SOLAR SPECTRAL IRRADIANCE DERIVED FROM SATELLITE DATA: A TOOL TO IMPROVE THIN FILM PV PERFORMANCE?

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CONTENT

‣ Background
  Why is spectral information so important to PV

‣ Concept
  How satellite data can help to provide this information

‣ Spectral mismatch
  Quantifying the spectral dependency

‣ Measurements
  Solar spectrum, PV system performance

‣ Results
Photovoltaic materials absorb sunlight in a rather narrow spectral interval according to their band gap.

All solar cells show a distinct sensitivity to the spectral distribution of sunlight.

"REAL" SOLAR SPECTRAL IRRADIANCE

Large deviations from Standard Test Conditions (STC)
**SPECTRAL SENSITIVITY WITH ATMOSPHERIC CONDITIONS**

Clouds, water vapor: shift to shorter wavelengths

Aerosols, air mass: shift to longer wavelengths

from radiative transfer calculations (libRadtran)

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**SPECTRAL RESPONSE & SHORT CIRCUIT CURRENT**

The spectrally resolved irradiance $G(\lambda)$ affects the short circuit current $I_{sc}$ of a PV device (with surface area $A$) depending on the materials’ spectral response (SR):

$$I_{sc} = A \int SR(\lambda) G(\lambda) d\lambda$$

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![Graph showing spectral response and short circuit current](image-url)
**APPROACH**

**Generic**
- Spectral solar irradiance
- Thin film SC spectral response
- Short circuit current

**Measurement**
- Module measurement
- Thin film SC simulation
- Short circuit current

**Simulation**
- Satellita data
- Modelled solar spectra
- Thin film SC simulation
- Short circuit current

**SPECTRAL IRRADIANCE ALGORITHM**

Cloud information from satellite data

- "HELIOSAT" algorithm
  - Clear sky index $k^*$
  - Spectral cloud correction
  - Spectrally resolved horizontal irradiance
  - Global-, direct and diffuse irradiance
  - Spectrally resolved irradiance on inclined plane

Solar geometry, atmospheric constituents (water vapor, aerosols, ozone)

- "SOLIS Clearsky" algorithm
  - Spectra $G_{clear}$

\[ G = k^* \cdot G_{clear} \]
PV MEASUREMENTS

- amorphous silicon (a-Si)
- poly-crystalline silicon (pc-Si)
- CIS
- a-Si/μ-Si tandem module

SPECTRAL MEASUREMENTS

Scanning spectrometer (SPECTRO 320) with single monochromator
- spectral range: 250–1700 nm (PMT and InGaAs photo detectors)
- one minute duration for one complete spectral measurement

Ulbricht sphere as optical input

Broadband irradiance measurements
**SPECTRAL MISMATCH**

Characterizing the effect of a non-STC (AM1.5) spectrum on the short circuit current

Normalizing the short circuit current with respect to Standard Test Conditions (STC)
- Normalizing the short circuit current with global irradiance
- Normalizing with STC irradiance

\[
\text{sMMF} = \frac{\int_{a}^{b} SR(\lambda) G(\lambda) d\lambda}{\int_{a}^{b} G(\lambda) d\lambda} \left( \frac{\int_{a}^{b} SR(\lambda) G_{STC}(\lambda) d\lambda}{\int_{a}^{b} G_{STC}(\lambda) d\lambda} \right)^{-2}
\]

--> spectral mismatch factor (sMMF)

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**SPECTRAL VS. REFLECTION EFFECTS**

Global irradiance in sMMF definition is corrected for reflection effects using a surface reflection model

![Graphs showing spectral vs. reflection effects](Image)
RESULTS: MODULE MEASUREMENTS COMPARED TO SOLIS

all sky conditions

- Relative gain at overcast situations (low clearsky index) for all modules – well reproduced by satellite data
- Overall spectral gain for a-Si and a-Si/μ-Si, loss for pc-Si and CIS
- Error bars represent error of data sheet information for $I_{SC,STC}$

RESULTS: SPECTRAL MEASUREMENTS COMPARED TO SOLIS

w/o overcast conditions

- Spectral measurements and satellite data show qualitatively same results
- Overall gain due to spectral shift
### VALIDATION WITH GROUND MEASUREMENTS

- One year of measurement data (Stuttgart, Southern Germany)
- Underestimation for low solar altitudes (i.e., large zenith angles)

![Graph showing comparison between ground data and SOLIS/satellite data for APE [eV] over solar altitude [°] on a clear sky index scale.](image)

### SUMMARY & OUTLOOK

- Quantitative good representation of spectral mismatch and its influence on system performance

- Further research necessary:
  - Spectral effects for irradiance on inclined surface (current algorithm shows a red shift)