PV Module Modelling in PVsyst, in View of IEC 61853

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André Mermoud, Bruno Wittmer
Bruno.Wittmer@pvsyst .com

PVSYST SA - Route du Bois-de-Bay 107 - 1242 Satigny - Suisse
www.pvsyst.com

Overview

- Low light behavior
- Power Classes
- IAM measurements: Indoor vs Outdoor
- PV module operating temperature
- Spectral corrections
- Summary and Outlook

Introduction: Production forecasts, simulation features

Basic parameters: STC specifications (P_{nom} nameplate)

Only measurement: factory output flash-tests (for sorting modules), uncertainty 3%

Real-life parameters: Module quality, LID, Mismatch, Ageing, …

used as input parameters (i.e. hypothesis) in the simulation

The norm doesn't describe these parameters.

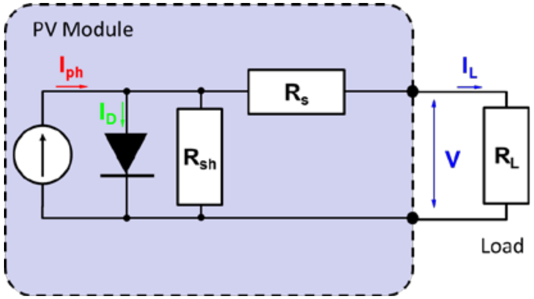
Simulation: describes the behavior acc. to environmental variables:

Irradiance:	Low-light performance data
Temperature:	One-diode model (almost linear, measurements)
IAM:	Measurements (outdoor or Indoor) of the IAM function
Spectral response:	Implemented for amorphous in PVsyst.
	Neglected for Crystalline and CIS technologies

Default values for the environmental simulation parameters lead to very similar PR results (only based on STC) for any module of a same technology.

Model Parameters in PAN File

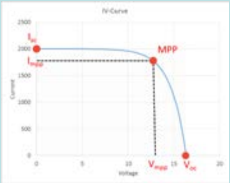
- File in PVsyst, holding all information on a PV module type.
- Central information are the Model Parameters.
- PVsyst uses the single-diode model with 5 (+3) parameters
- Minimum requirement to determine them, is a measurement at STC.



PAN file

Temperature Coefficients

3 points of IV curves at different irradiances and temperatures



3 points of IV curve at STC (min. req.)

Model Parameters

I_{ph} : Photocurrent

I_s : Saturation Current

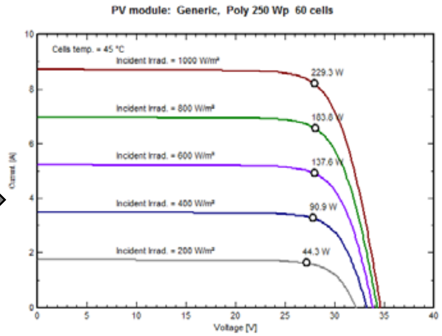
γ : Ideality factor ($\mu\gamma$)

R_{sh} : Shunt resistance (R_{sh0}, R_{shexp})

R_s : Series Resistance

Accessory information

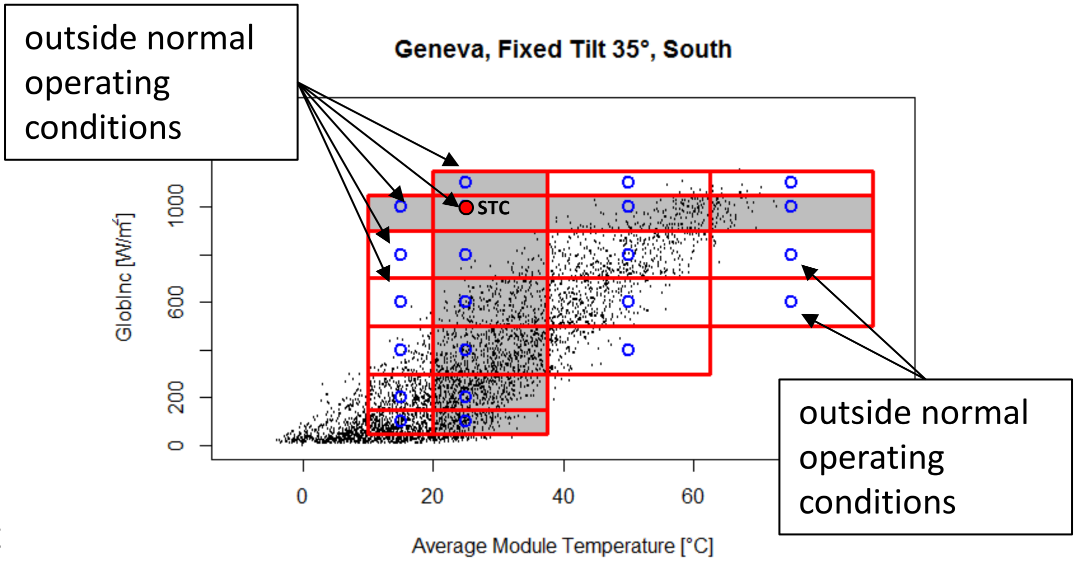
Module size	Nb. of bypass diodes	
Cell size	IAM behavior	etc...
Nb. of cells	Prices	



