Prediction of Global Horizontal Radiation in Vellore using Clearness Index Model

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Abstract—**This work aims at analysing the ground measurement of global horizontal radiation for the city of Vellore, India. This will help in forecasting the value of horizontal radiation, which will be necessary for effective design of the solar systems for thermal and photo-voltaic applications. For this purpose, a mathematical model has been developed using latitude of the location and the relative humidity at that location, as the input parameters. The meteorological data for the period 2000-2014 are collected. Using the measured values of global horizontal radiation and extra-terrestrial horizontal radiation for a given day, the theoretical clearness index, K (without the influence of atmospheric parameters), is determined. Using the theoretical values of K, a model is developed to calculate the horizontal global radiation for any given month. The model is also validated by calculating the theoretical global insolation in Vellore city, for one year and the error was found to be lie within 10%.**

Keyword- Clearness index, Meteorological parameters, Global Horizontal Radiation, Error, Vellore

I. INTRODUCTION

Due to the ongoing exploitation of the fossil fuels, one needs to start relying on renewable energy as an alternative to conventional sources of energy. The immense potential of the Sun, makes solar energy, the most important and widely available form of renewable energy. In order to design any photo-voltaic (PV) system, an accurate method to predict the global horizontal radiation at ground level, for any given location and day is needed. Due to change seasonal changes in the Sun's position, the values of these horizontal radiation, vary from time to time. Also, as the solar energy passes through the earth's surface, they get attenuated, due to the effects of the atmosphere.

Thus, the energy received at ground level, is much lesser than what strikes the atmosphere. This difference is accounted for by the Clearness Index (K), which is the ratio of global horizontal radiation to extra-terrestrial radiation. Accurate prediction of the value of K, will result in approximate values of the global horizontal radiation, which reflects the influence of the atmospheric paramters like relative humidity, temperature, pressure etc. Various methods have been developed for this purpose, some which use meteorological parameters, and some that are completely statistical.

Ravinder Kumar and L.Umanand (2005), have developed a theoretical model to calculate the global insolation on a horizontal surface , using the values of latitude and the total precipitable water content of the location. The error obtained by this method was found to be an appreciable value of 20%. Similarly, V. Sivamadhavi and R. Samuel Selvaraj (2012), developed regression equations using daylength to estimate monthly average values of global horizontal radiation, in Chennai. This model is applicable for tropical regions with a coastal climatic condition. Asif Ali Abbasi and M. Shahid Qureshi (2014), also adopted refression technique and used the measured values of the bright sunshine hours to estimate monthly average global and diffuse solar radiation, and calculated the regression coefficients a and b for the first order Angstrom correlation. The results obtained through four empirical models i.e., Angstrom, Liu and Jordon, Page, Hawas and Muneer were compared with values obtained from NASA Satellite-based Global and Diffuse radiation data. In another study, Mehmet Bilgili and Muammer Ozgoren (2011), developed five new equations based on meteorological data and date of the year, using multi-linear regression (MLR), multi- non linear regression (MNLR) and feed forward artificial neural network (ANN) methods to predict the daily total global solar radiation in Adana, Turkey. J. Almorox and C. Hontoria (2004), employed a variety of equations to determine the global solar radiation, using sunshine hours for 16 meteorological stations in Spain. The equations included were the Angstrom-Prescott linear regression and modified functions such as, quadratic, third degree, logarithmic and exponential functions. Zhengfang Wu et. al (2012), also used the Angstrom-Prescott model to determine the global horizontal solar radiation during the growing season in the Northeastern parts of China. Earlier, Anton Driesse and Didier Thevenard (2002), investigated a new relationship between the sunshine hours and the solar radiation on the surface of the earth, derived by Suehrcke. Following a different approach, J. Mubiru et al. (2007), assessed the performance of thirteen global solar radiation emperical relationships, in Kampala, Uganda, located in the equitorial region of Africa, using the method of ranking. For this purpose, the mean bias error, root mean square error and t-statistic values were calculated and evaluated. M.D Islam et. al (2004), measured and analysed the global solar radiation and surface temperatures for an entire year and calculated the clearness index, which matched the NASA model.

