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Performance assessment of a simulation model for PV modules of any available technology

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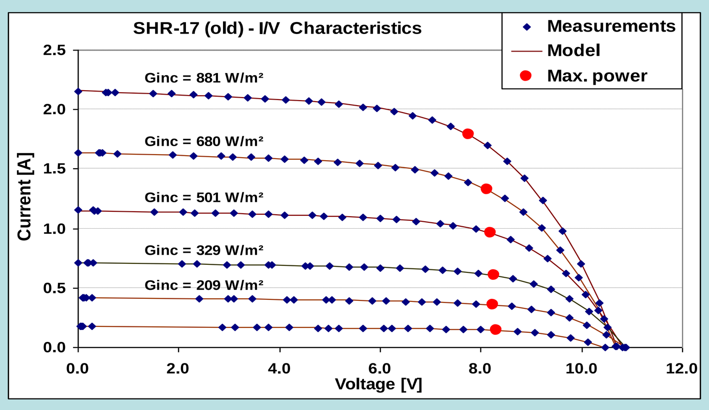
ABSTRACT

From long-term detailed measurements of several PV modules of all commercialized technologies, this work aims to analyze the results of the "standard" one-diode model, and suggests some modifications for improving it, especially for amorphous, microcrystalline and CdTe modules. We found that for any module an exponential behaviour of the shunt resistance parameter should be taken into account. We identified two other corrections (recombination losses and spectral correction) in order to improve the modelling of amorphous technology modules. These improvements are implemented in the PVsyst software developed at the University of Geneva.

1. Experimental setup

Model results evaluation

based on I/V measurements
under any Irradiance and
any Temperature conditions
(i.e. long term outdoor measurements).



Detailed I/V curve measurements

Time step 10 minutes.

Clean sample

Selection of measurements with stable Irradiance.

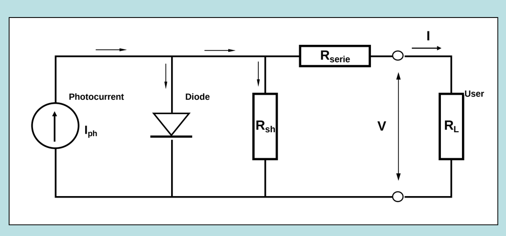
Technical corrections

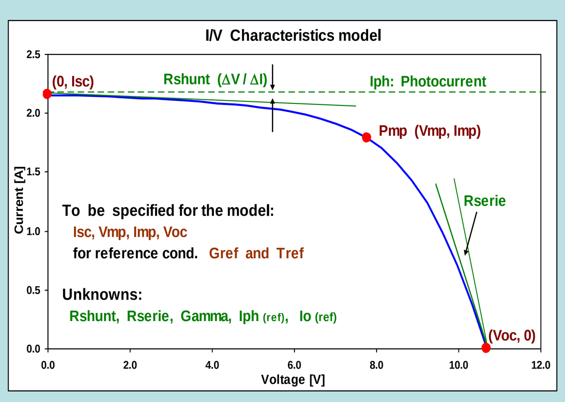
Incidence correction (IAM) on irradiance.

2. The standard "one-diode" model

I/V characteristics:

$$I = I_{ph} - I_0\left[e^{q\frac{V+I\cdot R_{serie}}{N_{cells}\cdot\gamma k T_c}} - 1\right] - \frac{V+I\cdot R_{serie}}{R_{shunt}}$$





The model has to pass through the 3 special points
(0,Isc), (Vmp,Imp), (Vco, 0)

