7TuPo.225
PVSEC27,
Shiga, Japan
Tues 14 Nov 2017
16:00-18:00 Room 7+8+9

Quantifying and analysing the variability of PV module resistances R_{SC} and R_{OC} to understand and optimise kWh/kWp modelling

Steve Ransome (SRCL UK) and Juergen Sutterlueti (Gantner Instruments AUT)

1) Introduction

- The IEC 61853-1 matrix method characterises PV module efficiency vs. irradiance (G_I) and module temperature (T_{MOD})
- Analysing IV curves to find I_{SC}, V_{OC}, I_{MP}, V_{MP}, R_{SC} and R_{OC} gives more useful information than just efficiency measurements at V_{MP}.
- Combining Loss Factor Model (LFM) type analysis of IV curves with IEC 61853-1 matrices gives best understanding.

2) Fitting IEC 61853-1 performance vs. G_I and T_{MOD}

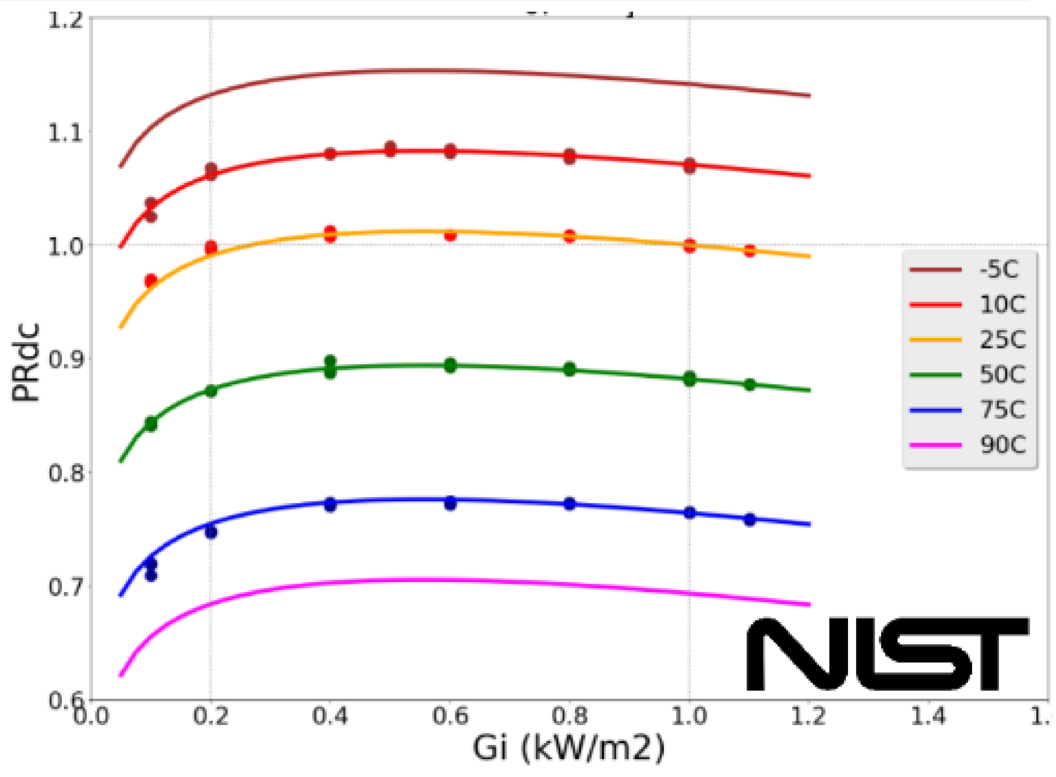
The Mechanistic Performance Model (MPM) fits PR_{DC} for both indoor and outdoor matrix measurements [1].
MPM has 6 meaningful, orthogonal, normalised and robust coefficients (for simplicity only C_1 to C_4 are used here)

$$PR_{DC} = C_1 + C_2 \times dT_{MOD} + C_3 \times Log_{10}(G_I) + C_4 \times G_I + C_5 \times WS + C_6/G_I$$

