# Measurement of the Intensity of Solar Radiation Using Pyranometer with Dual-Axis Tracking System

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**Abstract**

**Problem:** A pyranometer is used to find the global radiation. But, to measure the intensity of solar radiation accurately at a particular sunshine hour, it is required to focus the pyrometer perpendicular to the sun. It is not practical to adjust pyranometer manually to tract the path of two-directional movement of the sun every time accurately and it is a tedious task. For this, someone is required to be engaged to monitor the sun movement and to change the position of the pyranometer. **Approach:** To get maximum intensity of solar radiation an automatic controlled dual-axis solar tracking system has been used to get maximum intensity at any time with respect to latitude and longitude of the particular place of measurement. Thus, the problem of manual tracking can be avoided and maximum radiation can be measured at any sun-shine hour. **Findings:** Data have been obtained from the measurements of intensity of solar radiation on sunny days for both the winter and summer seasons at the latitude of $22.559579^0$ and longitude of $88.490036^0$.The time span has been considered from 6 a.m. to 6 p.m. i.e. 12 hours. Mathematical modeling has been done and computer programmings have been also used to find the values of the intensity of solar radiation theoretically at 12 sunshine hours to compare the theoretical and practical results. It shows the slight variation in the data obtained for theoretical and practical methods. **Conclusion:** Theoretical results have been obtained by assuming variation of intensity of solar radiation using mathematical model in the form of half-sine wave and practical measurements have been done using pyranometer. But, the readings given by the pyranometer depends on many climate conditions of a place. So, there are differences in the data of two cases. But, this study is useful to find the intensity of solar radiation of a place at different seasons at the particular latitude and longitude.

**Key words:** Solar radiation measurement; Solar tracking system; Pyranometer; Mathematical model; Intensity of solar radiation.

**Introduction:** To harness solar energy more and more, and then to utilize it effectively, it is required to put the devices in proper positions to face the sun [1, 2]. For examples – i) a photovoltaic system produces more electrical energy when the intensity of solar radiation is maximum[3], ii) a solar water heater produces hot water with high temperature when the solar intensity is more iii) a solar cooker produce maximum heat when the intensity of solar radiation is maximum and it oriented properly towards the sun [4]. The performances of all the solar energy harnessing devices depend largely on the intensity of solar radiation. So, it is an important parameter and its measurement requires proper instrumentation and method [5, 6]. There various devices to measure the intensity of total or global radiation, direct and diffusion radiations [7]. Pyranometer is used measure global radiation. Generally, to measure intensity of solar radiation, pyranometer is placed on a plane surface facing upward [8]. But, there is two-axis movement of the sun and it can measure the value of the intensity of solar radiation at a particular hour properly [9, 10]. Instead of placing pyranometer on the plane surface to measure the intensity of solar radiation, it can be fixed on the surface of the solar tracker that will follow the path of the sun in the sky [11]. There are various types of solar tracking systems [12]. These are – i) Manual solar trackers ii) Passive solar trackers and iii) Active solar trackers. The active solar trackers are more useful and efficient for collecting solar energy. Again, there are two types of active solar trackers, i.e. single –axis solar tracker and dual-axis solar tracker. The dual- axis solar tracker is most useful and appropriate system which helps in measuring the intensity of solar radiation using pyranometer. In this investigation, an attempt has been made to measure the intensity of solar radiation using a combined system consisting of a dual-axis solar tracker that can change its position both the directions and a pyranometer is mounted on the top surface of the tracker to measure solar radiationn. The data have been collected both in summer and winter seasons for a span of 12 sun-shine hours, i.e., 6 a.m. to 6 p.m. A mathematical model [13, 14, 15, 16] has been developed of the system of measurement and computer programming has been done to make comparison between the theoretical data and practical data. The results have been tabulated, shown graphically and discussed.

## Materials and Methods:

### Measurement system

Fig.1 shows the schematic diagram of a solar intensity measurement system with a two-axis sun tracker. It consists of a combined system having a digital pyranometer which is used to display the value of the intensity of solar radiation at any instant of and a two-axis tracker which is used to track the sun for two axes, i.e., East to West and North to South. The tracker is driven by mechanical unit consisting of a steeper motor and a control unit to adjust it and hence, the position of the pyranometer. The pyranometer is mounted on the tracker vertically. It moves with the tracker to receive maximum intensity of solar radiation at any instant.

