison to fixed system.

To obtained the maximum power output from any solar panel, a panel should be so placed that it receives the irradiations orthogonally because the sun reposition itself both in the course of the day as well as all through the year. The solution is to use a tracking gadget that continues the panel's orthogonal function with the sun radiations' direction. Today, there are numerous techniques and technology that enhances the performance of photovoltaic systems. One of these methods is a sun tracking device (sun tracker). Currently, solar trackers are divided into two essential agencies depending on their rotation mechanism, single-axis trackers and axis trackers. Both devices contributes significantly, to enhance the performance of solar panels.[2-5] Singh et al.,[2] have discussed the numerous techniques of sun tracking device which includes dual-axes, one axis, polar axis, open loop, closed loop, hybrid version, azimuth and tilt angle mechanism and additionally studied the numerous existing solar tracking systems in terms of the controller used like PLC, microcontroller, and concluded that dual axis sun monitoring systems has more energy generation in comparison to immovable structures. The authors have also mentioned that the microcontroller based tracking gadget are economical to PLC based systems of identical capacity and size. Kuttybay et al.,[3] has advanced an intelligent independent sun tracking system, which lets in to orient the solar panel horizontally in cloudy and rainy climate in real time by altering zenith and azimuth angle of the solar panel to obtain the more power output. Researchers have pronounced that 18% more energy was generated by solar panel mounted on biaxial solar tracker even during the cloudy weather. Ai et al.,[6] proposed and compared the azimuth and hour angle based three-step trackers. Day length in terms of hour angle for the solar panel facing due south was divided in to three identical duration in order to provide the tilt angle to the panel. They concluded that for the complete year, the radiation at the tilted solar panel and that for the 2-axis azimuth 3-step tracking were 30.2% and 72%, respectively to that of horizontal surface. Researchers did not observed any notable difference among one-axis azimuth 3-step monitoring and hour perspective three-step monitoring strength interms of power output. Michaelides et al.,[8] have done comparative study on a solar water heater surface placed in four different conditions such as; (i) surface tilted at 40^0 and mounted on fixed structure, (ii) Structure tracking the sun along its vertical axis, (iii) fixed surface tilt and variable azimuth angle and (iv) the collector slope is modified twice in a year. The simulation results depicts that better thermal performance was obtained with structure tracking the sun and collector mounted on fixed structure found economically suitable.

Grass et al.,[9] carried out comparative study on non-tracking compound parabolic concentrator collectors with two tracking collectors: a parabolic trough and an evacuated tube collector and study has established the fact that collectors in tracking mode has higher optical efficiency, but minor error in tracking the sun leads to significant effects on optical efficiency. Similar study was carried out by Helwa et al.,[10] on four different solar collectors, one is mounted on fixed structure with tilt angle of 40^0 due south, second is tracking azimuthally and tilted at 33^0, third collector track vertically and tilted at 68^0 and fourth tracked both horizontal and vertical axis.

Mumba[11] designed and constructed a solar air drier comprising 12V DC fan which is powered by manually tracked PV panel and compared with the same system powered by fixed and concluded 80% increase in thermal efficiency with manually tracked solar air heater.

Nurzhigit et al.,[12] has compared the performance of fixed and tracked PV panels under different weather conditions. The tracked panels work on schedule and Light Dependent Resistor (LDR) photosensors and reported that the PV panels with schedule (Astronomical) and LDR based solar tracking system are 4.2% and 57.4%, more efficient than fixed panels. Fahad et al.,[13] also reported that in comparison to fixed photovoltaic system one-axis and dual-axis solar tracker generates 32.2% and 36.8% more energy, respectively. But generation of 3.96% more energy by two axis solar tracker in comparison to its counterpart single axis is shadowed by its high cost of installation.

Koussa et al.,[14] has investigated the effect of using different sun tracking mechanisms on the photovoltaic system performances for a completely clear day, partially clear day and completely cloudy day and reported that the energy generation by the panels is mainly dependant on the clearness index and on the seasonal variation of day length values. Mousazadeh et al.,[15] has reviewed the different types of sun-tracking systems and discussed their cons and pros. The most efficient and popular sun-tracking device was found to be in the form of polar-axis and azimuth types.

It has been concluded from the literature review that the tracking of the sun gives significant gain in energy production from the same size and capacity of the solar panels and two axis solar trackers shows marginal increase in energy gain comparative to its counterpart single axis. But this gain is overshadowed by the high installation cost of two axis trackers. In this paper a single axis sun tracker mounted with 50 W solar panel was developed as energy generation and sun radiation received by the sun-tracked panel were compared with the panel inclined at fix angle facing due south.

Materials and Methods

The objective of this project is to design and fabricate one prototype automatic single axis sun tracking system which will be able to move and track the sun movement from sunrise time to the sunset time of the study area to maximize in harvesting sun energy and other one is fixed structure facing due south. Both the tracking and fixed type of system are consisting of solar panels of 50 W capacity so that the energy harvest by the systems could be compared. The proposed tracking system is a passive system which automatically changes its direction to keep the solar panel facing the sun throughout the day, so that the solar panel receives direct irradiation irrespective of time of the day. To rotate the panel in appropriate position, an electric linear actuator 12V DC motor, whose rotation is controlled by two relays as a driver and pre-programmed microcontroller is used. The main followed in this project are listed below.

