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Surface Solar Spectrum Characteristics in Tropical Regions with Specific Reference to Rwanda.

MC Cyulinyana *, H. Winkler

Physics Department, University of Johannesburg, Po Box 524, Johannesburg, South Africa

Abstract

We describe a model adopted for tropical regions showing the dependence of surface solar radiation reaching the ground level, on atmospheric constituents. The spectral solar shortwave irradiance is calculated from spectral transmittance in a cloudless tropical atmosphere, based on Rayleigh scattering and aerosol extinction factors parameterized according to conditions characteristics of African Great Lakes region. A Monte Carlo simulation is used to calculate the transmittance and reflectance of a homogeneous atmosphere based on Rwanda, which in turn determines the solar radiation reaching the ground level. The results show that this simple model is sufficient for deriving realistic representations of the incident solar radiation on Earth's surface for a range of atmospheric turbidity values.

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Keywords: Solar radiation; Monte Carlo Method; Rayleigh scattering; aerosols scattering; optical depth; transmittance; Rwanda.

1. Introduction

Solar irradiance is a measure of how much solar electromagnetic radiation is received on a specific receiver (i.e., power per unit area on the Earth's surface). Solar irradiance is not a constant value, but changes throughout the year depending on the season, the time of day and the weather [1, 2].

* Corresponding author. Tel.: +27-(0)11-559-2327; fax: +27-(0)11-559-2339.
E-mail address: 201333514@student.uj.ac.za

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Not all the solar radiation reaches the Earth's surface. At an average distance of 150 million kilometers from the Sun, the outer atmosphere of Earth receives approximately 1367 W/m^2 of insolation [2]. Shortwave radiation (280-2800 nm) is the energy source that drives evaporation, transpiration, photosynthesis, and many other important processes linked to agricultural systems [3, 4, 5].

It is difficult to obtain solar data at all locations because of the high cost of measurement equipment, operation and maintenance. Although there exist some empirical (sunshine based models) and meteorological models (meteorological parameters based models) to estimate solar radiation, these models often only have limited accuracy [2, 6]. Thus, developing a new model (i.e., based on atmospheric constituents) to characterize/predict solar radiation in tropical (i.e., Rwanda) regions based on Monte Carlo techniques is of great importance.

Based on its geographical location, Rwanda is claimed to have enough solar radiation (approximately equal to 5 kWh/m^2/day with a peak of Sun hours of almost 5 hours per day) from land cover aspect, and slope characteristics for the placement of solar energy production sites [6].

Till date, there have been many spectral irradiance models developed, each adopting different approaches to understand and compute the amount of solar radiation transmitted through the atmosphere [2, 4]. Rwanda didn't have any solar data records till 2013, reason why all the models were validated using satellite data. In this study, we are validating our model using recorded solar data.

To avoid mistakes in sizing the PV plant, transmittance and extraterrestrial solar energy should be well assessed for a given region and especially for any site expected to host a PV plant.

This paper represents a model designed to estimate the incident solar radiation at ground level, based on its interaction with atmospheric constituents. A Monte Carlo simulation is used to calculate the transmittance and reflectance of homogeneous atmosphere characteristic of Rwanda which in turn determines the solar reaching the ground level. In this simple model, the molecule and aerosols scattering plays a great role in determination of diffuse component of solar irradiance. By doing Rayleigh and aerosols scattering calculations under aerosol loading conditions typical for tropical high-altitude Africa (i.e. which wasn't done in the past), a model for estimating solar radiation was developed. The aim of this study is to contribute and give more information about solar energy resources over Rwanda, through transmittance, which plays a big role in determining the solar radiation reaching the ground level.

This work is laid out as follow: Section 2 presents the theory behind the model, Section 3 presents the method for case study used in this work, simulation results are discussed in Section 4, conclusion and future research are presented in Section 5

Nomenclature

$I_{0,\lambda}$	extra-terrestrial solar radiation (Wm^{-2})	PV	Photovoltaic
θ_z	solar zenith angle (°)	m	air mass (AM)
I_λ	incident solar flux (Wm^{-2})	τ_λ	atmospheric optical depth
$I_{dir,\lambda}$	direct irradiance (Wm^{-2})	T	atmosphere layer transmittance
$I_{diff,\lambda}$	diffuse irradiance (Wm^{-2})	k_{ext}	extinction coefficient
$I_{G,\lambda}$	global irradiance (Wm^{-2})	k_{sca}	scattering coefficient
ω_o	single scattering albedo	k_{abs}	absorption coefficient
a	surface albedo	P	site pressure (hPa)
R	atmosphere layer reflectance	P_o	standard atmospheric pressure (hPa)

2. Theory

Shortwave radiation, which is the focus of this study, can be separated into direct and diffuse components. The sum of these two components is called global radiation ($I_{G,\lambda}$). The direct irradiance incident to the horizontal is calculated by multiplying the direct irradiance ($I_{dir,\lambda}$) by the cosine of the zenith angle (θ_z). Diffuse radiation ($I_{diff,\lambda}$)