Risk reduction and decision support for financial investments in solar PV projects

Presented at Solar Power Africa
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CSIR
Touching lives through innovation

Outline

1. Introduction and motivation
2. Accelerated stress testing for PV module reliability
   a) Overview of the lab: https://www.csir.co.za/pv-lab
   b) Results from recent testing in South Africa
3. Summary

CSIR Energy Centre

Technology-focussed Research Groups

System-focussed Research Group

End user-focussed Research Groups

Energy Supply & Demand

- Energy Efficiency and demand shaping
- Energy Meteorology
- Renewable Energy technology
- Thermal energy

Electro-Chemical Energy Technologies

- Batteries
- Fuel cells

Energy Systems

- Energy System Design
- Energy System Operation

Energy Industry

Smart Utilities Programme

Real-world implementation of research programme

CSIR plants were not producing as predicted

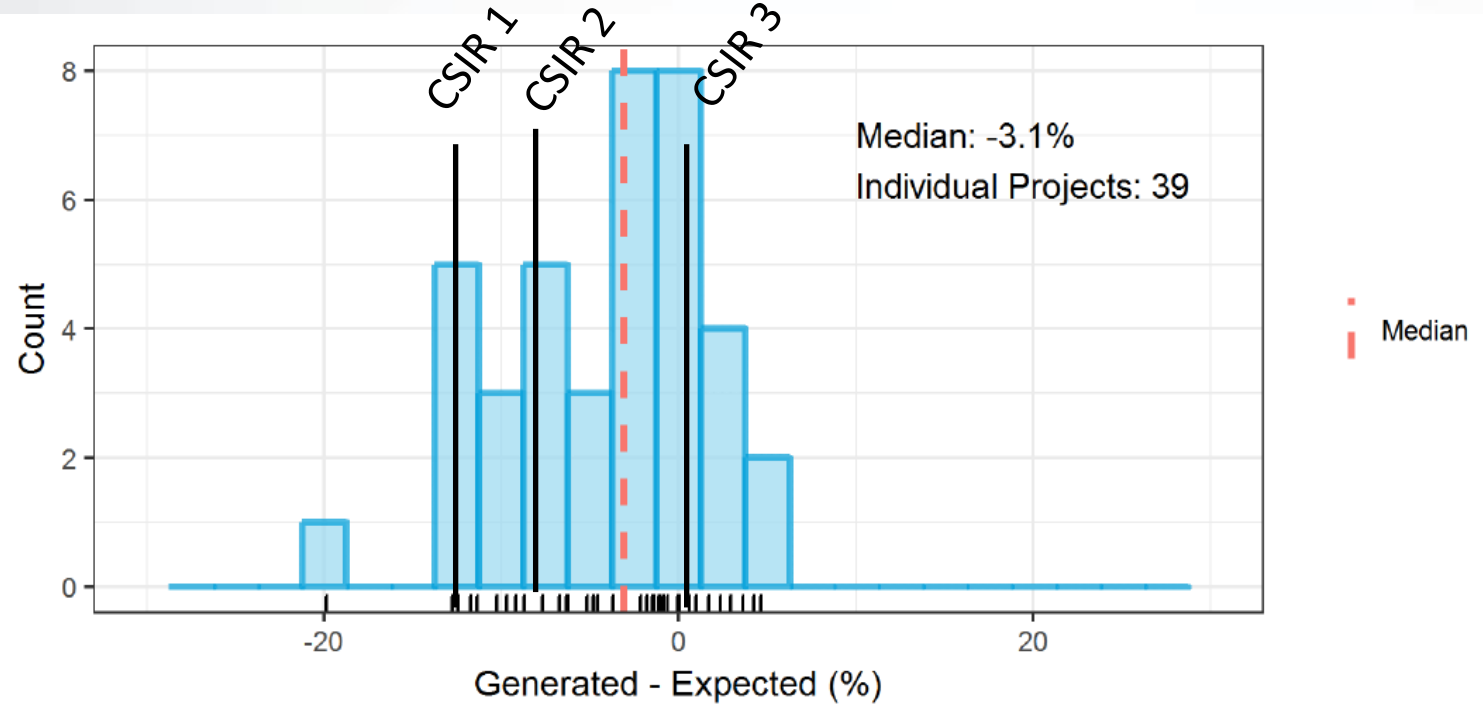


Figure ES-1 Project-average validation results, adjusted for interannual irradiance variability

- 50% of PV projects (1 MW +) in one study fell short of predicted electricity generation

WHY?