Typical indoor IEC 61853-1 data

Measured : points
MPM fit : lines
RMS fit error <0.2%

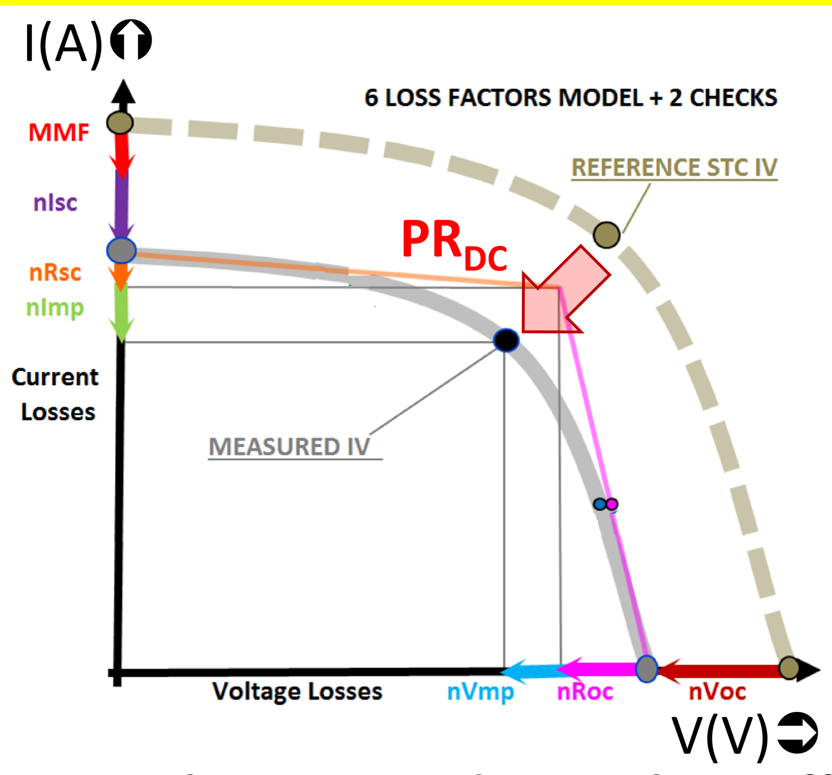
(NIST/CFV data)

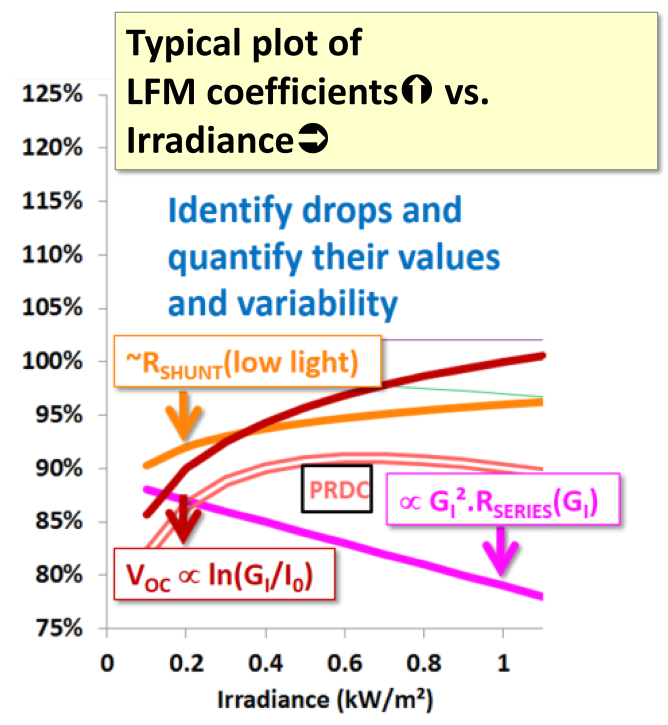


3) Characterising IV curves with the Loss Factors Model

LFM has 6 meaningful, orthogonal, normalised parameters [2] (spectral module mismatch factor MMF not used here)

$$PR_{DC} = [nI_{SC} \times nR_{SC} \times nI_{MP}] \times [nV_{MP} \times nR_{OC} \times nV_{OC}]$$





