Modeling of Global Solar Radiation in India

Afroj Alam[1], Md Nazeem Khan[2], Pramod Singh[3]

[1]*Department of Mechanical Engineering,AMUAligarh,India*

[2]*Department of Mechanical Engineering, DTU Delhi, India*

[3]*Department of Mechanical Engineering, GLBITM, Gr. Noida*

ABSTRACT

A study of measured monthly average global radiation data of Indian cities has been performed. This study involves the secondary data which was collected by Indian meteorological department (IMD) from 1986 to 2000 for 23 field station of radiation network in India. These 23 selected locations of India have been grouped in four zones according to their climatic conditions with help of Koppen-climatic classification system. For each zone, the correlation of global solar radiation (H_m)with two meteorological variables, noon altitude angle (S_m) and sunshine hour (h_m) have been developed by using non-linear regression analysis method. The results obtained from present correlations have been compared with measured data. Comparisons between measured and estimated data shows that deviations for any month rarely exceed than 15% and in most case it is much less. For validation and to show accuracy of present correlations statistical test of root mean square (RMSE), mean bias error (MBE), mean percentage error (MPE) ,mean absolute percentage error (MAPE), t-test and chi-square test have been performed.

Keywords-Global solar radiation, noon altitude angle, sunshine hour,t-test

I **INTRODUCTION**

Fossil fuel age is expected to span only 1000 years of human civilization (1700 AD to 2700 AD).With ever-increasing population, fuel consumption rates, increase in petroleum products prices and environmental imbalance; every country feels energy starvation. To avoid these problems, renewable energy sources are best options. The solar-based renewable energy is important, clean, cheap, and abundantly available source of energy. In any solar conversion system, the knowledge of global solar radiation is extremely important for optimal design and prediction of system performance. The best way of knowing the amount of global solar radiation at a site is to install pyranometers at many locations in the given region and look after their day to day maintenance and recording, which is costly exercise. The alternative approach is to correlate the global solar radiation with meteorological parameters at the place where the data is collected. The resultant correlation may then be used for locations of similar meteorological and geographical characteristics at which solar data are not available.[1]

Barbaro et al. [2] developed a simple relation as function of few parameters to predict the relating global radiation for the places lacking in actinometric stations. They modified the formula proposed by Sivkov [3] for fitting the data of 31 Italian stations and divided Italy into three zones, including locations with similar climatological characteristic. Then for each zone the global radiation was calculated by one formula with an error of not more than 10 percent.Present work is to propose a non linear empirical correlation for estimating the global solar radiation in India. For this monthly mean global radiation of 23 measuring station is surface fitted with Barbaro [1] correlation given for Itlay. These 23 Indian measuring stations are grouped in four zones and for each zone, one correlation is proposed. Many statistical tests are also performed to check the performance and accuracy of correlations.

II. METHODOLOGY

Solar radiation data of 23 stations of India were chosen for our study. These stations were written in Table 2.1 with altitude and latitude[4]

Table 2.1- Coordinates of radiation stations.

S. No.	Name	Abbreviation	Latitude(°N)	Longitude(°E)	Height(m)
1	Minicoy	MNC	08.30	73.15	1
2	Thiruvanthapuram	TRV	08.48	76.95	60
3	Port Blair	PBL	11.67	92.72	13
4	Bangalore	BNG	12.97	77.58	921
5	Chennai	CHN	13.00	80.18	10
6	Goa	GOA	15.48	73.82	58
7	Hyderabad	HYD	17.45	78.46	530
8	Vishakhapatnam	VSK	17.68	83.30	7
9	Pune	PNE	18.53	73.85	555
10	Mumbai	MMB	19.12	72.85	8
11	Nagpur	NGP	21.10	79.05	308
12	Bhavnagar	BHV	21.75	72.18	5
13	Kolkata	KLK	22.65	88.45	5
14	Ahmadabad	AHM	23.06	72.62	55
15	Bhopal	BHP	23.28	77.35	523
16	Ranchi	RNC	23.32	85.32	652
17	Varanasi	VNS	25.30	83.02	90
18	Shillong	SHL	25.57	91.88	1548

19	Patna	PTN	25.60	85.16	51
20	Jodhpur	JDP	26.30	83.02	217
21	Jaipur	JPR	26.82	75.80	390
22	New Delhi	NDL	28.48	77.13	273
23	Srinagar	SRN	34.08	74.83	1585

The measured data obtained are monthly average global solar radiation and corresponding monthly sunshine hour. Monthly average data can calculated by averaging daily data and day of month is selected which is equivalent to average data of months which is generally 15th or 16th day of month. Measured mean monthly global solar radiation data of one city, New Delhi with sunshine hour are given in Table 2.2.