Source: Solar Risk Assessment: 2019 Quantitative Insights from the Industry Experts

PV generators underperform for a variety of reasons

Problems

1. Predictions were too optimistic
   a) Honest mistakes
   b) Weather file accuracy
   c) Over-selling to win a bid
   d) Procurement process
2. Component degradation
   a) Module degradation
   b) Quality of manufacturing
   c) System degradation
3. Operations and Maintenance
   a) Soiling
   b) Tracker operations
   c) Recoverable losses
   d) Construction snags
4. Grid availability and load-shedding

Solutions

- Resource assessment and pre-feasibility studies to set realistic expectations for tenders

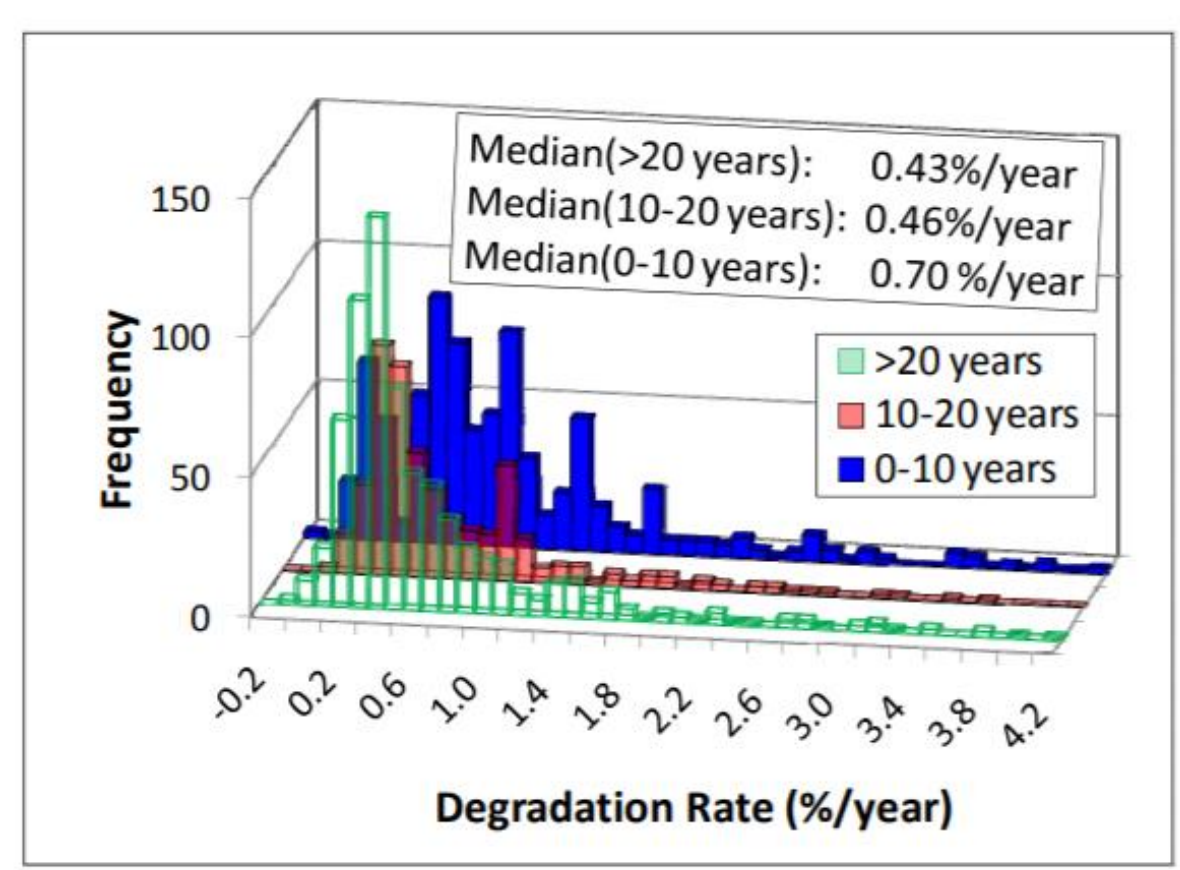
PV procurement guideline

- Accelerated stress tests to rule out high degradation risks
- Defect detection in EL images to rule out poor quality

- Performance monitoring and fault detection

Reference: Solar Risk Assessment: 2019 Quantitative Insights from the Industry Experts

Module/system degradation
Long right tail in degradation rates



- Compilation of degradation rates reported in the literature
- Many systems report degradation rates in excess of 1% per year
- **The distribution for newer systems shows higher rates of degradation (blue)**

Source: Photovoltaic Degradation Rates — An Analytical Review (2012)

Financial impact
High degradation rates erodes NPV

DC degradation (%/year)	LCOE real (R/kWh)	LCOE Relative to best case	NPV (million Rand)	Payback period (years)
0.5	90.5	na	17.5	6.3
1.0	95.0	1.05	15.8	6.4
1.5	99.7	1.10	14.2	6.5
2.0	104.5	1.15	12.6	6.6
2.5	109.4	1.21	11.2	6.7
3.0	114.5	1.27	9.9	6.8

1. Financial model for CSIR 558 kWp single axis tracker system
2. LCOE increases by roughly 5% for every 0.5% increase in degradation
3. NPV decreases by nearly 10% per year
4. We want to protect against high degradation rates in the tail

Module/system degradation
Trouble in South Africa

”Photovoltaic module manufacturers deliver modules exceeding contracted performance by 2–3% when batch testing is announced.” - IRENA

- 2 of 3 PV plants at the CSIR did not meet the guaranteed performance ratio at the end of the three-year O&M period
- Areas of concern include glass cracks, soiling, transposition model, tracker issues, monitoring systems, etc.
- Mulilo Sonnedix Prieska solar farm (ZAR 1.3 billion) may have issues with module backsheets cracking and delaminating
- We need to put the suppliers and contractors on notice that South Africa is paying attention