### Methods

The measurement of the intensity of solar radiation is started at 6 a.m. after the inspection of clear sky and normal sunrise. The mouth cover of the pyranometer is kept open to receive the solar radiation. The tracker with mounted pyranometer is adjusted to get the desired value of the intensity of global radiation. The value of the intensity of solar radiation is recorded for 12 sunshine hours, i.e. 6 a.m., 7 a.m., 8 a.m., 9 .a.m., 10 a.m., 11 a.m.,12 noon, 1 p.m., 2 p.m., 3 p.m., 4 p.m., 5 p.m. and 6 p.m. The two-axis tracker automatically takes position every time with the position of the sun. The measured values and the theoretically calculated values are tabulated and plotted to find the deviations between them.

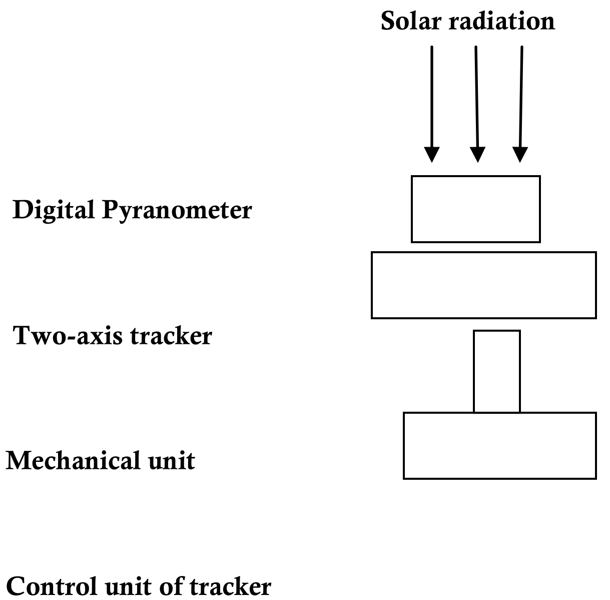


**Fig.1: Schematic diagram of a solar intensity measurement with two-axis sun tracker**

**Mathematical modeling of the solar radiation measurement system**

For obtaining the mathematical model, following assumptions have been made:
i) Clear sunshine day has been considered for measurement of total radiation.
ii) The latitude and longitude of the measuring location are $22.559579^0$ and $88.490036^0$ respectively.
iii) Variation of intensity with time in hour is in the form of positive half of sinusoidal wave.

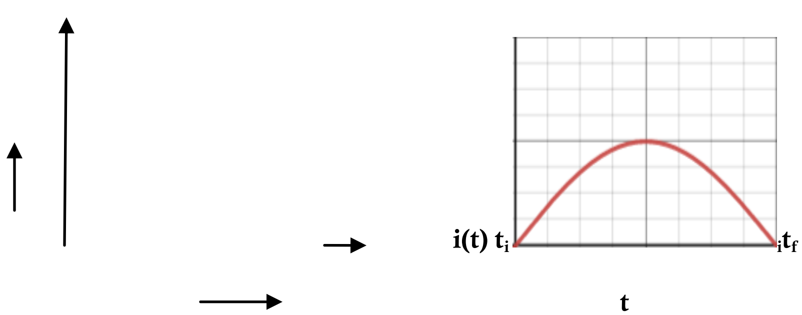


**Fig.2 : Variation of intensity of solar radiation with time**

**Results**

Fig.2 shows the graphical results for an ideal system without any loss. But, for actual system, results will vary due to many environment conditions as shown in Fig.3 and Fig.4. The comparative results between the theoretical and measured values are shown in Table-I and Table- II for summer and winter respectively and also shown graphically in Fig.3 and Fig.4. It can be seen from the Tables-I and Table – II, that there are a small variations in the data obtained in theoretical and practical values. The practical values are always slightly less than theoretical values. This is due to the fact that due the presence of dust and other particles in the atmosphere, a small amount of solar radiation is not reaching the measuring surface. There is also variation of results in summer and winter due to change in distance of the sun from the earth. The results will vary in cloudy and rainy day both in summer and winter due to more diffuse radiations. The results will also vary for the other location with latitude and longitude of the place.