LFM values vs. irradiance show efficiency is affected by
Low irradiance : nR_{SC} (dominated by R_{SHUNT}) and nV_{OC_T}
High irradiance : nR_{OC} (dominated by R_{SERIES})

4) High quality IV measurements are needed for the best analysis (e.g. from GI's OTF)

www.gantner-environment.com/products/outdoor-test-facility.html [3]

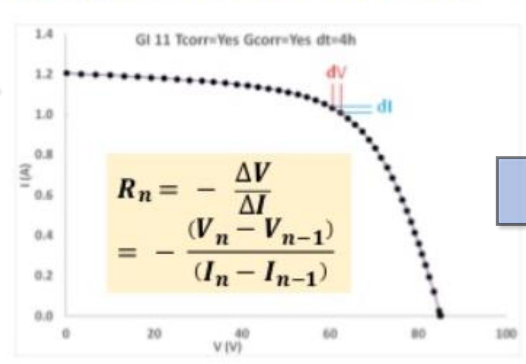
Measurement range: V: 0….60 V, I: 0 … 50 A, Pmax: 400 W (800 W max.)
24bit resolution (1200 VDC permanent)
Fast & high accuracy digitalization, 50 kHz sample rate per channel, accuracy 0.01 % typical
Fast response time: (10 … 100%): 30us
Dynamic sweep time and scan interval (from seconds to hours)
On the fly calculation of all key parameters Isc, Rsc, Imp, Vmp, Roc, Voc;
Real time performance prediction
Optional outdoor spectroradiometer
Reliable and proven industry components and calibrated sensors

GI OTF
(Shown in AZ)

Smooth IV curves are needed for good R_{SC} and R_{OC} calculations

Typical GI measured IV curve (CdTe)

"R_n = Apparent resistance between adjacent data points"

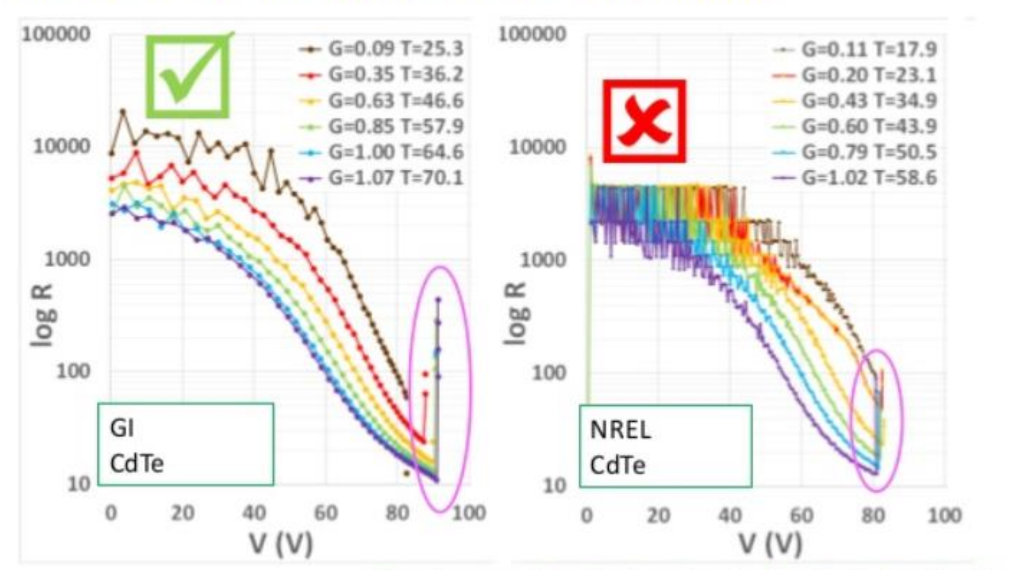


$$R_n = -\frac{\Delta V}{\Delta I} = -\frac{(V_n - V_{n-1})}{(I_n - I_{n-1})}$$

Note : Smooth IV curves result in most accurate analysis

Checking IV data quality with Log Resistance-Voltage (RV) curves

GI data much smoother than NREL's Daystar and therefore easier to fit.



