International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

Study of Solar Tracking Angle for Dish Type Concentrating Collectors

Falesh Mehta
Student,
School of Mechanical Engineering
VIT University, Vellore, India

Sudhakar Vyas
Student,
School of Mechanical Engineering
VIT University, Vellore, India

T Srinivas
Professor,
Department of Thermal and Energy Engineering
VIT University,Vellore, India

M Natarajan
Assistant Professor,
Department of Thermal and Energy Engineering
VIT University, Vellore, India

***Abstract*— The solar energy accumulated at the focal point of the concentrating collector for a whole day depends on how accurately it tracks with the position of the sun. The flux that incident on the solar collector throughout the year varies with the relative position of the sun during different seasons of the year. This paper focuses on the optimization of sun-tracking angle for two axes as well as single axis mode of tracking for complete one year. Coding has been done for accurate optimization of this angle and also to present the graphical results. Experimentation has been performed to analyze the comparison between a fixed surface and two axes tracker under this optimized angle. After the experimentation has been done and graphs been obtained, conclusion can be drawn that two axes tracker gives better efficiency than fixed axis and also azimuth angle as well as zenith angle have their own advantages varying on seasonal basis. Experimentation is performed at VIT Vellore.**

Keywords*— *Two axes tracking, Sun tracking angle, Solstice, Equinox.

I. INTRODUCTION

There has been much advancement in the field of solar energy. The amount of energy supplied to the earth in one day by the sun is sufficient to power the total energy needs of the earth for one year [4]. Solar collectors are one of the greatest improvements that have facilitated a lot in concentrating the sunlight for different purposes. But the problem is to keep the collector continuously oriented according to the movement of sun i.e. tracking of such collector and also to optimize the sun-tracking angle regularly to obtain maximum solar radiation. Solar collectors can be tracked by two kinds of approach, namely, active method and passive method.

This tracking is of two type single axis and two axes. Single axis trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of single axis trackers is either in E-W direction (horizontal tracking) or N-S direction (seasonal tracking).Two axes trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. Here both Azimuth and Zenith angles are being tracked, so such tracking becomes complicated.

The formula as a function of latitude and local climate data has been determined for optimum inclination [1]. Optimum tilt angles ranges from latitude up to latitude plus 20 for collectors operating with sufficient high solar fraction [2]. A mathematical procedure to compare the optimum tilt angles of collectors through monthly diffused radiation and actual monthly diffused radiations has been proposed [3]. The best orientation for solar collectors is south facing [3]. The tilting angle of a solar collector should be appropriate to receive maximum solar radiation and to avoid shading [5]. The optimum tilt angles increases during the winter months and reaches a maximum of 62° in December and the optimum tilt angle in June goes to a minimum zero degree [6]. The azimuth angle, orientation, and tilt angle are some of the most important aspects for the optimization of PV panels. The effect of various azimuth angles and orientations on solar energy is very low when the panel slope is fixed [7]. The optimum tilt angles for the periods January-March and September-December is the latitude of the location plus 16º while the optimum tilt for the period April-August is the latitude of the location plus 20º [8]. For higher efficiency, the design of collector should be such that the tilt angle can be at least changed on seasonal basis [9]. Reference [12] has given two different angles for summer and winter that, for summer the optimum tilt angle should be 10 to 15 degrees less than the latitude and for winter tilt angles should be 10 to 15 degrees more than the latitude, which can be considered as a gap as some researchers later on found that the yearly average of optimum tilt is equal to the latitude of the site [11]. Azimuth angle calculations can be done and tilt of the panel with respect to south direction (for panel in northern hemisphere) can be found out with good accuracy [13]. Later on researchers found out that horizontal tracking along with zenith angle will give the best efficiency to the system. The more number of the adjustments per year the better are the energy benefits [14].

Optimization of the sun-tracking angle has been done to harness maximum solar radiation. The sun-tracking angle optimization on a parabolic dish collector for different hours of a day throughout the year has been done. Graphs were obtained for Horizontal surface, Fixed surface, Seasonal tracking, Continuous tracking and Two axes tracking for

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

different hours of a day. Next sunlight intensity at the focus of Fixed collector and Two axes tracking collector was determined periodically from 9 am to 4 pm daylight hours and results were compared.