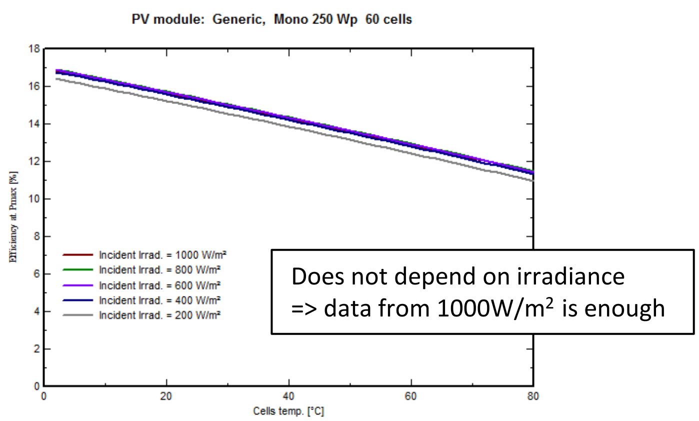
Complete IV curves for any temperature and irradiance

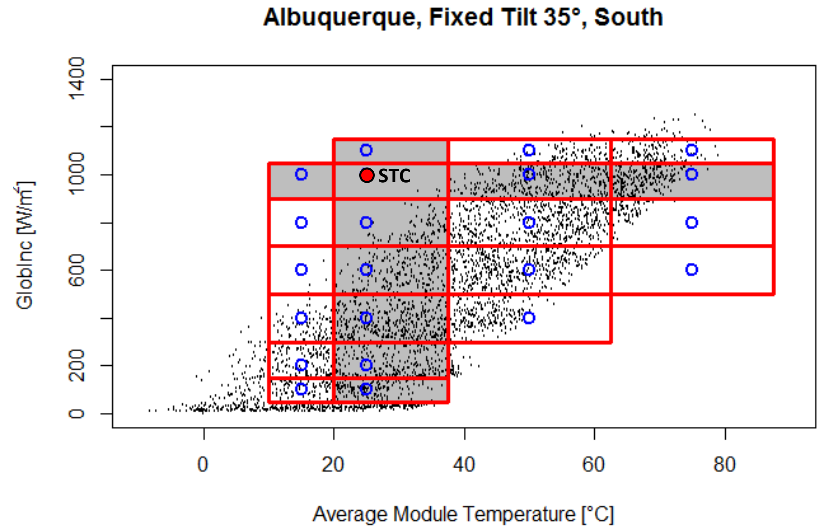
IEC 61853 Irradiance & Temperature Matrix

- STC do not represent normal operating conditions
- The IEC 61853 Matrix covers well typical operating conditions
- Not all points of the matrix have the same weight/importance for real PV installations
- To determine model parameters for the PVsyst database we use points at 1000 W/m^2 (Temperature dependences) and points at 25°C (R_s / low light behavior)
- It could be useful to use also the points at 50°C as constraint for the model parameters



