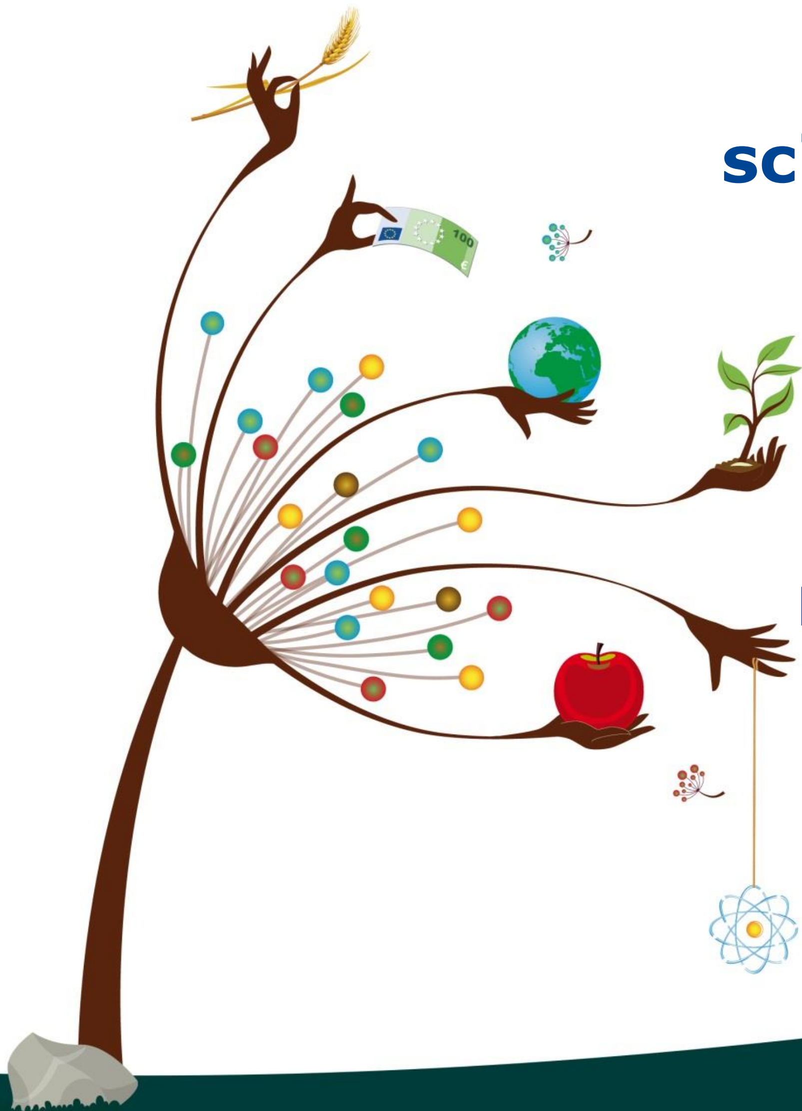
European Commission

The European Commission's science and knowledge service



Joint Research Centre

Directorate C. Energy, Transport and Climate

Energy Efficiency and Renewables Unit

Joint Research Centre

IEC 61853-3

Standard for calculating the energy rating of PV modules

Thomas Huld, Ana Gracia Amillo, Ewan Dunlop

European Commission, Joint Research Centre, Ispra

7th Energy Rating and Module Performance Modeling Workshop,
30th – 31st March 2017, Lugano

European Commission

Overview of presentation

1. Existing standards and IEC 61853 so far
2. Relation of IEC 61853-3 to the first two parts
3. Models included in IEC 61853-3

Why a standard on PV energy rating?

The existing standard for measuring PV module power calls for specific conditions (Standard Test Conditions):

- In-plane irradiance $G=1000 W/m^2$
- Module temperature $T_{mod}=25°C$
- A standard solar spectrum (so-called AM 1.5 spectrum)

These conditions are convenient for laboratory and factory measurements but do not represent real operating conditions in most places and times.

