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SOLAR RADIATION ESTIMATION TECHNIQUES: THE REVIEW

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ABSTRACT

Efficient utilization of solar energy is a great challenge to the researchers. Practically measurement of solar radiation at various locations for long time using measuring devices is a costly and difficult assignment. This paper gives the brief idea behind modeling of global solar radiation. Also, challenges behind radiation modeling and statistical evaluation methodologies are addressed.

Keywords—MAPE, MBE, Pyrheliometer, Pyranometer, Radiometer, RMSE, Solarimeter, TS.

I. INTRODUCTION

Energy (Power) is always an integral part of human being. As time passes the dependency on power is increasing day by day. One can not imagine toady's life without power. Coal, Fossil fuels, Energy from petroleum products were the main source of energy up to 20th century. But due to their limited availability and environmental constraints, it became necessary to think of the use alternative/ renewable source of energy. Sun, Wind, Rain, Tides, Waves and Geothermal Heat are the main source of renewable energy. Because ofabundancy and non-pollutant, Solar Energy is considered to be most preferable. Energy demand of the world for a whole year may be met with a single hour of solar radiation which is approximately 1, 20,000 TW [1] [2].

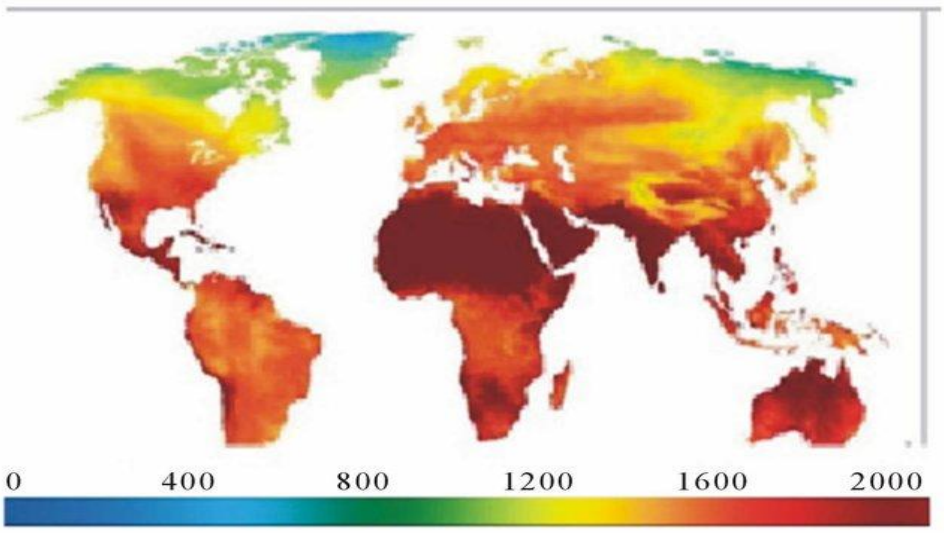

Fig. 1:World Solar Energy Potential (kW/m^2/year)

The National Aeronautics and Space Administration (NASA) releases map of World Solar Energy potential (fig 1), which significantly provides the ample potential of Solar Energy. So, in 21st century the maximization of Renewable Energy is going on. Solar radiation data provides the amount of Solar Energy that strikes the earth surface. Solar Energy have two parts: Global Solar Energy which is under the atmosphere and Extraterrestrial Solar Energy which is above the atmosphere. Global Solar Energy may have diffuse and direct beam Solar Energy. Direct beam solar radiation is measured by Pyrheliometerwhereas diffuse Solar Energy is measured by Solarimeter, Pyranometer, Radiometers etc. [3]. These are the devices by which the Solar Radiation can be measured practically. Section II and III gives review of empirical models and soft computing based models respectively. Also, section IV and V provides brief information of challenges in modeling of solar radiation and methods of model evaluation is also elaborated.

