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Comparison Model Hargreaves, Annandale and New Model for Estimation of Solar Radiation in Perlis, Malaysia

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Abstract

Sunlight is a potential source of electrical energy in the universe. Utilization of solar radiation is not optimal to be a source of electricity generation. Before harnessed solar radiation in order to know in advance the estimated potential energy. Modelling estimates of solar radiation in three models: models Hargreaves, Annandale and the proposed new model. The new model proposed solar radiation estimates based on models Hargreaves and Annandale. Some models for estimating solar radiation are discussed in this paper which aims to determine the potential of solar radiation into electrical energy potential. A new model is proposed to estimate solar radiation. Comparison of the three models are estimated using statistical analysis e (%), CRM, and RMSE is obtained that the proposed new model is better, when compared to other models.

Keywords: *Solar radiation, New models estimation, Statistical analysis, Potential electrical energy*

1. Introduction

The solar radiation contains a wide spectrum of frequency range from infrared to ultra-violet radiation [1]. Solar constant (*SC*) is the amount of solar energy perpendicular to the beam outside the Earth's atmosphere, which is about 1,367 W/m^2 [1, 2]. The global radiation of about 1,000 W/m^2 occurs when the sky is bright with direct sunlight in a perpendicular line of PV modules [1].

Although the maximum global radiation of the earth's surface is 1,000 W/m^2, the available radiation is usually much lower than the stated maximum value. The lower available radiation is caused by factors such as the rotation of the earth and climatic conditions (clouds), as well as the composition of the atmosphere. With a solar radiation of 1,000 W/m^2, the length of the time required to generate the energy equivalence of the total energy in one day is called the peak sun hours (PSHs) [3].

Predicting the hours of terrestrial radiation via direct beam, diffuse and global solar radiation is modeled and calculated based on the data measured daily for horizontal surfaces and tilted surfaces. Surface tilted towards the East and the West have the same tendency and the trend is almost the same for the other tilt angles. For surfaces sloping to the south, in the period between October to March, effect of the angle to the solar radiation received is relatively small, but the tilting angle has more significant effect between April and September. For surfaces tilted toward the North, solar radiation received is sensitive to the tilting angle whole year. During summer the West-East vertical surfaces receives higher solar radiation than North-South [4].

For a fixed tilt angle, the position of the PV modules must be evaluated at different places and time periods to obtain the maximum output of electric energy. PV performance is strongly influenced by the orientations and tilt angles as the orientation and tilt angles can affect the amount of solar radiation received by the PV module [5].

Electric power generated by PV systems is directly related to the solar energy received by the PV modules. PV modules can be placed in any orientations and tilt angles, but most local

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observatories only provides the data of solar radiation received on a horizontal surface. Thus, the estimation of solar radiation on a tilted surface is calculated by adding the light, deployment, and reflection components of the solar radiation on tilted surfaces [6].

To predict plant output and efficiency of the PV modules, the area for installing PV modules needs to be estimated. Conservative value is taken as 13% off the single crystal silicon modules, although higher efficiency modules are available [7]. PV module consists of multiple solar cells connected in series and parallel to obtain the specified voltage and current.

The influence of temperature on PV panel parameters through simulation and experimental outdoors, that the temperature at the PV panel affect on output power, as well as affect the quality and voltage generated by the PV panel [8].

Prediction of the effects of temperature and solar radiation on PV panel can be done with the least square support vector machine (LSSVM), and the results obtained that LSSVM simulation model can predict accurately the value of solar radiation [9].

The combination of lead acid battery system with typical hybrid wind-PV energy system to supply the electrical load from the desalination system in Mersa Matrouh. The simulation model with MATLAB / Simulink for hybrid power system with control strategy using Neural Network Control (NNC) and simulation end result shows effective battery operation [10].

The simulation study conducted on microgrid system to examine the combined impact of energy combination of individual and varying variables (solar / wind). Solar PV / wind hybrid generation provide voltage regulation more effective to microgrid system compared with each PV / wind turbines working alone. Coordination of hybrid PV / wind energy systems with energy storage, intelligent microgrid features, tends to bring the voltage back into legal limits and can improve the quality of the voltage profile and adjust the active power to the DS [11].

Estimation of solar radiation will be tested statistically to verify the accuracy of the predicted values against the measured values. The estimated value of daily solar radiation (R_{Sest}) is compared with the measured value (R_{Smea}). To determine the accuracy of the estimated daily solar radiation, three performance indicators are used, i.e. *CRM*, *RMSE* and e% a representation of the arithmetic mean solar radiation is measured [12-18].

