DETERMINING THE SOLAR RADIATION IN AYER KEROH, MELAKA BY USING HARGREAVES METHOD

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ABSTRACT

This analysis is conducted to determine the ability of Hargreaves method that uses temperature difference and the latitude of the location to estimate the solar radiation. Location of the data is measured is at the weather station at Kompleks Makmal Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Ayer Keroh (2.2667N,102.2833E). The measured and estimated data solar radiation were analyzed and evaluated by using graphical and statistical method. The analysis shows that there is 61.56% difference between the estimated and measured data and the estimated data is over-estimated. After consideration of other factor that can affect the estimated solar radiation data, the Hargreaves method is considerably suitable for estimating solar radiation of a location.

KEYWORDS*: Concentrating solar power; hargreaves method; solar radiation; solar power tower*

1.0 INTRODUCTION

Solar energy production by Concentrating Solar Power (CSP) technology is one of the fastest growing branches of renewable energy. Steam generator is used by CSP produce electricity after converting collected heat from the solar radiation (Félix, 2014; Paolo et al., 2010; Richter, et al., 2009; Taylor, 2012). However, the potential location for the CSP is restricted to the area that receive abundant amount of direct solar radiation and solar radiation differs according to the season change and location (Affandi, et al., 2013; Rosli, 2010). Solar radiation is also unsteady through the day as it can be reflected, or diffused by atmosphere, cloud, and dust. Thus, it is important to determine the

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direct solar radiation of the targeted location for CSP development radiation, Ra is the amount of solar radiation per unit area received by a surface normal to the rays that come in a straight line from the sun current position direction in the sky. The amount of the Direct Normal Irradiation (DNI) received by a surface can be maximized by keeping the surface normal to the incoming radiation. The DNI value that suitable for CSP power plant is between 1800kWh/m^2/year to 2100kWh/m^2/year (Trieb, Schillings, Sullivan, Pregger, & Hoyer-klick, 2009).

Solar radiation, R_a is the amount of solar radiation per unit area received by a surface normal to the rays that come in a straight line from the sun current position direction in the sky. The amount of the Direct Normal Irradiation (DNI) received by a surface can be maximized by keeping the surface normal to the incoming radiation. The DNI value that suitable for CSP power plant is between 1800kWh/m^2/year to 2100kWh/m^2/year (Trieb, et al., 2009).

By using available weather station data, solar radiation can be estimated by using Hargreaves method. Hargreaves method uses daily temperature difference and latitude of the location to estimate solar radiation. This study will investigate the ability of Hargreaves method in estimating daily solar radiation.

Hargreaves method introduced by Hargreaves and Samani in 1982. This method determines the daily solar radiation by using daily maximum and minimum temperature as input data as shown in equation 1. Hargreaves (1994) has recommended that the empirical coefficient, a value for interior regions is $a = 0.162$ and for coastal regions is a = 0.19 (Castellví, 2008; Samani, 2000). The Hargreaves method has been widely used for solar radiation estimation especially for research on potential location for solar power harvesting (Daut, et al., 2011; Quaschning, 2003; Solanki & Sangani, 2008; Syafawati et al., 2012).

$$\mathbf{R_a} = a\, H_o (T_{max} - T_{min})^{0.5} \tag{1}$$

2.0 METHOD OF SOLAR RADIATION, R_a MEASUREMENT

Ayer Keroh, Melaka climate which is located at 2.2667°N, 102.2833°E, a bit away from equator line is highly depending on the monsoon seasons that highly affected by the wind direction change according to the season. The tropic weather sky is usually covered with clouds and thus causes temperature fall and diffuse the sun radiation. In this study, Pyranometer has been installed with weather station at Kompleks Makmal Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Ayer Keroh as in Figure 1. The station is set to record the solar radiation, temperature, wind speed, wind direction, and humidity at every second. By using recorded temperature, the daily solar radiation estimated by using Hargreaves method is compared with the solar radiation recorded by Pyranometer (Daut et al., 2011; Feuermann & Zemel, 1993; Syafawati et al., 2012).