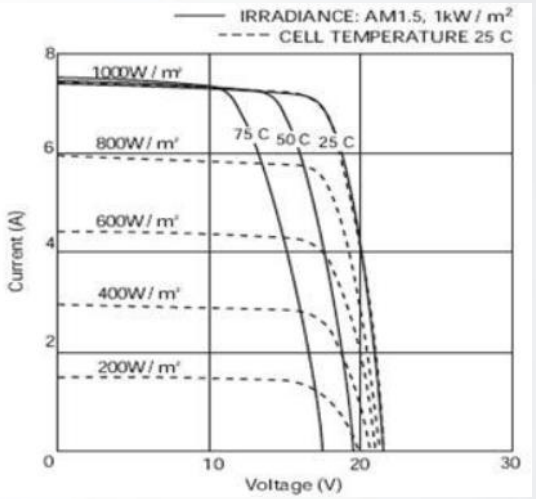
Source: IRENA, BOOSTING SOLAR PV MARKETS: THE ROLE OF QUALITY INFRASTRUCTURE

Accelerated stress testing – CSIR testing lab ready to support investments in PV

Thermal Cycling and Humidity Freeze with Power Supply Rack

Sun simulator with temperature chamber

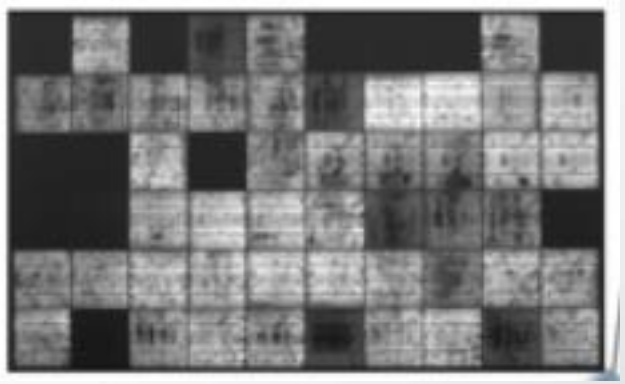
IV Curves



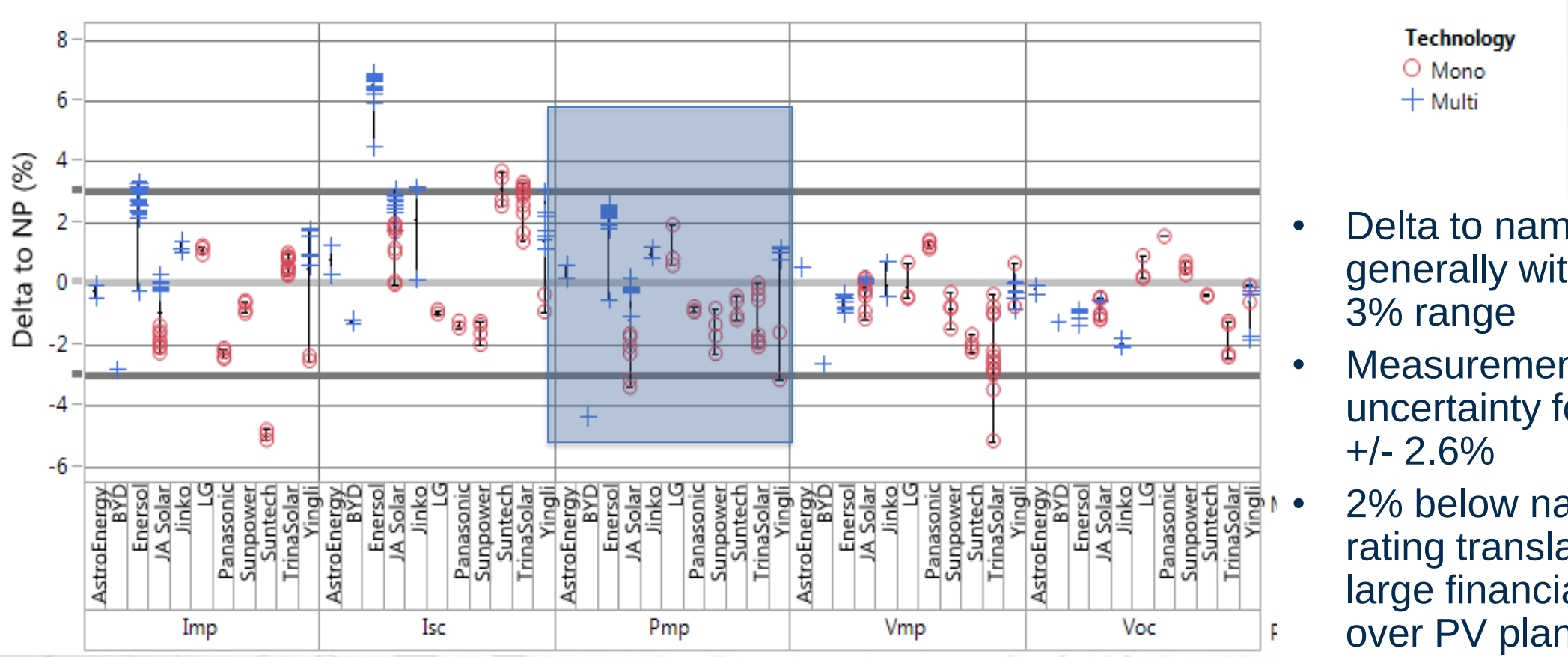
Damp Heat with PID Rack

Mechanical load tester

EL