Iph ≅ Isc is proportional to the irradiance

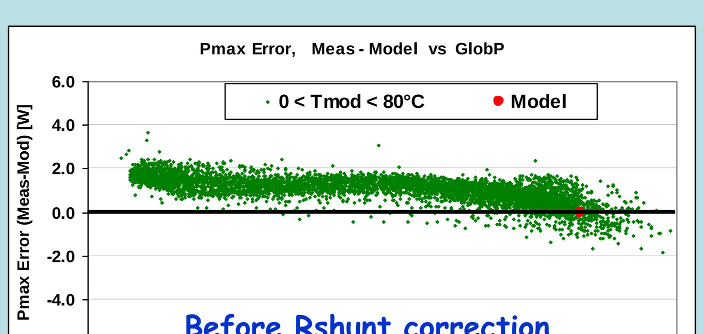
Thermal behaviour: depends exponentially on gamma and Egap:

$$I_0 = I_{0,ref}\left(\frac{T_c}{T_{c,ref}}\right)^3 \times e^{\left[\left(\frac{qE_{gap}}{\gamma k}\right)\left(\frac{1}{T_{c,ref}} - \frac{1}{T_c}\right)\right]}$$

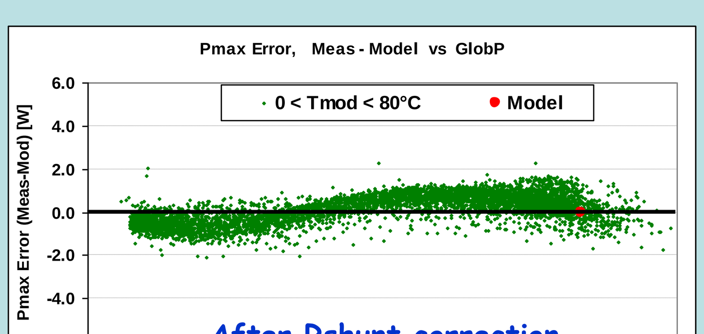
3. Model for SI-mono M-55

"Pure" standard model may be improved !

Measurements suggest an exponential behaviour of Rshunt according to Irradiance (see 5.A)



errors on Pmax: μ = 1.9% and σ = 1.1%
on Voc: μ = 1.1% and σ = 1.0%



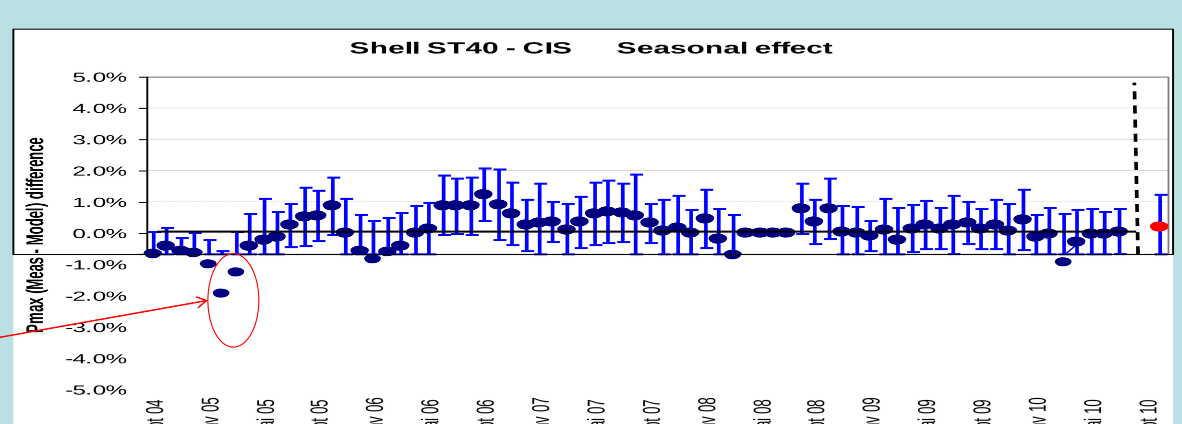
errors on Pmax: μ = 0.2% and σ = 1.2%
on Voc: μ = 0.4% and σ = 0.5%

4. CIS module Shell ST40

This module obeys quasi perfectly to the Standard model.

