Renewable and Sustainable Energy Reviews 42 (2015) 1326–1334

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Spatial variability and clustering of global solar irradiation in Vietnam from sunshine duration measurements

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ARTICLE INFO

Article history:
Received 26 May 2014
Received in revised form
28 July 2014
Accepted 1 November 2014

Keywords:
Solar radiation variability
Clustering techniques
Solar radiation in Vietnam
Sunshine duration measuring network in Vietnam

ABSTRACT

A study on the spatial variability of long term solar radiation in Vietnam and the results of clustering solar radiation into different regions are presented here. Vietnam has a dense and long network of sunshine duration measurements, and on the contrary the country has a scarce availability of solar irradiance measuring sites. The variability of long term solar radiation can be analyzed by determining daily global irradiation from sunshine duration. A model inspired in Angstrom equation has been developed using the canonical correlation analysis with good performance. The output of the model has been used for characterizing the dispersion of long term solar radiation and its spatial distribution has been also studied by clustering techniques. The comparison with the Köppen climatic information remarks that Vietnam could be divided into 3–4 well defined zones of different solar radiation variability.

Contents

1. Introduction

Solar radiation at the Earth's surface is an important variable in meteorology, climate, agriculture and energy issues and thus accurate information on solar radiation components at a given site or region is frequently needed. In particular, detailed knowledge of the spatial and temporal variability of solar radiation is a key factor to solar energy applications and deployment in a country, and consequently it is the main objective of solar resource assessment studies. Solar radiation incoming at the Earth's surface exhibits a large geographic variability due to its strong dependence on the atmospheric conditions and meteorology. Solar radiation is also highly variable in time. Therefore, the annual sum of incoming solar radiation can change significantly from year to year and from place to place in a country due to varying weather conditions.

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http://dx.doi.org/10.1016/j.rser.2014.11.014
1364-0321/

Nomenclature

a, b	regression coefficients
AOD	aerosol optical depth
G_0	daily extraterrestrial irradiation (kWh m^{-2} day^{-1})
GHI	global horizontal irradiation
H_j	daily global irradiation (kWh m^{-2} day^{-1})
H_{CS}	clear sky daily global irradiation (kWh m^{-2} day^{-1})
$\langle H \rangle$	monthly average daily irradiation (kWh m^{-2} day^{-1})
$\langle H_0 \rangle$	monthly average daily extraterrestrial irradiation (kWh m^{-2} day^{-1})
n	daily sunshine duration (hours)
N	daily maximum possible sunshine duration (hours)
$p1$ to $p4$	polynomial coefficients
S	monthly average daily sunshine duration (hours)
S_0	maximum possible sunshine duration and the middle of month (hours)
α	Angström exponent parameter
β	Angström turbidity parameter
Ψ_j	Output of Angström correlation (kWh m^{-2} day^{-1})

The study of spatial and temporal variability of solar radiation for a given region requires a dense network of ground stations with a long time measuring period; such a pyranometric database is generally unavailable in developing countries, since in addition to the economic cost of the equipment intense manpower for maintenance is also required. On the contrary, in many countries with lack of pyranometric data there are much more information on sunshine duration; in general, sunshine duration data are widely available from multiple regional and national weather services. This is the case of Vietnam where there is no much information available on ancillary measurements of the solar radiation components in Vietnam but it has a wide and dense network of stations recording sunshine duration. Thus, the different studies and attempts to quantify solar resource in Asia have traditionally been based on sunshine duration measurements rather than on radiometric irradiation measurements [7,15,19,20]. According to [19] all pyranometers and pyrheliometers instruments in former Vietnamese weather stations were imported from the former Soviet Union, and the observations were made every 3 h; in consequence, the data were not integrated over hourly intervals as in the case of many other countries. Most of the Angstrom and Angstrom-Prescott models estimate average global irradiation from average sunshine duration. One of the difficulties with Angstrom-type models was also the high uncertainty in estimating clear sky irradiation.

Nowadays there are many and accurate clear sky models [9,10,13] which can deliver very good estimations of solar irradiance under clear sky conditions, especially when accurate atmospheric input, mainly aerosol optical depth, is provided to these models.

In this work a simple model based on Angstrom equation is presented as an attempt to better exploitation the wide network of sunshine duration measuring sites existing in the country (171 stations). The model output has used for estimating a single parameter for characterizing the long term variability. Clustering techniques have been used then for identifying solar radiation zones of common variability. The clustering results have been compared with the Köppen climatic zones founding high similarity in the regions.

2. Data

The pyranometric data used in this work are hourly values of global horizontal irradiance for 11 ground stations in Vietnam. The measuring period for most of them was the year 2012, Da Nang and Can Tho stations included also some measurements during 2011, and in Lang station the measuring period was 2011. Daily sums of global irradiance, computed after basic quality checks performed to the hourly data, have been used in this work. Despite the limited measurements of solar radiation along the country, Vietnam has a large and broad network of sunshine duration stations. 171 stations distributed along the country have been recording daily values of sunshine duration since 1984. Fig. 1 shows the location of the radiometric stations (on the left) and of the sunshine duration stations (on the right). The sunshine duration measurements used in this work consisted of daily values of sunshine duration from 2003 to 2012 at every station. It is worth to remark that the radiometric ground stations with pyranometric data have also sunshine duration measurements so that there are available simultaneous data of daily global horizontal irradiation (GHI) and sunshine duration for 11 stations and for a period covering a year in most of the cases.

In addition, daily values of aerosol optical depth (AOD) at several wavelengths (469, 550, 670, 865 and 1240 nm) and of water vapor content are collected from MACC (Monitoring Atmospheric Composition and Climate) reanalysis (http://www.gmes-atmosphere.eu/). MACC reanalysis data consist of gridded data with global coverage of atmospheric composition at recent years (daily values from 2003 to 2012) as well as forecasting with a spatial resolution of $1.125 \times 1.125^{\circ}$, which are based on the ECMWF (European Center for Medium-range Weather Forecast) integrated forecasting system (IFS) coupled to a global chemical transport model for offering forecasting and reanalysis of different atmospheric constituents including aerosol optical properties [14].

3. Angström-type models

There are a huge amount of Angström and Angström-Prescott empirical correlations for determining monthly average daily global irradiation from sunshine duration. The original Angström regression used the ratio of monthly average daily irradiation to clear-sky daily irradiation [3]. However, the difficulties in estimating with high accuracy the clear-sky irradiation resulted in the Angström-Prescott formulation [22],

$$\frac{\langle H \rangle}{\langle H_0 \rangle} = a + b\left(\frac{S}{S_0}\right) \tag{1}$$

where $\langle H \rangle$ is the monthly average daily global irradiation, $\langle H_0 \rangle$ is the monthly average daily extraterrestrial irradiation, S is the monthly average daily sunshine duration, S_0 is the maximum possible sunshine duration, and a and b are empirical coefficients to be determined empirically. Based on Angström-Prescott formulation many local correlations have been proposed in the literature. Table 1 summarizes the main characteristics of most of them and establishes five general groups of models. In addition very good recent reviews can be found in [2,5,6,12]. Most of these kinds of correlations have a local usability since they are normally applicable in the region where they were developed. In consequence there has been a huge amount of proposals and it can be easily found up to 60 different correlations in the reviews [5].