Initial characterization – Delta to Nameplate



- Delta to nameplate is generally within the +/- 3% range
- Measurement uncertainty for Pmp is +/- 2.6%
- 2% below nameplate rating translates to large financial losses over PV plant lifetime

Initial characterization - electroluminescence

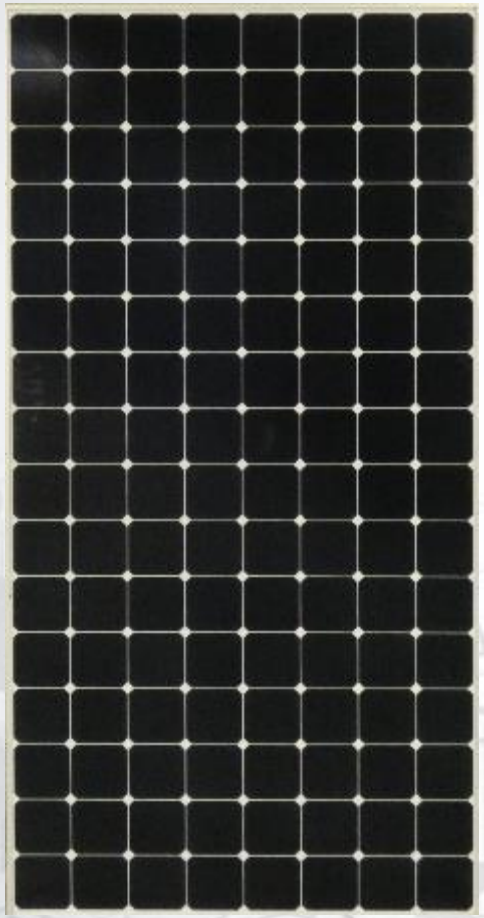


Fig 1: optical image SunPower-Mono

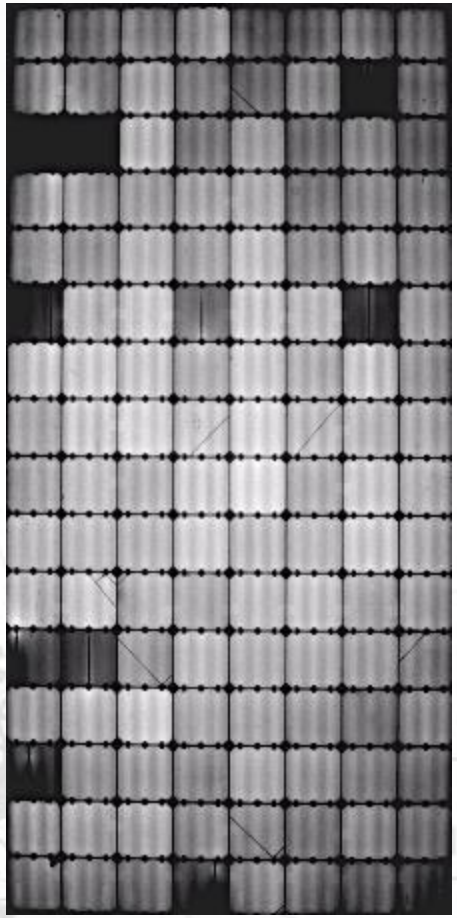
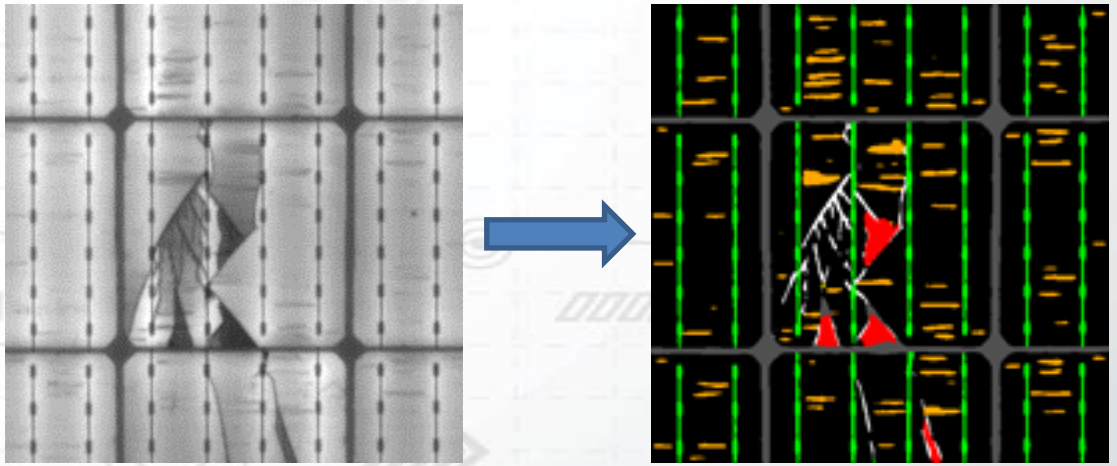


