Studies on Solar Radiation Estimation, Modeling and Analysis for Manipal

Shoham Das, Ayush Lodha, Amit Anand
Department of Chemical Engineering, Manipal Institute of Technology,
Manipal, India.

Dr. S. Shanmuga Priya, Associate Professor,
Department of Chemical Engineering ,
Manipal Institute of Technology, Manipal, India.

Dr. Manohara Pai M. M.
Associate Director(Innovation Centre)
Manipal Institute of Technology, Manipal, India.

Abstract- **In this study, the daily global solar radiation data at Manipal, India was investigated. Sunshine based models were used to measure the global solar radiation. The estimated values were compared with the measured values in terms of statistical error tests such as MAPE (Mean Absolute Percentage Error), MBE (Mean Bias Error), and RMSE (Root Mean Square Error). The model having the least error is selected to be best suited for Manipal region. A simple and more flexible model is introduced based on the input data. The proposed model demonstrates acceptable results and statistically displays lower RMSE and MBE values. The predicted values are found to be in accordance with the measured values.**

Keywords: global solar radiation, sunshine based models, linear model, non-linear model, fuzzy logic model.

I. INTRODUCTION

Solar energy is one of the most important forms of alternative energy resources presently available. There are very few stations equipped in the country which are capable of measuring daily global solar radiation in a consistent basis. Therefore, an accurate knowledge of solar radiation availability at a particular geographical location is of vital importance for the development of solar energy systems. In order to develop solar radiation models various parameters like extra-terrestrial radiation, cloud cover, latitude, sunshine hours etc. are taken into consideration. The most commonly used parameter for estimating global solar radiation is sunshine duration. Angstrom model is the most widely used model for estimation of global solar radiation. He proposed a linear relationship between the ratio of average daily global solar radiation to the corresponding value on a completely clear day and the ratio of average daily sunshine duration to the maximum possible sunshine duration.

For the measurement of cloud cover on a particular day Oktas rule has been applied. Sky conditions are estimated in terms of how many eighths of the sky are covered in cloud, ranging from 0 oktas (completely clear sky) through to 8 oktas (completely overcast) using mirrors.

These models represent biological and physical processes (climate change, hydrological, ecological and agronomic studies) and can be used to synchronize weather data to enable suitable analysis. The main objective of this paper is to estimate daily global solar radiation with measured daily sunshine duration data from Manipal and to determine the most accurate and suitable model for the estimation of global solar radiation at Manipal, India.

II. MODEL DEVELOPMENT METHODS

A. Key Parameters:

Manipal (13.347°N, 74.788°E) is located in south-west India at an altitude of 73m. The daily measured global solar radiation and sunshine duration of Manipal station is obtained from Innovation Centre, Manipal Institute of Technology, Manipal, India. Kipp and Zonen Product Documentation and Software version 1004 has been incorporated to obtain the daily solar radiation data. In this paper the time period for estimation of solar radiation data is from Oct 2012 to April 2013.

B. Solar Radiation Components

a) Solar radiation is classified into two main parts, extra-terrestrial solar radiation (G_{extra}) and global solar irradiation (G_t).

$$G_{extra} = I_o[1 + 0.034\cos(2\pi N/365)] \quad (1)$$

I_o = Solar constant, 1364 W/m^2

N= No. of days

b) The declination angle (δ) is the angle between the earth-sun vector and the equatorial plane.

$$\delta = 23.45 \sin [360 (284 + N) / 365] \quad (2)$$

N= No. of days

c) Hour angle (ω_s) corresponding to sunrise is defined as the angular displacement of the sun from the focal point.

$$\omega_s = - \tan\Phi \tan \delta \quad (3)$$

Φ= Latitude

d) Solar day length (S_o) is defined as the monthly average of the maximum possible sunshine hours per day at the location.

$$S_o = 2/15 \cos^{-1} (- \tan\Phi \tan \delta) \quad (4)$$

e)

$$E_{extra} = G_{extra} . S_o \quad (5)$$

$$E_t = G_t . S_o \quad (6)$$

E_t = Average daily global solar energy on a horizontal surface at a location (KJ/m^2-day)

E_{extra} = Average daily extra-terrestrial solar energy (KJ/m^2-day).

f) For cloud cover estimation, Oktas rule is applied.

$$S/S_o = (10 – 1.25C)/10 \quad (7)$$

C= Daily mean cloud cover, ranging from 0 for clear sky to 10 for overcast conditions.

S = No. of shining hours in a solar day.

