ARIZONA STATE UNIVERSITY
PHOTOVOLTAIC RELIABILITY LABORATORY

Failure and Degradation Modes of PV modules in a Hot Dry Climate: Results after 12 to 26 years of field exposure

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Acknowledgement

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OUTLINE

- **Objective of this presentation**

  To identify the key failure and degradation modes in a hot-dry climate

  (Future works will include: hot-humid and hot-cold climatic conditions)

- **Two hot-dry climatic sites**
  - **Site 1**
    - ✓ **Tempe, Arizona: 12-13 years; ~ 1700 modules**
  - **Site 2**
    - ✓ **Phoenix, Arizona: 26 years; ~ 4000 modules**

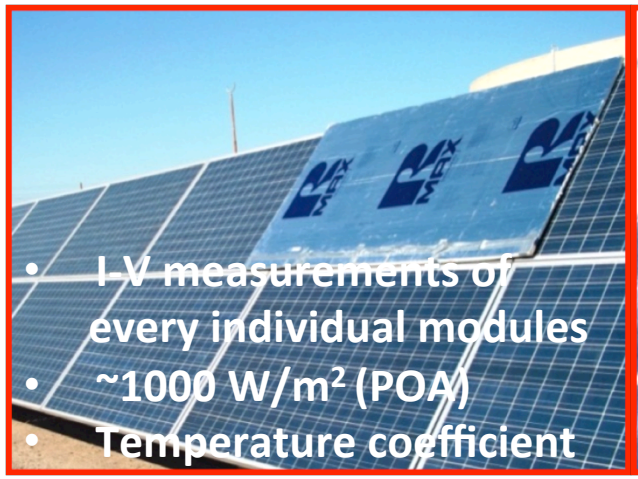
- **Characterizations and Results**
  - **I-V characterization**
  - **Visual inspection**
  - **Infrared imaging**

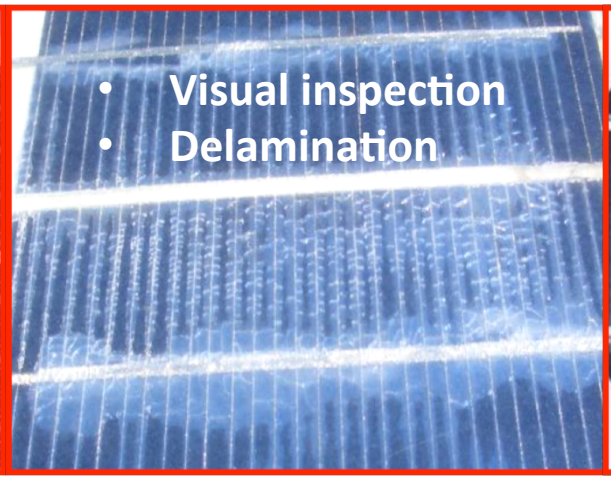
- **Conclusions**

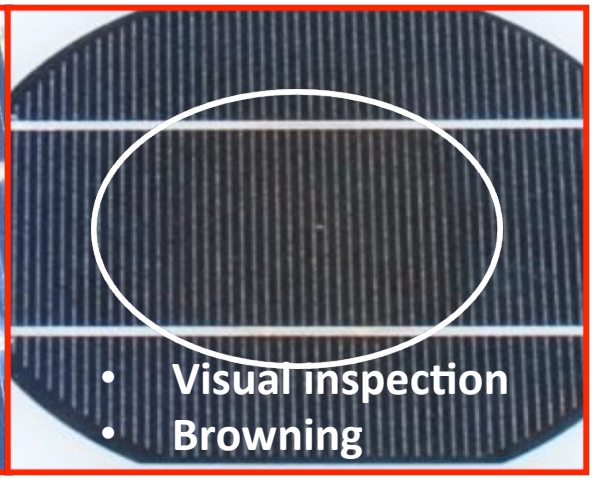
Hot-Dry Climate:
Site 1
(~1700 Modules; 12-13 Years Old)