Temperature dependence of efficiency

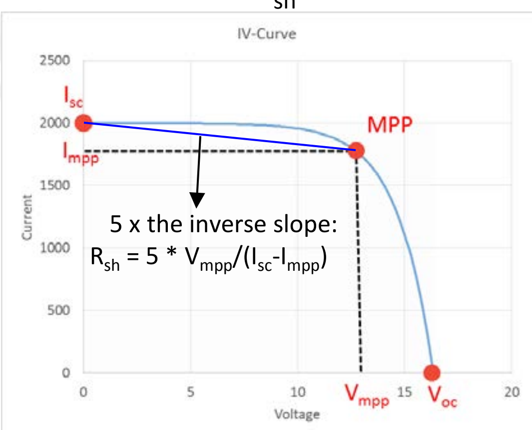




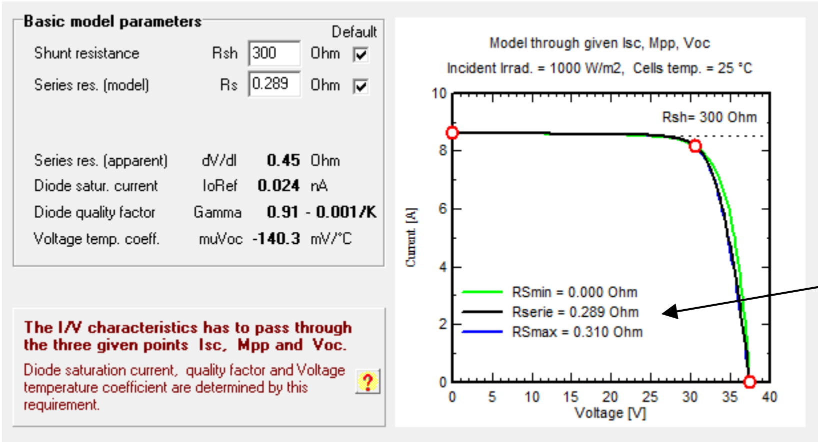
Determining Series and Shunt Resistance

To determine Single diode model parameters the minimal requirement are STC values (I_{sc}, V_{oc}, V_{mpp}, I_{mpp})
These points fix 3 of the 5 model parameters
R_s/R_{sh} can be varied within some range and still fit STC values
R_{sh} default estimation in PVsyst: $R_{sh} = 5 \cdot \frac{V_{mpp}}{I_{sc} - I_{mpp}}$

STC values and R_{sh} estimation



R_s range that fits given STC parameters (R_{sh} fixed)



$R_s = 0 – 310\ m\Omega$

R_s has a strong impact on the low-light behavior!

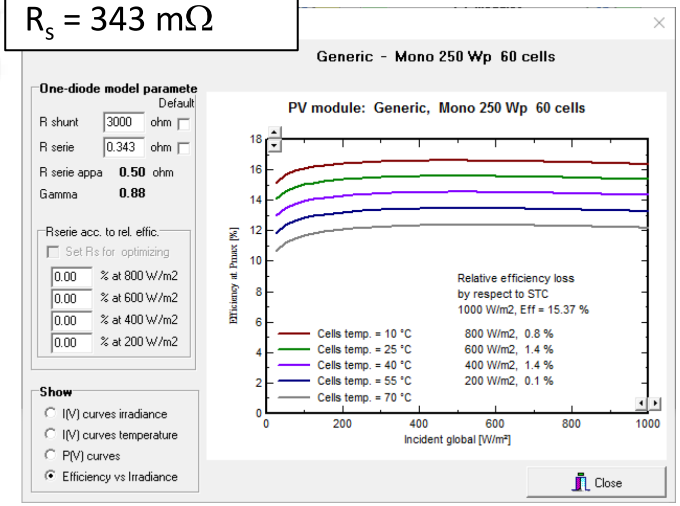
Series Resistance R_s and Low-Light Behavior