II. METHODOLOGY

First of all, the location was defined by Latitude and Longitude, i.e. coordinates 12.9833° N, 79.1833° E. For each day, Declination angle and Solar hour angle was calculated. Then for each day, sunrise time and sunset time was calculated, and with that data, length of the day was determined. Then Tilt angle, Zenith angle and Azimuth angle was defined according the type of surface. Now the length of the day was divided by 12 and for that time, Sun-tracking angle was calculated. Later, two types of graphs were plotted between watch time and Sun-tracking angle for each type of surface. First graph is made for four special days i.e. March (Vernal) equinox, September(Autumnal) equinox, Summer solstice, Winter solstice. Second graph is made for whole year from 6 A.M. to Noon.

The experimentation day and location was defined. Experimentation has been done on two identical dish type concentrating collectors, one was fixed and other was tracked in dual axes manually. Pyranometer has been used to calculate the intensity of the light at the focal point of two collectors. And a plot was made for experimental output.

Fig. 1 shows the flow chart of the methodology.

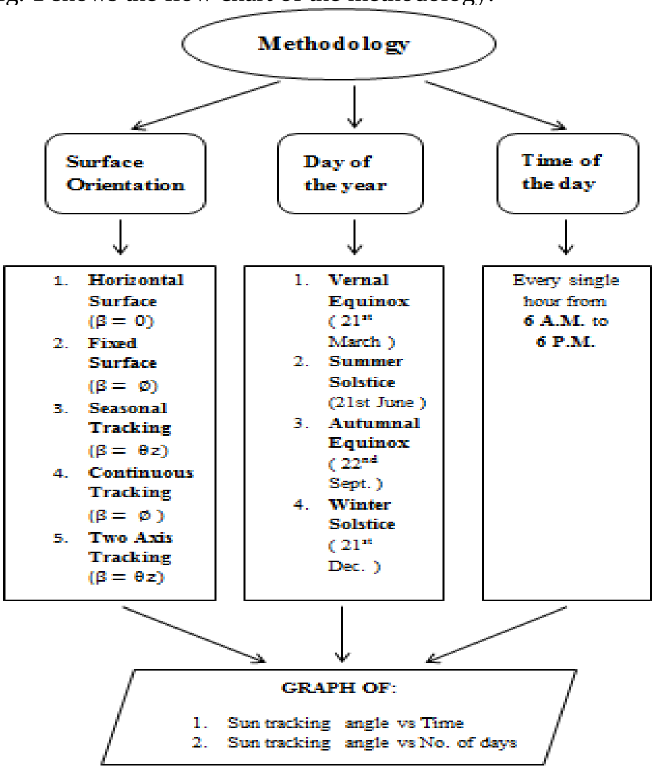

Fig. 1

III. DATA REDUCTION

Following formulas are being used to find various angles, like Sun-tracking angle, Azimuth angle, Zenith angle and Tilt angle:

1. $\delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$
2. $\omega = 15\ (\text{Solar Time} - 12)$
3. $\omega s = \cos^{-1}(-\tan\delta \tan\emptyset)$
4

$$\cos\theta = \sin\delta\ \sin\emptyset\ \cos\beta - \sin\delta\ \cos\emptyset\ \sin\beta\ \cos\gamma + \cos\delta\ \cos\emptyset\ \cos\beta\ \cos\omega + \cos\delta\ \sin\emptyset\ \cos\beta\ \cos\omega + \cos\delta\ \sin\emptyset\ \sin\beta\ \cos\gamma\ \cos\omega + \cos\delta\ \sin\beta\ \sin\gamma\ \sin\omega$$

5. $\cos\theta z = \cos\emptyset\cos\delta\cos\omega s + \sin\delta\sin\emptyset$

6. $\cos\gamma s = \frac{\cos\theta z\ \sin\emptyset - \sin\delta}{\sin\theta z\ \cos\emptyset}$

Where, the value of integer n varies from 1 to 365.

3.1 Declination angle (δ):

The declination angle, denoted by δ, is the angle between the sun ray and equatorial plane. It varies seasonally as the Earth is tilted on its axis of rotation and the Earth revolves around the sun. If the Earth was not tilted on its axis of rotation, then declination angle would always be equal to 0°. However, the Earth is tilted by 23.45°, so declination angle varies plus or minus this amount. During summer solstice declination angle is +23.45° in north of the equator and during winter solstice its value is -23.45°. Declination angle is 0° only during vernal and autumnal equinoxes.

3.2 Sun tracking angle (θ):

Sun tracking angle is the angle made by a ray of sun with a line perpendicular to a surface. So when a surface directly faces the sun, then Sun tracking angle becomes 0°. During sunrise or sunset, for horizontal surface, Sun tracking angle becomes 90°.

3.3 Zenith angle (θz):

The zenith angle is the angle between the sun and the vertical to the horizontal surface. Zenith angle is measured from vertical.

