Atmospheric parameters, spectral indexes and their relation to CPV spectral performance

Rubén Núñez, Ignacio Antón, Steve Askins, and Gabriel Sala

Citation: AIP Conference Proceedings **1616**, 290 (2014); doi: 10.1063/1.4897080

View online: http://dx.doi.org/10.1063/1.4897080

View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1616?ver=pdfcov

Published by the AIP Publishing

Atmospheric Parameters, Spectral Indexes And Their Relation To CPV Spectral Performance

Rubén Núñez[1], Ignacio Antón[1], Steve Askins[1] and Gabriel Sala[1]

[1]*Instituto de Energía Solar - Universidad Politécnica de Madrid*
ruben.nunez@ies-def.upm.es, Instituto de Energía Solar, ETSI Telecomunicación, Ciudad Universitaria 28040 Madrid, Spain

Abstract. Air Mass and atmosphere components (basically aerosol (AOD) and precipitable water (PW)) define the absorption of the sunlight that arrive to Earth. Radiative models such as SMARTS or MODTRAN use these parameters to generate an equivalent spectrum. However, complex and expensive instruments (as AERONET network devices) are needed to obtain AOD and PW. On the other hand, the use of isotype cells is a convenient way to characterize spectrally a place for CPV considering that they provide the photocurrent of the different internal subcells individually. Crossing data from AERONET station and a Tri-band Spectroheliometer, a model that correlates Spectral Mismatch Ratios and atmospheric parameters is proposed. Considering the amount of stations of AERONET network, this model may be used to estimate the spectral influence on energy performance of CPV systems close to all the stations worldwide.

Keywords: CPV, spectrum, SMR, air mass, aerosols, precipitable water, isotypes cells
PACS: 92.60.Mt, 88.40.jp, 88.40.F-

INTRODUCTION

Sunlight is absorbed and scattered by the atmosphere, concretely, by the atmospheric components, as atmospheric radiative transfer models describe, such as SMARTS or MODTRAN. These models provide spectrally resolved DNI and GNI for a particular site and moment. Basic description of an absorption process is given by Beer-Lambert law that declares a logarithmic dependence between light transmission in a medium and the distance the light travels through it. Applied to light passing through atmosphere, the medium is the set of atmospheric components, i.e. Aerosol Optical Depth (AOD) at a given wavelength, Precipitable Water (PW), Ozone (O_3), etc and the medium's distance is defined by the Air Mass (AM), the relative path length through the atmosphere [1].

Therefore a set of atmospheric parameters (including AM, that can be isolated as another parameter) for a particular instant and place (AM, AOD, PW, O_3 …) defines a unique atmospheric moment, moreover a solar spectrum. However there are several attempts to describe the atmosphere by the means the so called "spectral indexes", unique numbers obtained by different methods that give an approach to define an atmospheric moment, basically to determine the spectral mismatch in a photovoltaic device. Examples of these indexes are useful fraction [2], spectral factor [3] and average photon index [4]. Useful fraction and average photon index are obtained from calculations on the spectrum, however spectral factor (or mismatch factor, is equivalent) is calculated with the spectral irradiance distribution and a solar cell spectral response, so it is device dependant.

Some attempts have shown uniqueness for these indexes [5], however a different set of atmospheric parameters on SMARTS has proved that is not possible strictly speaking [6]. This uniqueness is true only for an admitted level of uncertainty, what can be perfectly valid for Photovoltaics and Concentrating Photovoltaics (CPV) needs.

SPECTRAL MISMATCH RATIOS AS SPECTRAL INDEXES

Spectral Mismatch Ratios are defined to describe the atmosphere (or part of it) that a Multi Junction (MJ) cell sees in a given moment respect the reference spectrum defined by AM1.5D standard, making SMR especially interesting to use them as spectral indexes for CPV devices.

SMR Definition

The SMR is obtained as the ratio of two component cells (isotype cells) photocurrents that reproduce those from a MJ subcells at a particular spectrum divided by the same ratio at reference spectrum. Subsequently, we can define n-1 SMRs, where n is the number of junctions of the MJ cell.

