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Experimental investigation of simple solar radiation spectral model performances under a Mediterranean Algerian's climate

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ABSTRACT

In this work, models are presented that, under cloudless atmosphere conditions, calculate solar spectral normal direct and horizontal diffuse irradiance. Based on different monochromatic transmission factors related to the main constituents of the atmosphere, the models evaluate the spectral irradiance between 0.29 and 4.0 μm. Absorption by water vapor, uniformly mixed gas, and ozone are considered as well as scattering by the atmospheric aerosols. Based on the equations relative to each one of the two retained models, a MATLAB program is developed to evaluate the spectral distribution of each solar irradiance component. Hence, the geographical coordinates of the site, and the monochromatic distribution of the extraterrestrial irradiance are used as input data. From three-year data measurement records made in Bouzareah site (temperate climate), thirty eight days characterized by a clear sky state have been selected from over different months of the year and the corresponding main meteorological parameters used as input parameters. So, because only the five-minute broadband data measurements are available, the modified numerical trapeze method is used to integrate the monochromatic curve values related to each solar irradiance component. Consequently, the precipitable water vapor amount, the Angstrom and Linke turbidity factors are evaluated and a multi-linear correlation relating the Linke turbidity factor to the precipitable water vapor and the Angstrom turbidity coefficient is established. Hence, according to the mean values of Linke and Angstrom turbidity factors and those of the precipitable water vapor, the site of Bouzareah is classified as a rural site. So, the effect of the main constituents of the atmosphere on the spectral distribution of solar irradiance is discussed and, it is also observed that the aerosol amount contained in the atmosphere affects most both of the diffuse and direct solar irradiance amount than that of the horizontal and inclined solar global components. Conversely, it is observed that it is less efficient in evaluating the horizontal diffuse components and its accuracy depends on several scattering phenomena, which are represented by scientists by means of constant values or expressions. The reasonable accuracy of the model and for it's simplicity make it for a number of solar applications.

1. Introduction

Over the last decades, owing to the high-energy consumption, according to the depletion of the oil resources and to the environmental issue associated to the conventional resources, energy production from clean and green resources has been paid must attention among researchers over the whole world, mainly in the developed countries.

As a green and lasting energy, solar energy and its applications has been widely studied and developed as solar water heating systems [1–9].

Recently, parabolic trough power plant has been considered as a unique and evolved means of solar electricity production in which the radiated sun energy is converted into useful thermal energy [10–17].

However, depending on the considered solar application, the type of the used collector and the needed precision, the choice of the input parameters, mainly those related to the energy sources such as global or direct solar radiation component and the time step of measurement, present a major importance.

In solar flat plate collector system design, the monthly mean daily or that of hourly data of inclined solar irradiation are needed for the estimation of long-term solar systems performances. While in solar concentrating systems design, the direct normal solar irradiation is generally needed as a main energetic input parameter in some specific applications or studies and in term of

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instantaneous values. Once more, in other specific applications, generally speaking the solar radiation data are needed in a detailed form, as available in the case of monochromatic solar irradiance. This is needed in photovoltaic applications as in the case of the spectral response of a specific solar cell study [18–25] works. This is also needed in radiative thermal studies, in the case where the selective absorptance and emissivity of a specific solar collector surface painting is considered [24–26], or in painting reflectance of building as presented in Refs. [27,28]. This is again needed in agricultural application studies which, generally, concern the effects of the specific spectral bands on the plants and foods behavior [29–32].

However, the best method of evaluating the solar irradiation reaching the ground level at any location on the earth surface is the measurement taking way. So, because of the high prices of the employed equipment and because of the related specific daily maintenance, few specialized stations are available locally, the same situation arises in other countries especially in the non-industrialized ones. In such situation, having recourse to the simulation methods is the most reasonable solution. This consists of using the available methodologies, which lead to the determination of the needed solar radiation data and calculation procedures. The most common among these are the Stochastic methods [33–37], or the statistical ones [38–54], the studied ones [55–62], or the analytical methods [63–66]. These methods have been elaborated to reconstitute the different solar radiation components for different sky state conditions, for different time steps and from some meteorological data measurements.

Thus, from the statistic models, for any sky state conditions and for the monthly mean of daily and hourly time scale, empirical models relating the clearness index coefficient K_T to the sunshine hour ratio have been proposed in Ref. [38,39] or correlations between the diffuse ratio and the global radiation K_D to the clearness index K_T or to the sunshine hour ratio have been proposed [42–47].