Remarquable stability: σ = 1 % over ~ 6 years of measurements

Displacement of temperature sensor



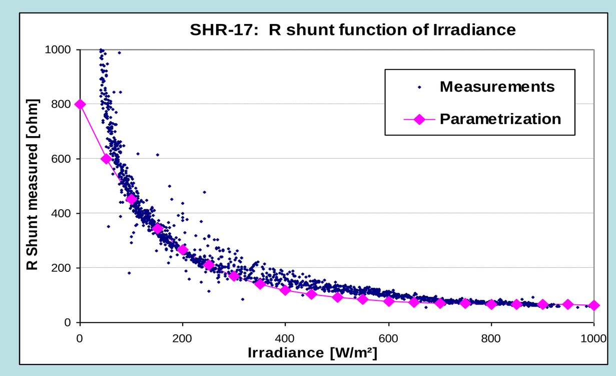
5. Amorphous: 3 modifications to the standard model

A. Exponential Shunt Resistance :

$$R_{sh} = R_{sh}(G_{ref}) + \left(R_{sh}(0) - R_{sh}(G_{ref})\right) \times e^{-R_{Sh}^{Exp}\left(\frac{G}{G_{ref}}\right)}$$

R_{Sh}^{Exp} value fixed = 5.5 ⇒ only one parameter free: $R_{sh}(0)$

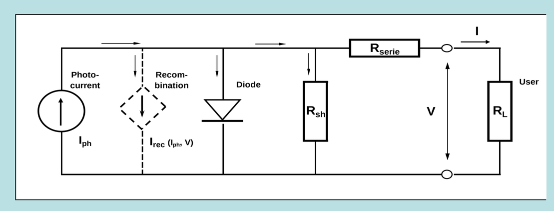
Observed for modules of any technology !



B. Recombination loss in the I layer

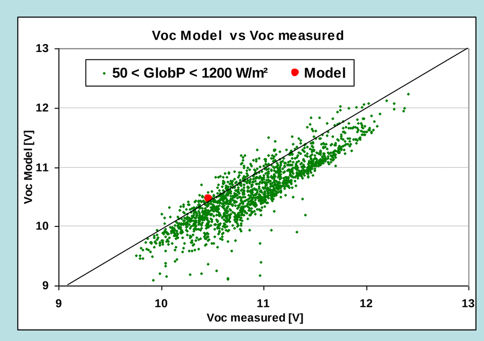
(proposed by J. Merten et al. 1998)

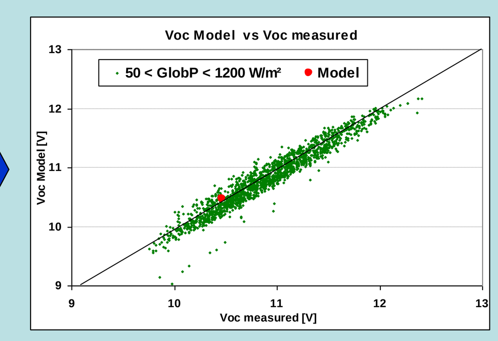
Add. a voltage-dependent current loss term in standard model.



Acts mainly on Voltage behaviour:

Effect of recombination correction

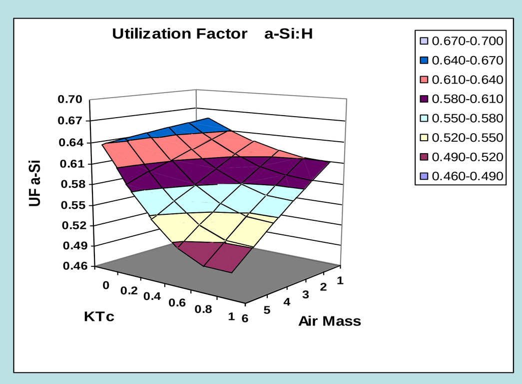


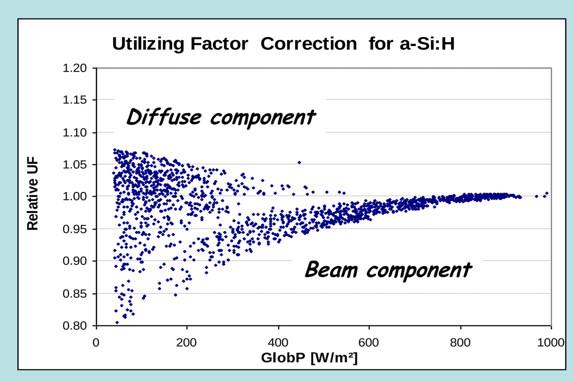


C. Spectral correction

(proposed by T. R. Betts et al. 2004, Univ. Loughborough)