3.4 Latitude (∅):

Latitude is a geographic coordinate that specifies position of a point on the Earth's surface in the north–south direction. Latitude is an angle ranges from 0° at the Equator to 90° (North or South) at the poles.

3.5 Surface azimuth angle (γs):

It is the angle made by the horizontal component of sunray and the local meridian line. At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude, thus making the azimuth angles -90° at sunrise, 0° at noon and +90° at sunset.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

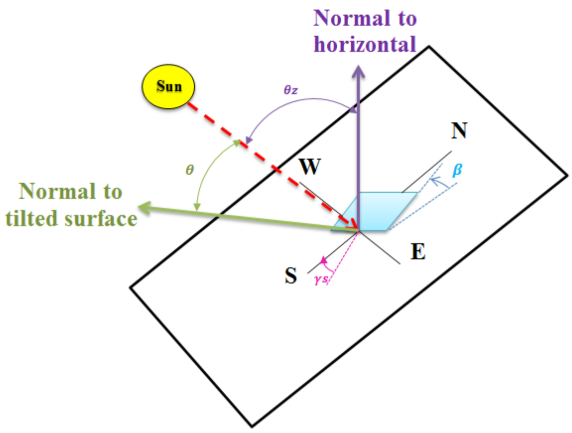

Fig. 2

Fig. 2 shows Tilt angle, Surface Azimuth angle, Zenith angle and Sun-tracking angle.

Graphs were made for sun-tracking angle for 5 following conditions:

1. *Horizontal surface* $(\beta = 0)$*:* Here the surface is horizontal, so the tilt angle is zero. Sun-tracking angle will be equal to zenith angle because the normal to the horizontal surface and the tracker coincide.
2. *Fixed surface* $(\beta = \emptyset)$*:* Here the surface is tilted, and tilt angle is equal to latitude. And horizontal component of the normal to surface is always parallel to the meridian line; hence surface azimuth angle is zero.
3. *Seasonal tracking* $(\beta = \theta z)$*:* Here the altitude of sun is tracked, so tilt angle is equal to zenith angle. And horizontal component of the normal to surface is always parallel to the meridian line; hence surface azimuth angle is zero. In this tracking system, tilt angle has to be changed once in a day, and tracking is done on single axis.
4. *Continuous tracking* $(\beta = \emptyset)$*:* Here the tilt angle is constant and equal to latitude. In this tracking system, solar azimuth angle has to be changed throughout the day, and tracking is done on single axis.
5. *Two axes tracking* $(\beta = \theta z)$*:* Here both tilt angle and solar azimuth angle are tracked. Tilt angle is equal to the zenith angle and solar azimuth angle is equal to the surface azimuth angle. In this tracking system, solar azimuth angle has to be changed throughout the day and tilt angle has to be changed every single day, and tracking is done on two axes.

IV. RESULTS

Graphs are obtained for above mentioned 5 conditions. For each condition, two graphs are there, the first graph is subplot of Sun-tracking angles Watch time (from sunrise time to sunset time) for two equinoxes (i.e. Vernal Equinox, 21st March and Autumnal Equinox, 22nd September) and two solstices (i.e. Summer Solstice, 21st June and Winter Solstice, 21st December). This graph is made to get sunrise time and sunset time for four special days and sun-tracking angle profile for the same. The second graph is Sun-tracking anglevs No of days. Second graph is plotted from 6 A.M to Noon. And from Noon to 6 P.M. is the mirror image of the graph with respect to x-axis. This graph is made to obtain the sun-tracking angle profile for different time throughout the year.