On having studied the above mentioned literature, the present work aims at developing a model that is capable of predicting the global horizontal solar radiation at any given day, using only two dominant parameters- the latitude of the location and the precipitable water vapour content at the location. The latitude is available using a geographical map. The precipitable water is calculated using daily values of relative humidity. Therefore, a model based only these parameters enables for quick and easy calculations.

II. METHODOLOGY

Our study area includes the city of Vellore, which is a city in Tamil Nadu, located between 12.15° and 13.15° Northern Latitude and between 78.2° and 79.5° Eastern Longitude. It covers a geographical area of 5920 sq.km. Vellore experiences low rainfall (996.7 mm annual rainfall) and has a semi-arid climate throughout the year. It lies in the Eastern Ghats region, on the banks of the Palar river. Its topography is almost plain with slopes from East to West. The hottest months are during April – June, whereas the coldest months are during December – January. During summers, the humidity ranges from 40-63% , whereas during winters, it ranges between 67-86%. Temperature in Vellore, ranges from a maximum of 40.5°C to a minimum of 18.4°C.

The modelling process developed by Ravinder Kumar and L.Umanand (2005) was used in this study. The values of daily global solar radiation are obtained for the city of Vellore for a period of 15 years (2000-2014). From these values, the yearly averages are calculated, for each month. This data, along with the value of extra-terrestrial horizontal insolation, are used to determine the value of clearness index (Kt). The extra- terrestrial horizontal radiation per day at a given place is determined by:

$$Ho = \left(\frac{24Io}{\pi}\right)[\cos(\varphi).\cos\delta.\sin\omega sr+\omega sr.\sin(\varphi).\sin\delta]$$

where,

Ho = Extra-terrestrial horizontal insolation in kWh/m^2

Io = Extra-terrestrial irradiance in kW/m^2, which is given by:

$$Io = Isc\ [1+0.033\cos\left(\frac{360N}{365}\right)]$$

Isc = solar constant = 1.367 kW/m^2

N = day number

Φ = latitude of the location, degrees

δ = declination angle, degrees; and is given by:

$$\delta = 23.45\sin[\frac{2\pi(N-80)}{365}]$$

ωsr = sunrise hour angle, radians; which is given by:

$$\omega sr = \cos\text{-}1(-\tan\varphi.\tan\delta)$$

Using the above formulae, the value of clearness index Kt can be determined by:

$$Kt = \frac{Hg}{Ho}$$

This value of Kt, obtained using the available data, neglects the influence of the atmosphere in the measurement of the global solar radiation.

Therefore, in order to include the effects of the atmosphere, the development of a clearness index model is required. For this purpose, the Fourier series is taken to be an appropriate curve fitting method. The clearness index thus calculated will take into account the effects of the atmosphere. Using this value and the value of the extra-terrestrial horizontal solar radiation, we can determine the actual value of the global horizontal radiation, using the formula:

$$Hgc = Kt.Ho$$

where, Hgc is the global horizontal solar radiation at any given day.

III. RESULTS

This study uses NASA satellite data obtained from the software RETScreen Plus. The following results were obtained.

A. Yearly variation of global horizontal radiation

Due to the seasonal variations and the effect of meteorological parameters such as rainfall, wind speed, clouds, humidity, there is a variation in the values of the global horizontal radiation that are measured throughout the year as shown in Fig.1.