Can ignore a few "bad end points" with V~0 or V > V_{OC}

5) Optimum performance analysis with LFM coefficients, MPM model and IEC 61853-1 matrix data

Fit all 6 LFM parameters with MPM type equations using matrix approach of G_I and T_{MOD} bins for each year

$$nLFM = C_{LFM1} + C_{LFM2} \times dT_{MOD} + C_{LFM3} \times Log_{10}(G_I) + C_{LFM4} \times G_I$$

<LFM/MPM>

KEY TO LEGEND :
YEAR LFM_PARAMETER MODID
Coefficients
1 C = constant (quality %)
2 dT = delta Tmod Temp Coeff (%/K)
3 LG = log10irrad (low light %)
4 G = GI (high light %)

Comparing 3 LFM parameters vs. G_I and T_{MOD} (coloured dots) for two technologies (GI measurements, 2014)

LFM parameter: nR_{OC} (~R_{SERIES}) nVoc nR_{SC} (~ R_{SHUNT})

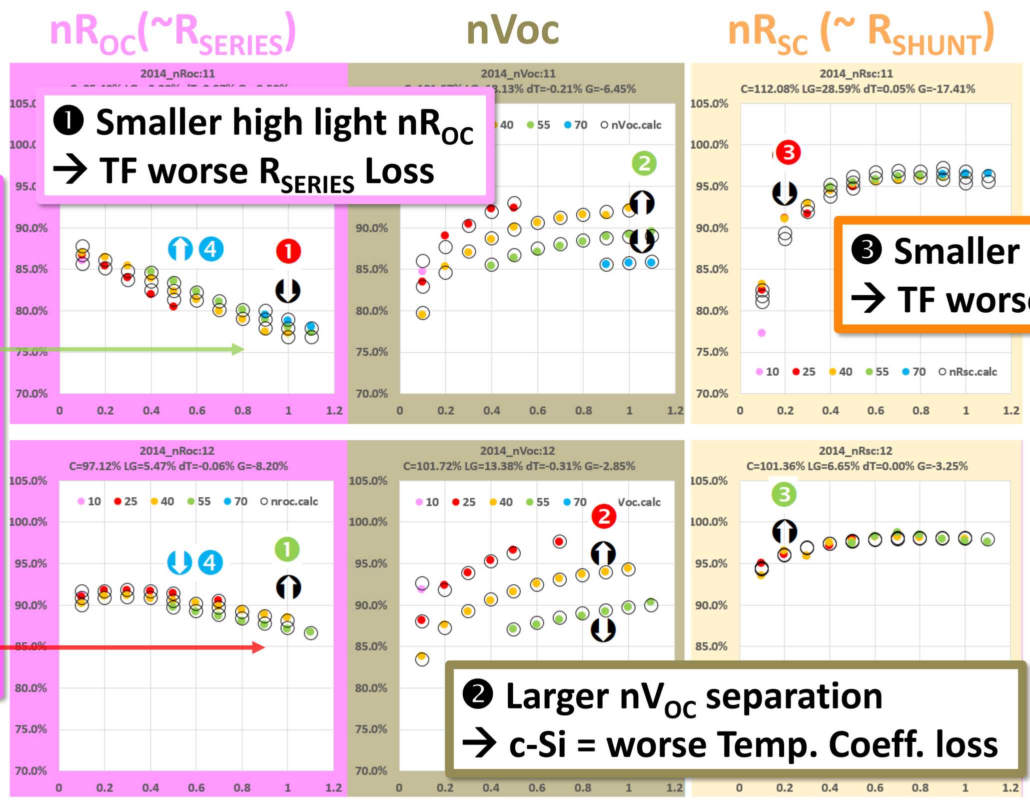
Degrading thin film #11

❹ R_{SERIES} Temp. Coeff. sign difference

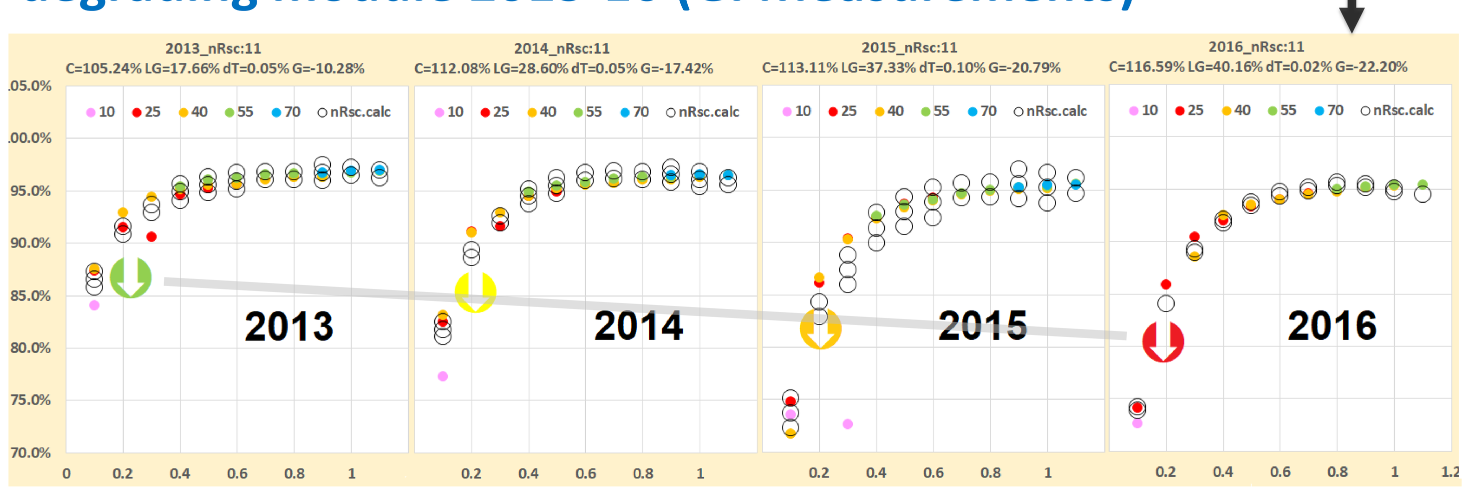
TF +0.07%/K (due to TCO sheet resistivity semiconductor)

c-Si -0.06%/K (due to tabbing metal)

Stable c-Si #12



nR_{SC} vs. Gi : Finding the cause and rate of drop of a degrading module 2013-16 (GI Measurements)



❶ 7% Performance fall at low light in 3 years is caused by degrading R_{SHUNT} causing nR_{SC} to reduce (Gantner Instruments data)
As PR_{DC} is the product of six coefficients –