Fig 2: EL image SunPower-Mono

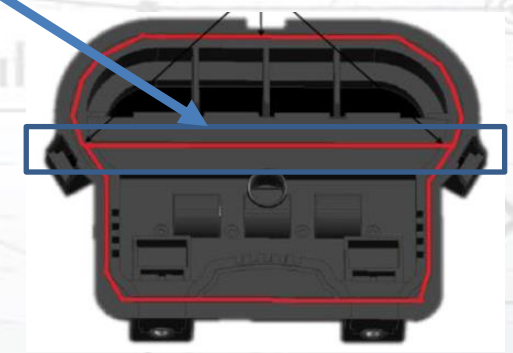
1. ‘X-ray vision’ for PV modules
2. EL identifies cracks and dead cells that can impact long-term performance
3. We are developing a machine learning model for defect classification and quantification in EL images



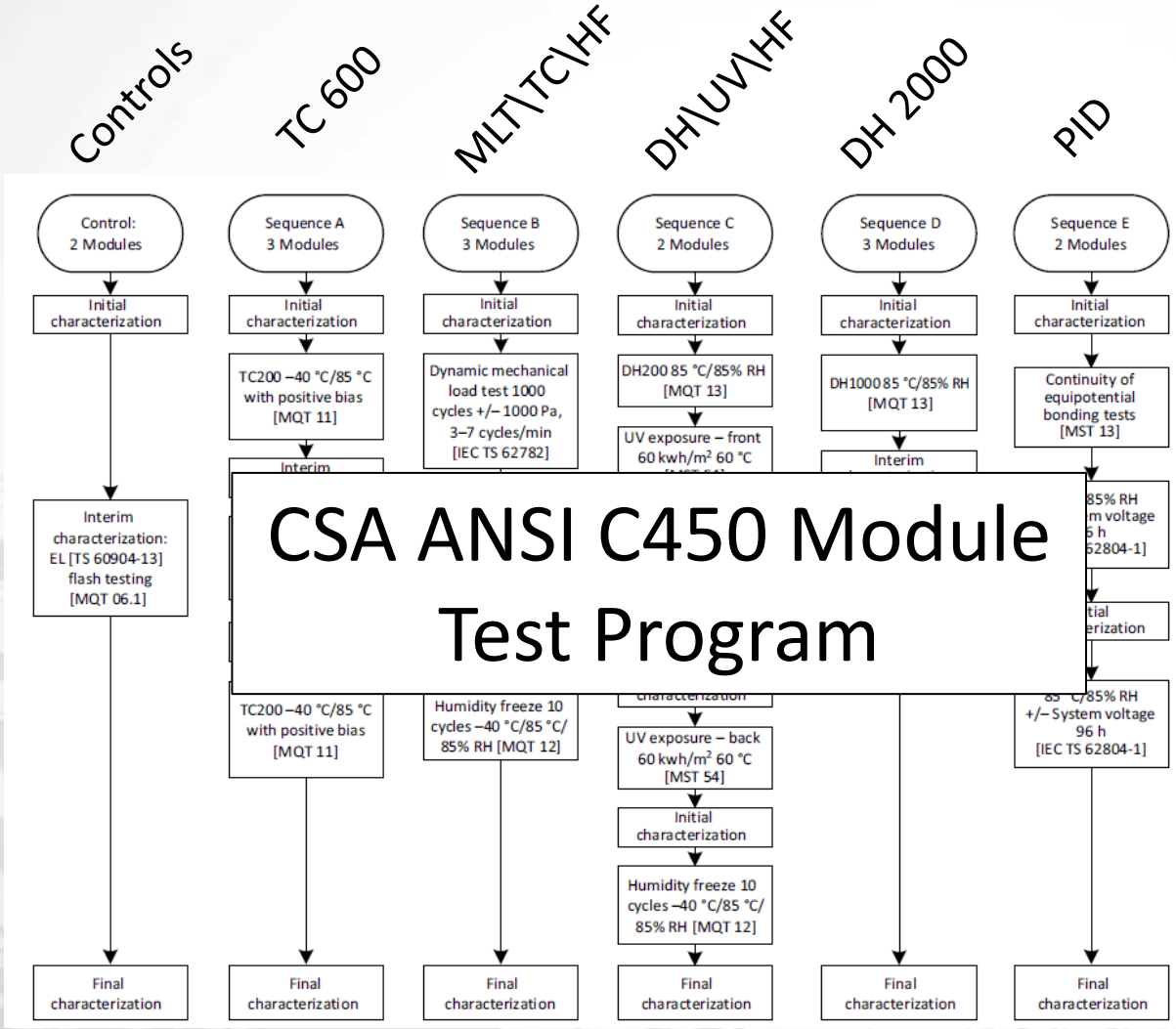
Initial characterization – Wet Leakage failures
Wet leakage safety test failure impacted 50% of plant

