# CHARACTERISING PV MODULES UNDER OUTDOOR CONDITIONS: WHAT'S MOST IMPORTANT FOR ENERGY YIELD


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## INTRODUCTION & OBJECTIVE

- The **Standard PV parameters** Final Energy Yield (YF) and Performance Ratio (PR) in IEC 61724 are **sums or averages** over time and do not allow detailed correlations with irradiance & temperature
- Previous studies have only done limited analysis of IV curves
- This work analyses IV curves in more detail to give a better understanding of the PV performance limiting effects of parameters such as $R_{SC}$ (~$R_{SHUNT}$)

## A NEW "LOSS FACTORS" MODEL (LFM)

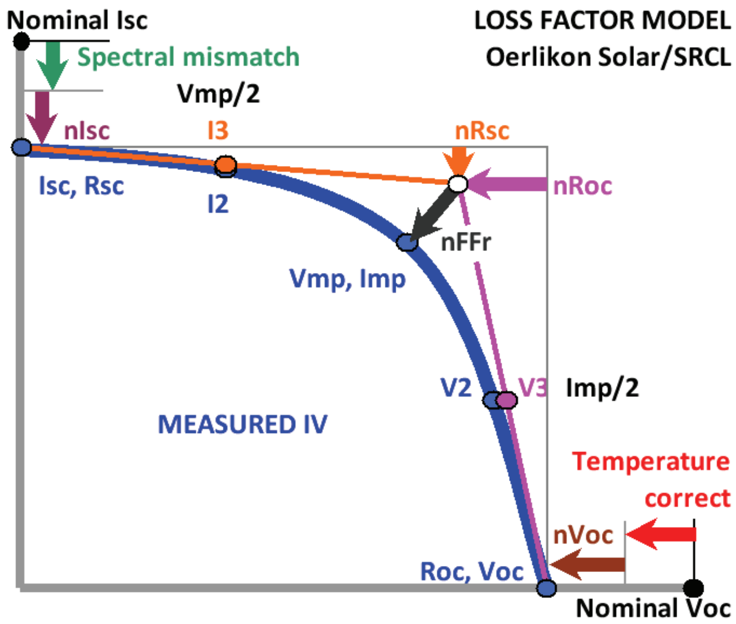
The "loss factors" model (LFM) fits measured outdoor IV curves to find 5 independent normalised loss factors:

**$I_{SC}$, $R_{SC}$, FF, $R_{OC}$, $V_{OC}$**

plus 2 corrections: spectral and temperature

**Performance Factor:**

= dc measured/STC efficiency is the product of all 7 values




$$PF = nI_{SC.G} * nR_{SC} * nFF_{R} * nR_{OC} * nV_{OC.T}$$

where: $nI_{SC.G}=nI_{SC}$ * spectral mismatch and $nV_{OC.T}=nV_{OC}$*Temperature correct

## BENEFITS OF THE LOSS FACTORS MODEL

1. Monitors relative changes in efficiency and finds the reasons
2. Normalises parameters by reference values (e.g. STC or flash test) - quick benchmarking of different modules (batches or technologies)
3. Identifies differences of nominally identical mass produced modules
4. Quantifies benefits to $P_{MAX}$ and energy yield from improvements (e.g. low light, temperature, spectrum)
5. Compares module measurements from different climates without correcting to STC
6. Distinguishes seasonal changes (e.g. annealing) from degradation
7. Can predict energy yield drop due to $R_{SC}$ and $R_{OC}$ losses
8. Will allow more reliable Energy yield & Performance prediction

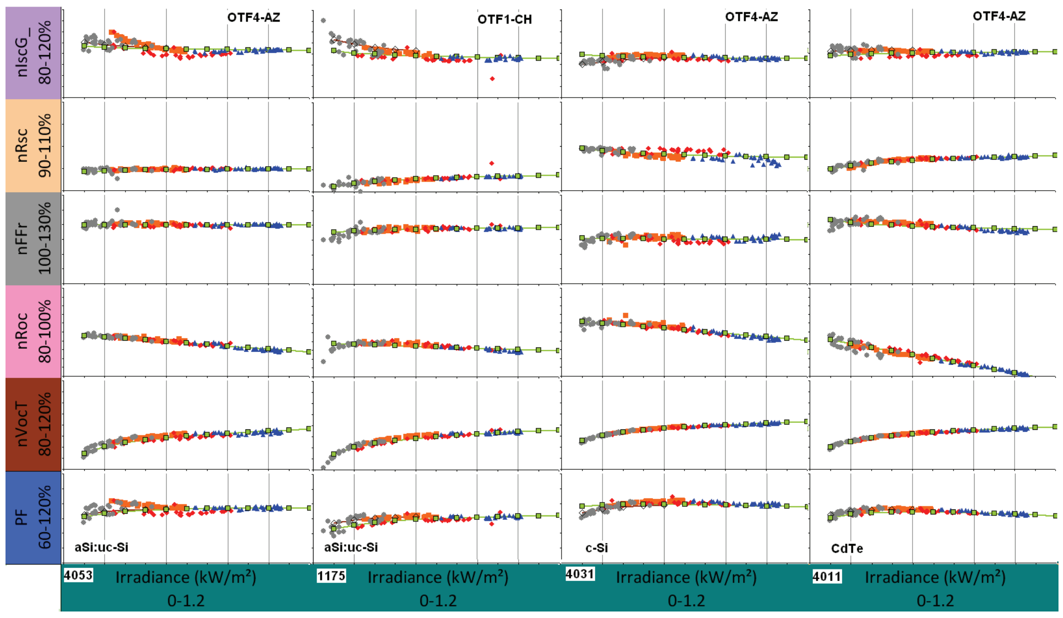
## OPTIMISE PARAMETERS FOR HIGH kWh

**After site selection, optimum orientation, minimal shading, ventilation, cleaning : Optimise the product of the loss factors (LFM)**