The low light efficiency is strongly influenced by the Series resistance R_s

Both R_s values fit the same STC measurement

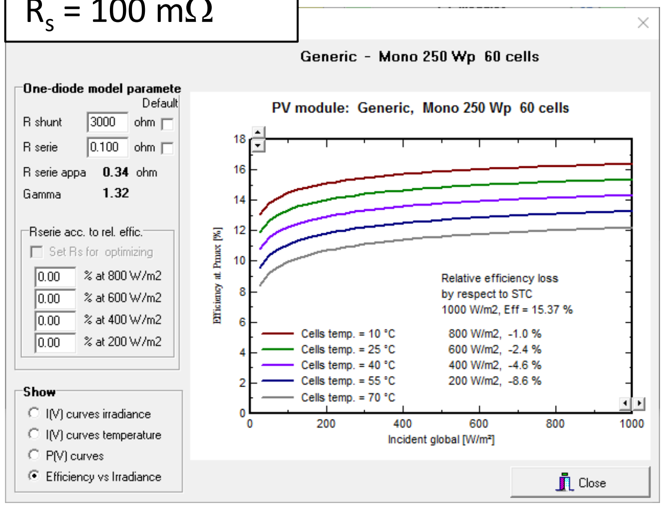
Large R_s -> No efficiency loss at low irradiance!

R_s = 343 mΩ



Small R_s -> Large efficiency loss at low irradiance!

R_s = 100 mΩ

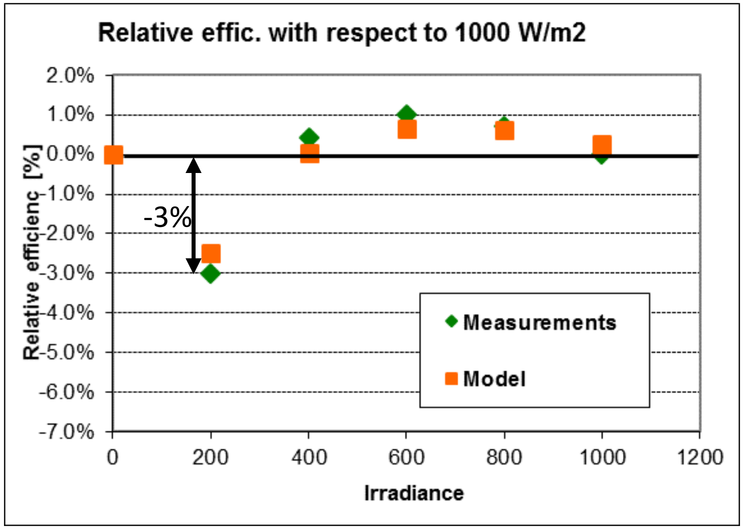


Choosing a deliberately high values for R_s will overestimate the module's low light performance

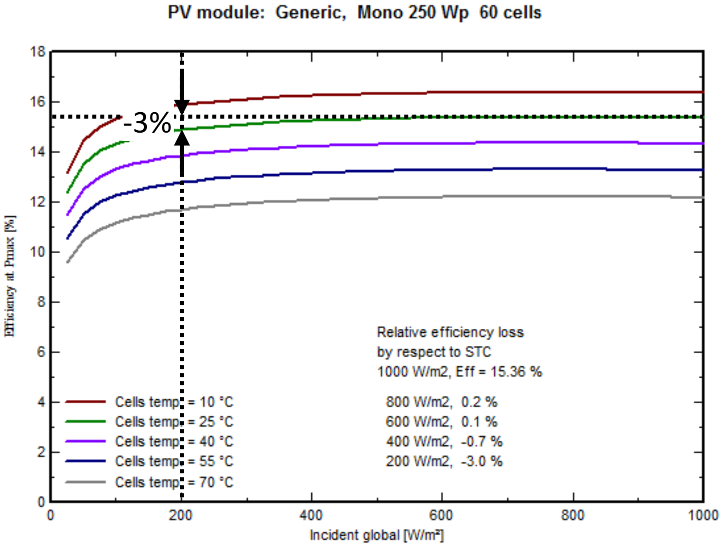
Determining R_s from Low-Light Behavior

The low light efficiency is strongly influenced by the Series resistance R_s => Determine R_s from low light measurements
If no measurements are available, we assume 3% of relative efficiency between 1000 W/m² and 200 W/m²at 25°C
The Irradiance/Temperature matrix in IEC 61853-2 fills this gap

Determining R_s from low light behavior



Only STC measurement available:
Default efficiency drop at 200W/m² is 3%



Recently very good Si-modules (small R_s) have appeared on the market with relative efficiency loss > 3%
=> Should the 3% be adapted to larger values?

Parameters for different Power Classes

- PV module performance data for several power classes is often based on measurements of a single power class.
- There is no standard way to extrapolate from one power class to another.
- Multi-parameter fits to all IEC 61853 Matrix points give very different results if performed on different power classes of the same module series.