Statistical models were used to test the proposed estimation using the percentage of error *e(*%), *RMSE* and *CRM.* The value of *e(*%) can be accepted if they are within the range of ±10%. *RMSE* would be optimum, if the value is <1, and *CRM* will be optimum, if it the value approache zero.

Solar radiation can be estimated by using several methods, such as Hargreaves and Annandale models. Solar radiation estimation aims to determine the potential of sunlight to used for electricity generation. In this research, the proposed model estimates the solar radiation by using a combination of Hargreaves and Annandale models.

The estimated global solar radiation to the sun can be written as [19]:

$$\frac{H_g}{H_c} = a + b\left(\frac{S}{S_{\max}}\right) \tag{1}$$

where:

H_g is monthly average of the daily global radiation on a horizontal surface at a location in (KJ/m^2-day).

H_c is monthly average of the daily global radiation on a horizontal surface at the same location on clear day (KJ/m^2-day).

S is monthly average of the sunshine hours per day at the location (h).

S_{max} is monthly average of the maximum possible sunshine hours per day at a location, that is the day length on a horizontal suface (h).

a are value of 0.16 to 0.19.

b are constants obtained by fitting data.

2. Research Method
2.1. Hargreaves Model
Estimation of solar radiation (R_S) was first proposed by Hargreaves and Samani by using data from the difference in the maximum and minimum air temperature [13], [17], [20]. The proposed equation for estimating the solar radiation is:

$$R_S = a.R_a (T_{\max} - T_{\min})^{0.5} \tag{2}$$

where:
R_S is solar radiation (MJ/m^2.day).
T_{max} and T_{min} are mean daily maximum and minimum air temperature (^{0}C).
R_a is extraterrestrial radiation (MJ.m^{-2}.d^{-1}) which is a function latitute and day of year.
a is an empirical coefficient, the value of a to be 0.16 for interior regions and 0.19 for coastal regions.
The amount of R_a is expressed by [21].

$$R_a = ((24)(60)/\pi)(G_{sc})(d_r)(\cos\phi\cos\delta\sin\omega_s + \omega_s \sin\phi\sin\delta) \tag{3}$$

where:
G_{sc} is the solar constant (1367 W/m^2 or 0.082 MJ.m^{-2})
d_r is the eccentricity correction factor of the earth's orbit, and can be calculated by the expression:

$$G_{sc} = 1.0 + 0.033\cos\left(2.\pi\left(\frac{JulianDay}{365}\right)\right) \tag{4}$$

ϕ is latitude of the site, can be calculated by the expression:

$$\phi = latitude\frac{\pi}{180} \tag{5}$$

δ is solar declination, can be calculated by the expression :

$$\delta = \left(\frac{23.45.\pi}{180}\right).\sin\left(2.\pi\left(\frac{284 + JulianDay}{365}\right)\right) \tag{6}$$

ω_s is mean sunrise hour angle, can be calculated by the expression:

$$\omega_s = \cos^{-1}(-\tan\phi.\tan\delta) \tag{7}$$

The value of R_a depends on Julian day, and the value of R_s is proportional to the difference between the maximum and minimum air temperature $(T_d = T_{\max} - T_{\min})$. If the value of T_d increases, the value of R_s will increase as well.

2.2. Annandale Model
Solar radiation estimated by the model of Annandale [22] is a modification of Hargreaves and Samani model, which was corrected for altitude. Annandale model can be written as follows:

$$R_S = R_a.A_{\mathrm{mod}}(1 + 2.7x10^{-5}.Z)(T_{\max} - T_{\min}))^{0.5} \tag{8}$$

where ;
R_a is the extraterrestrial radiation (MJ/m^{2}day)
A_{mod} is the coefficient of the model used (A_{mod} is 0.263).

Z is average altitude above sea level (Z is 12 m)
T_{max}, T_{min} are the maximum and minimum temperature respectively (^{0}C).
R_s in the form of linear equation can be written as follows:

$$R_S = d.R_a(T_{\max} - T_{\min})^{0.5} \tag{9}$$

where:

d is a constant, which can be expressed as: $A_{\mathrm{mod}}(1 + 2.7x10^{-5}.Z)$

2.3. Proposed Model

Solar radiation from the sun reaches the earth has a range of wavelengths from 300 nm to 4 microns [23]. The total solar radiation on a horizontal surface PV modules can be measured in the units of Wh/m^2 or J/m^2. To convert the unit from W/m2 to J/m^2, the values in W/m^2 is multiplied by 3600 [2].