10th International Conference on Concentrator Photovoltaic Systems
AIP Conf. Proc. 1616, 290-293 (2014); doi: 10.1063/1.4897080

$$SMR^i_j = \frac{CM^i_{j\,spec}}{CM^i_{j\,AM1.5D}} \quad (1)$$

where $CM^i_{\text{j}\,spec} = \frac{I_{L_i}}{I_{L_j}}$ $CM^i_{j\,AM1.5D} = \frac{I_{L_{iAM1.5D}}}{I_{L_{jAM1.5D}}}$

Spectral Index

Considering SMRs as spectral index would mean that a set of SMR values from a spectrum is directly correlated to the spectral parameters that define that spectrum. If this condition is true, it also means that a set of spectral parameters should correspond to a unique set of SMRs.

Consequently, it is necessary first to see the correlations between SMRs and AM, AOD and PW, as the most significant parameters that influence a spectrum, in decreasing order of influence.

EXPERIMENTAL PART

AERONET Network

AERONET network is a federation of ground-based remote sensing instruments (FIGURE 1), basically oriented to the measure of aerosols (AOD), but also includes other optical depth variables as water vapor, as PW (depth of water in a column of the atmosphere if all the water in the column were precipitated as rain, in cm).

Since AM is basically a function of solar geometry and altitude, it is possible using AERONET values to generate and describe a spectrum using a radiative transfer model, as SMARTS.

FIGURE 1. CIMEL Photometer, the instrument used by the AERONET network

AERONET instruments are worldwide and provide an excellent source of atmospheric parameters.

Isotypes Based Spectroheliometer

To obtain SMR values it is necessary an AM1.5D calibrated isotypes cells based spectroheliometer (FIGURE 2). The SMRs are obtained directly as a quotient between the instant photocurrents of two isotypes and then divided by the CM at reference spectrum.

The spectroheliometer used in this experiment is the tri-band spectroheliometer based in lattice-matched GaInP/GaInAs/Ge triple-junction isotypes. So there are two SMRs, SMR^{top}_{mid} (also named as SMR_1) and SMR^{mid}_{bot} (SMR_2).

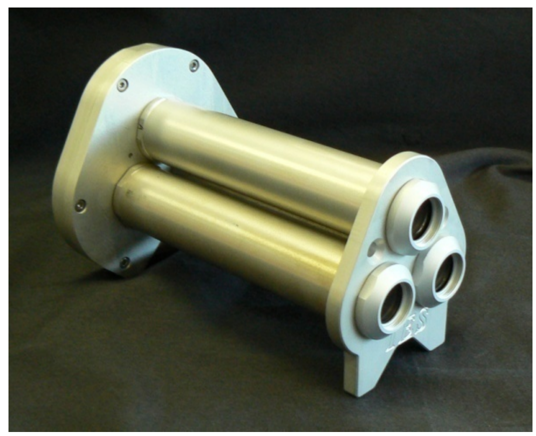

FIGURE 2. Tri-band spectroheliometer based in isotype cells

Isotypes networks are just now starting to be created. An example is the one under the European project SOPHIA, where a few spectroheliometers are being installed.

Experimental Data

In April 2012, a new AERONET photometer was installed in AEMET (Spanish Meteorology Agency), 300 m from IES-UPM building in Madrid, providing a unique chance to compare spectral parameters and SMRs.

Almost two annual periods of data are compared. SMRs are one minute resolution and AERONET data is acquired every 15 minutes. Only clear sky moments are considered.

ANALYSIS OF THE CORRELATION BETWEEN SPECTRAL PARAMETERS AND SMRS

Taking into account the part of the spectrum that the atmospheric parameters affect and the spectral response of the three component cells we can already guess some basic relations that orient the analysis below. AM and AOD affect basically top subcell and so on SMR_{mid}^{top}. PW does more on the bottom region and SMR_{bot}^{mid}.

In FIGURE 3**,** where we observe how a simple linear relationship between AOD and SMR_{mid}^{top} can be obtained; if the data are first filtered into bins of AM, showing that these parameters are easily to correlate. A similar analysis can be applied to SMR_{bot}^{mid}.