Example of one (non-PVsyst) approach:

1. Measurements are available for one power class (305Wp in the example)
2. Module parameters obtained from global fit on measurements
3. Data points from 305 W_p are extrapolated to 310 and 315 W_p and then the fit is repeated

P_{nom} [W]	R_s [W]	R_{sh} [W]	$R_{sh}(0)$ [W]	R_{shexp} [m^2/W]
305	0.550	399	1513	12.4
310	0.494	401	1516	12.4
315	0.471	385	1321	8.7

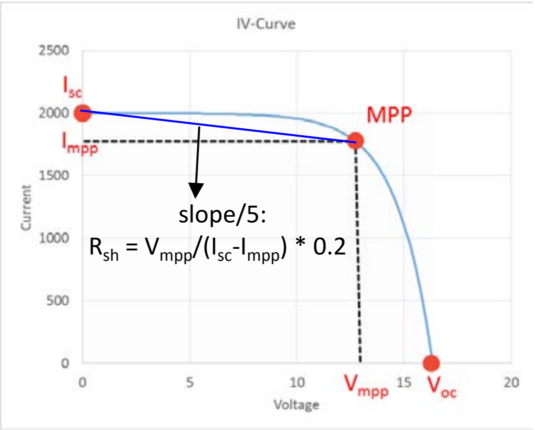
Model parameters do not seem to follow any pattern.
Extrapolating to yet another power class: need to go through the fit procedure on all rescaled data points.

PVsyst approach for different Power Classes

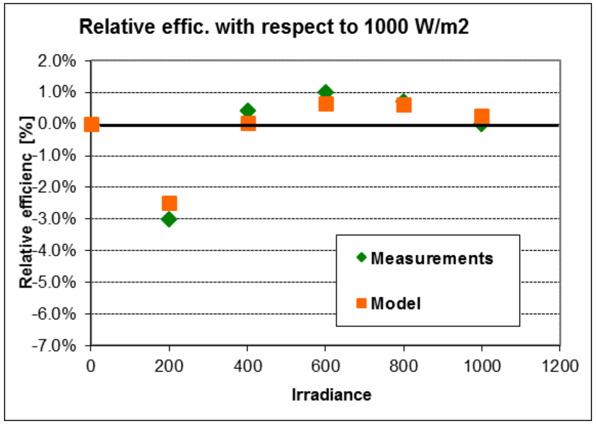
- PVsyst approach focusses on keeping model parameters stable
- Make it easier to introduce new power classes
- Works also if only STC values are available

Procedure:
1. STC values are known for each power class => R_{sh} can be estimated
2. Low light behavior of measured power class is known => R_s can be obtained for this class
3. Presently the low-light behavior (efficiency loss at 200 W/m²) is assumed to stay the same => R_s for all other classes

STC values and R_{sh} estimation



Determining R_s from low light behavior



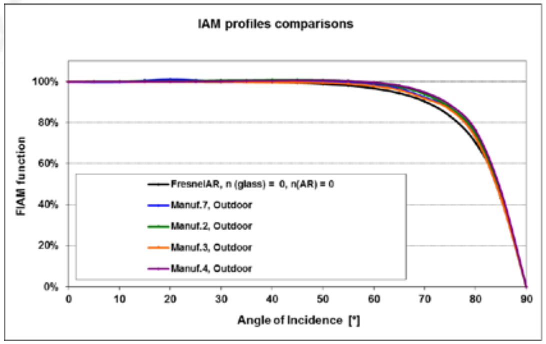
Are there thoughts to standardize any procedure to extrapolate to different power classes?

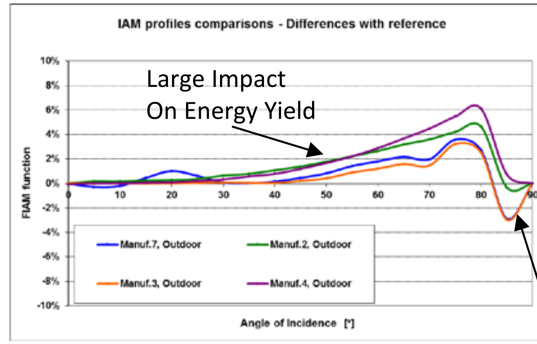
Measurements of different power classes are a necessity

Incidence Angle Modifier (IAM)

- Outdoor measurements display strong variations.
- Indoor measurements match very well basic Fresnel law calculations.