- Selection of Material
- Design of Mounting structure
- Calculation of Azimuth Angle

Selection of Material

PV Panel

Since it is a prototype system and hence decided to use a solar panel 50 Wp of and after adequate market survey the panel of Rhine Solar make is selected. The technical specifications of the panel are given in Table 1 and the photographic view with and dimensions shown in Figure 1.

Table 1.Technical Data of 50 W solar Panel

Electrical Data (at STC)	
Maximum Power	50Wp
Operating Voltage	24 V
Open circuit Voltage (Voc)	22.28 V
Short Circuit Current (Isc)	2.88 A
Maximum Power Voltage (Vmp)	118.55 V
Maximum Power Current (Imp)	2.71 A
Module Efficiency %	14.80
Operating Temperature	-40^0C to 80^0C
Mechanical Data	
Solar Cells	Polycrystalline 52.33 mm x 156.75 mm
Cell Orientation	36 Cells (9x4)
Module Orientation	545 x 670 x 35 mm
Weight (Kg)	4.60 Kg
Front Glass	3.2 mm toughened textured Glass
Back Sheet	White
Frame	Anodized Aluminium Alloy

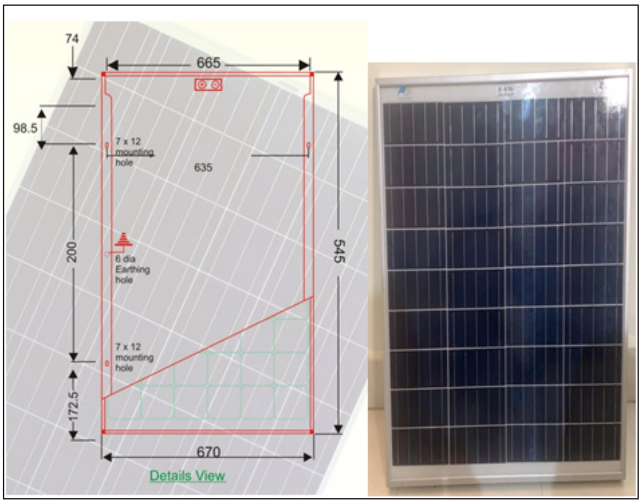

Figure 1.50 W Solar Panel Dimensions

Microcontroller

The original choice for microcontroller was a PIC microcontroller however as the fabrication stage advanced the controller of choice was changed to an arduino system, specifically an arduino nano, to match the weight requirements of the stand and to make coding of programs faster and better. Arduino is available as an open source on electronics platform and has a software package used to program the hardware part. To code the arduino microcontroller Arduino Desktop IDE software was used. The photographic view of the microcontroller is shown in Figure 2.

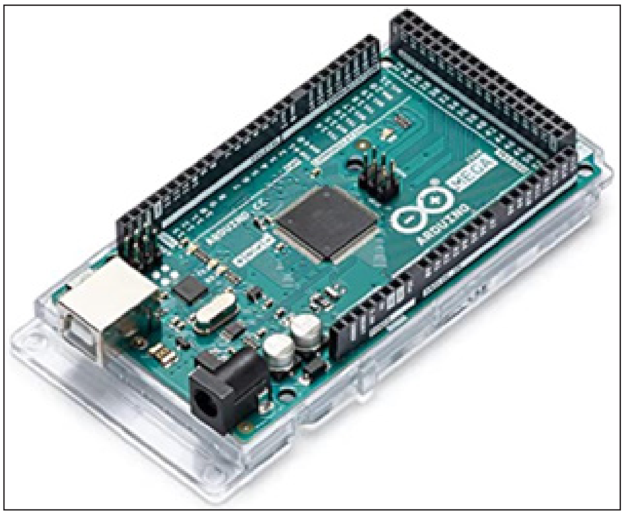

Figure 2.Arduino

Linear Actuator Powered by DC Motor

For this project the linear actuator selected to rotate the panel from east to west is powered by 12 V DC motor linear motion controller limiting switch and 300 mm stroke, schematic view of the system is shown in Figure 3.

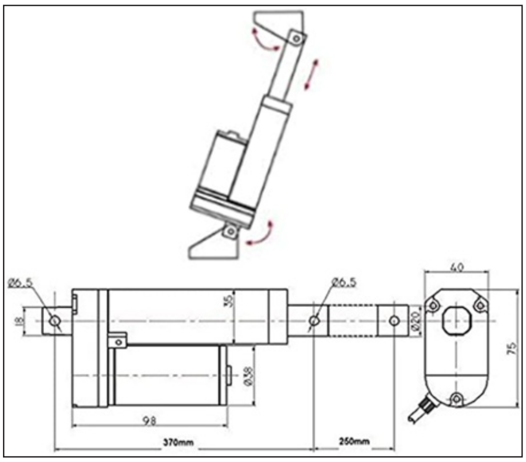

Figure 3.Linear Actuator

Design of Mounting Structure

The mounting structure is designed to bear the static load of the solar panel and 12V DC motor powered linear actuator as well as to provide stability to the whole unit so that structure may not overturn under the influence of torque provided by the motor to rotate the solar panel. The orthographic view along with the dimension of the base of the structure is shown in Figure 4. All these designs are prepared with Auto CAD.