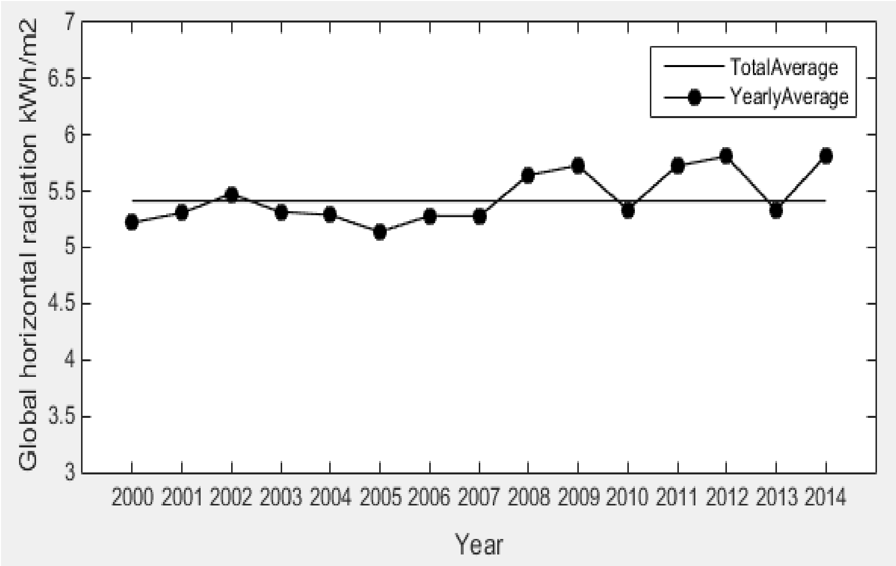

Fig. 1. Yearly variation of global horizontal radiation

In Vellore, the average value measured during the period 2000-2014, is 5.4133 kWh/m^2. The lowest value of the global horizontal radiation occurs during the year 2005 with a value of 5.1404 kWh/m^2, and the highest during 2012, with a value of 5.8075 kWh/m^2. The ranges of values lie within 1 to 7% from the average.

B. Comparison of monthly averages

In the plot below shown in Fig. 2, we compared the values of clearness index Kt, obtained using NASA data, and the value of Kt that has been obtained using the clearness index model defined above.

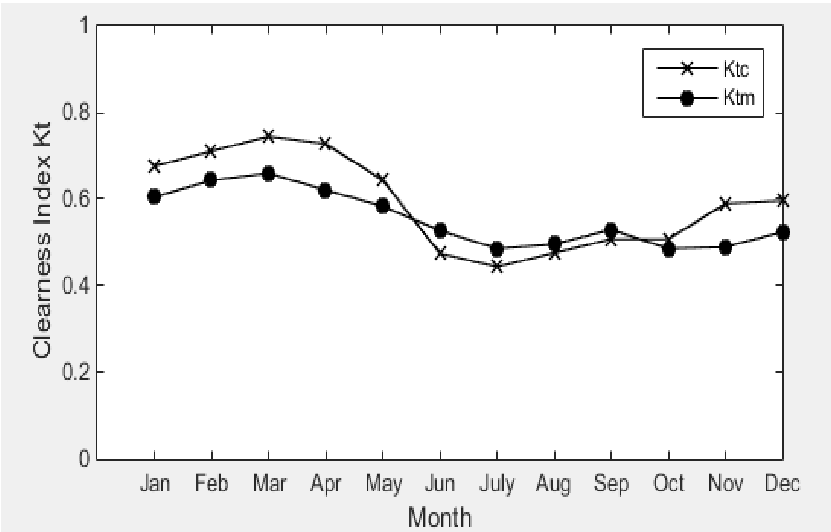

Fig 2: Comparison of the values of Clearness Index

We observe that the values of Kt obtained from NASA data range from 0.48 – 0.66, whereas the values obtained from the model range from 0.44 – 0.74.

On comparing the measured and the calculated values of the global horizontal radiation (Fig. 3), we find that the values for the measured global radiations vary from 4.6 – 6.67, whereas the values calculated from the model vary from 4.81 – 7.69. The maximum value is found to occur in April, whereas the minimum occurs in November.

