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Article

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Turbidity factor coefficient on the estimation of hourly solar radiation in Depok City, Indonesia

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Abstract

Indonesia is a country located on the equator and is a tropical country that has two climates namely rainy and sunny. Indonesia has a long solar radiation intensity time that started from 8 AM until 16 PM, which the effective time is along 5 h on peak solar time. The calculation of solar radiation intensity is needed to know the efficiency power applicable to solar power technology. This paper will discuss the estimation of hourly solar radiation compared with measured data in the Department of Mechanical Engineering Universitas Indonesia, Depok City, Jawa Barat Province, Indonesia. The estimation of hourly solar radiation is based on Liu and Jordan's empirical models. The comparison of empirical model with measured data in order to know the influence of solar radiation parameters like turbidity factor coefficients and climate conditions used to calculate the solar radiation at the studied site. The turbidity factor coefficient assumed as a normal sky condition with the value is 0.88 and 0.26, respectively for A and B. These values were chosen based on the cloud cover data from the measurement that show there is no cloud cover during the day.

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Keywords: Solar radiation model; Hourly solar radiation; Turbidity factor

1. Introduction

Solar based energy is sustainable power source ordered as free source energy that is practical and absolutely boundless, dissimilar to petroleum products that are which will run out in the end [1–3]. It is likewise a non-dirtying of energy and it does not transmit any ozone-depleting substances when delivering power [4]. The sun's position and the location of studied area will give impact to the potential solar radiation area [5,6]. The potential will change in every seconds depend on atmosphere, position (longitude and latitude), and time (day in a year and time of solar radiation) [7,8]. The value of solar radiation depends on several parameters like the angle of sun, hour angle, topography, the air composition, the morphology area, and the properties of area, wind and sea wave

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[9–11]. Indonesia as studied site has many potential of solar radiation because it is located in the tropical area [12]. Indonesia has several areas with the great solar energy potential from east until west region along the equator. The solar energy potential is considerable and it is estimated in 4.8 kWh/m² in all region [13]. Based on the longitude, it will analyze the solar radiation intensity based on recorded data from measurement set up in Department of Mechanical engineering, Universitas Indonesia, Jawa Barat, Indonesia (106.82 longitude, −6.36 latitude).

The estimation of solar radiation has discussed in several literatures but there very limiting discussing in Indonesia [14–16]. The results of estimation of solar energy will give solar radiation value that can be used for solar technologies. The differences between several literature and this paper are the selected days, the studied site, and the parameters on the studied site. To analyze of solar radiation intensity, start with estimate the solar radiation intensity based on several empirical models, then compared the prediction data with the measurement data from recorded, and evaluate the statically data use Mean Bias Error and Root Mean Square Error. The aim of this study is to know the solar energy power potential in Indonesia and the applicable of solar radiation in Indonesia as renewable energy and solar power technology.

2. Hourly solar radiation model

Solar radiation model in this paper includes several parameters and complexities based on meteorological parameters which is Earth–Sun distance, solar declination, and hour angle and geographical parameters such as sunshine duration, mean ambient temperature, maximum and minimum ambient temperature, relative humidity, cloud cover, precipitation, latitude, longitude, altitude, and extra-terrestrial radiation [17–19].

2.1. Earth–sun distance

The earth trajectory around the sun is an ellipse with the sun being one of its foci. The mean of the Earth–Sun distance varies from 144 to 154 million km (21 December to 21 June). The calculation of the correction of the Earth–Sun distance (dimensionless):

$$C_t = 1 + 0.034 \cdot \cos(j - 2) \quad (1)$$

where j is the day number of the year, ranging from 1 on 1 January to 265 on 31 December.