The proposed model estimates solar radiation by using a combination of Hargreaves and Annandale models. The advantages of using Hargreaves and Annandale are because these models only require the minimum and maximum measurement data from the sunlight, thus easier to estimate. The combination of Hargeaves and Annandale models aims to get a new model for estimating solar radiation. The proposed model is expressed by:

$$R_s = R_a(T_{\max} - T_{\min})^{0.5}\left(a + A_{\mathrm{mod}}\left(1 + 2.7.10^{-5}.Z\right) + b\right)(0.09) \tag{10}$$

where:
a is an empirical coefficient.
b is factor correction of modified model and 0.09 is factor of multifier.
A_{mod} is the coefficient of the model used.
Z average altitude above sea level.

2.4. Statistical Analysis Models

Comparison of the estimated value of daily solar radiation (R_{Sest}) with the measured value (R_{Smea}). To assess the accuracy of the predictions for daily solar radiation estimation, three performance indicators used, ie, coefficient of residual mass (CRM), root mean squared error (RMSE), and the percentage error (e) expressed as a percentage of the arithmetic mean of the measured solar radiation [12-18].

$$CRM = \frac{\sum_{i=1}^{n} R_{Smea,i} - \sum_{i=1}^{n} R_{Sest,i}}{\sum_{i=1}^{n} R_{Smea,i}} \tag{11}$$

Where $R_{Smea,i}$ is the measured daily solar radiation at i day, $R_{Sest,i}$ is the estimated daily solar radiation at i day, $\overline{R_{Smea}}$ is the average measured solar radiation and n is the day number of estimated solar radiation.

CRM showed overall value underneath or above the estimates. Estimates perfect, if the value are set to zero. For a positive value indicates a tendency under-estimate the model estimates the solar radiation is measured, whereas, the negative value indicate a tendency in above the estimate of solar radiation measured.

$$RMSE(\%) = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}(R_{Sest,i} - R_{Smea.i})^2}{n}}}{\overline{R_{Smea}}} x100 \tag{12}$$

The $RMSE$ is expressed as percentage to make it dimensionless, a lower value of it indicates better performance (Equation 12).

$$e(\%) = \frac{R_{Smea,i} - R_{Sest,i}}{R_{Smea,i}} x100 \tag{13}$$

A relative percentage error between -10% and +10% is considered acceptable (e.q 13). The mean percentage error can be defined as the percentage deviation of the estimated and measured monthly average daily solar radiation.

3. Result and Analysis

3.1. Daily and Monthly Solar Radiation

The daily solar radiation patterns of 2011 are shown in Figure 1. Whilst the monthly solar radiation is shown in Figure 2, and the monthly solar radiation data, the minimum solar radiation is 952 Wh/m^2 which occurred in July, the maximum solar radiation is 1105 Wh/m^2 which occurred in March, and the average solar radiation per year is 1000.7 Wh/m^2.