II. EMPIRICAL MODELING OF GLOBAL SOLAR RADIATION

There are several meteorological stations throughout the world which measures global solar radiation. Practically measured data is always most accurate but it is not easily available. Also, deployment of measuring devices and recording the data is a costly task. Considering this various models have been proposed and developed based on various meteorological parameters such as sunshine duration, cloud cover, ambient temperature, atmospheric pressure, wind speed, relative humidityetc. to predict global solar radiation well before. Some of them are empirical models which uses mathematical formulae. Some models are developed based on atmospheric characteristics and satellite data such as ozone absorption, Rayleigh scattering for estimation of solar radiation. In all the solar radiation estimation models, the meteorological parameters are the input and radiation data is the output. So, based on input, the models may be classified in following categories [4]:

1. Based on Sunshine.
2. Based on Cloud.
3. Based on Temperature.
4. Based on other Parameter.

A. MODELS BASED ON SUNSHINE

For estimation of Global Solar Radiation, Sunshine duration is the most commonly used. Using this, several models have been developed. Some of them are reviewed as under:

Model 1: Angstrom-Prescott model

This is deemed as the first radiation solar estimation model, developed in 1924 by Angstrom [5]. The global solar radiation is related with clear sky index as:

(1)

(2)

As in equation (1) is not easily determinable so Prescott [6] has modified it as

Model 2: Glower and Mc-Culloch model

Considering the effect of effect of latitude of the site (φ) as additional input, the below equation has been given as[7]:

(3a)

(3b)

Nomenclature

daily global solar radiation on horizontal surface averaged monthly.

extraterrestrial radiation on horizontal surface averaged monthly.

daily bright sunshine duration averaged monthly.

maximumaveraged monthly possible daily sunshine duration.

regression coefficients

latitude of location

solar zenith angle

mean max. min. daily temperature

cloud factor

number of days in each month

precipitable water vapor per unit volume of air

hourly beam & diffused beam

mean relative humidity

mean bias error

mean absolute percentage error

route mean square error

test statics

total number of observations

i^{th} observed value of global radiation

i^{th} calculated value of global radiation

Model 3: Rietveld model

This model claims to be applicable for calculation of global solar radiation across the globe is given as [8]:

(4)

Model 4: Page model

Page model also claims its applicability throughout the world. It provides coefficients of modified Angstrom model [9]:

(5)

Likewise,35-45 (approximately) models are there based onsunshine duration [4]. To keep the paper condensed they are notexplained here.

B. **CLOUD BASED MODELS**

Cloud plays most important role in restricting sun shine to reach the earth surface. Cloud causes reduction of solar radiation reaching the earth surface. Satellites, routinely records cloud data which is used to develop or design various solar radiation estimation models.

Model 1: Black model

Taking data from various part of world Black developed quadratic equation [10]:

(6)

C is the average of total cloud covered in day time hours.

Model 2: Paltridgeand Proctor model

Taking solar zenith angle (θ), day length (S_0) and cloud factor (CF) as input,Paltridge developed the new model as [11]:

$$\mathbf{H = (1 - CF) \int_{sunrise}^{sunset} I_b\ (\theta} \quad (7)$$

$$\mathbf{I_b = 3.422} \quad (7a) \qquad \mathbf{I_d = 0.00913}$$

(7b)

$$\mathbf{CF = \frac{(n_1) + 4.5(n_2) + 7.5(n_3)}{8(n_1 + n_2 + n_3)}}$$

Model 3: Badescu model

The correlations given by Badescu is given by [12]:

(8a)

(8b)

(8c)

Later on Daneshyar model and Paltridge model was modified by Sabziparvar [13].

C. **TEMPERATURE BASED MODELS**

Daily maximum and minimum temperature is more easily available comparative to sunshine duration and cloud data. Considering this 16-20 models has been developed [4]. Some of them are listed below.

Model 1: Hargreaves and Samanimodel

Hargreaves givessimple equation to estimate solar radiation considering maximum and minimum temperature [14]:

(9)

For costal regions a= 0.19 and for interior region a= 0.16

Model 2: Hunt et al. model

This is the modified Hargreaves model by adding an additional coefficient (b) [15]:

(10)

Model 3: Mahmood and Hubbard model

Based on maximum and minimum air temperature following model was proposed [16]:

(11)

Model 4: Chen et al. model

Following model [17] was proposed by Chen et al.:

(12a)

(12b)

D. **OTHER PARAMETER BASED MODELS**

Accurate prediction of global solar radiation needs long term average meteorological data. Various researchers used different parameters to develop the models. 20-30 such models are there [4].

