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A clear sky irradiation assessment using a modified Algerian solar atlas model in Adrar city

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ABSTRACT

The solar systems technology offers a promising method for the large scale use of solar energy in the southern zone of Algeria. The magnitude of solar radiation is the most important parameter for sizing these systems. The chief goal of this investigation is to contribute to the national efforts in establishing solar radiation in Algeria. Using the Algerian solar atlas model and the experimental monthly mean Linke turbidity factor a new model for the prediction of the solar radiation in the Sahara desert area of Adrar region, Algeria is developed. In this study, the Linke turbidity factor was obtained from radiometric and meteorological data recorded in the research unit in renewable energies in the Saharan medium, during October 2012 to May 2015. This investigation finds that the newly developed model performs more accurate estimation, with smaller relative errors between measured and computed values.

1. Introduction

Fossil fuels and especially the natural gas is the largest source of electricity production in Algeria. According to Himri et al. (2009) in 2007 about 98% of electricity is generated by the natural gas. The environmental problems caused by the use of fossil fuels are well known: air pollution, greenhouse gases and aerosol production. In the last years the electricity consumption has increased with the rapid growth in the residential, commercial and industrial sectors. Renewable energy resources especially solar energy offer interesting opportunities for facing this important increase. This strategic is motivated by the huge potential in solar energy in the south of Algeria. Marif et al. (2014) have shown that the mean yearly sunshine duration varies from a low of 2650 h on the coastal line to 3900 h in the south. In a first step hybrid concentrated solar power plant was installed in the south of Algeria (Hassi Rmel) since 2010 with electrical power of 25 MW. As referenced by Boukelia and Mecibah (2013), three further hybrid concentrated power plants will be completed in 2018 with 70 MW thermal solar power plants capacity for each one of them. These three power plants are part of the government's plan to export from thermal and photovoltaic solar power.

The study of solar radiation under cloudless skies is generally important for the utilization of solar energy and particularly for solar systems optimal design Mateos et al. (2010). In Algeria many approaches have been proposed in several studies to estimate the solar radiation. The first correlations were proposed by Capderou (1987) in the Algerian solar atlas, which developed theoretical approach based on the atmospheric Linke turbidity factor to estimate the instantaneous global solar radiation on a completely clear day conditions. Yaiche et al. (2014) created a global solar radiation map in Algeria from sunshine duration for all sky types. They found that the relative error is less than 7% between measured and computed values. Mefti et al. (2003) have estimated the global solar radiation incident on an inclined surface in any site of Algeria using monthly mean daily sunshine duration measurements, in this model the discrepancies observed between the estimated and measured values run from 10% to 35%. In order to correlating monthly mean daily diffuse solar radiation Boukelia et al. (2014) studied the performance of ten empirical models based on the ratio of monthly mean daily sunshine records to monthly daily mean daylight hours and on the ratio of monthly mean daily global solar radiation data to monthly mean daily extraterrestrial solar radiation at six Algerian stations: Algiers, Constantine, Ghardaia, Bechar, Adrar, and Tamanrasset. This study finds that the quadratic and cubic equation which based on global solar radiation data performed the best accuracy. Omar et al. (2015) compared the performance of seventeen clear-sky direct solar radiation models under Algerian

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climate to select the more accurate one, their results show that the ASHRAE model can offer more precise information. Six combined empirical models and a Bayesian neural network (BNN) model have been used by Yacef et al. (2014) to estimate daily global solar radiation from air temperature on horizontal surface in Ghardaïa city. After testing, the combined models appear to be more helpful than BNN. Based on the intelligent artificial neural network (ANN), two models have been proposed by Mellit et al. (2005, 2006) to predict the daily global solar radiation with a sufficient accuracy for any location in Algeria. Chegaar and Chibani (2001) proposed two models for estimating monthly mean daily global solar radiation on a horizontal surface in four Algerian locations (Algiers, Oran, Beni abbas and Tamanrasset). The first model is originally formulated by Barbaro et al. (1978) and modified by the authors and the second proposed model is a regression equation of the Angstrom type based on sunshine duration. Mecibah et al. (2014) correlating the monthly mean daily global solar radiation on a horizontal surface with monthly mean sunshine records and air temperature data for six Algerian cities (Algiers, Oran, Batna, Ghardaia, Bechar, and Tamanrasset). After testing, the sunshine based models appear to be more accurate than air temperature based models.

In this paper, a software application based on a clear-sky Algerian solar atlas model and on an experimental determination of the Linke turbidity factor is developed in order to evaluate the amount of solar radiation over different time intervals for the first time in Adrar town. In the following sections, a detail of the mathematical model, the description of the measurement station, the data series characteristics and the obtained results can be seen.