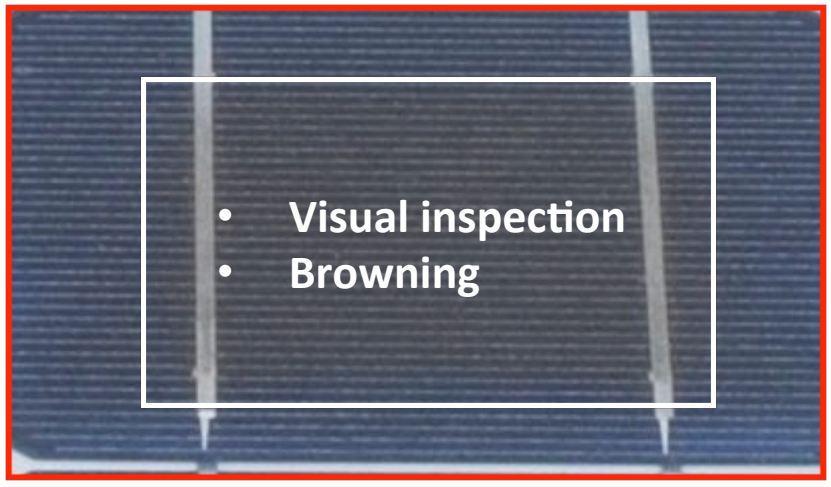
Site 1: Modules Evaluated - Six Manufacturers and 1-Axis Tracking

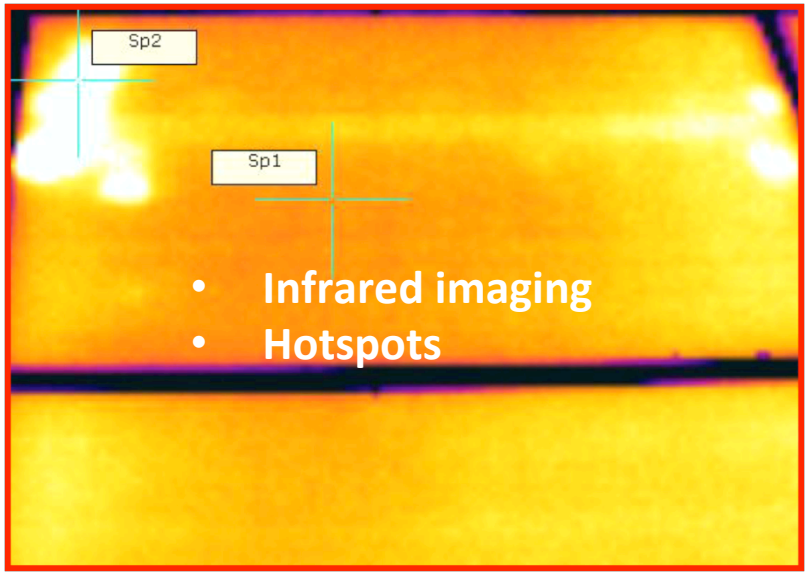
Site 1: Characterizations – Visual Inspection, IR Imaging & I-V Curves