There is a need for a better representation of PV performance.

Effects influencing PV conversion efficiency

The performance of PV modules depends on a number of external influences apart from, of course, the solar radiation:

- Reflection of light from the module surface depends on angle of incidence
- The PV conversion efficiency changes with module temperature and radiation intensity
- Module temperature in turn depends on local temperature, irradiance and cooling by wind
- Variations in the spectral content of sunlight influences PV power
- Long-term degradation depends on climatic conditions (but how?)

IEC 61853, the story so far

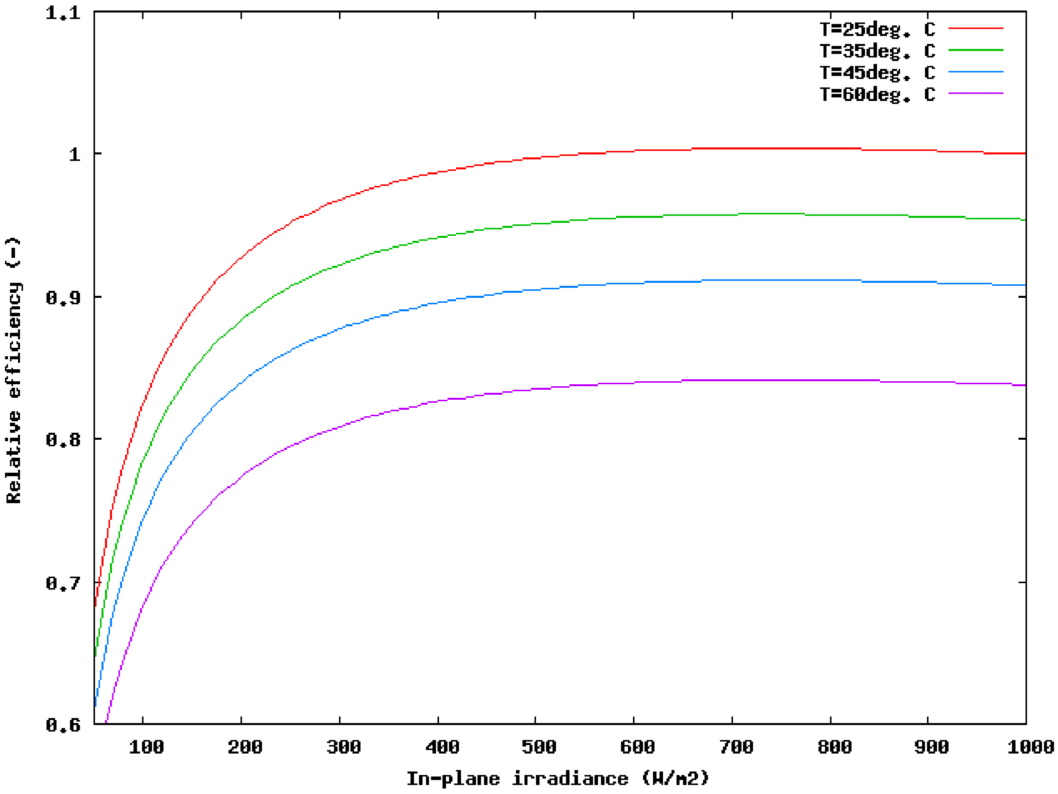
IEC 61853-1:

This part of the standard prescribes measurements of a ‘matrix’ of power values at different values of in-plane irradiance and module temperature:

- Irradiance values between 100W/m^2 and 1100W/m^2
- Module temperatures between 15°C and 75°C

A few of the measurements in the matrix are not needed because they correspond to conditions that are not found in reality (very high module temperature at low irradiance).