4.1 Horizontal Surface:

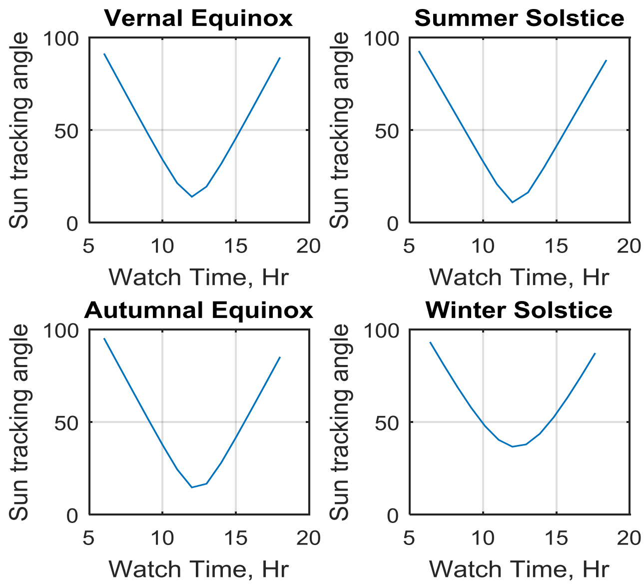

Fig. 3

From fig. 3, sun tracking angle is shown for four different days on horizontal surface. It can be observed that, in morning hours, the sun-tracking angle is higher because sun rises in the east direction and thus makes large angle with the line normal to the surface. And is reaches its lowest value at noon because elevation is higher and azimuth angle is zero. Then sun-tracking angle gradually increases and reaches at maximum value in evening because sun sets in the west direction and thus makes large angle with the line normal to the surface. At noon, value of sun-tracking angle is equal to the latitude on both the equinoxes. During summer, at noon, sun-tracking angle is little bit lower than the latitude, because of the higher altitude angle. During winters, at noon, sun-tracking angle is little bit higher than the latitude, because of the lower altitude angle. For both the equinoxes, i.e. fig. 3(a) and fig. 3(c), sunrise is at 6 A.M and sunset is at 6 P.M., so the day length is 12 hours. Also for summer solstice shown in fig. 3(b), the day length is more than 12 hours and for winter solstice shown in fig. 3(d) day length less than 12 hours.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

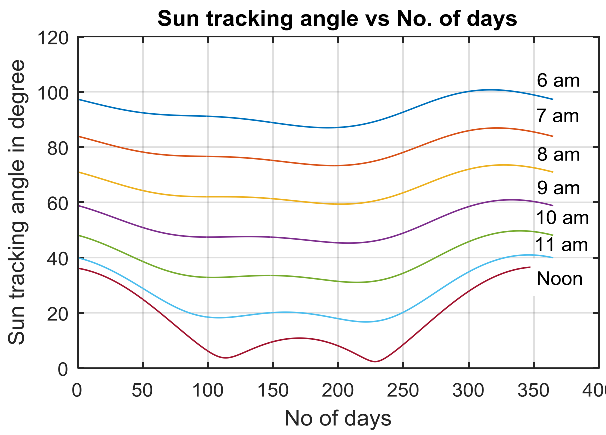

Fig. 4

From fig. 4, it is observed that throughout the year, sun tracking angle is higher in the morning and continuously decreases till noon time and then it increases till evening. It can be said that for horizontal surface, the value of sun-tracking angle is higher in winter than summer hence more solar energy can be harnessed in summer than winter.

4.2 Fixed Surface:

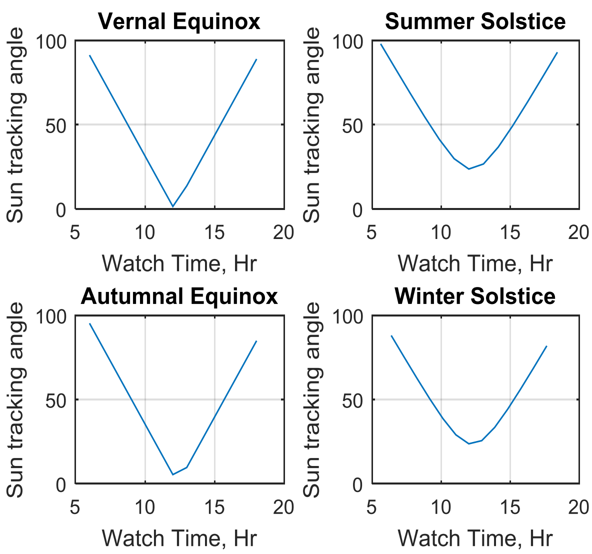

Fig. 5

From fig. 5, sun tracking angle is shown for four different days on fixed surface. Fig. 5(a) and fig. 5(c) have linear change in the angle, because tilt angle is kept as latitude angle so during equinoxes change in sun tracking angle is 15° per hour. For summer and winter solstice, i.e. fig. 5(b) and fig. 5(d) respectively, change of sun tracking angle is not linear and its value is higher as compared to fig. 5(a) and fig. 5(c) during noon time.