Site 1: Results – Visual Inspection and Hotspots

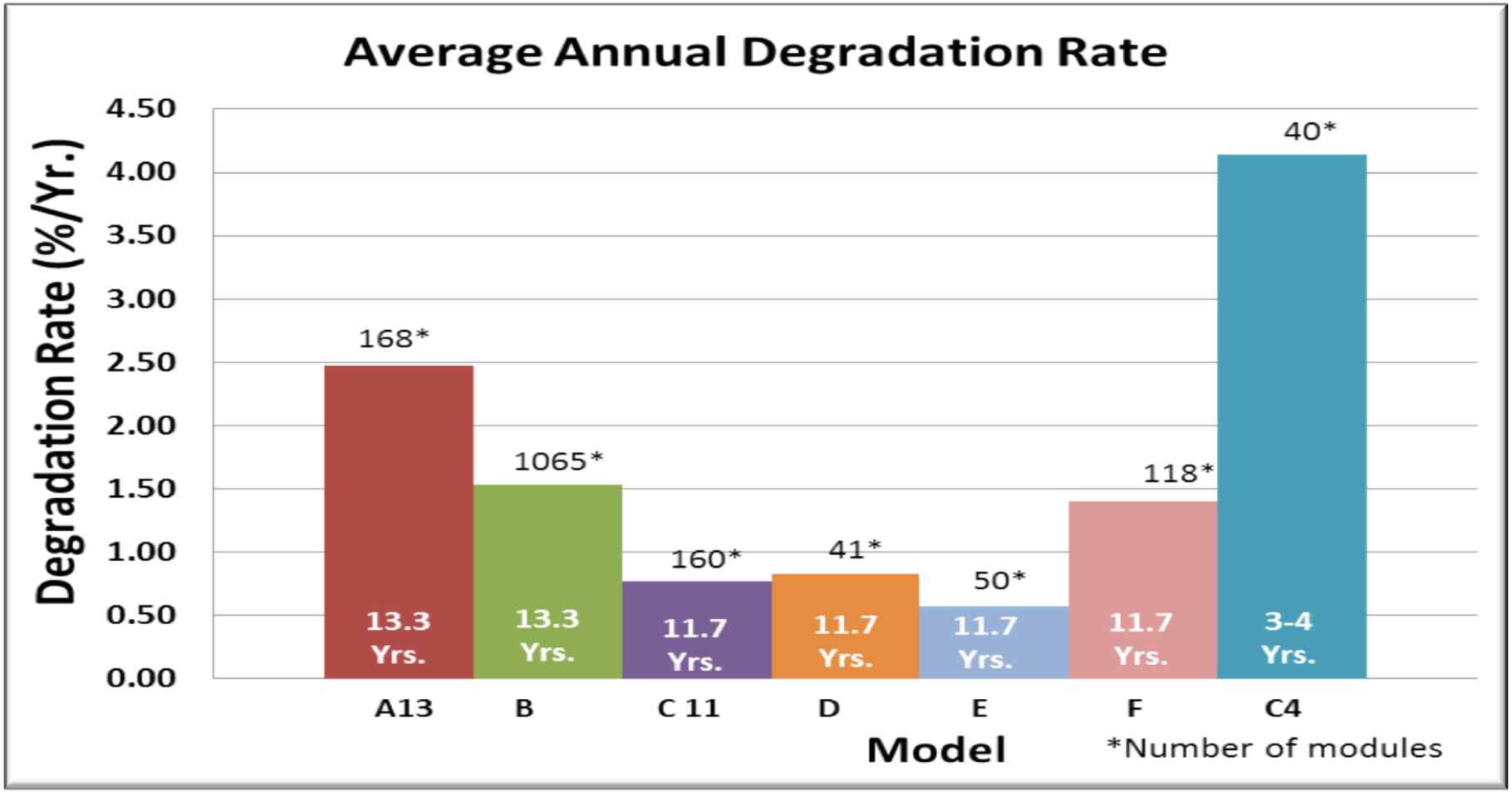
Encapsulant Browning

Model ID	No. of samples	Years Fielded	Cracked cells	Delamination	Discoloration (Browning) of Encapsulant	Cell Chipping	Cell Interconnect Failure	Connector Deterioration	Substrate (backsheet) Warping/Detaching	Burn Through Backsheet	Metallization discoloration	Seal Deterioration	Solder Melted	Hotspot with IR Camera
A13	168	13	0	0	168	0	0	0	0	0	0	168	0	4
B	1153	13.3	0	4	1153	0	0	0	630	0	0	0	1	7
C4	39	2.5 - 4	6	0	0	0	0	0	0	0	1	0	1	5
C11	177	11.7	45	74	1	2	0	0	0	0	1	0	0	20
D	48	11.7	0	0	37	0	0	0	0	0	0	0	0	4
E	50	11.7	0	0	0	0	0	0	33	0	0	0	0	0
F	120	11.7	0	0	0	0	0	0	1	2	22	15	0	6

Replaced modules

Glass/Glass modules

Site 1: Results – Average Annual Degradation Rate



C4 = Replaced modules under warranty

Power degradation appears to be primarily due to current drop (encapsulant browning) and fill factor drop (series resistance increase due to thermo-mechanical fatigue of solder bonds)