Other empirical models linking the various weather parameters data such as the relative humidity, dry air temperature and sunshine hour duration to K_T and to K_D are also proposed in Refs. [48–54], and in Ref. [67].

Nevertheless the above referred to methodology generally requires stationary data. At the contrary, the solar radiation is non stationary and presents a nonlinear character. The nonlinear approaches such as the artificial intelligence techniques were developed and used to solve this shortcoming, which are actually considered as a powerful tool. The artificial neural network can be found in the first rank in many technical fields as well used by many authors for forecasting the global solar irradiation. Hence several works considered the solar radiation prediction from the artificial neural network using multiple meteorological, astronomical and geographical parameters [68–74].

On another way, other relations called parametric models have also been proposed to predict the different solar irradiance compound incident on the ground surface, for the broadband of the solar spectrum and for a specific sky state condition as those presented in Refs. [75–82].

Once more, to evaluate the solar radiation reaching the ground surface under its detailed appearance such as in its monochromatic distribution form, several studies and models have been proposed [83–89], and in Ref. [71]. In this work, the models proposed in Refs. [85,86] are considered and an experimental investigation is performed respectively in terms of monochromatic solar normal direct solar irradiance and of the diffuse solar irradiance component. Hence, the instantaneous values of the precipitable water vapor thickness and of the Angstrom turbidity coefficient are considered and their evaluation performed by using the model and method proposed respectively in Refs. [88,89].

Furthermore, some modifications have been introduced into the equations leading to the calculation of the diffuse irradiance and the model proposed by Ref. [86] is also selected. This constitutes the main change and other minor adjustments are hereby presented.

However, the equations representing the transmission coefficient of the different atmospheric components, equations allowing for evaluating the main local atmospherical parameters as well as those leading to the evaluation of the monochromatic distribution of the different solar radiation components are used to develop a MATLAB program. The geographical coordinates of the site, the monochromatic distribution of the extraterrestrial irradiance are used as input data. A five-minute step time data of the main meteorological parameters (dry air temperature, the relative humidity, the air pressure) are used also as input data. Hence, the corresponding values selected from three-year data measurement records (January 2010 to June 2013) over different months of the year are used as input parameters. Thus, thirty eight days characterized by a clear sky state have been selected from the Renewable Energies Development Center situated at Bouzareah site, which is characterized by a temperate climate [90]. Hence, for each five-minute step time, the developed MATLAB program allows evaluating the atmospheric contents in terms of precipitable water vapor amount, the Angstrom and Linke turbidity factors which are considered as being pollution indicators. This program leads also to the evaluation of the monochromatic distribution of the different components of solar radiation at the ground level and an experimental investigation of the selected models performance is performed. So, because only the five-minute broadband data measurement are available, to evaluate the performance of the selected monochromatic models the modified numerical trapeze method is used to integrate the monochromatic curve's values of each solar irradiance component to obtain the corresponding broadband values. Thus in the first step, the calculated values of the diffuse irradiance related to each of the two chosen models have been subject to a statistical comparison with the corresponding measured data. As statistical indicator parameters of the model performances, the mean absolute percentage error MAPE, the normalized mean bias error NMBE, the Normalized root mean square error NMRSE and the linear fit parameters are used. It will also be noted that the daily values of the three components constituting the total diffuse solar irradiation are calculated separately and compared. The effect of the main meteorological parameters as the precipitable water vapour level, the Angstrom turbidity factor characterizing the amount of dust in the atmosphere and the Linke turbidity, on their amount was subject to special attention. In the second step, an experimental investigation employing the model [85] for the calculation of the direct normal solar irradiance is performed.

In the third step, the global solar irradiance incident on a horizontal surface is calculated by coupling the chosen direct and diffuse models and the evaluation of the performance of the resulting model made. In the same manner, the evaluation of the global solar irradiance incident on an inclined surface is made employing the same model leading to the evaluation of the direct solar irradiation component which is reported on the inclined surface and presented in Ref. [91] and the diffuse component is calculating by employing the anisotrope model proposed in Ref. [92].

2. Mathematical formulation

For a cloudless sky, a number of formulations based on the so called parameterization method are available in the literature and some of the more well-known models are presented and summarized by Brine et al. [86]. These models are expressed in terms of the

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