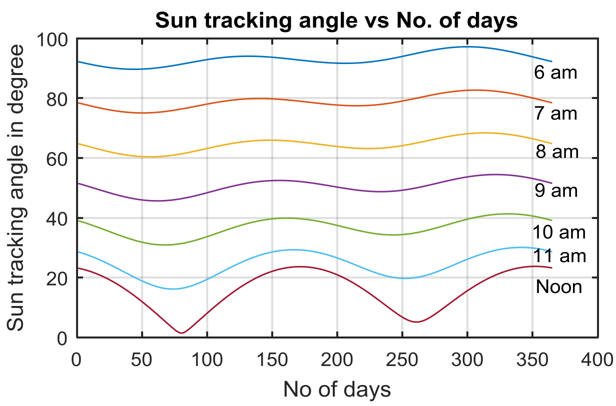

Fig. 6

From fig. 6, it can be observed that, sun-tracking angle is almost same for all days for all the time except noon time. Sun-tracking angle reaches its highest values during summer and winter Solstice, and minimum value during Vernal and Autumnal Equinox. Because tilt angle is equal to latitude angle, at noon time during equinox, the sun-tracking angle will be very low.

4.3 Seasonal tracking:

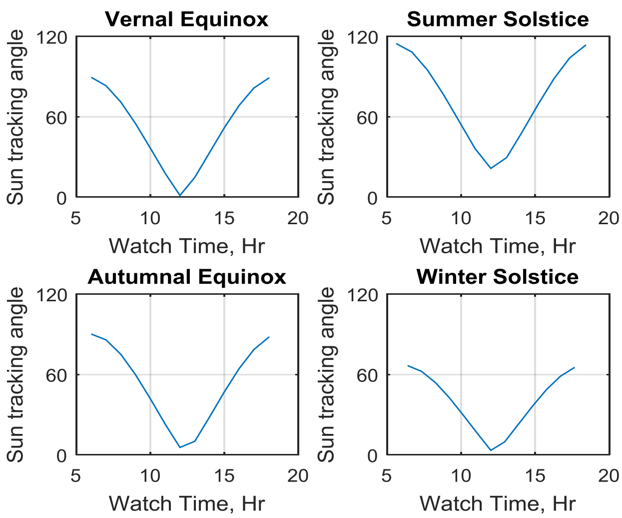

Fig. 7

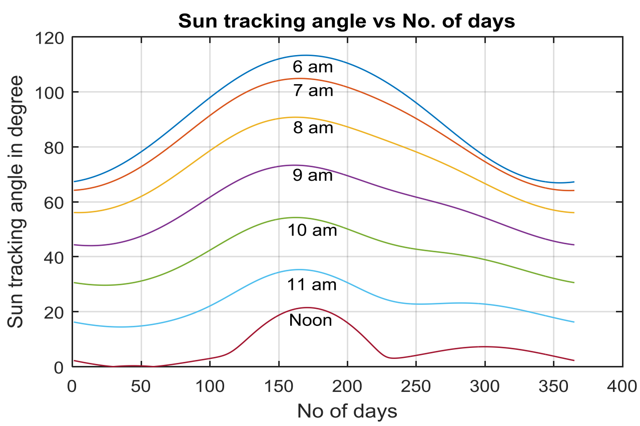

Fig. 8

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

From fig. 8, it can be observed that, sun-tracking angle is lower compared to the Fixed surface during the month of January, February, March, September, October, November and December. During the month of April, May, June and July, the sun-tracking angle is higher than Fixed surface. That means, if solar energy is used during winters (for water heater etc.), then Seasonal tracking is beneficial over Fixed surface solar collector. And if solar energy is used during summer (for solar refrigeration etc.), then Fixed surface solar collector is beneficial over Seasonal tracking.

4.4 Continuous tracking:

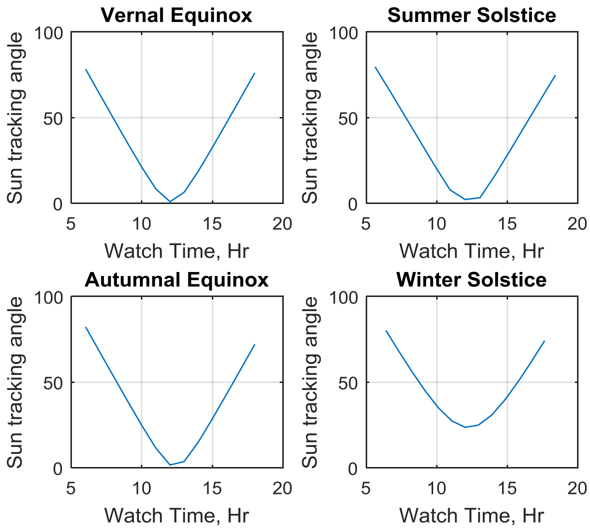

Fig. 9

From fig. 9, sun tracking angle is shown for four different days on Continuous tracking. On winter solstice shown in fig. 9(d), sun tracking is higher than other days during noon time, because altitude of sun is lower during winter.