PV efficiency curves



Efficiency as a function of irradiance and temperature, c-Si modules

IEC 61853, the story so far

IEC 61853-2:

This part of the standard deals with other effects influencing PV performance:

- Variations in reflectivity as a function of incidence angle (angle-of-incidence effect)
- Spectral response measurements
- Module temperature as a function of irradiance, ambient temperature and wind speed

For the AOI effect and the module temperature, part 2 specifies fitting the measured data to models.

Models and data needed in IEC 61853-3

Angle-of-incidence (AOI) effects, model by Martin&Ruiz, 2001.

- Requires in-plane direct and diffuse irradiance

Spectral response, numerical integration of spectral response curve.

- Requires in-plane direct and diffuse spectrally resolved irradiance, corrected for AOI

Module temperature, model by Faiman (2008).

- Requires in-plane AOI-corrected irradiance, ambient (air) temperature and wind speed

PV module power, interpolation of power matrix measured according to IEC 61853 part 1.

- Requires in-plane AOI-corrected irradiance and module temperature

Angle-of-incidence (AOI) effects

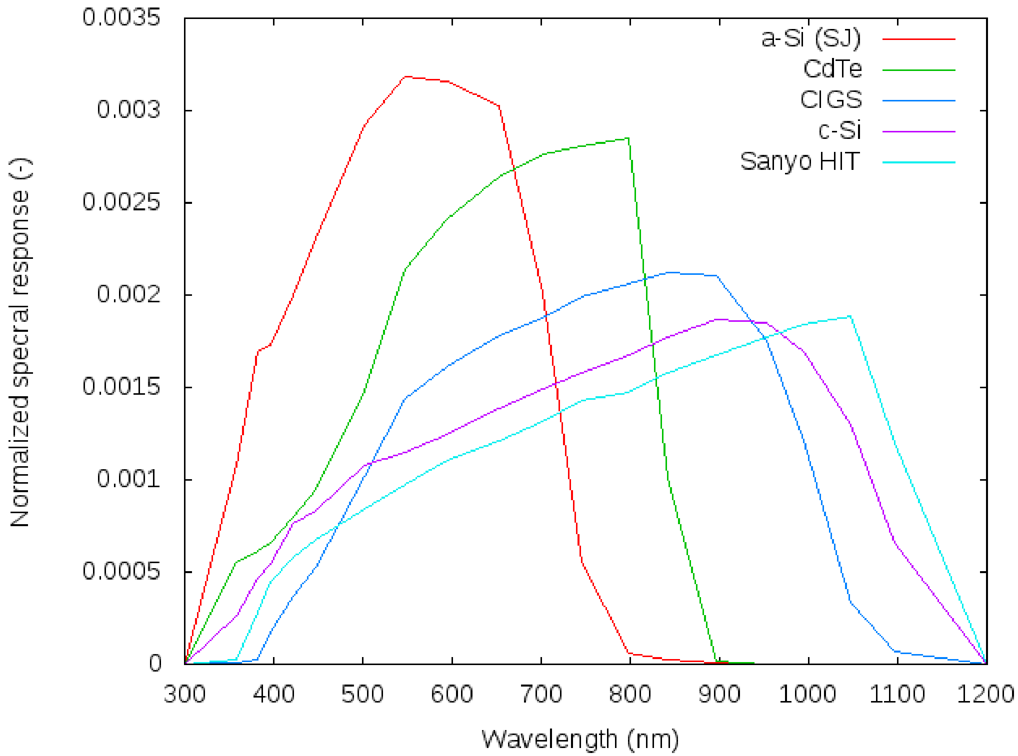
Given the in-plane beam and diffuse irradiance, B_p and D_p, the corrections due to AOI can be written (Martin&Ruiz, 2001):

$$B_{corr} = B_p \left[\frac{1 - exp\left(-\frac{\cos\theta}{a_r}\right)}{1 - exp\left(-\frac{1}{a_r}\right)} \right]$$

$$D_{corr} = D_p \left\{ 1 - exp\left[-\frac{1}{a_r} \left(\frac{4}{3\pi} \left(\sin\beta + \frac{\pi - \beta - \sin\beta}{1 + \cos\beta} \right) + (0.5a_r - 0.154) \left(\sin\beta + \frac{\pi - \beta - \sin\beta}{1 + \cos\beta} \right)^2 \right) \right] \right\}$$

Here, θ is the angle between the module surface normal and the incident direct irradiance, β is the inclination angle of the module from horizontal, and a_r is a coefficient that must be determined from measurements (IEC 61853 part 2).