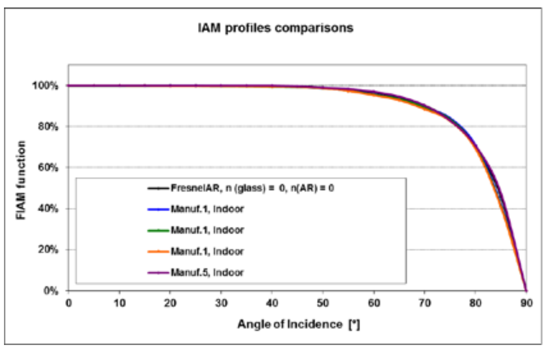
Outdoor
Measurements
(AR coating)

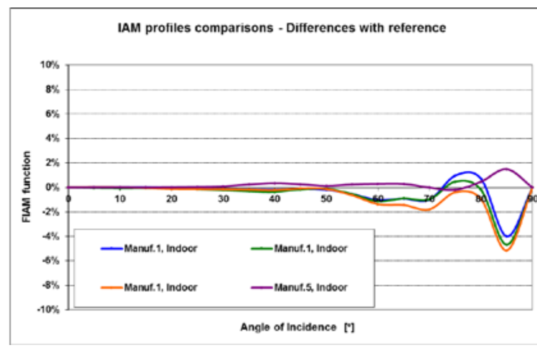




Examples of measurements received from different manufacturers

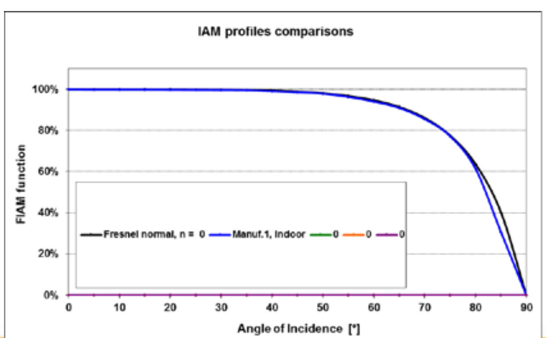
Indoor
Measurements
(AR coating)

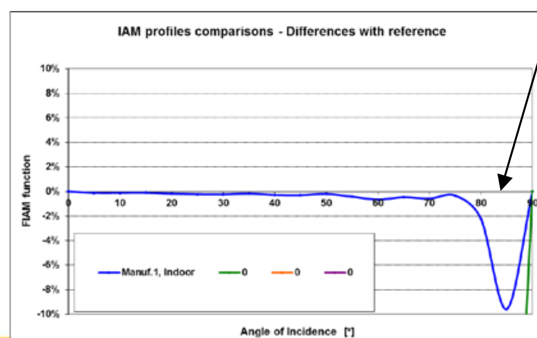




IAM of large angles
is always hard
to measure

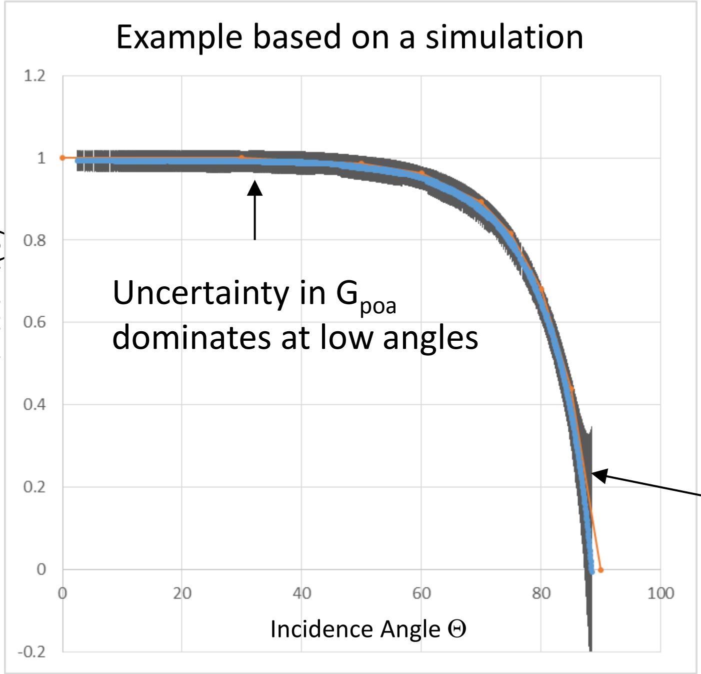
Indoor
Measurements
(no coating)