2.2. Solar declination

The solar declination is the angle between the Sun directions with the equatorial plane of the Earth. It varies from $-23^\circ 29'$ in winter solstice to $+23^\circ 27'$ at equinoxes it is null. The equation of solar declination is:

$$\delta = 23.45 \sin(0.986 (j + 284)) \quad (2)$$

2.3. Hour angle

The hour angle ω (degree) is the angle between the meridian plane passing through the Sun center and the vertical plane of place (meridian) and it defines the true solar time T_{sv} (h).

$$\omega = 15(12 - T_{sv}) \quad (3)$$

where T_{sv} (h) is the true solar time at a given position and the equation of the following relationship is:

$$T_{sv} = T_1 - DT_1 + (D_{hg} + E/60)/60 \quad (4)$$

where's:

T_1 ; local time (h)

DT_1 ; difference between local and standard time (h)

D_{hg} ; time difference (advance of 4 min per degree)

E ; equation of time, which is calculate by the below equation (s)

$$E = 450.8 \sin(2\pi j/0.026903) + 595.4 \sin(4\pi j/365 + 0.352835)$$

2.4. Liu and Jordan radiation model

Liu and Jordan's model [20] proposes the value of direct solar radiation and scattering on a flat surface which depends on direct atmospheric transmission values and scattering as the formula below:

$$G = I + D \quad (5)$$

$$I = I_{sc} \cdot \sin h \cdot \tau_{dir} \quad (6)$$

$$D = I_{sc} \cdot E_0 \cdot \sin h \cdot \tau_{dif} \quad (7)$$

$$\tau_{dir} = A \cdot \exp\left(\frac{-B}{\sin h}\right) \quad (8)$$

$$\tau_{dif} = (0.2710 - 0.2939\tau_{dir}) \quad (9)$$

I_{sc} is the solar constant with the value is 1366.1 W/m², E_0 (dimensionless) is the eccentricity correction-factor of the Earth's orbit; τ_{dir} and τ_{dif} (dimensionless) as in Eqs. (6) and (7) are the direct and diffuse atmospheric transmittances respectively. Value of A and B (dimensionless) are the turbidity factor coefficients.

3. Measurement of solar radiation

The solar radiation hourly was recorded using weather station complete with pyranometer installed on the roof of building Department of Mechanical Engineering, Universitas Indonesia (106.82 longitude, −6.36 latitude). as shown in Fig. 1. Weather stations or weather monitors can be done manually and automatically with weather testing equipment. Manual observation is done at least once a day to report the weather conditions of the day, while automatic observations can be done every minute to see changes in weather conditions in a place or region. The weather station used in the research is the Davis Vantage Pro2 Console Weather Station. The Vantage Pro2 Console Weather Station is equipped with pyranometer sensor to measure the solar radiation data. The precision of this pyranometer detects solar radiation at wavelengths of 300 to 1100 nanometres. Solar radiation data is required (along with an anemometer and a temperature/humidity sensor) enables the weather station to report ET and THSW Index [21]. The weather station displays and stores all data from the weather measurement equipment, provides graphics and alarms and also displays the results on a computer that has the Weather Link application installed.

Based on data collection starting from August 28, 2017, to October 3, 2017, several data can be used as a comparative study. The data used is data that has the most stable solar intensity throughout the day without any clouds has been obtained on 2 September 2017. Cloud cover during this date shown in the me shown in Table 1, from the recorded data there no cloud cover on this date. Other environmental data such us UV intensity, humidity and rainfall shown in Fig. 2.

Table 1. Cloud cover during measurement date.

Date	Time	Cloud cover
2 September 2017	6:00	0%
	9:00	0%
	12:00	0%
	15:00	0%
	16:00	0%

4. Result and discussion

Based on the analysis of environmental conditions, it was chosen on September 2, 2017 as the reference date for calculating the estimated radiation value through Liu and Jordan models. The turbidity factor coefficient used for the estimation of hourly estimation is 0.88 and 0.26, respectively for A and B values. These values were chosen based on the cloud cover data from the measurement that show there is no cloud cover during the day and can be assumed as a normal condition. The results of the comparison between estimated solar radiation and the measurement results



Fig. 1. Weather station.