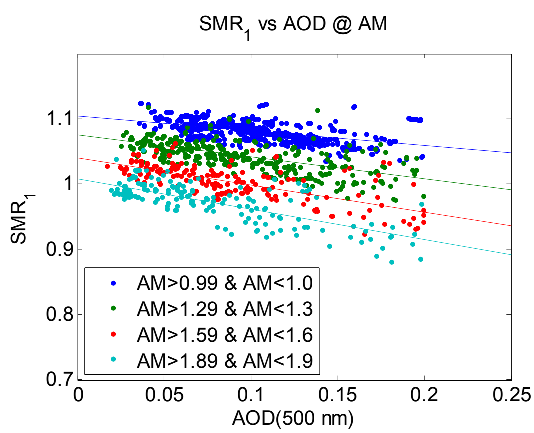

FIGURE 3. SMR_1 as functions of Aerosols and Air Mass

Using the data from spectroheliometer and AERONET station, taking into account the previous relationships and limiting the values to those where the 90% of accumulated energy is located in Madrid, (0.96>AM>2.24, 0.19>AOD>0.02, 0.45>PW>1.75) we have found a simple second order fit for the three main atmospheric parameters with the SMR_{mid}^{top}:

$$SMR._{mid}^{top} = 1.199 - 0.113AM - 0.0676AOD + 0.0256PW - 0.273AM \cdot AOD - 0.126AOD \cdot PW \quad (2)$$

Residual from fitting values minus the measured ones shows the good agreement of the proposed relationship. Additionally, in FIGURE 4 it can be noticed the fitting with only AM and AM+AOD. It is clear that AM cannot explain well SMR_{mid}^{top}, presenting a non-centered in zero fitting. The addition of PW improves slightly the standard deviation.

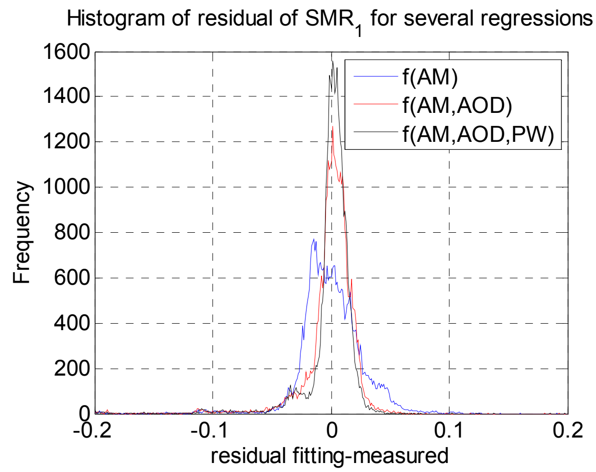

FIGURE 4. Histogram of residuals model-measurements for different models for SMR_1

TABLE 1. SMR_1 fitting goodness using different parameters

Fitting parameters	σ [residuals]
f(AM)	3.39%
f(AM,AOD)	3.00%
f(AM,AOD,PW)	2.96%

A similar fit has been found for SMR_{bot}^{mid}:

$$SMR_{bot}^{mid} = 0.921 - 0.181AOD + 0.0887PW - 0.0412AOD \cdot PW \quad (3)$$

Notice the lack of AM term, due to the low correlation coefficient between SMR_{bot}^{mid} and AM, and this in turn is due to a low influence of AM in the bottom subcell spectral region.

Both fits show symmetry and low dispersion in residuals, specially the one from SMR_{bot}^{mid}.

TABLE 2. SMR_2 fitting goodness using different parameters

Fitting parameters	σ [residuals]
f(AOD)	3.10%
f(PW)	1.82%
f(AOD,PW)	1.65%

From fittings it can be concluded that SMR_{mid}^{top} is strongly correlated to AM and AOD, since both affect basically the top subcell region and SMR_{bot}^{mid} can be used to explain the PW in the atmosphere, in this case due to the most of the water absorptions peaks are located in the bottom region. These correlations can be confirmed by SMARTS simulations, as it can be seen in FIGURE 5-7.

