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Assesment of Day to Day Global Solar Radiation in Tropical Region of Tamil Nadu using Anfis Soft - Computing Technique

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Abstract: ***In this study, the assessment of daily global solar radiation for the particular location is investigated. The Approximate Sunshine input based models are developed with Adaptive Neuro-Fuzzy Interface system (ANFIS). The statistical indicator is analyzed for different Fuzzy membership function. The solar radiation data collected for a period of five years from Tamil Nadu Agriculture University. Trichy is hottest city, where the abundant source of solar energy is available in southern region of Tamil Nadu. The global solar radiation is essential parameter for designing and modeling of solar system in a particular site. The estimation of DGSR for a new location where there is no observatory station exists is the important key feature. This estimation result all further validated through real time measurement through pyranometer.***

Index Terms: Keywords—Approximate solar radiation; Adaptive Neuro-Fuzzy Interface system (ANFIS) ; Modeling.

I. INTRODUCTION

Estimation of daily global solar radiation (GSR) is a key parameter in modeling and designing of solar energy system for particular location. The approximation model obtained for monthly global solar radiation [1]. Most of estimation is developed for monthly radiation and analyzed with different number of input parameter. The detailed study of number of hidden layer and transfer function has been evaluated [2]. The appraisal radiation model has developed for six cities and is obtained by using curve fitting method [4]. The particulate matter can be taken as an input parameter which gives the more accurate estimation model for Tehran [5]. A geostatistical interpolation and stochastic simulation based solar irradiance model has performed [6]. The outlier and over fitting difficult has overcome by fuzzy regression function of support vector machine [8]. The coefficient model is analyzed for different radiation and best is evaluated as global solar radiation [10]. The evaluation of monthly average daily GSR has focused in many literatures. Therefore the assessment of global solar radiation for Trichy location has developed and analyzed by Artificial Neural Network.

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II. METHODOLOGY ADOPTED

A. *Resource Assessment*

Resource data's are collected from Tamil Nadu Agricultural University, Madurai and Ministry of New and Renewable Energy (MNRE) and from National Renewable energy Laboratory (NREL). The collection of resource data are temperature, solar radiation and power generation potential. The simulation result is developed by using MATLAB. RRMSE, MPE, MAPE are statistical tools used to evaluate the performance of the irradiance models. The models are especially focused on different latitudes (10.79° N) and (78.70° E) in southern state of Tamil Nadu. Essential of energy in the world increases day by day, especially for developing countries such as India. Renewable energy is a non-polluting to the environment, when compared to other non-renewable resources. The instrument measuring of solar radiation cost is high and cannot be implemented in all location. Therefore prediction of daily global solar radiation is essential aimed at developing countries. Trichy is the hottest city in southern region of Tamil Nadu. And therefore the idea has extended to assess the global solar radiation in Trichy. In this paper, the pyranometer data has used for developing the solar radiation model. The approximate bright sunshine duration has taken as input parameter. The approximate bright sunshine is also known as irradiance values which is greater than 120W/m^2 has considered as radiation for that particular day.

B. *Mathematical Model Development*

The global solar radiation is taken as single input variables. In the present study, the models were developed by correlating the data of $\left(\frac{\overline{H}}{\overline{H}_0}\right)$. $\overline{H}$ Is the global solar radiation on the horizontal surface is about 250 [MJ/ (m^2 day)] and $\overline{H}_0$ is the extraterrestrial radiation is about 120 [MJ/ (m^2 day)]. Kadir Bakirci [2017] has developed regression relation associated with extraterrestrial radiation and sunshine duration [1]

$$\bar{H}_o = \frac{24}{\pi} Hsc\left(1 + 0.033\cos\left(\frac{360}{365}\times n\right)\right)\left(\cos\emptyset\cos\delta\ \sin\omega s + \frac{\pi}{180}\omega s\sin\emptyset\sin\delta\right) \quad (1)$$

Where, H_{sc} is the solar constant with the value of 1367W/m^2, n is the Julian day of the year, $\emptyset$ is the location latitude, and δ and ωs is mathematically defined as:

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$$\delta = 23.45 \sin\left[\frac{360(284+n)}{365}\right] \quad (2)$$

and,

$$\cos\omega s = -\tan\emptyset \tan\delta \quad (3)$$

Presently, regression analysis has carried out between the diffuse fraction and clearness index data. The 2/3rd of the data has taken as training dataset used to develop the models and the remaining 1/3rd of the data is taken as validation dataset.