- Batch testing for the CSIR 1 MW rooftop project during pre-construction
- 50% failed the wet leakage test out of the box, pre-stress

Gaps in silicone sealant lead to wet leakage failure around this ‘vented’ junction box

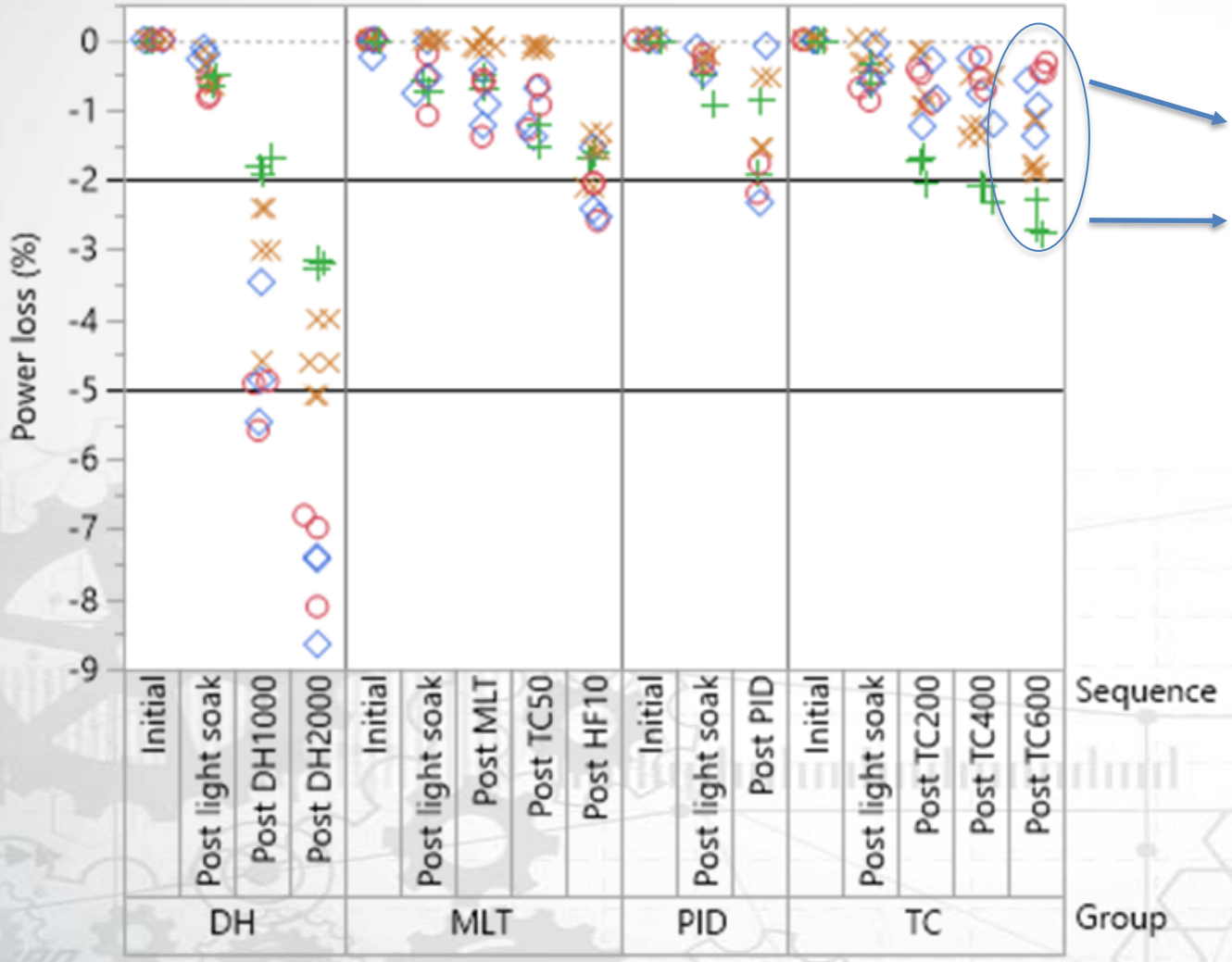


Accelerated stress testing – Global standards tested on local PV modules



- 5 separate legs designed to provoke field failures
- Initial test results available in one week, while the full sequence requires 3-4 months
- **Performance and safety tests are used to assess degradation that correlate to real-world performance**