Site 1: Results – Hotspot modules degrade at higher rate

Model of Module	All Modules % Degradation/Year	Only Hotspot Modules % Degradation/Year
A 13	-2.47%	N.A
B	-1.53%	-2.95%
C 11	-0.77%	-1.90%
C 4	-4.14%	N.A
D	-0.83%	-1.25%
E	-0.57%	N.A
F	-1.40%	-4.96%

Modules with hotspot issues seem to degrade at higher rate than the non-hotspot modules. Periodical IR scanning may be useful for the early identification and potential removal of the hotspot modules from the power plants to mitigate future module mismatch issues.

Site 1: Conclusions

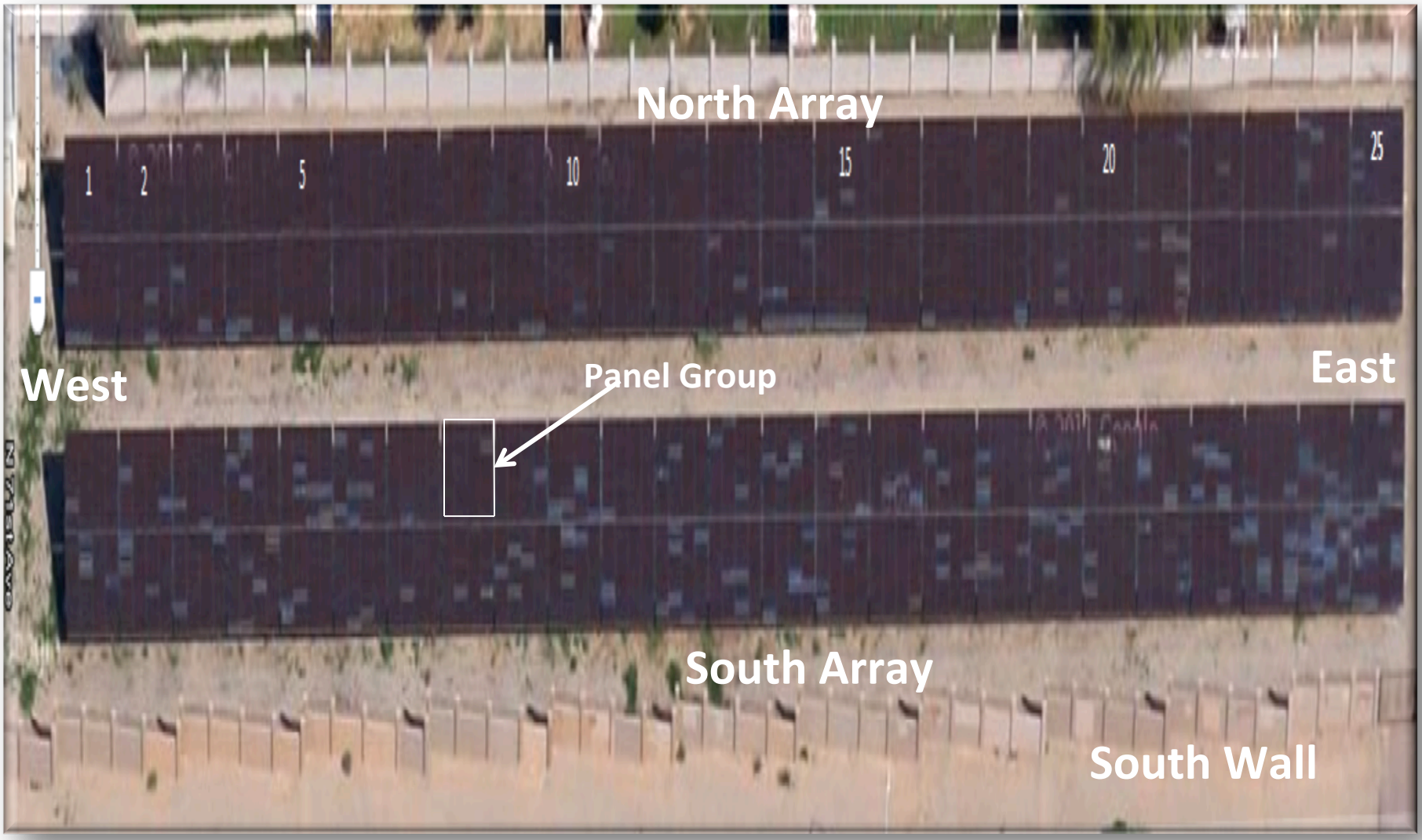
- The degradation rate of these 12-13 years old modules ranged between 0.6%/year and 2.5%/year depending on the manufacturer