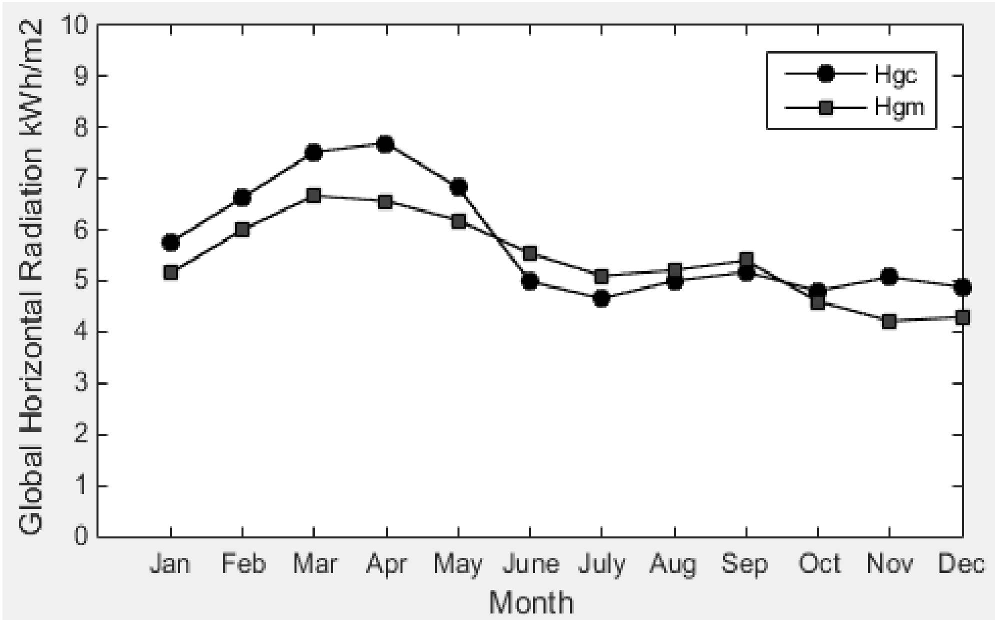

Fig 3: Comparison between measured and calculated values of global horizontal radiation

From this it was observed that there is variation between the measured and the calculated values. This variation is plotted in the graph below (Fig. 4).

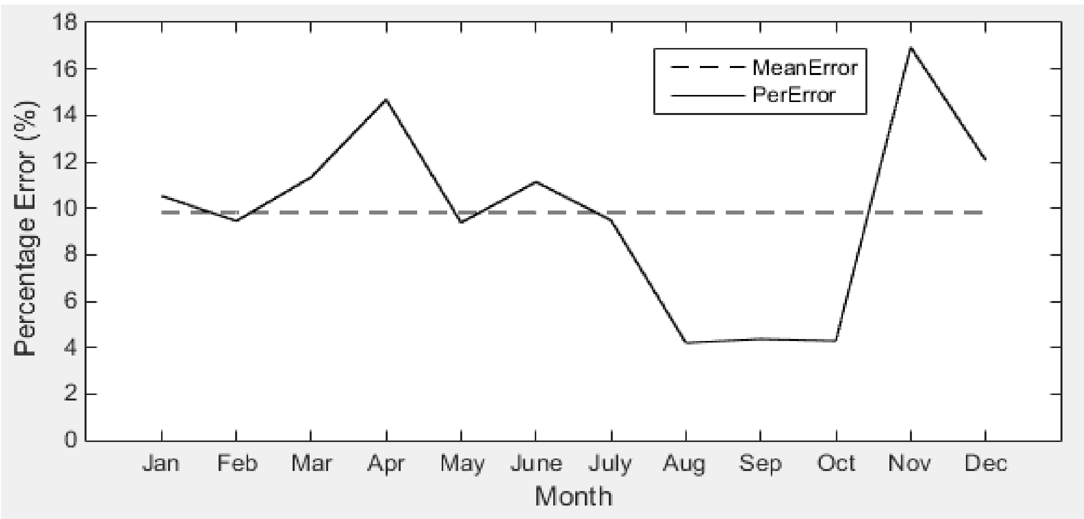

Fig 4: Variation in the values of error obtained

The graph shows the variation in the error percentage over the years, for each month. The maximum error is found to occur in November (16.94%), while the error is a minimum in August (4.19%). The mean error is found to be 9.82%.

IV. Conclusion

The yearly radiation values are fairly a constant around 5.41 kWh/m^2. The variations in the monthly average values are due to the prevailing atmospheric conditions such as the presence of moisture, particulate matter, as well as due to the seasonal changes over the years.

The clearness index values obtained from the model help us in accurately predicting the values of global horizontal solar radiation on any given day, in Vellore. Hence, forecasting of solar radiation can be done with a minimal error of 9.82%. The accuracy can further be increased by considering the exact values of the Fourier coefficients, instead of approximating, which contributes to truncation error.

For further study, the effects of scattering can be incorporated in order to obtain a model, to predict values of diffused solar radiation.

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