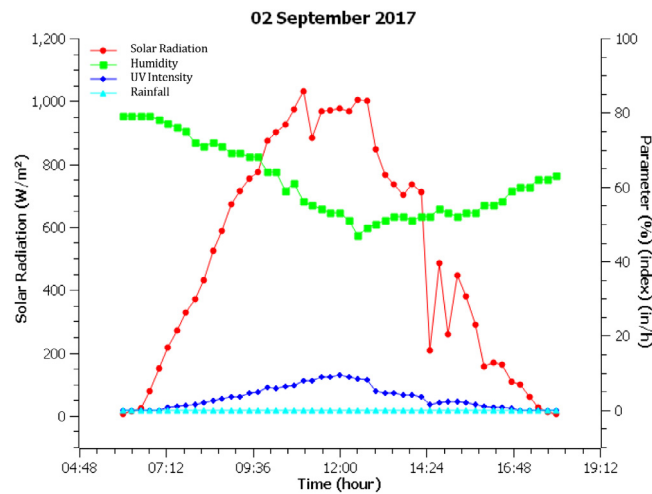


Fig. 2. Measured solar radiation on 2 September 2017.

are shown in Fig. 3. The assessment of comparison results between estimation and measurement data was used Mean Bias Error (MBE) and Root Mean Square Error (RMSE) by Eqs. (10) and (11) [22].

$$MBE = \frac{1}{K} \sum (G_{estimated}^i - G_{measured}^i) \quad (10)$$

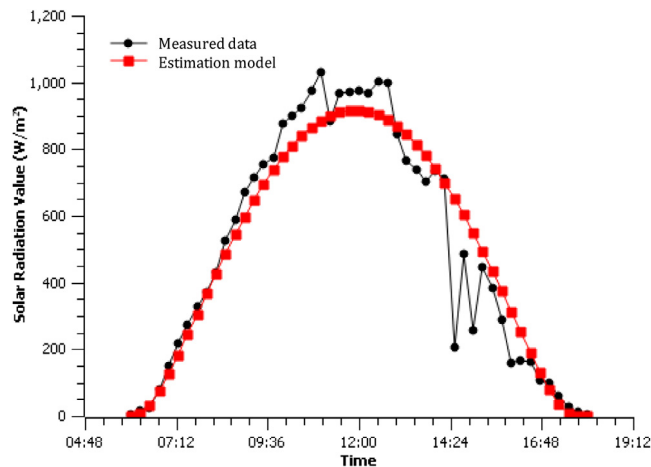


Fig. 3. Comparison measured hourly solar radiation and estimation model.

$$RMSE = \left(\frac{1}{K} \sum (G_{estimated}^i - G_{measured}^i)^2 \right)^{1/2} \quad (11)$$

Based on the results of the calculation of solar radiation estimation using Liu and Jordan Model which can be used as a potential reference for the calculation of the value of subsequent solar radiation by producing a value of Mean Bias Error of 8.29 and Root Mean Square Error of 100.93. In addition to analyzing error values in each calculation model, the model used as a reference for calculating the value of solar radiation must be reviewed in terms of the physical condition of the calculation model. Liu & Jordan model prioritizes the physical condition of a clean atmosphere free from dust or pollution and in sunny weather without clouds so that it can be used as a reference for the calculation model. This is because the parameters in the calculation model are very common where there are no complete parameter factors which only present the value of water molecular content. Although this model is a calculation model studied in the United States and Canada, the calculation factor can be applied. In calculating this model there is also no climate factor for a year, because this measurement is carried out in the summer so that the value of solar radiation at the time of the study can be considered the same as the area in Indonesia. Moreover, with the estimation of sun based radiation in Indonesia particularly in Depok city, the estimation results can be utilized as reference data for simulations related to solar radiation. For instance, the effects of solar radiation on the cooling load of the refrigerated container using a CFD simulation method [23,24].

5. Conclusion

The calculation of solar radiation and evaluation of several parameters are very important in development of the renewable energy and solar power technology. The estimation of hourly solar radiation has been using Liu and Jordan model. The estimation result was compared with measurement data taken from Weather Link Station in Department of Mechanical Engineering Universitas Indonesia, Depok City, Indonesia. The comparison between measured data and estimation model has good agreement with Mean Bias Error of 8.29 and Root Mean Square Error of 100.93. The turbidity factor coefficient assumed as a normal sky condition with the value is 0.88 and 0.26, respectively for A and B. These values were chosen based on the cloud cover data from the measurement that show there is no cloud cover during the day.

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