- Primary degradation modes in this hot-dry climate site appear to be encapsulant browning and (thermo-mechanical) fatigue of solder bonds. Encapsulant browning leads to current drop and solder bonds fatigue leads to fill factor drop

- Modules with hotspots appear to degrade at higher rate than the non-hotspot modules (which could lead module mismatch issue in a module-string)

Hot-Dry Climate:
Site 2
(~4000 Modules; 26 Years Old)

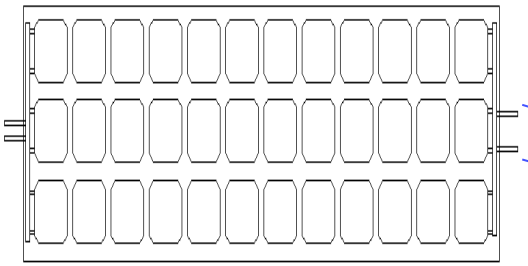
Site 2: Modules Evaluated - One Manufacturer and Fixed Latitude Tilt

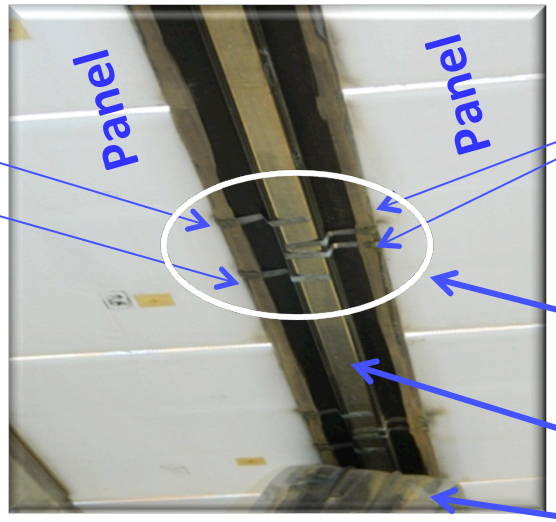


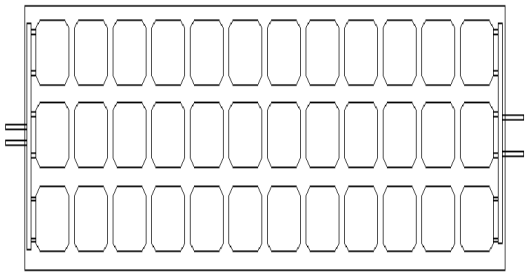
4000 Modules = 100 Panel Groups (4 panels per group with 10 modules in each panel)

Note: White spots on the photo are due to the replaced modules or modules with glass cracks leading to encapsulant bleaching. Modules were often replaced due to vandalism (stone throwing across the south wall)