Model 1: Garg&Garg model

Garg proposed double linear relation [18] for obtaining monthly mean global solar radiation:

(13)

cw is the atmospheric precipitable water vapor per unit volume of air.

Model 2: Ojosu&Komolafe model

Following equation was proposed [19]:

$$\frac{H}{H_0} = \qquad (14)$$

III. SOFT COMPUTING BASED MODELING OF SOLAR RADIATION

In the 20th and 21st century the application of computer has increased. Gradually, empirical models becomes obsolete and in place of that machine learning techniques, artificial intelligence techniques (artificial neural networks, support vector machine, genetic programming, fuzzy logic etc.) based models are being developed. In all these models computers are not explicitly programmed rather they are used. Some of them are reviewed as under.

A. ARTIFICIAL NEURAL NETWORK BASED MODELING

ANN is the efficient way to provide nonlinear relation between number of inputs and one or more output of global solar radiation estimation models. In reference [20], M. Benghanem, A. Mellit, S. N. Alamri developed an ANN based model for estimating daily global solar radiation using global irradiation , diffuse irradiation , air temperature *T*, & relative humidity . Six ANN models were proposed by them for different combination of input. They observed that the model with input as sunshine duration and air temperature gives considerably better result as correlation coefficient is 97.65 %. In reference [21], J. Mubiru, E.J.K.B. Banda explored the possibility of developing prediction model using ANN on weather station data such as sunshine duration, maximum temperature, cloud cover and location parameters such as latitude, longitude & altitude. A correlation coefficient of 0.974 was obtained with MBE of 0.59 MJ/m^{2}and RMSE of 0.385 MJ/m^2. Reference [22], M. Rijwan, MajidJamil, D. P. Kothari details the generalized ANN approach for global solar energy estimation in India. They proposed the GNN based model which overcomes the problem of ANN such as large number of neurons and layers for complex function approximation. They found the relative error of 4% which is lower than that of fuzzy logic of 6%. Reference [23], Soteris A. Kalogirou gives the importance of ANN in solar radiation prediction. ANN is useful in system modeling such as complex mapping and system identification. He presented various applications of neural network mainly in renewable energy.

B. FUZZY SYSTEM BASED MODELING

Fuzzy logic is a form of multivalued logic which deals with reality. It deals with grammarian values rather than fresh values. Logic lies between completely true and completely false (0-1). Likewise probability, fuzzy logic is also a technic of expressing uncertainty. Fuzzy logic deals with the membership functions such as 'Π' trapezoidal, 'Γ' function, 'Λ' triangular and Gaussian fuzzy set. Reference [24] L. Suganthi, S. Iniyan, Anand A. Samuel gives classification of fuzzy logic based models along with their applications. They indicated that the fuzzy based models provide realistic estimates. Reference [25], M. Rijwan, MajidJamil, D. P. Kothari performed modeling using fuzzy logic as mean duration sunshine, temperature, latitude, longitude, altitude and moths of a year as input parameters. The MPE, using fuzzy logic for New Delhi, Jodhpur, Kolkata and Shillong are 5.11%, 5.17%, 5.53% and 5.67% respectively where as it is 4.87%, 4.89%, 4.81% and 5.97% respectively using ANN. Reference [26], SaurabhBhardwaj, Vikrant Sharma, SmritiSrivastava, O. S. Sastry et al. used Hidden Markov Model (HMM) with Pearson R model for extraction of shape based clusters from the input meteorological parameters and it is then processed by Generalized Fuzzy Model (GFM). They used meteorological data of three years (2009-2011). 750 days data used for training of model and 165 days for validating the model. The RMSE, MAPE and R-value of prosed model have been found as 7.9124, 3.0083 and 0.9921 respectively. Reference

[27], R. IQDOUR, A. ZEROUAL presented a newer method based on Takagi-Sugeno (TS) fuzzy system. TS models defined by If-Then rules and it is a non-linear technic. They compared the model on high order statistics and different procedure and found the fuzzy model provides better results.