| Loss factor | Optimal value |
|---|---|
| $nI_{SC}$ | High from low dirt and good AR coating |
| $nR_{SC}$ (~$R_{SHUNT}$) | High $R_{SHUNT}$ minimise losses at low light levels, $R_{SC}$>90% |
| $nFF_{R}$ | Good FF >110% (c-Si), >120% (TF) |
| $nR_{OC}$ (~$R_{SERIES}$) | Low $R_{SERIES}$ minimises losses at high light levels $R_{OC}$>85% |
| $nV_{OC.T}$ | Good β coefficient, low $T_{MODULE}$ |
| Spectral correction | Max. absorption of each junction, matched for best site yield |

## VALIDATION OF THE LOSS FACTORS MODEL

- Oerlikon Solar measure outdoor performance of their own, customers' and competitors' modules at several sites around the world
- Data is shown from **central Europe (OTF1-CH)** and **South West USA (OTF4-AZ)**.



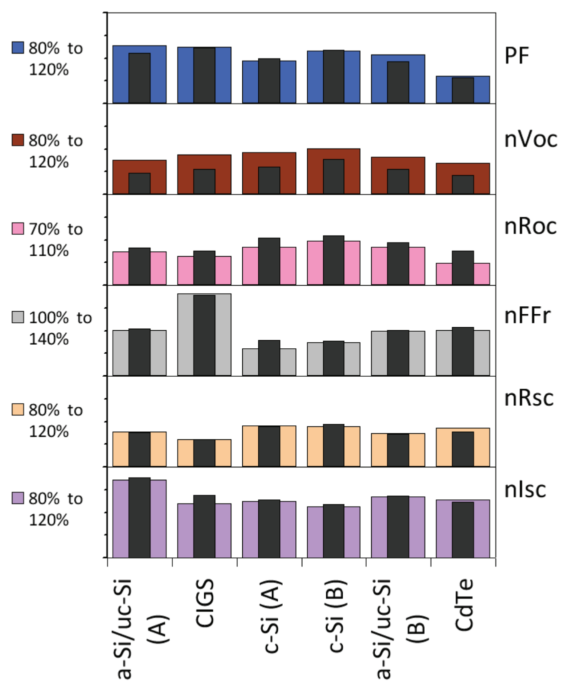

**Weather types**

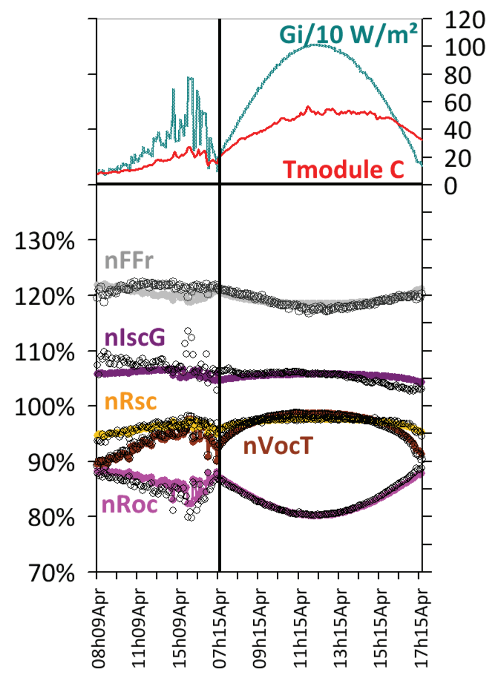
- Clear Morning
- Clear Noon
- Clear Evening
- Diffuse

- Analysis is based on **4 different "weather types"** at **2 different sites – Switzerland and Arizona**
- Results of LFM fitting to data points vs. Irradiance
- micromorph Modules: similar modules at both locations

**LFM works for fixed and tracked modules and all technologies. Different locations give similar results for similar modules !**

## LOSS FACTORS – MEASURED vs. MODELLED




Left:
**Fitted loss factor coefficients** from **6 different technologies** at OTF4-AZ at (800W/m², coloured bars) and (200W/m², black bars) spectrally and thermally corrected

Right:
Typical **fitted (coloured) vs. measured (black)** loss factor parameters and weather data for a thin film module measured at OTF4-AZ showing good agreement for a diffuse and a clear day.

## IMPORTANCE FOR ENERGY YIELD

- **Energy Yields (in kWh/kWp) are important for:**
  - **design and validation of a PV system**
  - **its levelised cost of electricity (LCoE)**
- **Optimized LFM parameters within mass production leads to:**
  - **higher confidence about production quality**
  - **realistic lifetime expectations**
  - **confidence for energy yield harvest and performance prediction**

- **With LFM System Developers and Investors will be able to:**
  - **reduce their financial risks with detailed characterised PV devices**
  - **lower uncertainties and better confidence of the real PV Power Plant performance**
- **R&D improvements can be validated quickly and accurately**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**For further Information see Oral Presentation 4DO.6.4 "Improving and Understanding kWh/kWp Simulations" by S. Ransome and J. Sutterlueti, Thursday @ 17:45**

Visit our booth in Hall A4 / A11