Site 2: Modules Evaluated – Construction of Module and System







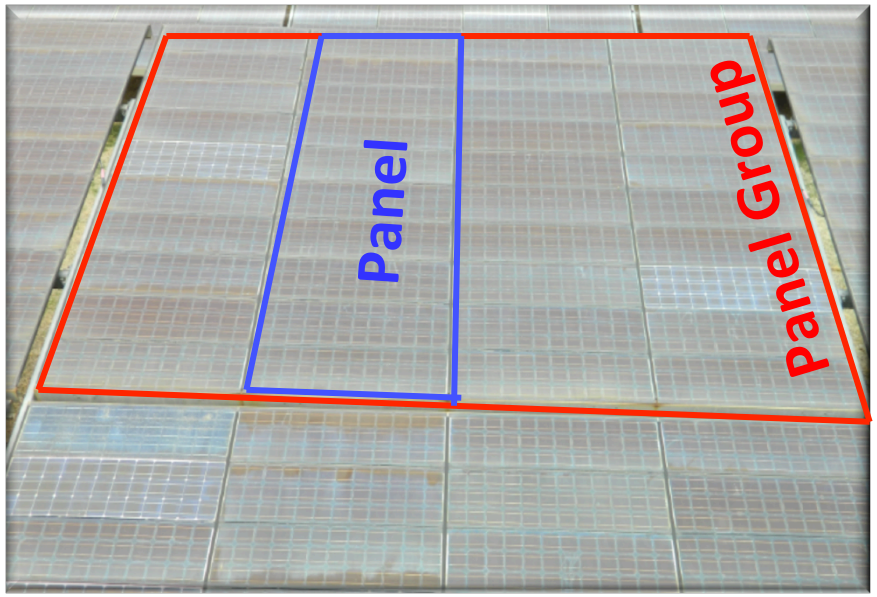
Non-cell interconnect ribbons

Inter-Panel Busbar

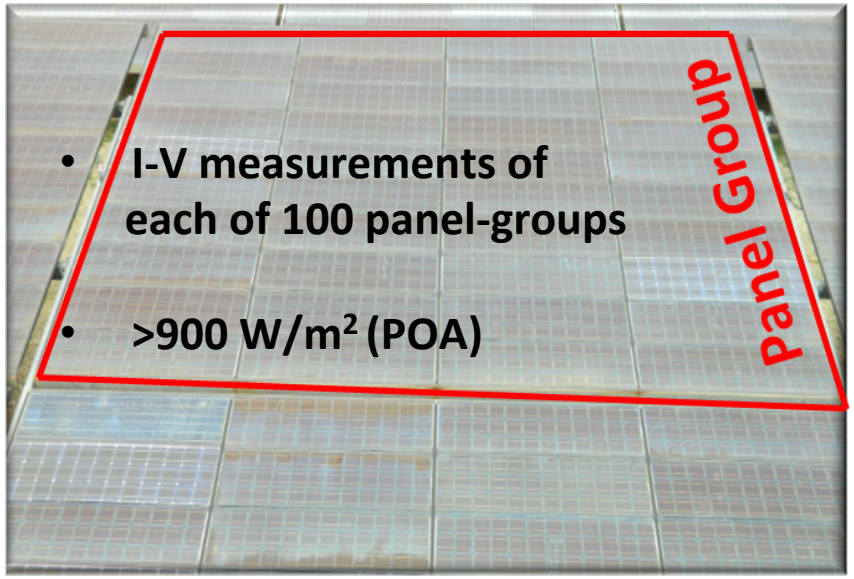
Plastic cover to protect busbar and interconnects (leaky cover; corrosion)