2. Mathematical formulations

2.1. Experimental Linke turbidity factor

Many solar radiation models for clear day refer to the Linke turbidity factor T_L. This parameter describes the optical thickness of the atmosphere due to both absorption by the water vapor and the absorption and scattering by the aerosol particles. A review of the literature showed that T_L can be obtained from several methods. Kasten (1980) presented a simple calculation methodology to facilitate the experimental determination of the Linke turbidity factor where the pyrheliometric measurements of the direct normal solar irradiation (DNI) on the horizontal plane are known. Cucumo et al. (1999) developed a general calculation model using experimental data of beam solar irradiation on the horizontal plane. As documented by Diabaté et al. (2003), T_L was estimated using the approach proposed by Aguiar in the European Solar Radiation Atlas ESRA (2000). In this research, the experimental Linke turbidity factor has been calculated using a method developed by Kasten, which have been used in previous papers (Djafer and Irbah, 2013; Trabelsi and Masmoudi, 2011; Li and Lam, 2002). The expression of T_L is given by the following equations:

$$T_L = T_{Lk}\frac{\frac{1}{\delta_{Ra}}}{\frac{1}{\delta_{Rk}}} \tag{1}$$

T_{Lk} is the atmospheric Linke turbidity factor under clear sky according to Kasten, δ_{Rk} is the Rayleigh integral optical thickness given by the same author and δ_{Ra} is the integral optical thickness given by Louche et al. (1986) and adjusted by Kasten (1996):

$$T_{Lk} = (0.9 + 9.4\sin(h)) \,.\, \ln\left(\frac{I_0\varepsilon}{I_n}\right) \tag{2}$$

$$\frac{1}{\delta_{Rk}} = 9.4 + 0.9m_A \tag{3}$$

$$\frac{1}{\delta_{Ra}} = 6.5567 + 1.7513m_A - 0.1202m_A^2 + 0.0065m_A^3 - 0.00013m_A^4 \tag{4}$$

where h is the sun elevation angle (in degrees), ε is the Sun–Earth correction distance. I_0 and I_n are respectively the sun constant (1367 W/m^2) and the direct normal solar irradiation (in W/m^2). The atmospheric air mass m_A which depends on the sun elevation angle and local air pressure P (in Pascal), the value of m_A is given by Trabelsi and Masmoudi (2011):

$$m_A = \frac{P}{101325}\left[\sin(h) + 0.15(h + 3.885)^{-1.253}\right]^{-1}. \tag{5}$$

2.2. Algerian solar atlas model

Capderou (1987) in the Algerian solar atlas has proposed mathematical equations based on the theoretical approach of Perrin de Brichambaut and Vauge (1982). The direct solar radiation expression under clear sky condition I_d (in W/m^2) is given by the following equation:

$$I_d = I_0\varepsilon\cos\theta\exp(-T_{Lc}m_{Ac}\delta_{Rk}) \tag{6}$$

where θ is the incidence angle (in degrees). T_{Lc} and m_{Ac} are the atmospheric Linke turbidity factor and the atmospheric air mass given by Capderou respectively:

$$T_{Lc} = T_0 + T_1 + T_2 \tag{7}$$

T_0 is the atmospheric turbidity caused by water vapor absorption:

$$T_0 = 2.4 - 0.9\sin\varphi + 0.1A_{he}(2 + \sin\varphi) - 0.2Z - (1.22 + 0.14A_{he})(1 - \sin h) \tag{8}$$

T_1 is the atmospheric turbidity corresponding to the molecular diffusion:

$$T_1 = (0.89)^Z \tag{9}$$

T_2 is the atmospheric turbidity relative to the aerosol diffusion coupled with a slight absorption:

$$T_2 = (0.9 + 0.4A_{he})(0.63)^Z \tag{10}$$

$$\text{Where}: \; A_{he} = \sin\left(\frac{360}{365}(n - 121)\right) \tag{11}$$

$$m_{Ac} = \frac{1}{\sin(h) + 9.4\times10^{-4}(\sin(h) + 0.0678)^{-1.253}} \approx \frac{(0.89)^Z}{\sin(h)} \tag{12}$$

Z: the altitude (in km)
n: the number of days in the year
φ: the latitude angle (in degrees)

The diffuse solar radiation (in W/m^2) depends on the diffusive turbidity factors T_1 and T_2. In the case of horizontal surface:

$$I_{fh} = I_0\varepsilon\exp\left(-1 + 1.06\log(\sin h) + a - \sqrt{b^2 + a^2}\right) \tag{13}$$

$$\text{Where} \quad a = 1.1 \text{ and } b = \log(T_1 + T_2) - 2.8 + 1.02(1 - \sin h)^2. \tag{14}$$

In the case of inclined surface the diffuse radiation is divided into two components, skies diffuse (I_{f1}) and grounds diffuse (I_{f2}):

$$I_{f1} = \delta_d\cos\theta + (I_{fh} - \delta_d\sin h)\frac{1 + sin\beta}{2} + \left(\frac{-0.02a_hI_{dh}}{\sin h\,(a_h^2 + a_hb_h + 1.8)}\exp(\sin h)\right)cos\beta \tag{15}$$