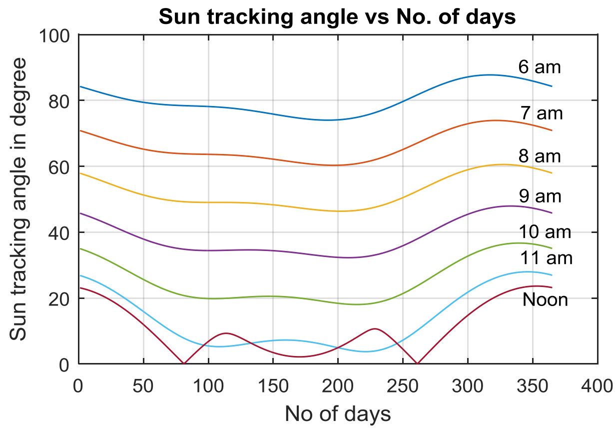

Fig. 10

From fig. 10, it can be observed that, sun tracking angle is lower than the Fixed surface. And, sun tracking angle is almost constant for a particular time throughout the year. Comparing fig.8 and fig. 10, it can be concluded that Continuous tracking is better than Seasonal tracking during summer and Seasonal tracking is better than Continuous tracking during winters.

4.5 Two axes Tracking:

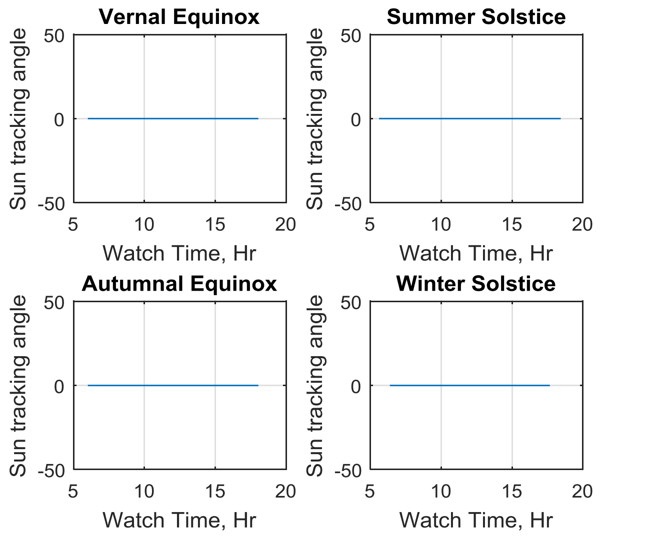

Fig.11

From fig. 11, it can be observed that, sun-tracking angle is 0° for all four days. And as the sun-tracking angle is 0°, we get maximum output.

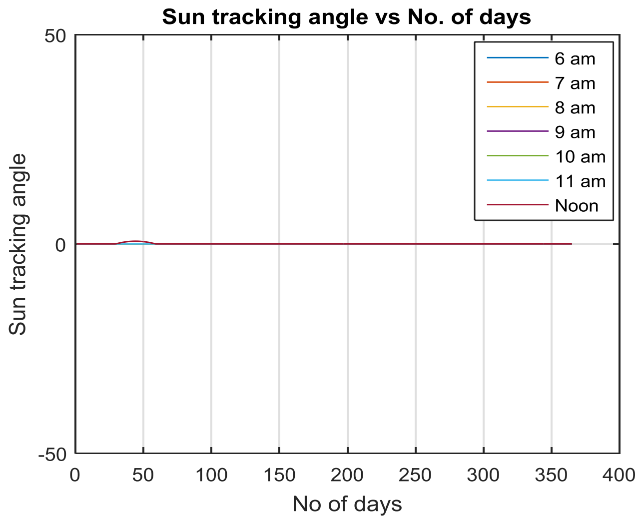

Fig. 12

From fig.12, it can be observed that, sun tracking angle is 0° for all the time throughout the year. And as the sun-tracking angle is 0°, we get maximum output. Comparing fig. 12 with fig. 10, fig. 8, fig. 6 and fig. 4 , it can be found that for Two axis tracking sun-tracking angle is minimum and equal to 0°, that means sunrays strikes the normal to the surface. So sun-tracking angle is optimized in Two axes tracking.

V. EXPERIMENTATION

Intensity of sunlight at the focal point of two geometrically identical parabolic solar collectors has been compared on 18th Feb 2016, periodically from 9 A.M. to 4 P.M. at Vellore. Fig. 13 shows two concentrating type collectors, one collector was manually tracked in two axes (two axes tracking) and the other was fixed. The accurate angular orientation of both the collectors is done manually.

