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New decomposition models to estimate hourly global solar radiation from the daily value

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Abstract

Daily global solar radiation decomposition models (DGSRD models) are important to solar photovoltaic, solar thermal utilization and building energy assessment. The existing DGSRD models are analyzed with hourly global solar radiation data measured from January 2009 to December 2011 on Jiading Campus, Tongji University. The results show the existing models established in the form of a Gaussian equation are comparatively accurate, followed by models adjusted or modified from the Whillier – Liu & Jordan models, and the Newell model is of the lowest accuracy. Among the existing models, the CPRG model is the most accurate one. Then four new decomposition models of daily global solar radiation (DGSRD model 1 to DGSRD model 4) are established based on consideration of the solar altitude angle, the solar azimuth angle, the solar hour angle, clearness index and temperature. Based on the analysis of correlation coefficient, relative standard error, mean bias error, mean absolute bias error, root mean square error, Nash–Sutcliffe Equation and t-statistic (t-stat), it is demonstrated that new DGSRD models (DGSRD model 1, DGSRD model 2 and DGSRD model 4) are more accurate than those existing ones, in which the DGSRD model 4 is the most accurate one.

Keywords: Global solar radiation; Daily value; Hourly value; Decomposition models

1. Introduction

At present, the longitudinal study of solar radiation data in China is mostly for daily values (Zhao et al., 2013). However, for other scientific engineering applications such as solar photovoltaic, thermal utilization, heat gain of buildings, energy simulation, hourly values are generally needed (Pandey and Katiyar, 2009; Karatasou et al., 2003; El-Sebaii et al., 2010; Chandrasekaran and Kumar, 1994). Therefore, it is necessary to study global solar radiation decomposition models that transform daily solar radiation values into hourly values. However, for most meteorological stations in China, hourly solar radiation data is not recorded. Even if some hourly values have been recorded, one is still unable to perform the long-term forecasting due to their short recording time (Whillier, 1956). In addition, even with hourly solar radiation data, it is still necessary to obtain daily values from meteorological stations, which can combine with daily global solar radiation decomposition models (hereinafter abbreviated as the DGSRD models) to solve the missing data problems caused by equipment failure or maintenance, etc. (Tarhan and Sarı, 2005; Spencer, 1982). Therefore, studies of

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Nomenclature

a	intermediate variable (dimensionless)
b	intermediate variable (dimensionless)
c_a	is the average of the calculated values (MJ/m^2 in this paper)
c_i	is the ith calculated value (MJ/m^2 in this paper)
H	daily global solar radiation on horizontal surface (MJ/m^2)
H_0	daily extraterrestrial global radiation on horizontal surface (MJ/m^2)
I	hourly global solar radiation on horizontal surface (MJ/m^2)
I_0	hourly extraterrestrial global solar radiation on horizontal surface (MJ/m^2)
I/H	the ratio of hourly to daily global solar radiation on horizontal surface (dimensionless)
h	solar altitude angle (degree)
h_0	daily-average solar elevation outside of the atmosphere (degree)
I_{sc}	the solar constant (W/m^2)
k_t	hourly clearness index (dimensionless)
K_t	daily clearness index (dimensionless)
K_T	monthly average daily clearness index (dimensionless)
m_a	the average value of measured value (MJ/m^2 in this paper)
m_i	the ith measured value (MJ/m^2 in this paper)
n	the number of calculated or measured values (dimensionless)
S	day length (h)
t	hours from solar noon (h)
t_s	solar time (h)
t_L	local time (h)
t_{n-2}	air temperature at hours $n-2$ (°C)
$t_{\max}$	daily maximum air temperature (°C)
$t_{\min}$	daily minimum air temperature (°C)
α	solar azimuth angle (degree)
ω	solar hour angle (degree)
ω_0	sunrise hour angle, $\cos\omega_0 = \tan\delta\tan\phi$ (degree)
ω_s	sunset hour angle, $\cos\omega_s = -\tan\delta\tan\phi$ (degree)
σ	intermediate variable (dimensionless)
ϕ	latitude (degree)
δ	solar declination (degree)

DGSRD models can transform long-term accumulated daily values into average hourly values, which improve solar radiation application.

According to parameters, constructing methods and physical significance of DGSRD models, the existing models can be divided into three categories.

The first kind of models only involves the factor of time (solar hour angle, day length, solar time or local time). The typical models are the Whillier and the closely related Liu & Jordan model, and others of this kind are generally adjusted or modified versions of these two models. The models of the first type include the Whillier model, Liu & Jordan model, Collares-Pereira & Rabl model, CPRG model, Gueymard model and Garg & Garg model. Whillier (1956) first proposed a DGSRD model to calculate hourly values from the daily value, and this model assumed that the weather conditions are constant (atmospheric transmission is a constant) to study the long-term average solar radiation. Then Liu and Jordan (1960) slightly simplified the diffuse radiation decomposition formula of the Whillier model. Collares-Pereira and Rabl (1979) obtain a DGSRD model by fitting the measured solar radiation data, and this model is the classic one, which has been widely cited in the solar radiation field (Al-Sulaiman and Ismail, 1997; Srivastava et al., 1995; Wan et al., 2012). After that, many scholars (Newell, 1983; Gueymard, 1986, 2000; Garg and Garg, 1987) presented their models on the basis of Liu & Jordan model or Collares-Pereira & Rabl model. For example, Gueymard (1986), based on the modification of Collares-Pereira & Rabl model, proposed his own model (Gueymard, 2000), which was used to predict the monthly-average hourly global solar radiation distribution from its daily value. Garg and Garg (1987) modified the Liu & Jordan model with Indian global radiation data, and compared the modified model with the Collares-Pereira & Rabl model. The result shows that the Collares-Pereira & Rabl model is consistent with the observed values, but the modified model is much simpler than the Collares-Pereira & Rabl model. It is noted that only the time of day is considered in these models, and random changes in weather conditions are not included. Therefore these models are only suitable for calculating the long-term average value of solar radiation, but they are difficult to adapt to the short-term (e.g. hourly) estimation.

The second kind of models is established in the form of Gaussian function, including the following models: Jain model 1, Jain model 2, Baig et al. model, Shazly model. Jain (1984, 1988) established DGSRD models, and then Baig et al. (1991) and Shazly (1996) respectively introduced correction factors to the Jain model based on a Gaussian distribution function. It is noted that these models propose the assumption that the variation of weather conditions are