Figure 1. Weather station at Kompleks Makmal FKM UTeM

2.1 Daily solar radiation estimation by using Hargreaves method

2.1.1 Daily Extraterrestrial radiation

Daily extra-terrestrial radiation, Ho of a location is computed by using the following formula:

$$H_o = \left(\frac{1440}{\pi}\right) G_{SC} d_r [\cos\emptyset \cos\delta \cos w_S + w_S \sin\emptyset \sin\delta] \quad (2)$$

Where

G_{SC} the solar constant =1367 W/m^2

d_r inverse relative distance Earth-sun

w_S sunset hour angle

δ solar declination angle

$\emptyset$ latitude of the location (rad)

$$d_r = 1 + 0.033\cos(2\pi n/365) \quad (3)$$

$$w_S = \cos^{-1}(-\tan \emptyset \tan \delta) \qquad (4)$$

Declination angle δ is the angle between line drawn from the center of the earth to the center of the sun and the equator plane. Thus, it varies due to the rotation of the earth around the sun and the tilt of the earth on its axis.

$$\delta = 23.45 \sin[2\pi\,(284 + n)/365] \qquad (5)$$

2.2 Model evaluation

The estimated solar radiation data is evaluated by using graphical and statistical method. The estimated and measured solar radiation data is plotted against day number for the graphical analysis. For statistical analysis, the estimated and measured data is compared for perfect fit test. The coefficient of residual mass (CRM), root mean squared error (RMSE), coefficient of determination (r^2), and percentage error (EF) is the mathematical model to describe the comparison (Hagi-Bishow & Bonnell, 2000; Loague & Green, 1991).

The CRM is used to indicate the tendency of the measured data to over-estimate (CRM<0) or under-estimate (CRM>0) the measured data. The value of CRM must be zero for perfect fit estimation. The calculation of CRM shows in equation 6.

$$CRM = \frac{\sum_{i=1}^{n} R_{mea,i} - \sum_{i=1}^{n} R_{est,i}}{\sum_{i=1}^{n} \bar{R}_{mea,i}} \qquad (6)$$

Where $R_{mea,i}$ is the measured solar radiation value at *i* day, $R_{est,i}$ is the estimated solar radiation value at *i* day, R_{mea} is the mean average of the measured solar radiation value and n is the day number of year.

The RMSE is the value that expresses the percentage of how much the estimation data is under-estimated or over-estimated than the measured data. This value can be calculated by using equation 7.

$$RMSE = \frac{\sum_{i=1}^{n} R_{est,i} - \sum_{i=1}^{n} R_{mea,i}}{\sum_{i=1}^{n} \bar{R}_{mea,i}} \qquad (7)$$

The r^2 or also known as Nash-Sutcliffe equation (NSE) is used demonstrate the ratio between the estimated value and the average of the measured value. The method used is more efficient if the r^2 value is closer to 1 (estimated data perfectly match with measured data) while less efficient if closer to zero. The calculation is given by equation 9.

$$r^2 = 1 - \frac{\sum_{i=1}^{n}\left(R_{mea,i} - R_{est,i}\right)^2}{\sum_{i=1}^{n}\left(R_{mea,i} - \bar{R}_{mea,i}\right)^2} \quad (8)$$

The percentage error is used to compare the estimated value and the measured value. Error between -10% and 10% is considered acceptable. If the value of the EF is negative, the measured mean is better predictor than the estimated value. Equation 9 is used to calculate the EF value.

$$EF(\%) = \frac{R_{mea,i} - R_{est,i}}{R_{mea,i}} \quad (9)$$

2.0 ANALYSIS AND DISCUSSION

The data for this analysis was recorded from March 2012 to October 2012. The solar radiation change corresponding with the temperature at the solar noon (12pm-3pm) can be seen from the Figure 2. Solar noon occur at maximum elevation angle which is the highest point of the solar arc. Thus, the solar radiation value is also the highest during that time.

The graph shows that the solar radiation is proportional to the temperature as the R_a value is increase with increasing temperature. This shows that temperature can be used for solar radiation estimation. The graph shows that most of the measured solar radiation value is above 400W/m^2.The measured solar radiation value fluctuates might be due to the unpredictable presence of cloud that can obstruct the estimation of solar radiation value by the Pyranometer or the weather changes.

The daily measured data is analyzed and plotted into graph of the measured and estimated solar radiation values versus day number. Figure 3 shows the estimated and measured solar radiation value for different day number. The daily average estimated solar radiation is 180.055W/m^2 while the average measured solar radiation is 209.00W/m^2. The highest estimated solar radiation was 258.83W/m^2 estimated on 8 April 2012. The highest measured solar radiation was 256.52W/m^2 measured on 11 May 2012.