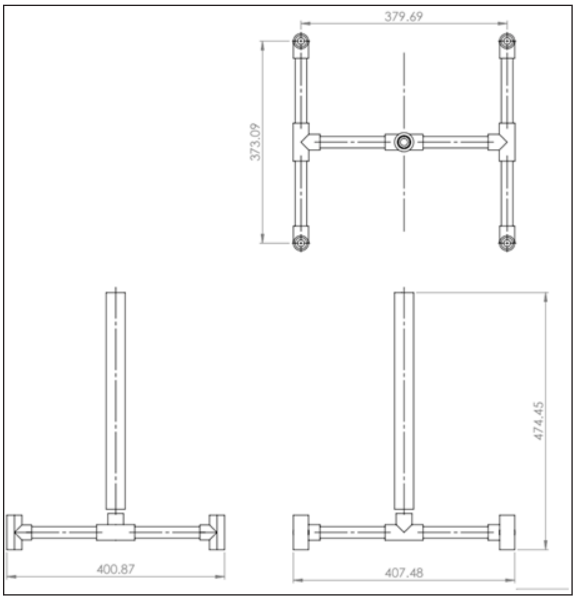

Figure 4.Orthographic View of Structure Assembly

The complete structure is constructed by welding given sizes of iron pipes. For better incite all the members of the structure were assembled and CAD model of the complete assembly of the mounting structure with solar panel mounted on its top is shown in Figure 5.

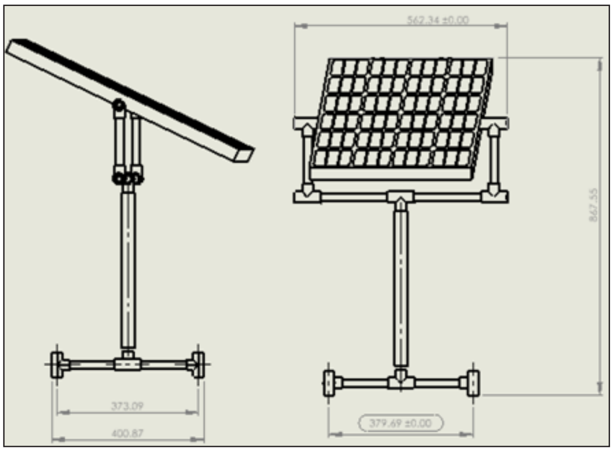

Figure 5.Orthographic View of the Complete Assembly of Mounting Structure

The frame for holding the solar panel is of U shape made up of same size of rectangular shaped iron pipes. The U shape frame is holding the panel to adjust the zenith angle according to the location and for days of the year. The frame of the panel is mounted on the vertical pipe of the base of the mounting structure in such a way that the DC motor powered linear actuator can rotate the panel frame from east to west. For smooth rotation of the frame a suitable size of ball bearing is placed between base pipe and panel frame. Figure 6, shows the 3-D CAD model of the mounting structure assembly carrying solar panel.

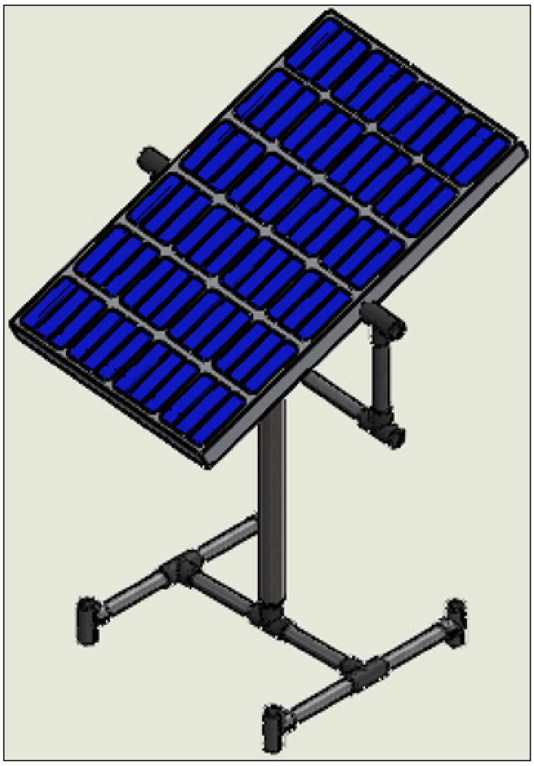

Figure 6.CAD Model of Complete Assembly of Structure Mounted with Solar Panel

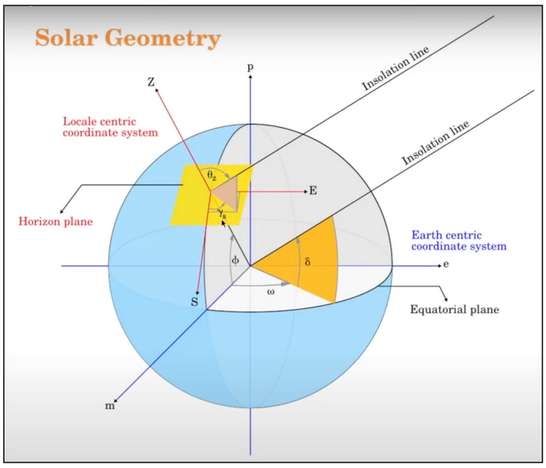

Figure 7.Various Sun-Earth Angles

Calculation of Azimuth Angle

Earth is spherical in shape and its 3-D model is shown in Figure 7. The horizontal line running middle of the sphere marked as 0^0 starts from equator and vertical line marked 90^0 termed as north and south poles. The solar radiation may come from any direction are represented by 'Ib' and falling normal to the surface are represented, as "Ibn" bn; b stands for beam radiation. The equivalent beam flux falling normal to the surface will be:

$$Ibn =. Ib \cos \theta. \qquad (1)$$

The solar radiation falling on the surface constitute angle 'θ' with the normal to the surface can be converted to equivalent beam flux by using the equation (1). This angle θ is termed as angle of incidence and is a function of many angles like Zenith angle (x_z), Latitude (Angle of latitude) (ϕ), Angle of Declination (δ), Hour Angle (ω), Slope (tilt angle) (β) and azimuth angle (γ).

A line emerging from the centre of the earth and considered to join the centre of the sun, which represent the incident radiations from the sun, Figure 8. The angle subtended between the line of insolation and its projection on the equatorial plane is called the angle of Declination (δ) and this angle define the sun position with respect to earth's latitude during any day of the year when the line of insolation intersects the particular latitude.[17,18] Mathematically it can be expressed as:

$$\text{Declination } (\delta) = 23.45 \text{ Sin}\left(\frac{360}{365} X(284+n)\right) \qquad (2)$$

Where 'n' is julian day of the year. This angle of declination varies from maximum to minimum value of 23.5^0N and 23.5^0S, sun's position at tropic of cancer on 21st June and tropic of Capricorn on December 21, respectively. To calculate the values of 'δ' a code was developed in JAVA and values so obtained are shown in Table 3.

Table 3.Angle of Declination on Day of a Month

Date	Julian Day of the Year	Angle of Declination (δ)
17 Jan	17	-20.91
16 Feb	47	-12.95
16 Mar	75	-2.41
15 Apr	105	9.41
15 May	135	18.79
11 June	162	23.08
17 July	198	21.18
16 Aug	228	13.45
15 Sep	258	2.21
15 Oct	288	-9.59
14 Nov	318	-18.9
10 Dec	344	-23.04

Due to rotation of the earth around the sun the sun's position with respect to sun keep changing along the year which causes the variation in the values of declination and hence day length of location changes. When δ = +ve 23.5^0, the days are longest and at δ = -ve 23.5^0 the day are shortest but at δ = 00 the day and nights are equal. Therefore, for designing of the system an average value of δ was taken as zero for all calculations.

Another important angle is an Hour angle (ω), it is the angle subtended between the meridional axis and the projection of line of insolation on equatorial plane, Figure 7. This angle uses to define the angular displacement of sun from east to west along the day. The earth rotating about its polar axis and sun appears to be displaced from east to west and for each degree of longitude traverse it takes four minutes. At any location on the earth surface where the meridian of the location is directly under the sun then hour angle has zero magnitude and condition can be termed as solar noon. It can be expressed as:

Hour Angle (ω) = $\cos^{-1}$ (- tanx.tanx) (3)

An hour angle was calculated by taking the value of the following angles as:

$x = 29.05^0$
$x = 0^0$
The value of hour angle (ω) = 89.56^0

Zenith Angle (x_z) gives an idea about the inclination of sun rays falling on the horizontal surface with respect to the line normal to the surface, Figure 8. This angle is helpful in determining whether the sun is rising or setting. The smaller the value of zenith angle the higher the sun in the sky. Further the value of zenith can be reduced by tilting the surface. It can be expressed mathematically as;

Cos (x_z) = (Sinϕ.Sinδ + Cosϕ.Cosδ.Cosω). (4) (x_z) = $\cos^{-1}$ (Sinx. Sinx + Cosx.Cosx.Cosx) (5)

The value zenith was calculated by taking the value of other angles as

$x = 29.05^0$
$x = 0^0$
x = 89.96
The value of Zenith angle (x_z) = 89^0

Most important angle is solar azimuth (x_s) which ensure that the surface is facing the sun and receiving the sun radiations directly. The role of sun tracker is to track the sun so that the solar panel keep facing the sun along the day. Therefore, to program the microcontroller this angle is vital to develop code so that the micro controller may guide the stepper motor to synchronise the panel's rotation with the sun's displacement due to earth's rotation. The solar azimuth angle can be calculated by using the following mathematical equation.

Cos x_s = (Cos . Sin – Sin)/ (Sin) (6)

Taking the values of the following angles as:

$x = 29.05^0$
$x = 0^0$

The value of azimuth angle is 89.56^0. To calculate the various angles like; declination, hour angle zenith angle and azimuth angle a code was developed in JAVA,

Working of System and Instruments

In this prototype single axis sun tracker, the DC motor powered linear actuator is used to rotate the tracker along the vertical axis to track the sun from east to west, Figure 8. But to harness the maximum energy throughout the year the manual tracking option was also created to adjust the slope of the surface depending on the sun's position on a particular day of the year by measuring the angle of declination and zenith angle.