**TABLE-I: Variation of intensity in w/m$^2$ with time( hour) in Summer**

| T | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I (T)-TH. | 0 | 207 | 400 | 566 | 693 | 773 | 800 | 773 | 693 | 566 | 400 | 207 | 0 |
| I (T)-PRACT. | 5 | 206 | 398 | 565 | 691 | 772 | 799 | 772 | 691 | 563 | 397 | 204 | 4 |

**TABLE-II: Variation of intensity in w/m$^2$ with time( hour) in Winter**

| T | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I (T)-TH. | 0 | 168.2 | 325 | 460 | 563 | 628 | 650 | 628 | 563 | 460 | 325 | 168.2 | 0 |
| I (T)-PRACT. | 0 | 165 | 324 | 458 | 560 | 627 | 649 | 628 | 562 | 458 | 323 | 164 | 0 |

**Conclusion**

Though there are variations of the data between the theoretical and practical cases, but this study is useful to find the intensity of solar radiation in appropriate manner using pyranometer mounted on a two-axis sun tracker. The theoretical data are obtained at different sunshine hours using the mathematical model given by the equation (1) and it will remain same at any place of the world. But, the practical data will vary from place to place and they will depend on the geographical and atmospheric conditions of the place. The theoretical results have been obtained by assuming the positive half-sine-wave variation of intensity of solar radiation with time in India. But, this assumption of variation may not fit for other countries.