Final characterization
Electrical performance versus environmental stress



TC600 ≈ 600 diurnal cycles ≈ 1.6 years

BOM 19034 = -0.3%/yr

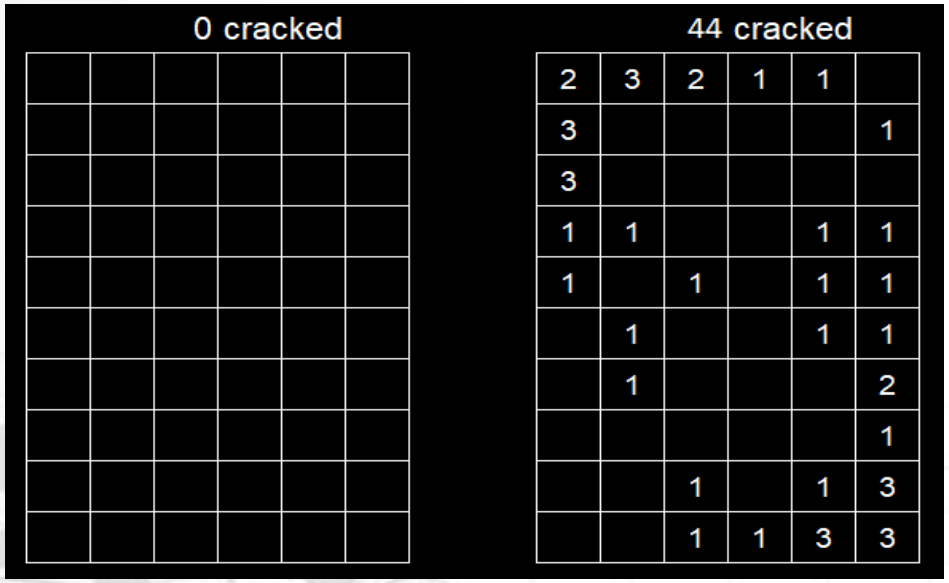
BOM 19040 = -1.5%/yr

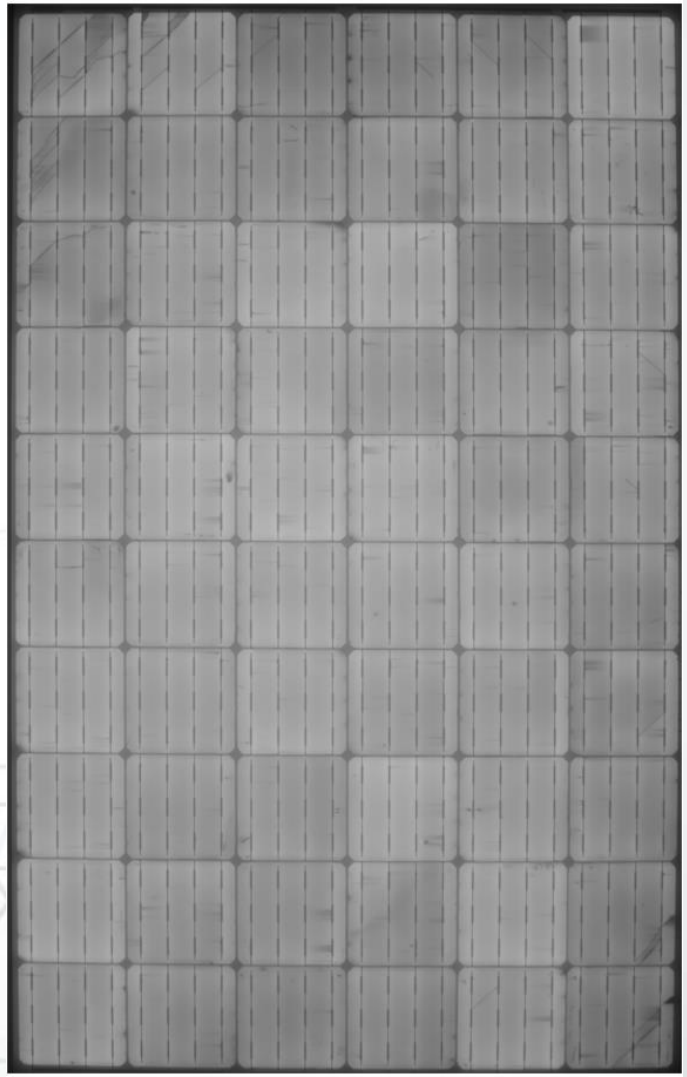
1. Two module BOMs degraded by more than 5% after Damp Heat 2000 hours, but show significant recovery after IEC 61215-2 MQT 19.3
2. In less than 3 months, we have a clear difference in reliability performance following TC600 (-0.5% versus -2.5%)

Final characterization – EL measurements
TC600 stress induced unusual pattern in cracked cells