The prototype system developed in this project presented a single axis tracking system using a single 50 W capacity polycrystalline solar panel and the vertical axis is rotated by on DC motor rotor, while another axis is adjusted manually by angles at 25°, 30°, 35° and 40°. This is technologically can be called as a chronological solar tracking system because it is a time-based tracking system where the system collector or module moves with a fixed rate and a fixed angle throughout the day as well for different months. The DC motor powered linear actuator is controlled to rotate at the low rate (15° per hour approx.). This tracking system is a typical open loop control tracker based on a chronological model of its motion. In this solar tracker, solar panel is mounted on the structure to follow the path of the sun. Two Light Dependent Resistors (LDRs) were used to track the position of the Sun in the tracking system. The linear actuator rotate the solar panel depending on the output of two LDR sensors, which are fed into the controller to generate an output from the actuator. The electric linear actuator 12V DC motor allows linear motion around its axis both clockwise and counter-clockwise.

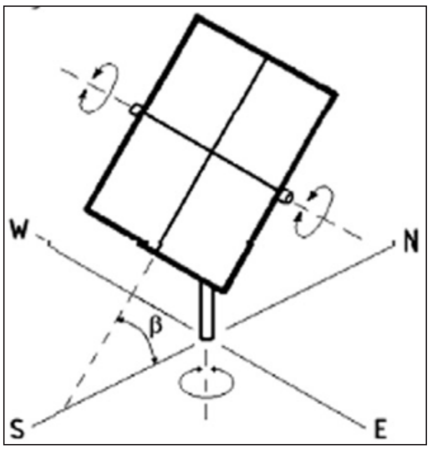

Figure 8.Arrangement on Single Structure for Azimuth and Zenith Tracking

Data Collection

To collect data from our project solar tracking solar panel we need to calculate and evaluate all the important parameters. To assess our systems performance, need to require. For this purpose, multimeter is used in our project to find the voltage being produced by the solar panels at many different stages, when solar panel was incident by sunlight. First the voltage checked when sunlight was perpendicular to the solar panel. Second time voltage checked when solar panel was tracking the sunlight. We repeated this process throughout the daytime. The power output from the panels was obtained mathematically as:

$$P_{OUT} = VI \text{ formula} \tag{7}$$

Incident solar radiations were measured with the help of solarimeter in W/m2. The photographic view of the multimeter and solarimeter is shown in Figure 9.

Figure 9.Photographic View of Multimeter and Solarimeter

Research Methodology

Experiments were conducted for comparison between single axis tracking systems and fixed solar panels and the data was recorded in terms of solar radiations and voltage and current using the instruments discussed in section 4. The data related to solar radiation recorded at site was compared with the solar radiation recorded by pyranometer located in the university. Adequate literature review was done, and market survey was done to determine the range of prices of these existing systems. Discussions with experts in the field of renewable energy were conducted to determine the key areas to focus on and their subsequent recommendations were taken aboard during the design stages. The results were compared and helped to justify the need for implementing tracking systems.

Result and Discussion

The solar radiations were recorded on the surface of a panel oriented due south and its slope (tilt angle) is varied manually for 25^0, 30^0, 35^0 and 40^0. Are shown in Table 4. The radiations were recorded from 900 hours to 1700 hours in a interval of one hour.

Figure 10, shows the plots of solar radiations falling on the surface facing due south at different tilt angle ranging from 25^0, to 40^0, at an interval of 5^0 tilt of surface. Also, the radiations were recorded on horizontal surface ($\beta = 0^0$). Plots of radiations shows that the radiation falling on the solar panel are minimum in the morning at 900 hours and attain the maximum value at 1200 hours at noon and then again start decreasing. The reason of this is the path followed by the sun along the day from rising to setting. The angle of altitude is low before and after 1200 hours and hence radiation falling on the solar panels in this duration having larger value of zenith angle. To lower the value of zenith angle, the surface (solar panel) has been provided some tilt angle. Plots of radiations at different tilt angle (β) shows the higher the angle of tilt, the radiations falling on the surface have smaller zenith angle and hence surface receives more radiations. At 1200 hours the radiations received at surface tilted at angles 0^0, 25^0, 30^0, 35^0, and 40^0 are 730, 1009, 1086, 1109, 1123 w/m^2, respectively.

Table 4.Solar Radiations on a Fixed Surface Facing due South

Time	Radiations (W/m²)				
	$\beta = 0^0$	$\beta = 25^0$	$\beta = 30^0$	$\beta = 35^0$	$\beta = 40^0$
9:00	277	443	466	490	530
10:00	618	845	835	864	983
11:00	690	963	1009	1046	1060
12:00	730	1009	1086	1109	1123
13:00	689	964	1045	1085	1101
14:00	647	935	962	946	990
15:00	468	680	700	720	770
16:00	245	292	315	320	337
17:00	120	130	145	152	156