Fig. 13

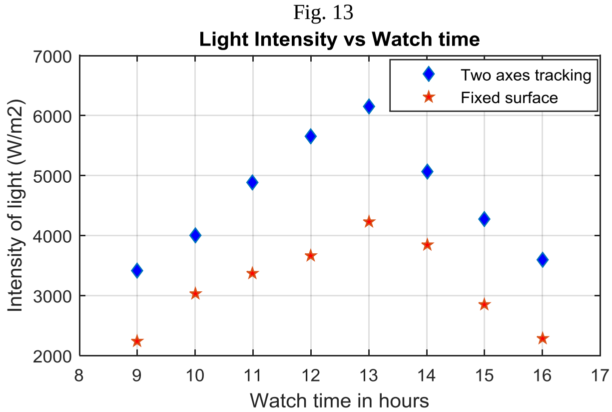

Fig. 14

Fig. 14 shows the Intensity of light at the focal point of the collectors on 18th Feb 2016. It can be observed that Two axes tracking gives better output than the Fixed surface. The maximum intensity is achieved at 13:00 hours for Two axes tracking and Fixed surface. Maximum percentage difference in intensities of Two axes tracking and Fixed surface is 54.24% which occurs at 12:00 hours.

For Fixed surface and Two axes tracking, Azimuth angle and Tilt angle were calculated for different time on 18th Feb 2016.

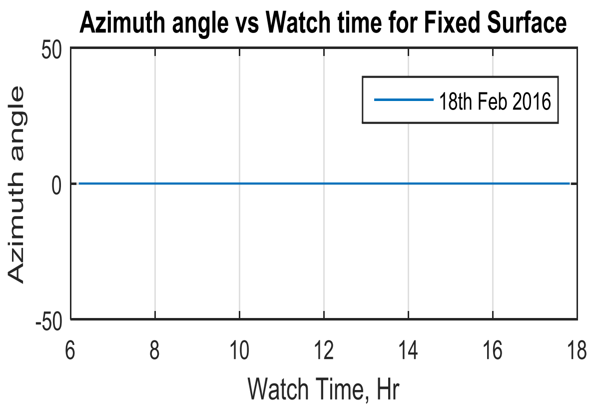

Fig. 15

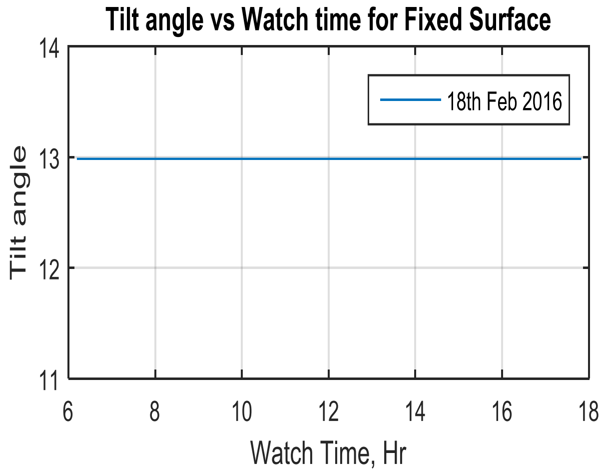

Fig. 16

For Fixed surface, on 18th Feb 2016 at Vellore, Azimuth angle is zero throughout the day, which can be seen from fig. 15and tilt angle is equal to latitude angle (12.9833°) throughout the day, which can be seen from fig. 16.