C. Types of Models

a) Linear Model:

$$E_t / E_{extra} = a + b (S/S_0) \quad (8)$$

b) Non-Linear Model:

$$E_t / E_{extra} = a(S/S_0)^2 + b (S/S_0) + c \quad (9)$$

a, b and c are Angstrom constants.

c) Fuzzy Logic Model:

- IF sunshine duration is “short” THEN the solar energy amount is “small ($0 \le S/So \le 0.5$).”
- IF sunshine duration is in the “medium” range THEN the solar energy amount is “medium ($0.5 \le S/So \le 0.7$).”
- IF sunshine duration is “long” THEN the solar energy amount is “high ($0.7 \le S/So \le 1$).”

D. Model comparison using Errors

For the analysis of global solar radiation, linear, non-linear and fuzzy logic models are used. Root Mean Square Error, Mean Absolute Percentage Error and Mean Bias Error will now be calculated based on these models. These errors will describe the accuracy of the correlations developed. The least error will determine which model is best suited for Manipal.

Mean Absolute Percentage Error=

$$1/n \Sigma^n_{i=1}|((G^i_m - G^i_c) / G^i_m)| \text{ x}100 \quad (10)$$

$$\text{Mean Bias Error} = \Sigma^n_{i=1}((G^i_m - G^i_c) / n) \text{ x}100 \quad (11)$$

$$\text{Root Mean Square Error} = \{\Sigma^n_{i=1}((G^i_m - G^i_c)^2 / n)\}^{1/2} \quad (12)$$

G^i_m = Actual Value
G^i_c = Forecast Value
n = No. of fitted points

Mean Absolute Percentage Error is a measure of accuracy of a method for constructing fitted time series values in statistics. The absolute value in this calculation is summed for every fitted or forecasted point in time and divided again by the number of fitted point’s *n*. The calculation of Mean Bias Error gives us an idea about the long term performance of the models. A low Mean Bias Error is desired.

A positive Mean Bias Error indicates an over estimation of an individual observation and it nullifies a negative Mean Bias Error which signifies under estimation of a separate observation. The Root Mean Square Observation puts light on the short term performance of the correlation by giving a term by term comparison of the actual deviation between the predicted and the measured values.

III. RESULTS AND DISCUSSIONS

Linear Model:

$$\mathbf{E_t / E_{extra} = 0.2779 + 0.4178 (S/S_0)} \quad (13)$$

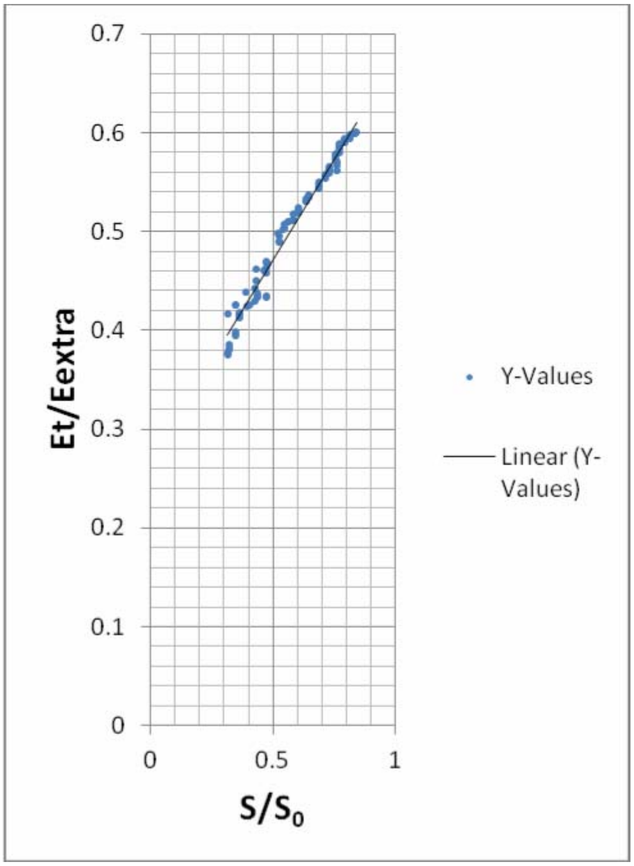

Fig 1: Linear Model Plot

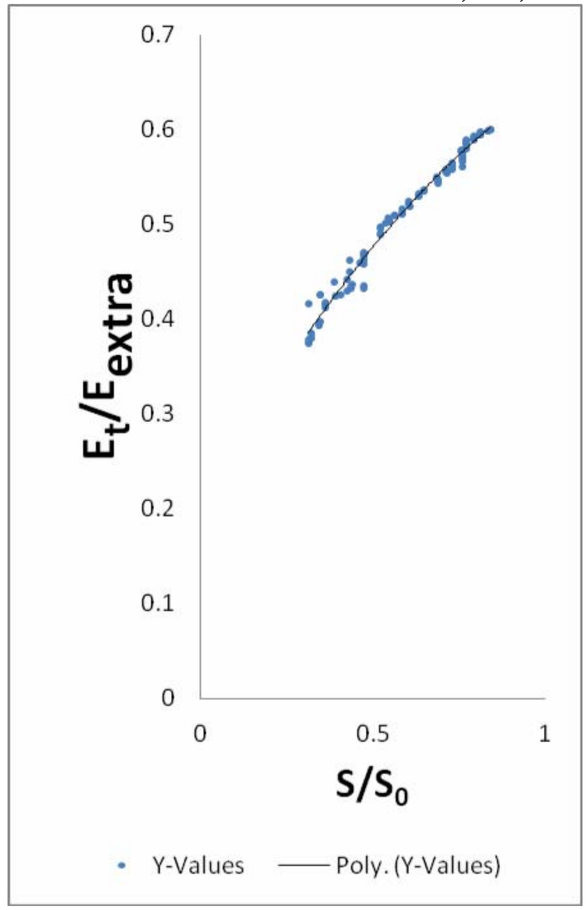

Fig 2: Non-Linear Model Plot

Non linear model:

$$\mathbf{E_t / E_{extra} = -0.247(S/S_0)^2 + 0.7235\,(S/S_0) + 0.1553} \quad (14)$$

Fuzzy Logic Model:

$$\mathbf{E_t / E_{extra} = 0.2005 + 0.550(S/S_0)\ for}\ 0 \le S/S_o \le 0.5 \quad (15)$$

$$\mathbf{E_t / E_{extra} = -0.690(S/S_0)^2 + 0.8630(S/S_0) + 0.2470\ for}\ 0.5 \le S/S_o \le 0.7 \quad (16)$$

$$\mathbf{E_t / E_{extra} = -1.2133(S/S_0)^2 + 2.143(S/S_0) - 0.3513\ for}\ 0.7 \le S/S_o \le 1 \quad (17)$$

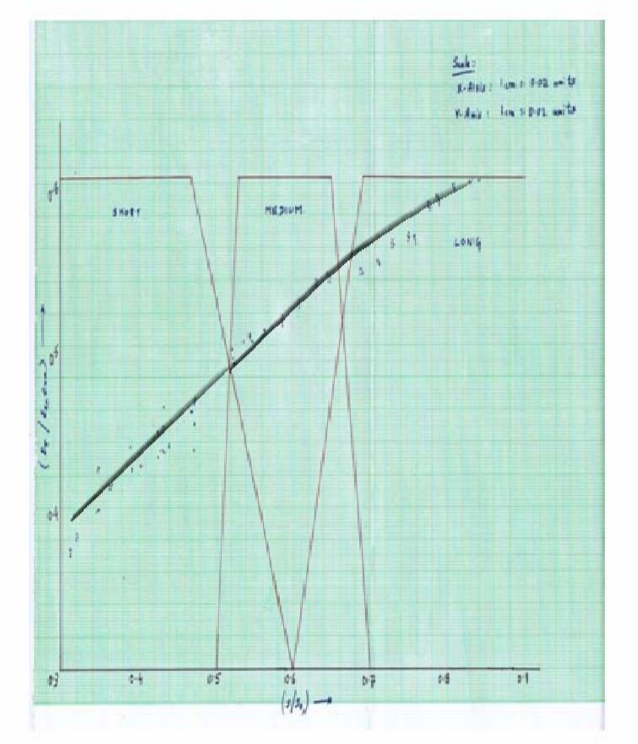

Fig 3: Fuzzy Logic Model Plot

Table 1 gives the errors for the three global solar radiation models namely linear, non linear and fuzzy logic models. The Mean Absolute Percentage Error values are higher as compared to Mean Bias Error and Root Mean Square Error values and it depicts an over estimation of the models as it is positive for the three models.

Mean Absolute Percentage Error, Mean Bias Error and Root Mean Square Error values for fuzzy logic model are lesser as compared to the respective values of the other two models. Hence, fuzzy logic model is best suited for Manipal.

Table 1: Error prediction for the three models

Model Types	MAPE(%)	MBE	RMSE
Linear Model	3.622	0.2944	0.3302
Non-Linear model	2.947	-0.240	0.254
Fuzzy Logic Model	1.883	-0.235	0.1858