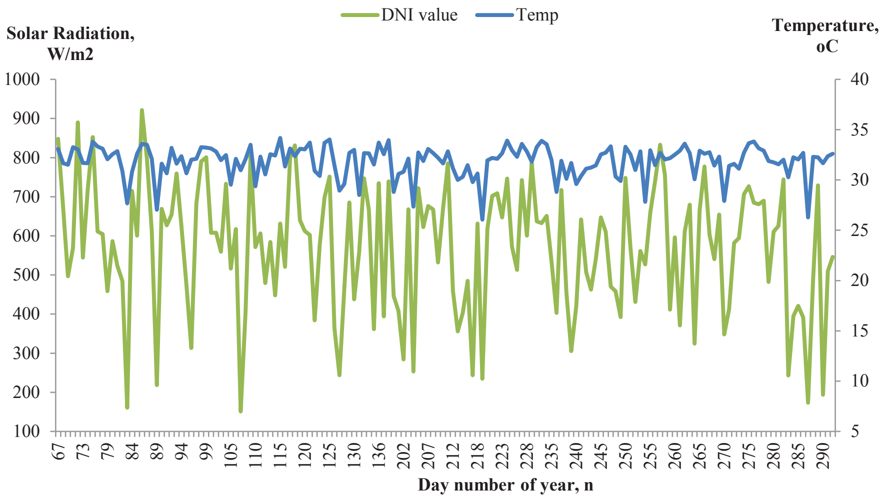

Figure 2. Relationship between Temperature and DNI value

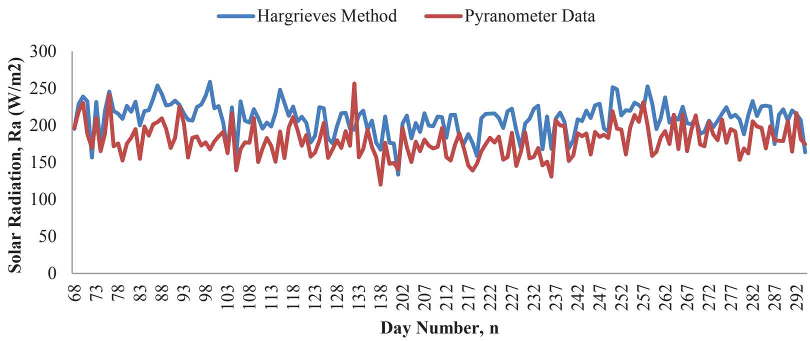

Figure 3. Solar Radiation data for Hargreaves Method and Pyranometer Apparatus

The solar radiation value estimated by using Hargreaves method is compared with the daily solar radiation data measured by using Pyranometer. This comparison is expressed by the value of CRM, RMSE, r^2, and EF in Table 1. The determined CRM value is -0.3664 which indicate that the Hargreaves method data is over-estimated the measured solar radiation. This is maybe due to the seasonal climate changes of the location and technical problem occurred to the apparatus. The value of RMSE is 61.56% indicates that there are large difference between the estimated data and the measured data. The determined r^2 value of this analysis is -0.71. Efficiency close to 1 indicates the perfect match between the estimated data to the measured data. The EF of the analysis is small, -14.77% which shows that the measured data is better predictor than the evaluated data.

Table 1. Validation of daily measured and estimated solar radiation data

Validation	CRM	RMSE	r^2	EF
	-0.3664	61.56%	-0.71	-14.77%

The data validation proves that the estimated solar radiation value is higher than the measured solar radiation. This is might be affected by the presence of the cloud where it is usually only temporary but the accumulated temperature only slightly or did not change causes only slight temperature deflection. In contrast, slight obstructions (cloud) occur between Pyranometer affect the solar radiation reading. For this problem, cloudiness index method can be used for more accurate solar radiation estimation.

3.0 CONCLUSION

The estimation of solar radiation for targeted location for CSP technology development is essential. The Hargreaves method analysis shows that the Hargreaves model can be used to estimate the solar radiation of a location. The comparison of the estimated data from the measured data is validated by using CRM, RMSE, r2, and EF. The validation analysis proved that the solar radiation data can be measured by using daily temperature difference of the location. For a more accurate estimation, other factor such as the cloudiness index which represents the presence of cloud of the area can be taken into account for solar radiation estimation.

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