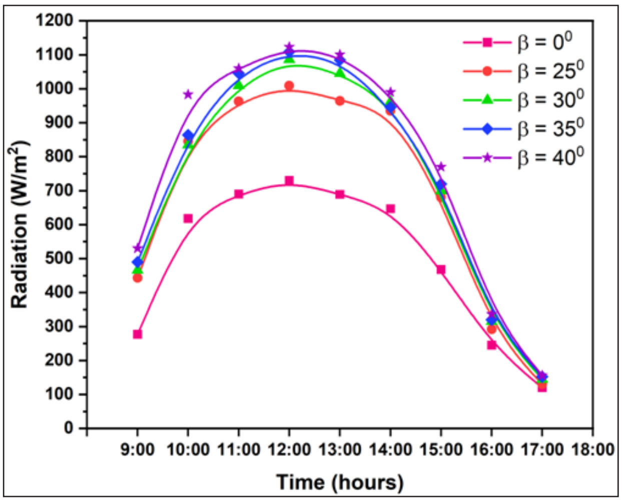

Figure 10.Solar Radiation on Tilted Surface Facing due South

It is observed from Table 5, solar radiations received by tilted surface facing due south is more than the horizontal surface along the day. Further observation shows that the irrespective of the time of the day and intensity of the radiations the increase in tilt angle led to the increase in % age receiving of solar radiations by the surface. At 900 hours the tilted surface at angle 25^0, 30^0, 35^0 and 40^0 receives maximum percentage of radiations of the order of 59.91, 68.23, 76.89 and 91.33 % in comparison to the radiations received by the horizontal surface. Since the sun occupied different positions during the year and hence at a fixed tilt angle the surface wouldn't be receiving the maximum radiations. But one peculiarity is observed that at 1200 hours the tilt surface at 30^0, 35^0 and 40^0 receives around 50% more radiations in comparison to horizontal surface. So, the fixed installation of solar panels at this latitude (29.05^0) can be sloped at 30^0 to receive optimum radiations by the panel during the year.

Table 5.Percentage Increase in Solar Radiation on Fixed Surface at Different Tilt Angle

Time	Radiations (%)				
	$\beta = 0^0$	$\beta = 25^0$	$\beta = 30^0$	$\beta = 35^0$	$\beta = 40^0$
9:00	277	59.91	68.23	76.89	91.33
10:00	618	36.73	35.11	39.8	59.06
11:00	690	39.56	46.23	51.59	53.62
12:00	730	38.2	48.76	51.91	53.83
13:00	689	39.91	51.66	57.47	59.79
14:00	647	44.51	48.68	46.2	53.01
15:00	468	45.29	49.57	53.84	64.52
16:00	245	19.18	28.57	30.61	37.55
17:00	120	8.33	20.83	26.66	30.00

Table 6, shows the solar radiations recorded on the tilted surface at 25^0, 30^0, 35^0 and 40^0, tracking the sun from east to west along the day length. Considering the facts that in the month of December the sun is farthest from test location (29.05^0 N) and hence sun rays have maximum inclination to the normal of horizontal surface. For further incite the plots of solar radiations received by the tilted surface tracking the sun are developed and shown in Figure 11. Like the plots of fixed surface (Figure 10) these plots are also showing the increasing trend from 900 hours onwards, achieved maximum value and then shows downward trend with time. It is also evident from the Table 6 and plots of Figure 11, that the increase in tilt angle leads to increase in radiations received by the surface for all time of the day. It is also observed that the surface at all the tilt angle i.e. $\beta = 25^0$, 30^0, 35^0 and 40^0 are receiving the solar radiations around or above 1000W/ m^2 from 1000 hours to 1400 hours, which is a value of standard test condition for the solar panels. It is also worth noting that these radiations are received during the day of the year when sun is located at farthest (x = -23.2^0) from the test location. From the above discussion it can be safely concluded that optimum tilt angle and tracking the sun from east to west i.e. azimuth tracking may help to harness more sun energy from the sun.

Table 6.Solar Radiations on a Surface Tracking the Sun

Time	Radiations (W/m^2)				
	$\beta = 0^0$	$\beta = 25^0$	$\beta = 30^0$	$\beta = 35^0$	$\beta = 40^0$
9:00	277	553	592	633	670
10:00	618	990	962	1026	1033
11:00	690	988	1034	1050	1095
12:00	730	1100	1176	1209	1290
13:00	689	1092	1148	1198	1208
14:00	647	1068	1100	1185	1140
15:00	468	720	755	868	878
16:00	245	324	339	388	412
17:00	120	183	198	205	223

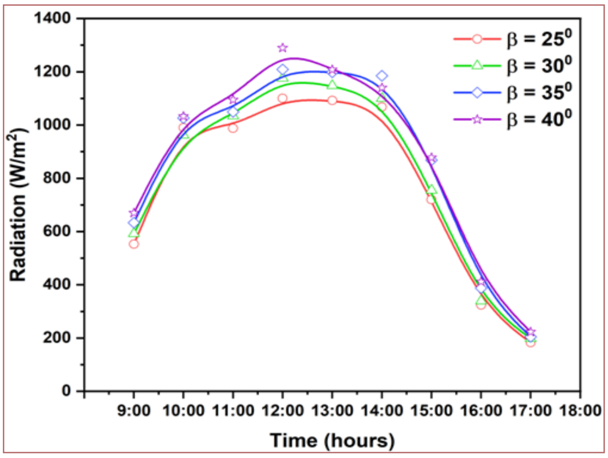

Figure 11.Solar Radiation on Tilted Surface Facing due South

For understanding the effect of tracking on the radiation received by the solar panel in comparison to fixed solar panels the plots are developed and shown in Figure 12-15. Figures shows the plots of radiation received by the surface facing due south and surface tracking sun and tilted at an angle 25^0, 30^0, 35^0 and 40^0, respectively. Plots for all the tilt angle depicts that the radiations received on the surface tracking sun is varying between 110 W/ m2 to 143 W/ m2 and same trend is observed for 1000 hrs, 1200 hrs, 1300 hrs and 1400 hrs. The difference in radiation received at sun tracked surface compared to fixed surface is narrowed down significantly and probable reason of this is human error in recording the values. It is also observed that in the evening from 1500 hrs onward the intensity of.