III. Evaluation Criteria

A. *Mean absolute percentage error*

Mean absolute percentage error is expressed in percentage of the data. It indicates the accuracy of derived model. It may be expressed as:

$$MAPE = \frac{1}{n}\sum_{i=0}^{n}\left|\frac{(H_{i,e}-H_{i,m})}{H_{i,m}}\right| \times 100 \quad (4)$$

Where $H_{i,e}$ is measured Value, $H_{i,m}$ is estimated Value, and n number of observations is taken. If the Mean absolute percentage error is zero, then predicted value is best. Predicted value is closer to observed.

B. Mean error

The mean error is deviation between the calculated and estimated value. It provides the information of long term performance. Mean error is given by:

$$ME = \frac{1}{p}\sum_{i=0}^{p}(H_{i,e} - H_{i,m}) \quad (5)$$

The over-estimation in the predicted value can be evaluated by mean bias. If Mean error value is positive then estimated value is higher than measured value.

C. Root Mean Square Error

Short-term performance can be derived from variation around the measured data to predicted values. The Root Mean Square Error is given by following equation:

$$RMSE = \frac{\sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(H_{i,e}-H_{i,m})^2\right)}}{\frac{1}{n}\sum_{i=1}^{n}(H_{i,m})} \times 100 \quad (6)$$

RRMSE is the Standard deviation between predicted value and actual value.

D. *Mean square error*

$$MSE = \frac{1}{p}\sum_{i=0}^{p}(H_{i,e} - H_{i,m})^2 \quad (7)$$

Where $H_{i,e}$ is measured Value, $H_{i,m}$ is Predicted Value. If the error is zero then estimated and measured error is minimized.

E. *Goodness fit*

$$R^2 = \sum_{i=1}^{n}\frac{(H_{i,e}-H_{i,m})^2}{(H_{i,e}-H_{i,m})^2} \quad (8)$$

R^2 is the correlation evaluated through regression model and sample data variation. If R^2 has the value 1 then the relative correlation between the estimated and measured value is good.

IV. MODEL DESCRIPTION

Sunshine duration data is collected for five years for a selected location. Steps and procedure are shown in Fig.1. The model is analyzed with input parameter and best model is selected for validation based on statistical error.

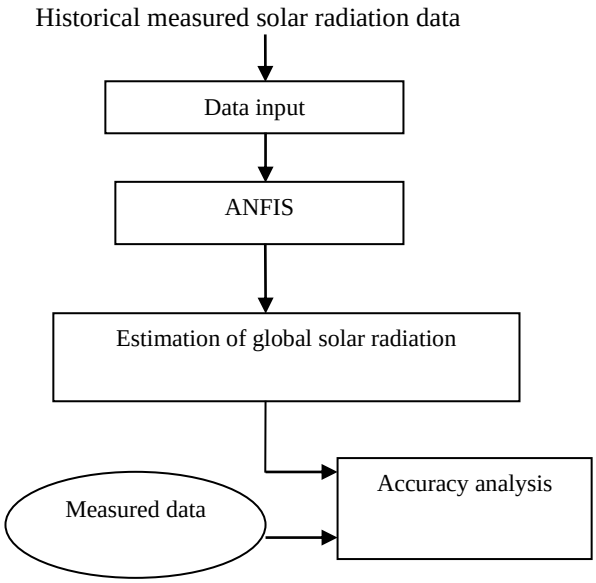

Fig.1. Block diagram for model description

The generation of specify input output pair through constructing a Fuzzy if-then rules along with membership function. The ANFIS is functionally equivalent to FIS and has minimum constraints. It should be feed forward and piecewise differentiable. Multilayered feed forward network has node which performs the particular function on the incoming signal. The nature and choice of the node function depends upon overall input output function. The links just indicate the flow and it does not associated with weights. The following models have used to assess the global solar radiation.