Table 2.2- Mean monthly radiation data for New Delhi[4]

Name	Month	Mean monthly global radiation MJm^{-2}	Sunshine hours
New Delhi	Jan	13.32	8.7
	Feb	16.42	8.7
	Mar	20.64	9
	Apr	24.07	9.7
	May	24.43	9.7
	Jun	22.54	9.4
	Jul	19.07	8.4
	Aug	17.79	7.8
	sep	18.9	8.6
	Oct	16.8	9.6
	Nov	14.13	8.7
	Dec	11.93	8.1

2.1 Classification of Indian climate

To start our modeling we first classified Indian states according to their climate as we know Indian climate is not similar everywhere. So Koppan climate classification [5]method has been opted in this study for obtaining separate relation for different zone. According to Koppan climate classification system India is classified in six climate zone; Montane ,Humid subtropical, Tropical wet and dry, Tropical wet, Semi arid and Arid.These six climates are further grouped in four zones for reducing the no of correlation equation and making the analysis compact and easier. These are grouped in Table 2.1.

Table 2.1-Climate zone of India

Zone 1	Zone 2	Zone 3	Zone 4
Humid subtropical	Tropical wet and dry Tropical wet	Semi arid Arid	Montane

Now, the 23 cities selected for study were grouped according to their zone as follow in Table 2.2.

Table 2.2- Indian radiation measuring station grouped under their zone

Zone 1	Zone 2	Zone 3	Zone 4
Shillong Patna Ranchi Bhopal Varanasi	Minicoy Thiruvanthapuram Portblair Chennai Goa Hyderabad Vishakhapatnam Mumbai Kolkata	Bangalore Pune Nagpur Bhavnagar Ahmadabad Jodhpur Jaipur New Delhi	Srinagar

2.3 Fitting of Radiation Data

After getting a two independent variable; sunshine hour, s and elevation angle, h and dependent variable , monthly average Global solar radiation , H we have selected the non linear form of equation which given by Barabaro et al[2] for Italy as given below:

$H_m = k(s_m)^{1.24}(h_n)^{-0.19} + 10550(sin\ h_n)^{2.1} + 300(sin\ h_n)^3$----------------- (1)

Where k =8, 9.5, 11 for zone 1, zone 2 and zone 3 respectively.

This equation is modified for Indian sites for each zone by fitting the data of Indian cities and obtained different constant parameters.

So the general form of this equation is

$$H_m = k_1(s_m)^a(h_n)^b + k_2(sin\ h_n)^c + k_3(sin\ h_n)^d \text{------------------------------ (2)}$$

In the present study, we have fitted the data in above non-linear relationship using MATLAB non-linear interactive surface fitting to obtain constant parameters for estimating the monthly average global radiation of four different zone of India as classified earlier. The regression constant k_1, k_2, k_3, a, b, c and d are determined by least square method.

III. RESULT

After fitting the solar radiation data to the equation (2) we got k_1, k_2, k_3 a, b, c, and d parameters used in this equation. One or two data of each zone which were contributing very large error and making the fit awkward have been excluded. Then, for final equation for different zone can be written as follows;

For Zone1:

$$H_m = 0.7341(s_m)^{0.6249}(h_n)^{0.3416} + 4.619(sin\ h_n)^{1.39} + 3.943(sin\ h_n)^{1.424} \text{----- (3)}$$

For zone 2:

$$H_m = 0.372(s_m)^{2.013}(h_n)^{-0.2526} + 4.26(sin\ h_n)^{3.418} + 5.992(sin\ h_n)^{3.43} \text{-------- (4)}$$

For zone 3:

$$H_m = 0.1933(s_m)^{1.66}(h_n)^{0.0918} + 4.389(sin\ h_n)^{2.01} + 5.508(sin\ h_n)^{1.972} \text{--------- (5)}$$

For zone 4:

$$H_m = 0.605(s_m)^{0.7284}(h_n)^{0.4454} + 1.914(sin\ h_n)^{-1.876} + 0.9008(sin\ h_n)^{1.253} \text{---- (6)}$$

Equation (3)-(6) shows the correlation for four different zone of India. Based on these correlations predicted value of global radiation against the corresponding value of measured global radiation was obtained.