IAM Measurement Uncertainties

- Outdoor measurements suffer more from measurement uncertainties.
- Especially the diffuse component introduces additional difficulties



● $1 + (G_{eff}-G_{poa})/(G_{dni}\cos(\Theta))$

● IAM function

▌ Uncertainty range

2% uncertainty on G_{poa}
0.5° uncertainty on Θ

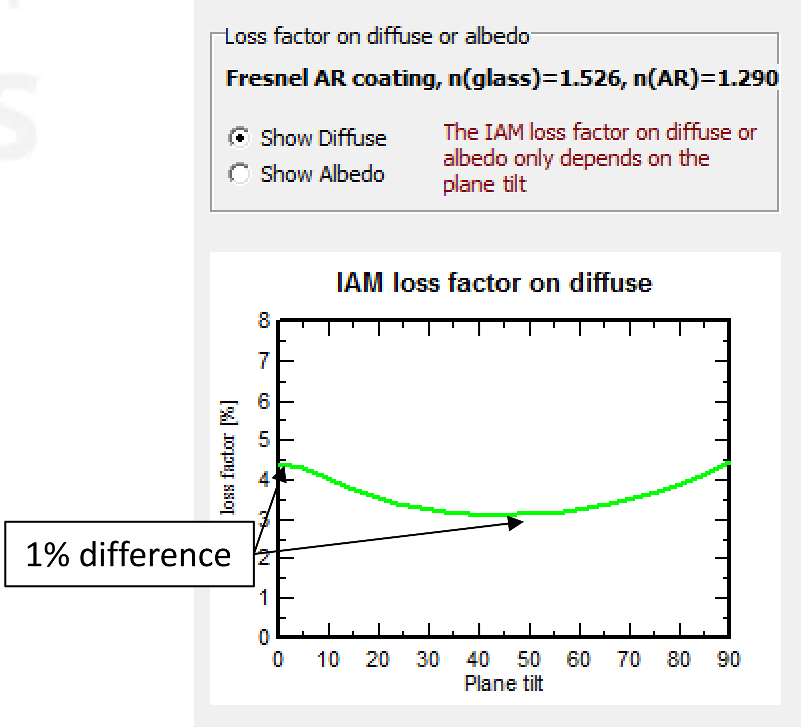
Uncertainty in Incidence Angle Θ dominates at large angles

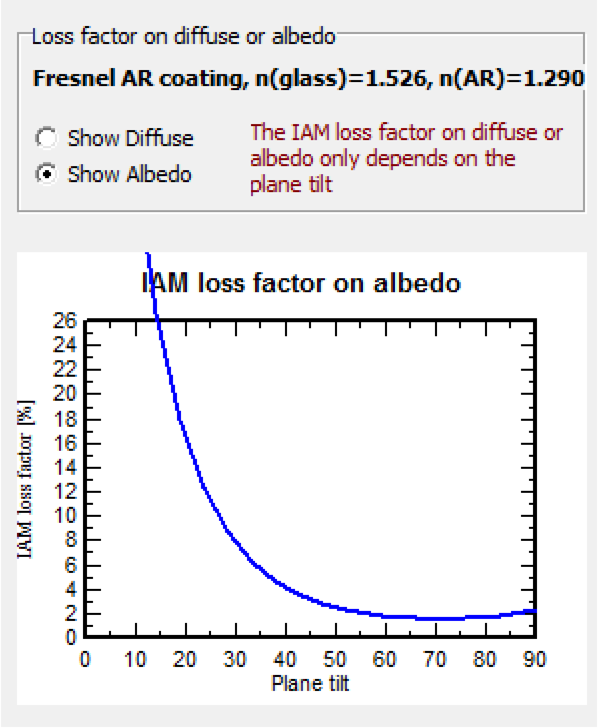
Uncertainty in G_{dni} has almost no impact
G_{eff} is obtained from I_{sc} (small measurement uncertainty)

For indoor measurements only Incidence Angle Θ and Short-Circuit current I_{sc} need to be measured.
Incidence Angle Θ can be controlled better in indoor measurements.