a. Guassmf model

$$\mu Ai(x) = e^{\frac{-(x-c)^2}{(2\sigma)^2}} \quad (9)$$

b. Triangular model

$$\mu Ai = \max\left\{\min\left(\frac{x-a}{b-a}\right), \left(\frac{c-x}{c-b}\right), 0\right\} \quad (10)$$

d. Trapezoidal model

$$\mu Ai = \max\left\{\min\left(\frac{x-a}{b-a}\right), 1, \left(\frac{d-x}{d-c}\right), 0\right\} \quad (11)$$

c. Bell- shaped model

$$\mu Ai(x) = \frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}} \quad (12)$$

e. Sigmoidal mode

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$$\mu Ai(x) = \frac{1}{1+e^{-a(x-c)}} \quad (13)$$

f. Pi mode

$$f(x,a,b,c,d) = \begin{cases} 0 \ , & x \le a \\ 2\left(\frac{x-a}{b-a}\right)^2, & a \le x \le a+\frac{b}{2} \\ 1-2\left(\frac{x-b}{b-a}\right)^2, & \frac{a+b}{2} < x \le b \le x \le c \\ 1-2\left(\frac{x-c}{d-c}\right)^2, & c \le x \le \frac{c+d}{2} \\ 2\left(\frac{x-d}{d-c}\right)^2, & \frac{c+d}{2} \le x \le d \\ 0 \ , & x \ge d \end{cases} \quad (14)$$

V. RESULT AND DISCUSSION

The performances of different function in ANFIS are shown in Table 1. It had been seen that pimf which has the minimized error when compared to the other function in ANFIS.

A. *Training Result*

Pimf, which shows the first best performance (12.4%) and the second best performance are trapmf, Gbellmf and Guassmf (12.5%). And the worst performance is guass2mf, Dsigmf and psigmf (12.6%).

Table 1 Error analyses of different membership function.

FUNCTION	ERROR (%)
Trimf	0.126
Trapmf	0.125
Gbellmf	0.125
Guassmf	0.125
Guass2mf	0.126
Pimf	0.124
Dsigmf	0.126
Psigmf	0.126

The best model is pimf which is used to predict solar radiation by loading the input to the ANFIS. The spline curve can fit the more scattered plot. The rule view of the ANFIS is shown in the Fig.2. The membership function is evaluated at the points and determined by the vector. Where a and d locate the "bottoms" of the curve, while b and c locate its "take up". ANFIS info: The network function consist of number of nodes: 35, Number of linear parameters: 9, Number of nonlinear parameters: 24, Total number of parameters: 33, Number of training data pairs: 250, Number of checking data pairs: 115, Number of fuzzy rules: 9.The starting error of Pimf membership function is 0.1278 and it is minimized while training is 0.121.

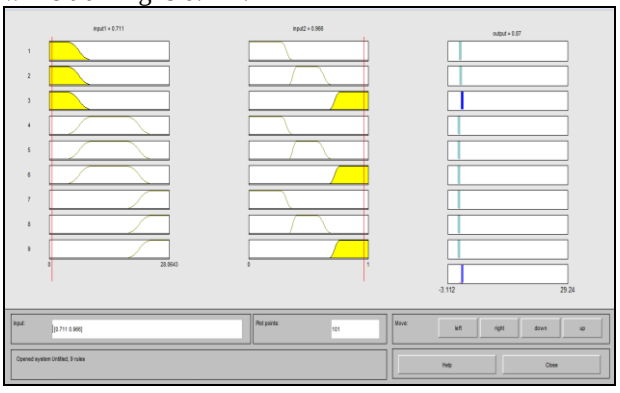

Fig.2 Rule view of ANFIS

The estimated and measured daily global solar radiation is developed by using ANFIS are shown in the Fig.3.
From this figure it can analysis the correlation between the estimated and measured value is good. The accuracy is enhanced in ANFIS and error is minimized.