Error Percentage Vs Types of Models

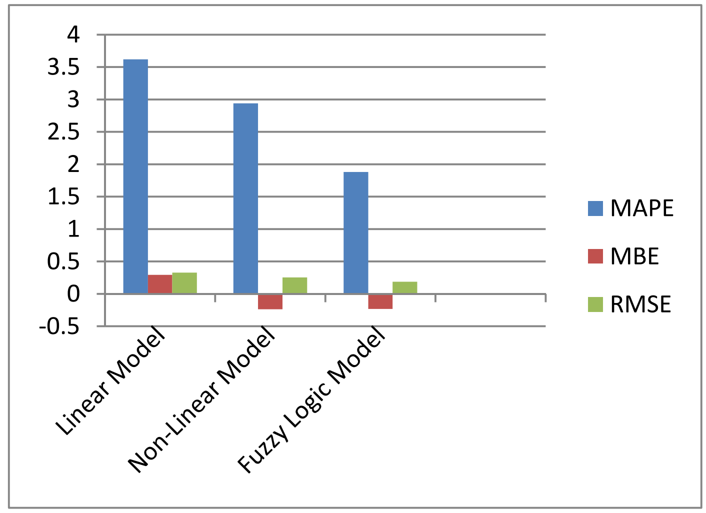

Fig 4: Error Percentage Column Graph

IV. CONCLUSION

Three sunshine based models are developed by virtue of comparison between measured and predicted values at Manipal, India. Fuzzy Logic Model is the ideal model for this region. However, all these models have higher Mean Absolute Percentage Error values as compared to Mean Bias Error and Root Mean Square Error in solar radiation estimation. It is of little consequence for solar energy operated systems because when the global radiation is small, it comprises of only a small part of the whole radiation. Hence, fuzzy logic model can be used for global solar energy estimation at Manipal, India.

ACKNOWLEDGEMENT

This project has been financially supported by Innovation Center, Manipal Institute of Technology, Manipal. We express our sincere thanks to Manipal University for providing us the financial support for purchase of Kipp and Zonen solar radiation instruments from Netherland.

REFERENCES

[1] N.Z. Al-Rawahi, Y.H. Zurigat and N.A. Al-Azri,(2011), “Prediction of Hourly Solar Radiation on Horizontal and Inclined Surfaces for Muscat/Oman”, Department of Mechanical and Industrial Engineering, College of Engineering, Sultan Qaboos University, Al Khoud, Muscat, Oman , Vol 8 No 2, Page No:19-31.

[2] Korachagaon. I.; Bapat V.N, (2012), "Validation of Iranna-Bapat's generalized empirical models for the estimation of global solar radiation for few locations in Chinese province", Advances in Engineering, Science and Management (ICAESM) International Conference, Page(s): 16 – 19.

[3] Yingni Jiang, (2010), "Calculation of daily global solar radiation for Guangzhou, China", Optics Photonicsand Energy Engineering (OPEE), International Conference Volume:1, Page(s): 41 – 43.

[4] Gayathri Vijayakumar, Michaël Kummert, Sanford A. Klein, William A. Beckman, (2005), "Analysis of short-term solar radiation data", Solar Energy, Volume 79, Issue 5, November 2005, Pages 495-504.

[5]D.H.W. Li, T.N.T. Lam, V.W.C. Chu, (2008),"Relationship between the total solar radiation on tilted surfaces and the sunshine hours in Hong Kong", Solar Energy, Volume 82, Issue 12, December 2008, Pages 1220-1228.

[6] Nazzareno Diodato, Gianni Bellocchi, (2007),"Modeling solar radiation over complex terrains using monthly climatological data", Agricultural and Forest Meteorology, Volume 144, Issues 1–2, 14 May 2007, Pages 111-126.

[7] M. Rivington a, G. Bellocchi , K.B. Matthews , K. Buchan, (2005), "Evaluation of three model estimations of solar radiation", Macaulay Institute, Landscape Change, Craigiebuckler, Aberdeen, AB15 8 QH Scotland, UK Agriculture Research Council (Research Institute for Industrial Crops), Via Corticella, 133-40128 Bologna, Italy.

AUTHORS PROFILE

Mr.Shoham Das and **Mr.Ayush Lodha** have completed their B.E degree in Chemical Engineering in 2013 from Manipal Institute of Technology, Manipal. They have carried out this work as a part of project work in their curriculum.

Mr.Amit Anand have completed his B.E from Nagarjuna college of Engineering and currently pursuing M.Tech in Chemical Engineering from MIT,Manipal.

Dr.S.Shanmuga Priya is working as an Associate Professor in Department of Chemical Engineering, Manipal Institute of Technology, Manipal University, Karnataka, India. She has five years of research experience and four years of teaching experience. She has more than 10 journals, 30 Conferences, 3 book chapters to her credit in International and National publications. She is also a life member in the Solar Energy Society of India, Institution of Engineers (I) and Renewable Energy Network (RENET).

Dr. Manohara Pai M M is working as an Associate Director, Innovation Centre CEO and Secretary, MUTBI (DST, Govt. of India supported Incubator) and Professor, Department of ICT, Manipal Institute of Technology,Manipal. He has many publications in National and International journal/conferences. He has received the prestigious Dr TMA Pai Endowment Chair Award for his outstanding contribution in the field of Data Analytics and Cloud Computing in 2013.