Initial EL

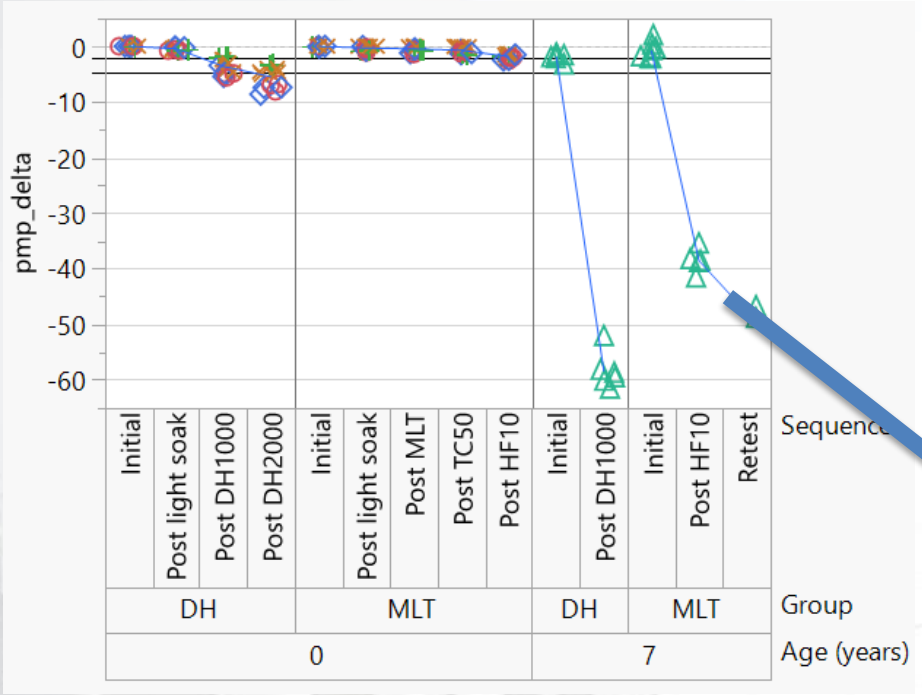
Post TC600



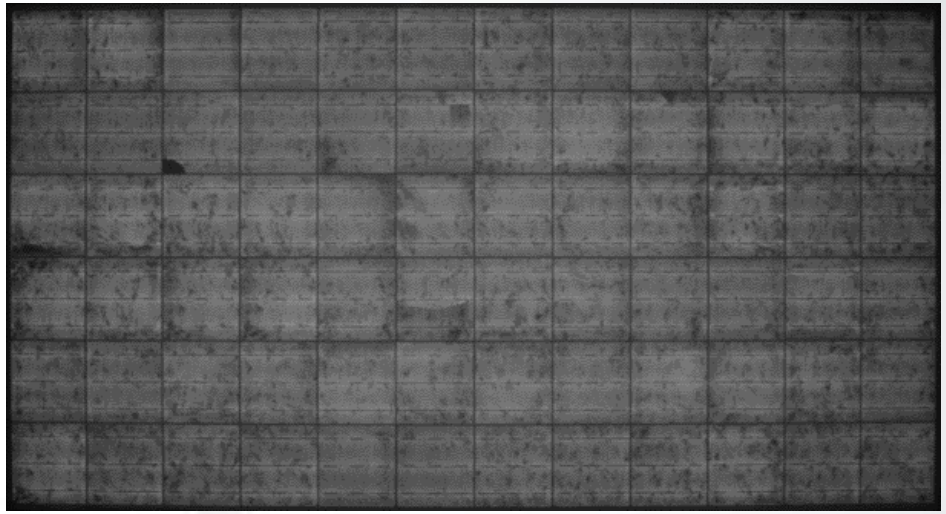


- One BOM showed excessive cracking post TC600
  - 44 cracked cells on three modules post TC600
  - Micro cracks can lead to excessive power loss over time
  - Framing issue?

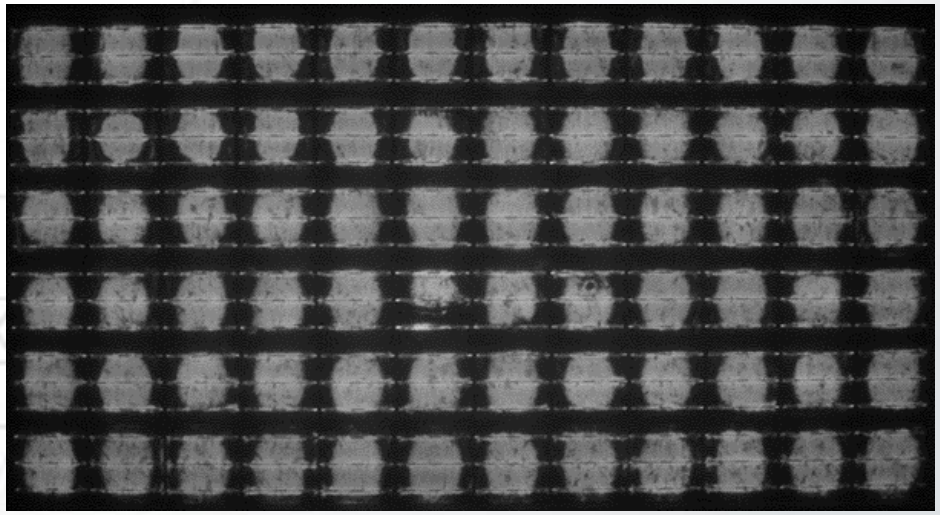
Accelerated stress testing
Pre-construction testing versus fielded modules



Pre
HF10



Post
HF10



1. Fielded modules may be tested for handover/re-sale/warranty claims/faults/etc.
2. Damp heat (1000 hours) -> 60% power loss
3. Humidity freeze (10 cycles) -> 40% power loss

Summary

1. PV plant performance depends on module quality and reliability
2. PV module Quality and reliability testing can lead to higher lifetime performance when the testing is linked to contracts
3. Accelerated stress tests provide valuable information for decision support regarding the future performance of new and fielded modules