IAM Measurements Outdoor vs Indoor

– Outdoor measurements suffer more from measurement uncertainties.
– IAM on diffuse sky and albedo is neglected
– Circumsolar contribution is treated as direct irradiance -> uncertainty in Θ
– **For the Module Database in PVsyst, only indoor measurements are now accepted.**





PV Module operating temperature

- The determination of the temperature coefficients as described in the standard are slightly different than the PVsyst model.
- PVsyst starts from energy balance, including module efficiency and reflection losses.
- The model in IEC 61853 assumes a constant module efficiency. This can lead to a small systematic bias in the temperature behavior.

IEC 61853 $$(U_0 + U_1 \cdot v) \cdot \Delta T = G \qquad U_{c,v} = U_{0,1} \cdot \alpha(1 - Eff)$$

PVsyst $$(U_c + U_v \cdot v) \cdot \Delta T = G \cdot \alpha \cdot (1 - Eff) \qquad U_{0,1} = \frac{U_{c,v}}{\alpha(1 - Eff)}$$

ΔT : Module Temperature – Ambient Temperature

G : Irradiance in Plane of Incidence

v : Wind Speed

α : Absorption coefficient (0.9)

$Eff(T, G)$: Module Efficiency (depends on Temperature and Irradiance)

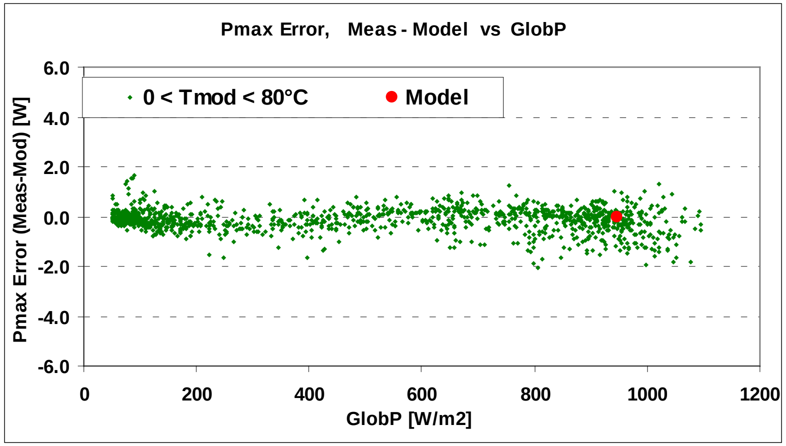
Spectral corrections in PVsyst

Amorphous: Parametrization proposed by CREST, fct (air mass, Kt)

CdTe: Correction proposed by First Solar (from precipitable water contents)
Not yet implemented in PVsyst.

Crystalline and CIS: Neglected in PVsyst

Justification: continuous I/V measurements at sun during one year at Geneva
Measurement in any conditions of irradiance and temperature



P_{mpp} Difference Model-Measurement:

Crystalline : RMS = 1.0 % of P_{nom}
CIS: RMS = 0.7 % of P_{nom}

These differences include:

- measurement errors
- model uncertainties

$\Rightarrow$ The possible spectral correction for Geneva climate is part of these model uncertainties !!!

Summary and Outlook

- IEC 61853-2 measurements are very important to specify low-light behavior.
- Extrapolation to different power classes is not covered by standard.
- Outdoor IAM measurements suffer from measurement uncertainties.
  For the PVsyst database only indoor measurements are now accepted.
- Module operating temperature coefficients are defined slightly differently in PVsyst and IEC 61853-2 and need to be converted.
- In PVsyst spectral corrections are only applied for a-Si modules.
  Crystalline Si spectral correction seems negligible.
  First Solar spectral correction for CdTe will be implemented.
- IEC 61853 part 3&4 Energy ratings calculated for specific climates are the aim of PV modelling programs. The values from the standard could be mentioned on the final report for reference only.