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Anisotropic Diffuse Shading Model for Sun-tracking Photovoltaic Systems

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Abstract

This work is part of a methodology and set of tools being developed to increase the accuracy of yield predictions for one- and two-axis-tracking photovoltaic plants. The paper presents enhancements incorporated to consider the effects of diffuse irradiance components. Focus resides on the calculation of shading losses based on an anisotropic sky model and considering the effects of the moving 3D tracker arrangement over a complex landscape. Shading factors for two ground-reflected- and three sky-diffuse-irradiance components are calculated individually, on a time-step basis, and for multiple points over the tracker plane. Simulation results are presented for an example two-axis-tracking plant. Effects of geometrical framework, shading of different irradiance components, and simulation detail are discussed. A comparison with state-of-the-art simulation assumptions and practices is performed.

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1. Introduction

Accurate and reliable yield forecasts have become a necessity for project planning and development in the increasingly competitive market of utility-scale photovoltaic plants; yet, in commercial simulation tools, a long series of simplifications and assumptions currently restrict simulation accuracy beyond the unavoidable uncertainty attributable to climatic variability. Transposition of horizontal irradiance into Plane of Array (POA), shading, and reflection are among the largest sources of uncertainty in photovoltaic performance simulations. According to Vanicek and Haselhuhn [1] they can account for errors of up to $\pm 5\%$, $\pm 3\%$, and $\pm 2\%$ respectively. In commercial software packages beam shading analysis is often

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limited to simplistic geometrical descriptions of the PV-Plant (e.g. rectangular trackers, regular 2D arrays); excluding the possibility of precise array layout optimization. Shading of the diffuse irradiance components can have an effect of the same order of magnitude as that of beam shades (consider e.g. performance verifications on systems with back- or true-tracking [2]), yet its calculation is carried out, if at all, under the unrealistic isotropic assumption (see[2][3][4] and results in section 3).

The present work focuses on the improvement of the aforementioned simulation aspects, while seeking to overcome other limitations in commercial simulation software (e.g. one-hour-time-step resolution; ability to model large, non-uniform arrays over complex terrain) which are becoming critical as larger and more complex projects are being developed, and increased simulation accuracy is sought after.

Nomenclature

GHI	Global Horizontal Irradiance
DHI	Diffuse Horizontal Irradiance
BNI	Beam (Direct) Normal Irradiance
POA	Plane of Array
G	Global incident irradiance
B	Beam (direct) irradiance
D	Diffuse irradiance component
\circ_j	$j \in \{cs, hb, iso, \rho\}$ circumsolar, horizon-brightening, isotropic, and albedo components, resp.
\circ_t	Variable on Plane of Array
\circ_s	Variable after consideration of shading
g	Shading factor
θ'_z	Incidence angle
θ_z	Solar zenith angle
θ_t	Array (tracker) tilt angle
$K_{\tau\alpha}$	Incidence Angle Modifier (IAM) function
A	Area (solid angle) of a region in the visibility dome
\circ_p	Variable after Radiance-Preserving Projection
F'_1, F'_2	Weighting factors for the circumsolar and horizon-brightening components
k_d	Diffuse fraction, $k_d = \text{DHI/GHI}$
ρ	Albedo factor
λ	Radiance / radiant intensity

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