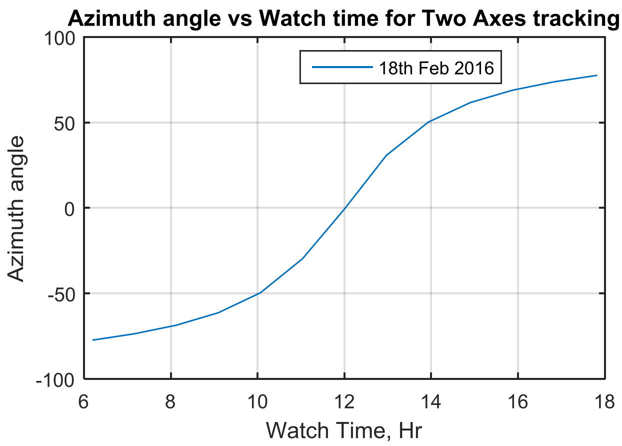

Fig. 17

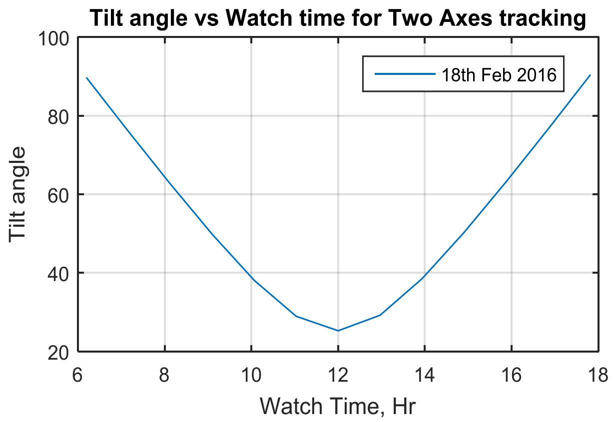

Fig. 18

For Two axes tracking, on 18th Feb 2016 at Vellore, fig. 17 shows Azimuth angle profile and this angle was manually tracked. Fig. 18 shows Tilt angle profile and this angle was also manually tracked.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

VI. CONCLUSION

The value of sun-tracking angle for five different conditions for different time for whole year has been found out. For experimentation, Azimuth angle and the Tilt angle was calculated for the Fixed surface and the Two axes tracking. And through experimentation, it was found out that the Two axes tracking is overall better than the Fixed surface, which could be predicted from sun tracking angle profile of the Two axes tracking and Fixed surface. The seasonal variations of intensity are also compared .Experimentation results showed that maximum intensity was achieved at 13:00 hours for Two axes tracking and Fixed surface. And maximum percentage difference in intensities of Two axes tracking and Fixed surface was 54.24% which occurs at 12:00 hours.

VII. REFERENCES

[1] A. Adell, "Determination of the optimum inclination of a flat solar collector in function of latitude and local climatic data", revue phys. Appl. 17, pp. 569 -576, September 1982

[2] A. Shariah, M.A Al-Akhras, I.A. Al-Omari,"Optimizing the tilt angle of solar collectors", Renewable Energy 26 , pp 587 - 597, 2001.

[3] Tang R. and Tong W., "Optimum tilt angles for solar collectors used in China", Applied Energy 2004; 79:239-248.

[4] A. Khaligh and O.C.Onar, Energy Harvesting, Taylor and Francis Group: CRC press, 2010, pp.1

[5] B. R. Elhab, K. Sopian, Sohif Mat, Ch Lim, M. Y. Sulaiman, M. H. Ruslan, OmidrezaSaadatian, Optimizing tilt angles and orientations of solar panels for Kuala Lumpur, Malaysia, Scientific Research and Essays Vol. 7(42), pp. 3758-3765, 7 November, 2012

[6] AbhishekAgarwal , Vineet Kumar Vashishtha, Dr. S.N. Mishra, Comparative approach for the optimization of the tilt angle to receive maximum radiation, International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 5, July - 2012 ISSN: 2278-0181

[7] Fadaee, M., and M. A. M. Radzi. 2012. Multi-objective optimization of a stand-alone hybrid renewable energy system by using evolutionary algorithms: a review. Renew. Sustain. Energy Rev. 16:3364–3369.

[8] Felix A. Uba and Emmanuel A. Sarsah, Optimization of tilt angle for solar collectors in WA, Ghana, Advances in Applied Science Research, 2013, 4(4):108-114.

[9] M. Benghanem, Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia, Applied Energy 88 (2011) 1427–1433.

[10] S. A. Keshavarz, P. Talebizadeh, S. Adalatia, M. A. Mehrabian, M. Abdolzadeh, "Optimal Slope-Angles to Determine Maximum Solar Energy Gain for Solar Collectors Used in Iran", International Journal of Renewable Energy Research, Vol.2, No.4, 2012

[11] AmitaChandrakar, YogeshTiwari, Optimization of Solar Power by varying Tilt Angle/Slope, International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 4, April 2013).

[12] JA. Duffie, WA. Beckham, Solar Engineering of Thermal Processes, 4 th ed., Wiley, 2013, pp. 113- 114, 11 – 40.

[13] Shaurabh K. Singh, Utsav A. Jain, Gundabattini Edison, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 5 Ver. III (Sep- Oct. 2014), PP 27-32

[14] YohannesBerhaneGebremedhen, International Journal of Renewable Energy Research, Vol.4, No.4, 2014

[15] Sukhatme, S. P. (2008). Solar Energy: Principles of Thermal Collection and Storage (3 ed.). Tata McGraw-Hill Education. p. 84. ISBN 0070260648