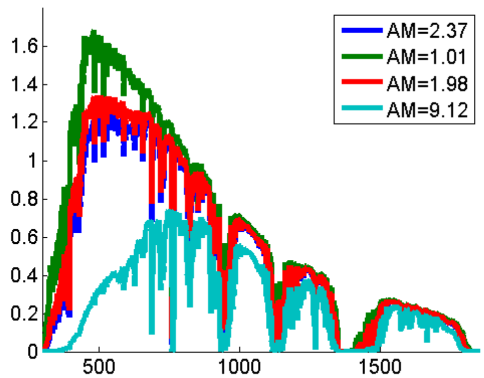

FIGURE 5. Influence of Air Mass on solar spectrum for typical values for Madrid

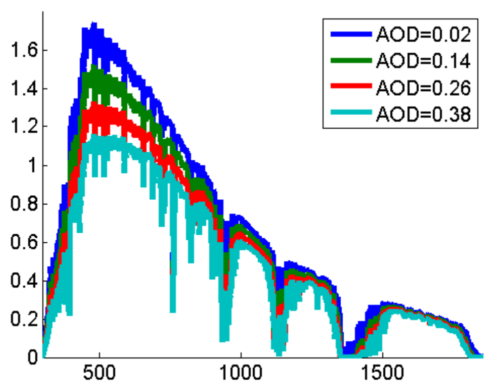

FIGURE 6. Influence of Aerosols on solar spectrum for typical values for Madrid

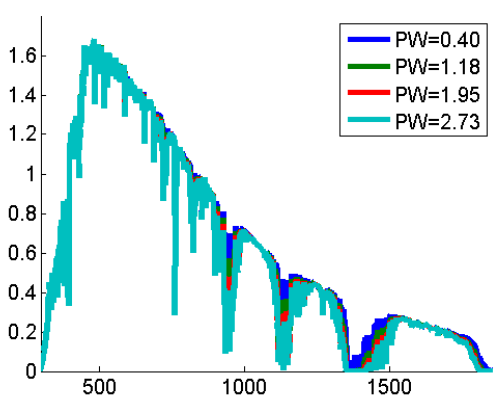

FIGURE 7. Influence of Precipitable Water on solar spectrum for typical values for Madrid

CONCLUSIONS

Since a CPV module can be in equivalent spectral conditions (in terms of performance) during different atmospheric parameters values, the most direct way to obtain the energy losses associated with spectral variation for specific CPV technology at a specific site is to collect SMRs values over the course of a year, for example with a Tri-band Spectroheliometer. However, in locations where such SMRs data is not available, but AERONET-type atmospheric data is, the simple correlation between atmosphere parameters and SMRs presented here may be used to estimate the spectral influence on energy performance of CPV systems based on MJ cells.

ACKNOWLEDGMENTS

The authors want to thank the AERONET responsible and concretely Juan Ramón Moreta González as the principal investigator of AEMET station in Madrid. This work has been partially supported by the Spanish Ministry of Science and Innovation under the SigmaPlantas Project (SIGMAPLANTAS IPT-2011-1468-920000) and by the European Commission through the funding of the project NGCPV (Grant Agreement No. 283798). Rubén Núñez is thankful to the Spanish Ministerio de Economía y Competitividad for his FPI grant.

REFERENCES

1. M. Muller, et al, “An investigation into spectral parameters as they impact CPV module performance” in AIP Conference Proceedings (2010), p. 307.
2. R. Gottschalg, et al, “The effect of spectral variations on the performance parameters of single and double junction amorphous silicon solar cells” Solar Energy Materials and Solar Cells **85**, 415 (2005).
3. J.J. Pérez-López, et al,” Experimental solar spectral irradiance until 2500 nm: results and influence on the PV conversion of different materials” Progress in Photovoltaics: Research and Applications **15**, 303 (2007).
4. T.R. Betts, et al, “Impact of spectral effects on the electrical parameters of multijunction amorphous silicon cells” in Photovoltaic Energy Conversion, 2003. Proceedings of 3rd World Conference on (2003), pp. 1756–1759.
5. T. Minemoto, et al, “Uniqueness verification of solar spectrum index of average photon energy for evaluating outdoor performance of photovoltaic modules” Solar Energy **83**, 1294 (2009).
6. C.A. Gueymard, “Daily spectral effects on concentrating PV solar cells as affected by realistic aerosol optical depth and other atmospheric conditions” in Optical Modeling and Measurements for Solar Energy Systems III (2009), pp. 741007–741007–14.