Spectral response curves



Normalized spectral response curves for 5 different modules, measured at the ESTI laboratory

Calculating the influence of spectrum

Given the spectral response of a subcell *l* of a PV device (*SR)*, the short-circuit current can be written as:

$$I_{sc,l} = k \int SR_l(\lambda)\, G_\lambda\, d\lambda$$

where *k* is a proportionality factor and G_λ is the spectrally resolved irradiance. At each point in time we define a spectral correction factor: $C_{s,l}$ for subcell *l*:

$$C_{s,l} = \frac{\int SR_l(\lambda)\, G_\lambda\, d\lambda}{\int SR_l(\lambda)\, G_{\lambda,STC}\, d\lambda} \frac{\int G_{\lambda,STC}\, d\lambda}{G_\lambda\, d\lambda}$$

Here, $G_{\lambda,STC}$ is the STC spectrally resolved irradiance.

Since SR is measured at discrete wavelengths the integrals are evaluated using numerical integration

Calculating the influence of spectrum

The overall spectral mismatch of the device can then be found using:

$$MM = \frac{\sum_{j=1}^{N} C_{s,l} \ G_j}{\sum_{j=1}^{N} G_j}$$

In this calculation $C_{s,l}$ is the spectral correction factor for the subcell that is current-limiting at hour j.

Model for module temperature

Given ambient temperature T_{amb}, wind speed v and in-plane irradiance G_p (corrected for AOI), the module temperature T_{mod} is given as:

$$T_{mod} = T_{amb} + \frac{G_p}{u_0 + u_1 v}$$

This model is taken from Faiman (2008). The coefficients u_0 and u_1 must be determined by fitting to measured data (IEC 61853 part 2).

Calculating PV power

Once we have the spectrally corrected irradiance and the module temperature we can calculate the PV power.

For (G,T_{mod}) values inside the boundaries of the measured matrix, the power value is found by bilinear interpolation.

In case the (G,T_{mod}) values lie outside the range of measured values in the matrix, the power values are found by bilinear extrapolation from the last pair of values in the matrix.

Values of in-plane G and T_{mod} are calculated from the standard data sets supplied as part of IEC 61583-4.

Acknowledgments

Part of the work presented here was carried out within the EMRP ENG55 Project “Towards an energy-based parameter for photovoltaic classification”.

European Commission

References

1. Martin, N.; Ruiz, J. *Solar Energy Mater. Solar Cells,* **70**, 25–38 (2001)
2. Faiman, D. Prog. *Photovolt. Res. Appl.,* **16**, 307–315 (2008)
3. Müller, R.; Behrendt, T.; Hammer, A.; Kemper, A. *Remote Sens.*, **4**, 622–647, (2012)
4. Koehl, M.; Heck, M.; Wiesmeier, S.; Wirth, J. *Solar Energy Mater. Solar Cells,* **95**, 1638–1646 (2011)
5. Huld, T.A.; Friesen, G.; Skoczek, A.; Kenny, R.A.; Sample, T.; Field, M.; Dunlop, E.D. *Solar Energy Mater. Solar Cells,* **95**, 3359–3369 (2011)
6. Gracia Amillo, A.; Huld, T.; Vourlioti, P.; Müller, R.; Norton, M. *Energies*, **8**, 3455-3488 (2015)
7. Huld, T. and Gracia Amillo, A. *Energies*, **8**, 5159-5181 (2015)