Note: OUTDATED CABLIG METHOD

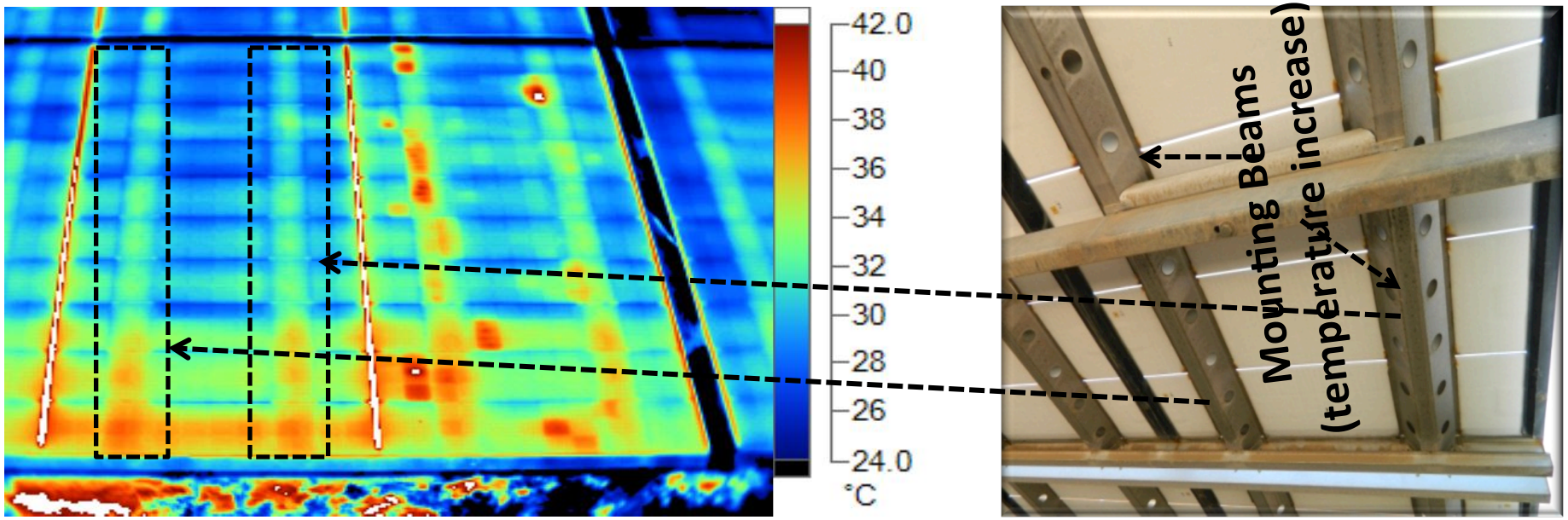
- No module cable
- No module connector
- Non-cell interconnect ribbons are directly welded on inter-panel busbar