Amorphous: Egap=1.7 eV => not sensitive to photons of lower energy (λ<0.73 μm)
Spectral Correction (FU): Parameterization as function of Clearness index (Kt) and Air mass.

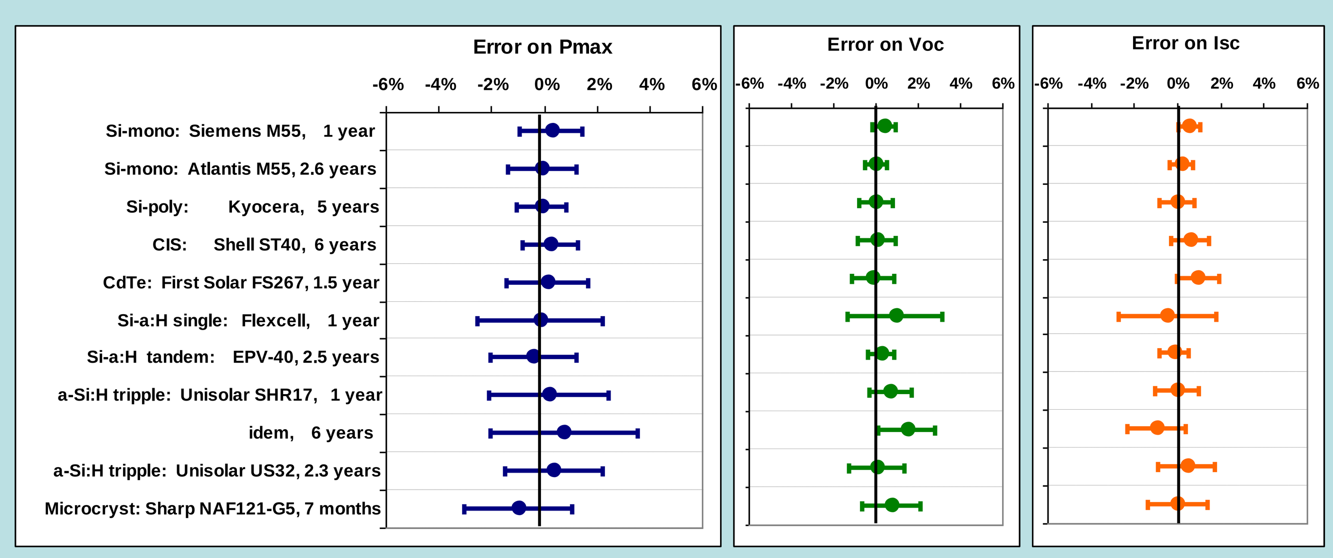




Spectral correction effect: favours cloudy skies and penalizes clear sky in the morning and evening

6. Conclusions

Final results, (measurements – model) differences
on long-term measurements of PV modules of all technologies



Crystalline modules :

"Standard model": established using only one I/V characteristics of the sample.
Exponential behaviour of Rshunt improves the results.

CIS module :

Obeys perfectly to the "standard model" with exponential Rshunt
Stability of the module and measurements: σ = 1% over 6-years measurements

Amorphous (single, tandem and tripple junction)

3 corrections to the "standard model"
Special parameters (d²/μτ, Rserie) are estimated by minimizing the σ (RMSE) value.

CdTe modules :

Behave like amorphous (recombination losses), spectral correction not suited.

Micro-crystalline :

Behave like amorphous, measurements still in progress.