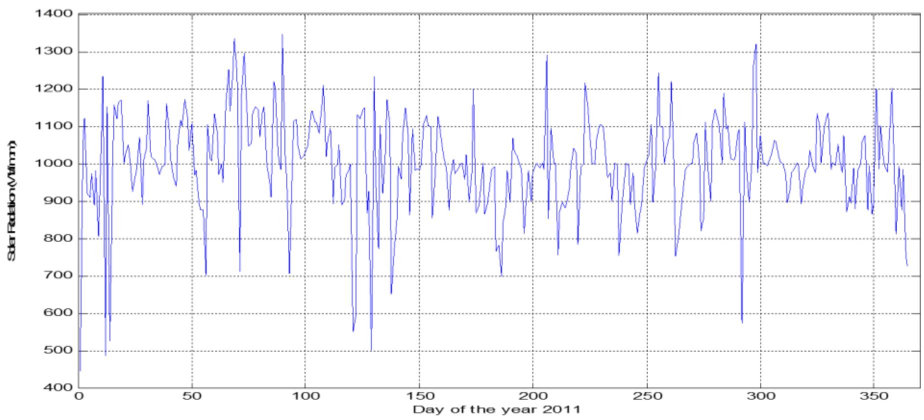

Figure 1. Daily solar radiation throughout the year of 2011

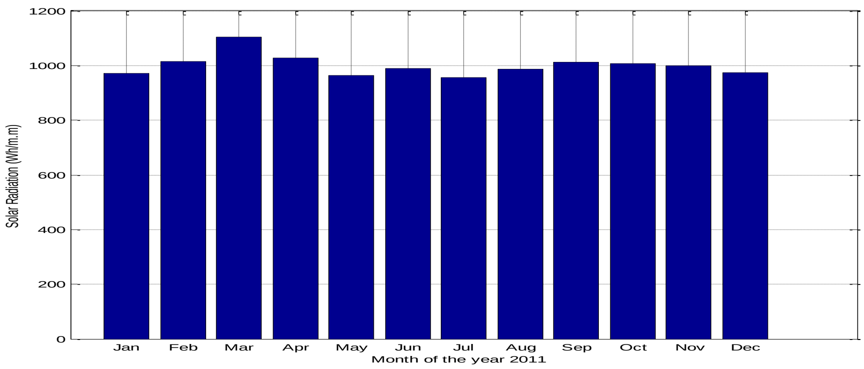

Figure 2. Monthly solar radiation in 2011

For January 2011, a comparison between the minimum, average and maximum solar radiation as shown in Figure 3. The highest value of minimum solar radiation occured on 4 January, 2011 which is 135 Wh/m^2, and the highest value of maximum occured on 11 January 2011 which is 1232 Wh/m^2. Based on the above data outdoor air temperature have minimum, average amd maximum values of 24.80^{0}C, 26.33^{0}C, and 29.10^{0}C respectively. Whilst the humidity have minimum, average and maximum values of 79%, 89.6% and 95%. The values of the outdoor temperature, the highest temperature, lowest temperature and air humidity are shown in Table 1.

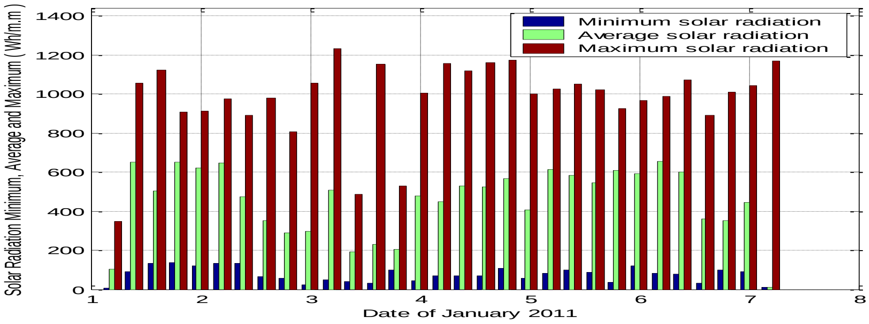

Figure 3. Comparison of solar radiation minimum, average and maximum in January 2011

Table 1. Temperature and humidity in Kangar, Perlis

Value	Temperature Outdoor (^{0}C)	High Temp.(^{0}C)	Low Temp.(^{0}C)	Outdoor Humidity (%)
Avg	26.33	26.37	26.29	89.6
Min	24.80	24.80	24.80	79.0
Max	29.10	29.20	28.90	95.0

Based on the above data, the air temperatures have minimum, average and maximum values of 24.80^{0}C, 26.33^{0}C, and 29.10^{0}C respectively. Whilst the relative humidity have minimum, average and maximum values of 79%, 89.6% and 95% respectively.

The difference between the minimum temperature, maximum and difference for 2011 are shown in Figures 4.

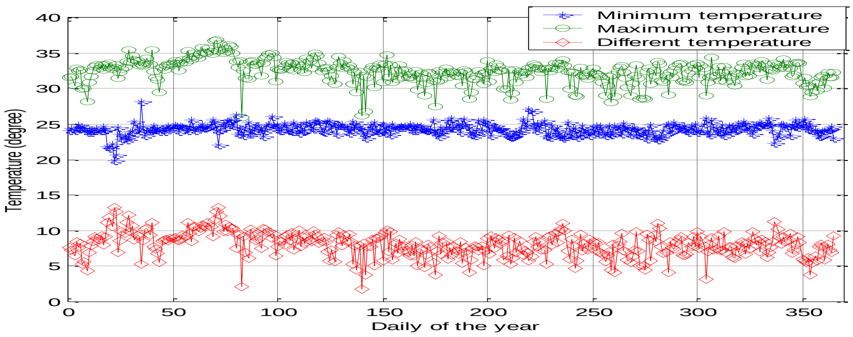

Figure 4. Temperature throughout in Perlis 2011

The solar radiation estimation by using the proposed method is shown in Figure 5. From Figure 5, the minimum, maximum and average solar radiations are 429.25Wh/m$^{2.}$, 1,223.00Wh/m^2 and 919.09Wh/m^2 respectively.