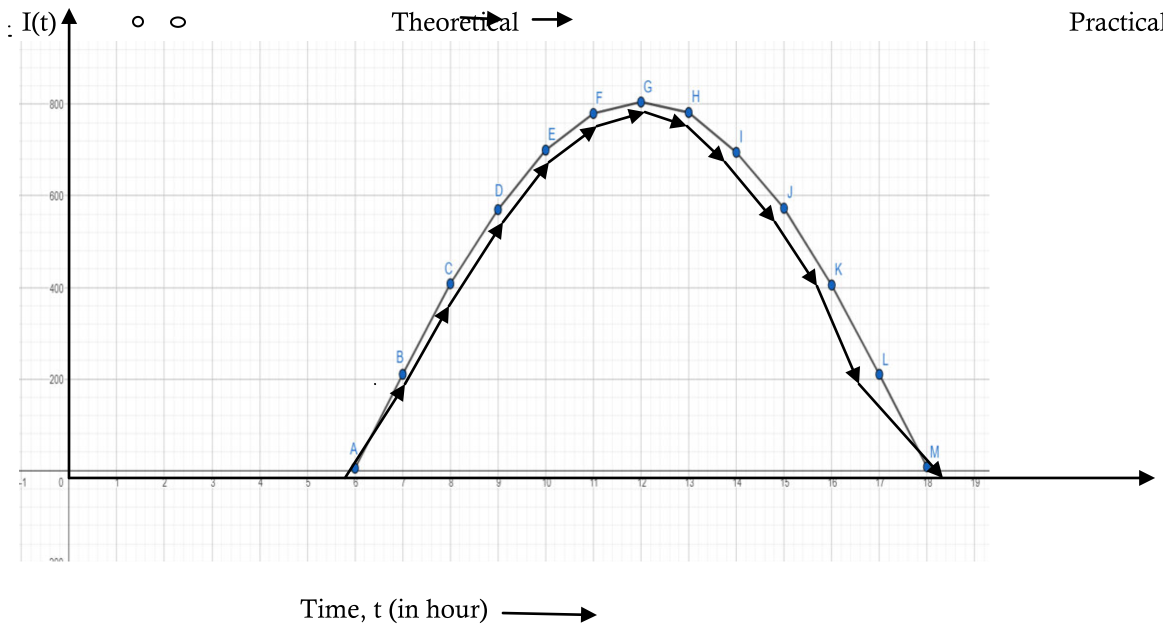


**Fig.3 : Variation of intensity, I ( w/m$^2$) with time, t ( hour) in Summer (May)**

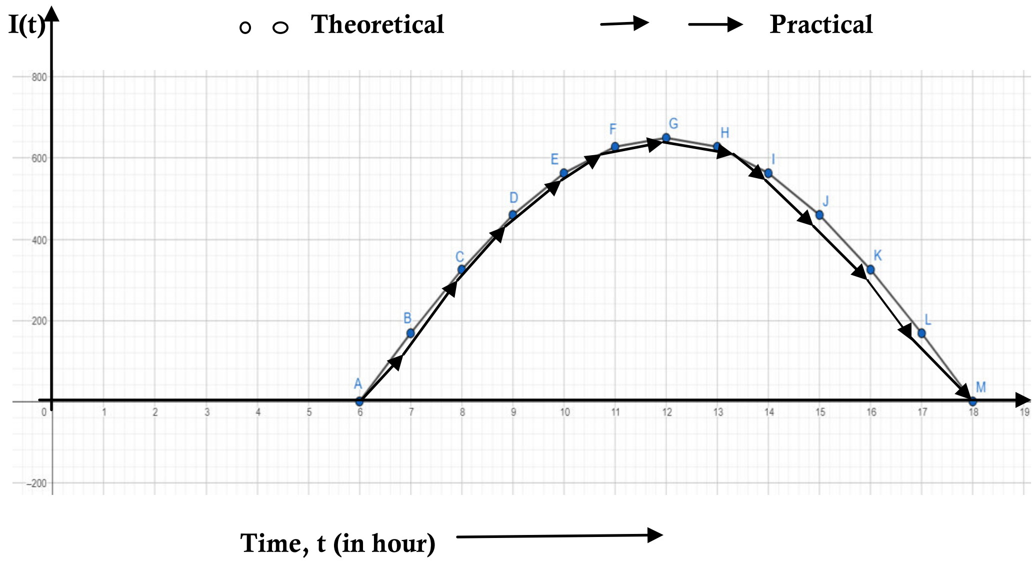


**Fig. 4 : Variation of intensity, I( w/m$^2$) with time, t ( hour) in Winter (January)**

## References

1. Kipp and Zones, 'Solar radiation measurement for solar energy application'. www.kippzones.com guide (2023).
2. Mulu Bayray, Yacob Gebreyyohannces, Hally Gebreiwot , Fana Filli, 'Measured solar irradiance data for resource assessment at four sites in Geba catchment, Tgray, North Ethiopia', ELSEVIER (2022).
3. Zequiang Bian, Lei Chong Wei Ding, Wel Yang, 'Analysis and research on quality control method of global radiation observation data', The Journal of Engineering, (23), pp. 8975-8979 (2019).
4. Ogelman H., Ecevil A., Taemiroglu E., 'A new method for estimating solar radiation from bright sunshine data', Journal of Solar Energy, vol. 33, pp. 619 -625 (1984).
5. Rai G.D., 'Non-conventional Energy Resources', Khanna Publishers, New Delhi (2012).

   Nagrath I.J. and Gopal M., Control system Engineering, New Age International (P) Ltd. New Delhi, India ( 2005).
6. Chen J.L., He L., Yang W., Ma M., Chen Q., Wu S. J., Xiao Z.L., 'Empirical model for estimating monthly global solar radiation: A most comprehensive review and comparative case study in China', Renewable Sustain Energy, Review, vol.108, pp. 91 -111 (2019).
7. Mohammad Jamilu Ya'u, Gele Mohammad Adullahi , Ali Yerima Yasif, 'Global Radiation Model: A Review'.Journal of Photonic Materialas and Technology, 4(1), pp. 26-32 ( 2018).

8. Mohammad Jamilu Ya'u, Gele Mohammad Adullahi , Ali Yerima Yasif, 'Global Radiation Model: A Review'.Journal of Photonic Materialas and Technology, 4(1), pp. 26-32 ( 2018).
9. Solar Tracker, Wikipedia(2023).
10. Miloud Li Qi, Bessafi and Peng Li, 'Intermittency study of Global radiation under tropical climate: Case study on Reunion Island', Scientific Reports (11), (2023).
11. Jesious –Ignacio Prieto, David Gracia , 'Global solar radiation models: A critical review from point of view of homogeneity and case study', Renewable and Sustainable Energy Reviews (155), Science Direct, (2022).
12. Muneer T., Younes S., Munawwar S., 'Discourses on solar radiation modeling', Renew Sustain Energy Review, vol. 11, pp. 551 -602 (2007).
13. Jahani B., Dinpashah Y., Nafchi A. Raisi, 'Evaluation and development of empirical models for estimating daily solar radiation', Renewable Sustain Energy Review, vol. 73, pp. 878 -891 (2017).