IV. ERROR ANALYSIS

Table 4.1 Statistical test of present correlation with other model

Statistical Tests	Present Model				Sivkov Model[3]	Mechlouch model[7]
	Zone 1Eq (3)	Zone 2Eq (4)	Zone 3Eq(5)	Zone 4Eq(6)		
MPE	-1.4156	-0.7159	0.2291	-0.1477		
MAPE	8.7520	6.8120	7.1930	8.1209	9.9	4.5
MBE	0.0481	-0.0083	-0.1987	-0.1877	3.3	1.9
RMSE	1.9941	1.5724	1.7989	1.0293	66	33
t-statistic	0.1850	0.0547	1.0833	0.6152		
χ^2 value	12.922	14.3967	17.023	1.2803		

A various statistical tests were performed to check the performance of present correlation which discussed earlier. For each zone MPE, MAPE, MBE, RMSE, t-statistic and chi-squre value have been shown in following Table4.1[6]

V . DISCUSSION

The mean monthly global radiation calculated with correlation (3) – (6) have been compared with experimental data of the Indian actinometric stations. The comparison show that formulas fit well enough the data of all zones and the mean absolute percentage error(MAPE) do not exceed 10 percent and percentage error of most of the stations are generally much lower than 10 percent

In Zone1 most of city has deviation less than 10 percent or nearer to it except Bhopal and Varanasi in the month of July and august which is more than 20 percent. Due to rainfall the sunshine hour and measured global radiation fall from other months.

In zone 2 Minocoy shows more than 20 percent deviation in month of November because of its geographical situation, a city in the Island, Lakshadweep, India. This agrees with the duration of sunshine of Minicoy in the month of November is lower than the mean values of the relating zones.

Zone 3 shows better fitting of data comparison to zone 1 and zone 2 because most of city has deviation much less than 10 percent. Only Bhavnagar in the months of summer has deviation more than 20 percent which is considerably higher than data for whole zone.

Zone 4 consists of mountain and elevated city of India. Srinagar has deviation more than 20 percent in the month of winter January and December because of its geographical location and lees than 10 percent in other month. Duration of sunshine hour is very less in winter season.

Other statistical tests have also been performed to check the performance of present correlation which is MPE, MBE, RMSE, t-statistic and chi-square vale shown in Table 4.1. MPE and MBE are closer to zero and RMSE is nearer to one which shows goodness of fit. These values have also been compared with the Sivkov[3] model shown in Table 4.1.

VI. CONCLUSION

On the basis of obtained result, it has been shown that mean absolute percentage error (MAPE) is lower than 10 percent for all four zones of India. MPE, MBE, RMSE, t-statistic value and chi-square value have also lesser value which is preferred for the empirical correlation. Comparison of present correlation with other model also shows lesser value of statistical test than later. Therefore, it is concluded that correlation (3)-(6) can be used for the estimation of monthly global radiation for their respective zonal city. At any location in India, monthly global radiation can be calculated by simply selecting the zonal empirical formula within accuracy limit. So there is no need of setting up of radiation measuring instrument and taking reading for long time which is costly and time taking procedure. These correlations will be useful for estimation of global radiation received in India which is necessary for design of photovoltaic and solar thermal Instruments.

REFERENCES

[1]Duffie J A and Beckman W A, Solar Engineering Of Thermal Processees, *3rd edn, Wiley:New York,1991.*

[2] Barbaro S, CoppolinoS, Leone C and Sinagra E , Global solar radiation in Italy, *Solar Energy , . 20,1977, 431-435.*

[3]Sivkov S I, To the methods computing the possible radiation in Italy, *Trans. Main Geophys. Obs. 160 ,1964*

[4] TayagiAjit P., Solar Radiant Energy Over India, Report,2009, *Indian Meterological Department of India*, available@ http://www.mnre.gov.in/centers/about-sec-2/solar-resources/

[5]Koppen Climate classification System, available@http://geographyias.blogspot.in/2011/04/koppen-climate-classification-system.html

[6] Khan Maroof ,M.Tech Dissertation, AMU,2012

[7]RidhaFethiMechlouch and Ammar Ben Brahim, A Global Solar Radiation Model for the Design of Solar Energy Systems, *Asian Journal of Scientific Research, 1, 231-238.*