IV. CHALLENGES BEFORE MODELING OF SOLAR RADIATION

There are various issues which are faced during modeling of solar energy. Some of them are briefed below:

a) Model Input- maximum of models takes input as sunshine duration, ambient temperatute, maximum and minimum day time temperature etc. but authors do not considers the probablity of sunshine duration, ambient temperature etc.

b) Architecure of ANN model- calculation of hidden neurons in ANN is too difficult because they works on trial and error approach. Still then ANN is supposed to be best technology of global solar radiation modeling.

c) Prediction Accuracy- accuracy is probably the most imortant thing in modeling. It is proved that the huristic approach is more accurate than any other techniques.

d) Data Availabilty- for proper analysis long term data is required but it is not readily available dueto highcost of measuring devices and difficulties related to measuring sites.

e) Model Simplycity- non linear models are assumed to be more accurate and simple than the linear one. But calculation of linear model coefficient is simpler. MATLAB/ PYTHON provides various fitting tools for models coefficients.

V. MODEL EVALUATION

The solar energy estimation models may generally be evaluated based on various statistical error tests such as:

a) Mean Bias Error (MBE):

a) $MBE = \frac{1}{K}\Sigma\left(G^i_{estimated} - G^i_{me}\right.$ (15)

MBE provides information on long term performance of the model. Negative MBE denotes the average amount of under estimation in the predicted values but positive MBE gives average amount of over estimation in the predicted values.

b) Mean Absolute Percentage Error (MAPE):

a) $MAPE = \frac{100}{K}\Sigma\left|\frac{\left(G^i_{estimated} - G^i_{m}\right.}{G^i_{measure}}\right.$ (16)

MAPE is always positive. It avoids error cancelation. Since this gives absolute value of error so it do not differentiate the models properly.

c) Route Mean Square Error (RMSE):

a) $RMSE = \left(\frac{1}{K}\Sigma\left(G^i_{estimated} - G^i_{measure}\right.\right.$

(17)

This allows comparison of actual deviation term by term between the calculated value and measured value. This is always positive and provides short term performance of the models.

d) Test Stastics (TS):

$$TS = \quad (18)$$

This was proposed by stone (1993). This determines the significance of particular confidence level.

VI. CONCLUSION

In this paper global solar radiation techniques are discussed starting from the empirical modeling to the soft computing techniques such artificial intelligence, soft computing, fuzzy logic etc. Also, challenges before modeling and method of evaluation of models are presented. From deep literature review it has been found that artificial intelligence technique based models gives less errors with best possible results.

REFERENCES

[1] Kapoor K, Pandey KK, Jain AK and Nandan A, "Evolution of Solar Energy in India: A review," Renewable and Sustainable Reviews, 40 (2014) 475-485.

[2] Abedelhak BEN JEMAA, Souad RAFA, Najib ESSOUNBOULI, Abdelaziz HAMZAOUI, Faicel HNAIEN, Farouk YALAOUI, " Estimation of Global Solar Radiation using Three Simple Methods," ELSEVIER, ScienceDirect, Energy Procedia 42 (2013) 406-415.

[3] Tamer Khatib, Azah Mohamed, K Sopain, " A review of Solar Energy modeling techniques," Elsevier, Renewable and Sustainable Energy Reviews 16(2012) 2864-2869.

[4] Fariba Besharat, Ali A. Dehgan, Ahmad R. Faghih, " Empirical models for estimating global solar radiation: A review and case study," ELSEVIER, Renewable and Sustainable Energy Reviwes 21 (2013) 798-821.

[5] Angstrom A., "Solar and Terrestrial radiation," Quartely Journal of Royal Meteorological Society, 1924, 121-125.