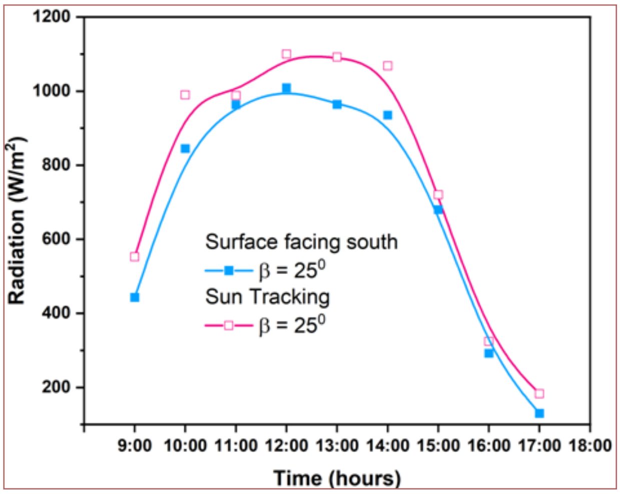

Figure 12.Solar Panel Facing due South and Tracking Sun Tilted at 25^0

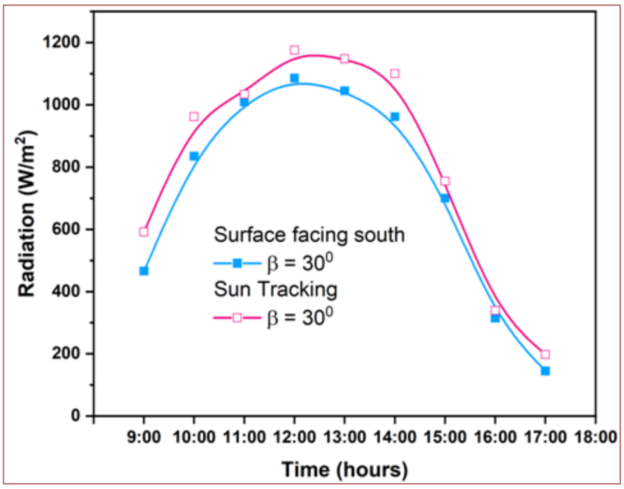

Figure 13.Solar Panel Facing due South and Tracking Sun Tilted at 30^0

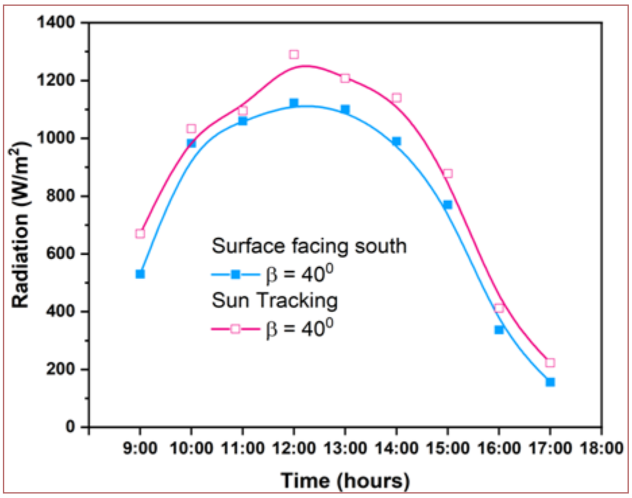

Figure 14.Solar Panel Facing due South and Tracking Sun Tilted at 35^0

Radiation decreases and the difference in radiations received at sun tracked surface, comparatively reduced below 50 W/ m2 except for tilt angle 35^0 and 40^0 at 1300 hrs. It is concluded from the above discussion that from 900 hrs till 1400 hrs the radiation received by sun tracked surface are significantly high in comparison to fixed surface.

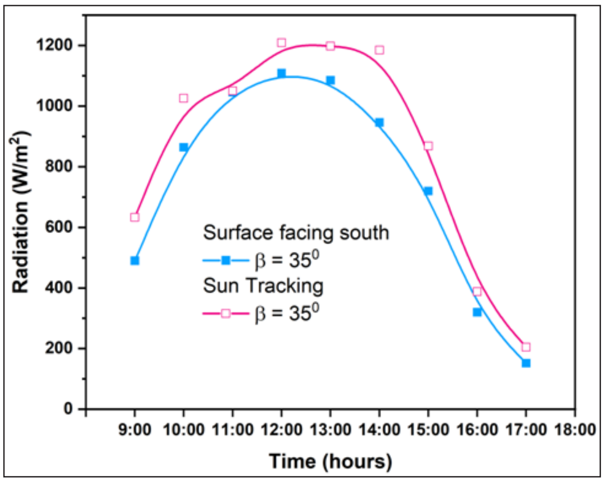

Figure 15.Solar Panel Facing due South and Tracking Sun Tilted at 40^0

Conclusion

From the above study following conclusions are drawn:

- Higher the angle of tilt, the radiations falling on the surface have smaller zenith angle and hence surface receives more radiations
- Irrespective of the time of the day and intensity of the radiations the increase in tilt angle led to the increase in %age receiving of solar radiations by the surface
- At 900 hours the tilted surface at angle 25^0, 30^0, 35^0 and 40^0 receives maximum percentage of radiations of the order of 59.91, 68.23, 76.89 and 91.33 % in comparison to the radiations received by the horizontal surface
- At 1200 hours the tilt surface at 30^0, 35^0, and 40^0 receives around 50% more radiations in comparison to horizontal surface
- Solar panels at this latitude (29.05^0) can be sloped at 30^0 to receive optimum radiations by the panel during the year

Acknowledgement

Authors express their gratitude to Chairperson, Centre of Excellence of Energy and Environmental Studies of Deenbabndhu Chhotu ram University of Science and Technology for allowing an access to their departmental laboratory and indebted to the faculty incharge of the laboratory for helping us in to explain the technical subtilities of the single axis sun tracker, sun geometry and providing necessary instruments to record the radiations and energy generation etc.

References

1. Serhan M, El-Chaar L. Two axes Sun Tracking System:

Comparison with a fixed system. International Conference on Renewable Energies and Power Quality, at Granada Spain, 2010. https://www.icrepq.com/icrepq%2710/227-Serhan.pdf
2. Singh R, Kumar S, Gehlot A et al. An imperative role of sun trackers in photovoltaic technology: A review. Renew. Sustain. *Energy Rev* 2018; 82: 3263-3278. [CrossRef]
3. Kuttybay N, Mekhilef S, Saymbetov A et al. An Automated Intelligent Solar Tracking Control System with Adaptive Algorithm for Different Weather Conditions. In Proceedings of the IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS), Shah Alam, Selangor, 2019. DOI: 10.1109/I2CACIS.2019.8825098
4. Mousazadeh H, Keyhani A, Javadi A et al. A review of principle and sun-tracking methods for maximizing solar systems output. Renew. Sustain. *Energy Rev* 2009; 13: 1800-1818. [CrossRef]
5. Saymbetov AK, Nurgaliyev MK, Tulkibaiuly Y et al. Method for Increasing the Efficiency of a Biaxial Solar Tracker with Exact Solar Orientation. *Appl Sol Energy* 2018; 54: 126-130. [CrossRef]
6. Ai B, Shen H, Ban Q et al. Calculation of the hourly and daily radiation incident on three step tracking planes. *Energy Conversion and Management* 2003; 44: 1999-2011. 10.1016/S0196-8904(02)00229-7
7. Agee JT, Obok-Opok A, Lazzer MD. Solar tracker technologies: market trends and field applications. *Advanced Materials Research* 2007; 339-44. https://doi.org/10.4028/www.scientific.net/AMR.18-19.339
8. Michaelides IM, Kalogirou SA, Chrysis I et al. Comparison of performance and cost effectiveness of solar water heaters at different collector tracking modes in Cyprus and Greece. *Energy Conversion and Management* 1999; 40: 1287-303. 10.1016/S0196-8904(99)00020-5
9. Grass C, Schoelkopf W, Staudacher L et al. Comparison of the optics of non-tracking and novel types of tracking solar thermal collectors for process heat applications up to 300 ^{0}C. *Solar Energy* 2004; 76(1-3): 207-215. https://doi.org/10.1016/j.solener.2003.07.031
10. Helwa NH, Bahgat ABG, Shafee AMRE et al. Computation of the solar energy captured by different solar tracking systems. *Energy Sources* 2000; 22: 35-44. https://doi.org/10.1080/00908310050014199
11. Mumba J. Development of a photovoltaic powered forced circulation grain dryer for use in the tropics. *Renewable Energy* 1995; 6(7): 855-62. https://doi.org/10.1016/0960-1481(94)00088-N
12. Nurzhigit K, Saymbetov A, Mekhilef S et al. Optimized Single-Axis Schedule Solar Tracker in Different Weather Conditions. *Energies* 2020; 13: 5226; https://doi.org/10.3390/en13195226
13. Fahad HM, Islam A, Islam M et al. Comparative Analysis of Dual and Single Axis Solar Tracking System Considering Cloud Cover. Proceedings of the International Conference on Energy and Power Engineering (ICEPE), Dhaka, Bangladesh. 2019; 14-16.
14. Koussa M, Cheknane A, Hadji S et al. Measured and modelled improvement in solar energy yield from flat plate photovoltaic systems utilizing different tracking systems and under a range of environmental conditions. *Applied Energy* 2011; 88(5): 1756-1771. https://doi.org/10.1016/j.apenergy.2010.12.002
15. Hossein M, Keyhani A, Javadi A et al. A review of principle and sun-tracking methods for maximizing solar systems output. *Renewable and Sustainable Energy Reviews* 2009; 13: 1800-1818. doi:10.1016/j.rser.2009.01.022
16. Nsengiyumya W, Shi GC, Hu L et al. Recent advancements and challenges in Solar Tracking Systems (STS): A review. *Renewable and Sustainable Reviews* 2018; 81(1): 250-279. https://doi.org/10.1016/j.rser.2017.06.085
17. Sukhatme SP, Nayak JK. Solar energy. McGraw-Hill Education.
18. Kadyan H, Berwal AK. Evaluation of Solar radiation in humid subtropical climatic belt in north India. *Design Engineering* 2021; 8397-8413.