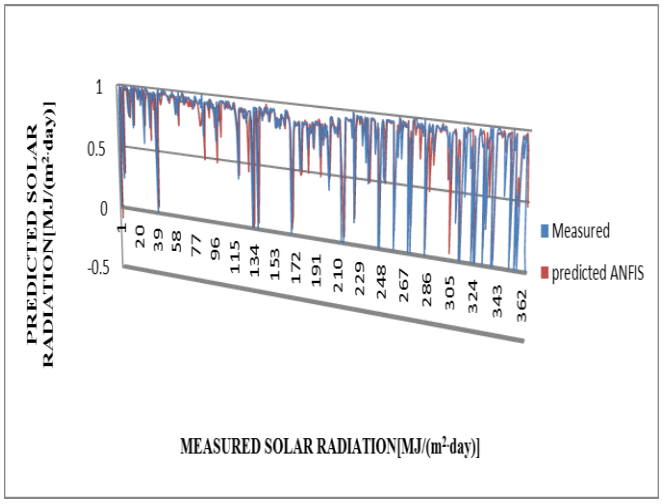

Fig.3 Dialy global solar radiation of estimated and measured in ANFIS

There estimating the daily global solar radiation. Therefore, approximate is the better agreement with the spline based model for the global solar radiation parameter as network input parameter is important in predicting the solar radiation. ANFIS uses the gradient descent search method and least square method.

B. *Validation Result*

Through the statistical indicator such as mean absolute error, mean absolute percentage error, mean square error, root mean square error and adjusted R^2, the performance of the model was evaluated. The performance of model with respect to errors is shown in the table 2. It was analyzed that model has an excellent performance with mean absolute error (0.006 MJ/m^2·day), mean absolute percentage error (0.7%), mean square error (4×10^{-6} MJ^2/m^4·day), root mean square error (0.63 MJ/m^2·day) and adjusted R^2 about 0.81.

Table 2 Performance of model with respect to error analysis

Model & software tool	MAE MJ/(m²·day)	MAPE %	MSE MJ²/(m⁴·day)	RMSE MJ/(m²·day)	R^2	Accuracy
ANFIS	0.006	0.7	4×10^{-6}	0.63	0.81	Good

A form of mathematical model that reflects result in a curve between a two variable such as predicted and measured solar radiation. The accuracy of the predicted value and correlation is enhanced due to the Π model membership function. The regression analyses of predicted and measured are shown in the Fig.4. The curve fits the plot of the measured and predicted solar radiation. It is observed that the correlation between the predicted and observed solar radiation about 0.8096.

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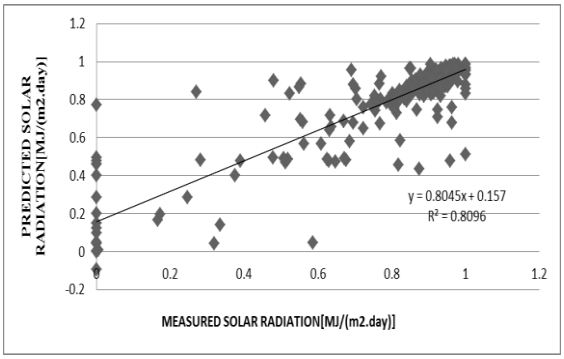

Fig4. Regression analysis of measured and predicted data in ANFIS

If the correlation value is one then the accuracy of the model is good. Hence the accuracy of the model, since the accuracy evaluated between estimated and observed is closer to one.

VI. CONCLUSION

In this work, the estimation of daily global solar radiation for a Trichy location is performed. The statistical error is analyzed for various membership functions with Adaptive Neuro-Fuzzy Interface system (ANFIS). The polynomial based curves (pimf) indicate the minimum error of 0.124%. And further these developed models were also validated for the present location. The accuracy of selected best model is obtained as $\mathbf{R^2}$=0.81.

This paper may also further extend to estimate the daily global solar radiation for different location of south India. And to improve accuracy of correlation coefficient, it must essential to focus on selection of most appropiate input parameters.

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