[6] Prescott JA, "Evaporation from water surface in relation to solar radiation," Transactions of Royal Society of Australia, 1940, 114-118

[7] Glower J, McGulloch JSG, "The empirical relation between solar radiation and hours of sunshine," Quartely journal of the Royal Meteorological Society, 1958, 84:125.

[8] Rietveld M., "A new method for estimating the regression cpefficients in the formula relating solar radiation to sunshine," Agricultural Meteorology, 1978, 243-52.

[9] Page JK, " The estimation of monthly mean values of daily total short wave radiation on vertical and inclined surfaces from sunshine records for latitudes", Proceeding of UN conference on new sources of energy, 1961, 378-90.

[10] Black JN, "The distribution of solar radiation over earths's surface," Archivfur Meteorologie, 1956, 7:165-1889.

[11] Paltrige GW, Proctor D., "Monthly mean solar radiation statistics for Australia," Solar Energy, 1976: 18(3): 235-43

[12] Badescu V., "Correlation to estimate monthly mean daily global irradiation: application to Romania., Energy 1999: 883-93.

[13] Sabziparvar AA., "A simple formula for estimating global solar radiation in central arid deserts of Iran," Renewable Energy 2008: 33: 1002-10.

[14] Hargreaves GH, Samani ZA, "Estimating potential evaporisation," Journal of Irrigation and Darinage Engineering, 1982, 223-30.

[15] Hunt LA, Kucharb L, "Estimation of solar radiation for crop modeling," Agricurtural and Forest Meteorology, 1998, 292-300.

[16] Mahmood R, Hubbar KG, " Effect of time of temperature observation and estimation of daily solar radiation for USA, Agronomy Journal, 2002, 723-33.

[17] Chen R, Ersi K, Yang J, Lu S, " Validation of five global radiation models with measured daily data in China," Energy conversion and management, 2004, 1759-69.

[18] Garg HP, Garg ST, " Prediction of global solar radiation from bright sunshine hours and other meteorological parameters," Solar-India proceedings on national solar energy convention," New Delhi: Allied Publishers, 1982, 1.004-7.

[19] Ojosu JO, Komolafe LK, "Models for estimating solar radiation availability in south western Nigeria," Nigerian Journal of Solar Energy, 1987, 69-77.

[20] M. Benghanem, A. Mellit, S. N. Alamri, " ANN based modelling and estimation of daily global radiation data: A case study," ELSEVIER, Energy Conversion and Management 50 (2009) 1644-1655.

[21] J. Mubiru, E.J.K.B. Banda, "Estimation of monthly average daily global solar irradiance using artificial neural networks," ELSEVIER, ScienceDirect, Solar Energy 82 (2008) 181-187.

[22] M. Rijwan, Majid Jamil and D. P. Kothari, " Generalized Neural Network Approach for Global Solar Energy Estimation," IEEE Transactions on Sustainable Energy, Vol. 3, NO. 3, July 2012'

[23] Soteris A. Kalogirou, " Artifical neural networks in renewable energy systems applicattions: A Review," PREGAMON, Renewable and Sustainable Energy Reviews, 5 (2001) 373-401.

[24] L. Suganthi, S. Iniyan, Anand A. Samuel, "Applications of fuzzy logic in renewable energy systems- A Review," ELSEVIER, Renewable and Sustainable Energy Reviews, 48 (2015) 585-607.

[25] M. Rijwan, Majid Jamil and D. P. Kothari, " Fuzzy logic based modeling and estimation of global solar energy using meteorological parameters," ELSEVIER, Energy xxx (2014) 1-7.

[26] Saurabh Bhardwaj, Vikrant Sharma, Smriti Srivastava, O. S. Sastry, B. Babdopadhyay, S. S. Chandel, J. R. P. Gupta, " Estimation of solar radiation using a combination of Hidden Markov Model and Generalized Fuzzy model," ELSEVIER, SciVerse ScienceDirect, Solar Energy 93 (2013), 43-54.

[27] R. Iqdour, A. Zeroual, " Prediction of daily global solar radiation using fuzzy systems," International Journal of Sustainable Energy, 26:1, 19-29.