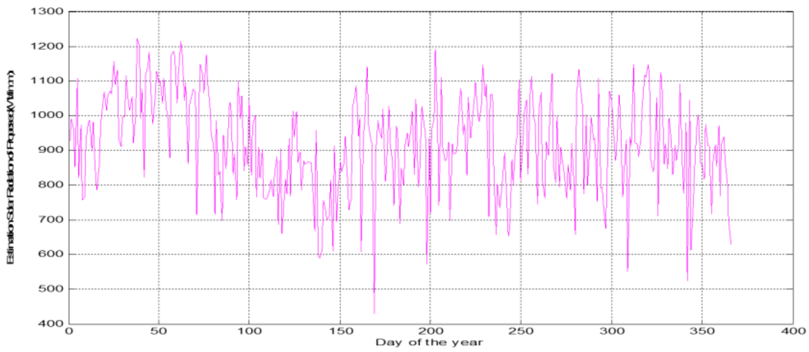

Figure 5. Solar radiation estimation by using the proposed method

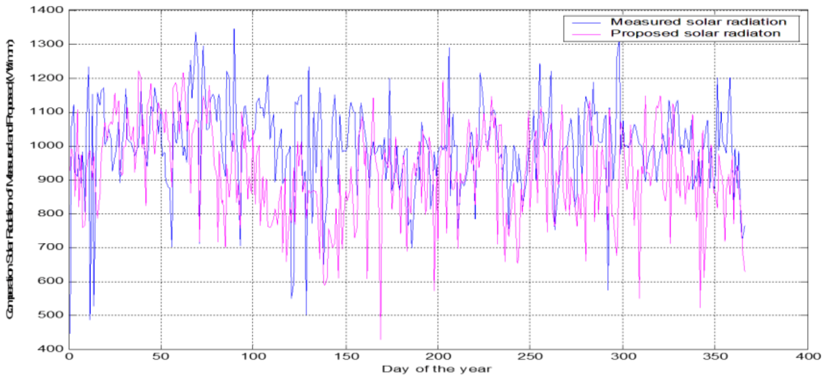

Figure 6. Comparison of the measured solar radiation and proposed

Figure 6 shows comparison of the measured solar radiation and proposed, magenta colour is proposed method and blue colour is measured of solar radiation. The minimum and maximum daily solar radiation are 446 Wh/m^2 which occured in July and 1346 Wh/m^2 which occurred in March, respectively. Whilst the average annual solar radiation is 1000 Wh/m^2.

The comparison between the measured and estimated solar radiation, as well as error comparison between the estimation models are shown at Table 2, shows that the estimated solar radiation using Hargeraves, Annandale and the proposed method. The error rate of the proposed solar radiation is smaller than the other methods (Hargreaves and Annadale method), so the proposed model in estimating the solar radiation are better than of estimation others and acceptable.

Table 2. Comparison of error between the measured solar radiation and estimation

Value	Solar radiation				Percent error (%)		
	Mea	Hars	Ann	Prop	Har (%)	Ann (%)	Prop (%)
Min (Wh/m^2)	446	419.71	411.71	429.25	5.89	7.69	3.75
Max (Wh/m^2)	1,346	1,173.9	1,173	1,223	12.79	12.85	9.14
Avg (Wh/M^2)	1,000	893.45	882.03	919.09	10.65	11.80	8.09

Description: Mea=Measured; Har=Hargreaves; Ann=Annandale; Prop= Proposed.

The results of the statistical model used Hargreaves, Annadale and proposed models are shown in Table 3. Compared to the other models, the proposed model is more acceptable, because the values of *e*(%), *RMSE* and *CRM* from the proposed model are 6.89 %, 8.09 % and 0.08 %, respectively, which have a smaller value than the other models.

Table 3. Statistical models of solar radiation

Models	Solar radiation		
	CRM	RMSE(%)	e(%)
Hargreaves	0.1066	10.6568	9.9823
Annandale	0.1180	11.7988	11.3812
Proposed	0.0809	8.0924	6.8916

4. Conclusion

The results of the statistical model used Hargreaves, Annadale and proposed models (new models) are as, compared to the other models, the proposed model is more acceptable, because the values of *e*(%), *RMSE* and *CRM* from the proposed model are 6.8916%, 8.0924% and 0.0809%, respectively, which new models have a smaller value than the other models.

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