any drop or change has a direct influence on PR_{DC} and therefore energy yield.

6) Glossary + references

LFM	Loss Factors Model [2]
MPM	Mechanised Performance model [1]
G_I	Plane of array instantaneous irradiance (kW/m²)
T_{MOD}	Module Temperature (C)
dT_{MOD}	Module temperature rise - 25 (C)
OTF	Outdoor Test facility as sold by Gantner Instruments
STC	Standard Test Conditions 1kW/m², 25C T_{MODULE}, AM1.5, 0 ms^{-1}
LLEC	"Low light efficiency coefficient" = ($Eff_{0.2kW/m^2}/Eff_{1kW/m^2}$)
NOCT	T_{MODULE} @ (0.8kW/m², 20C $T_{AMBIENT}$, AM1.5, 1ms^{-1})
I^2Rs	% Loss in series resistance = $I_{MAX}^2 * R_{SERIES}/P_{MAX.STC}$
nLFM	normalised LFM coefficient
nLFM_T	Temperature corrected LFM coefficient

[1] MPM (papers 79, 81, 82) steve@steveransome.com
[2] LFM (paper 70) steve@steveransome.com

7) Conclusions

- The causes and rates of PV performance degradation (e.g. "R_{SHUNT} at low light") can easily be found using these methods with high quality IV data such as from GI's OTF
- Optimized MPM curve fitting has been generalised and combined with the LFM
- MPM coefficients give normalized values for quality, temperature dependence, low light (due to $V_{OC}(G_I)$ and $R_{SHUNT}(G_I)$) and high light drops due to $I^2.R_{SERIES}$
- [3] Gantner Instruments www.gantner-environment.com/products/gantnerwebportal.html