Site 2: Characterizations – Visual Inspection, IR Imaging & I-V Curves



- Infrared imaging
- Hotspots



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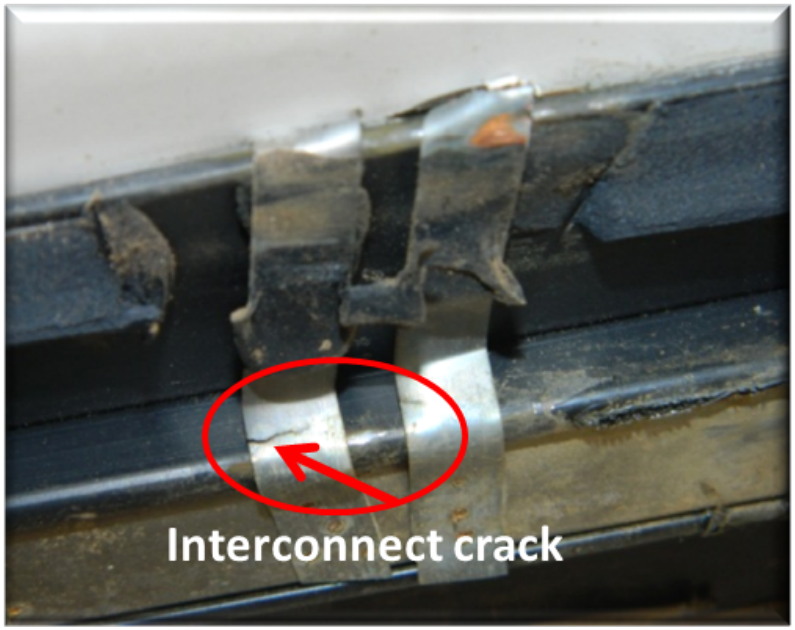
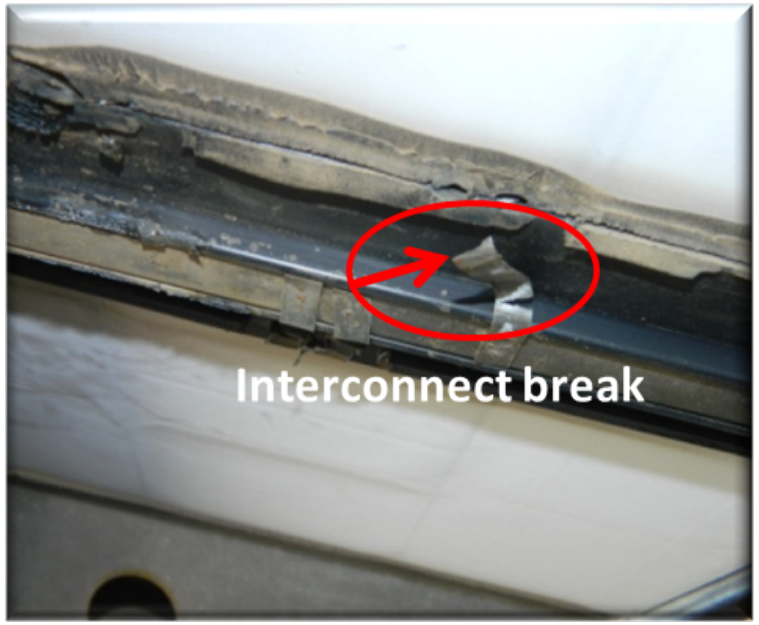
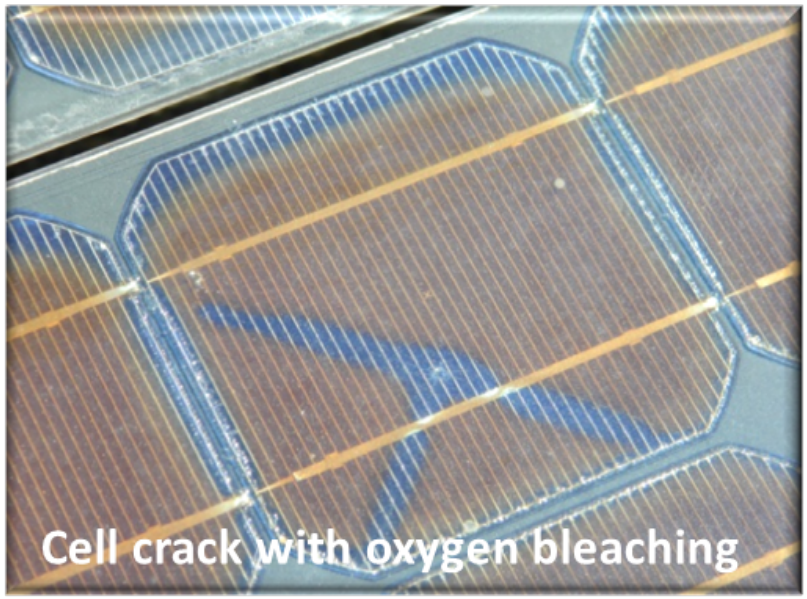
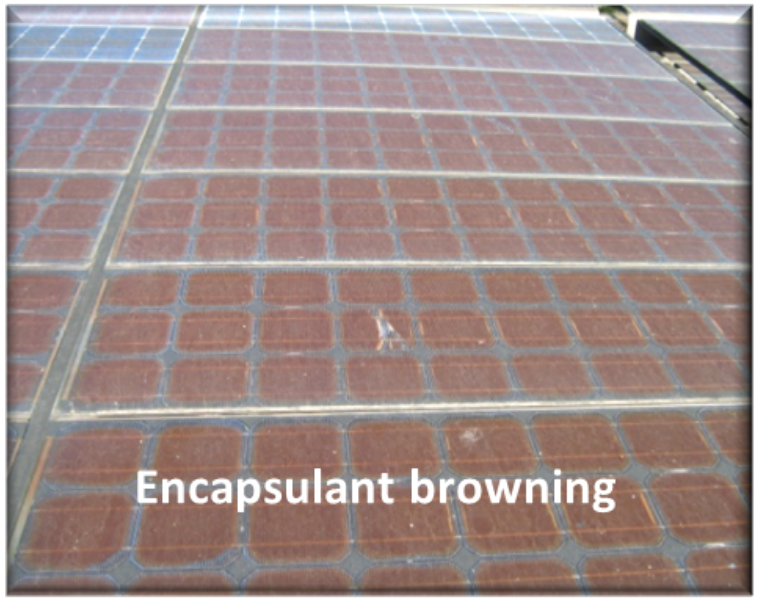


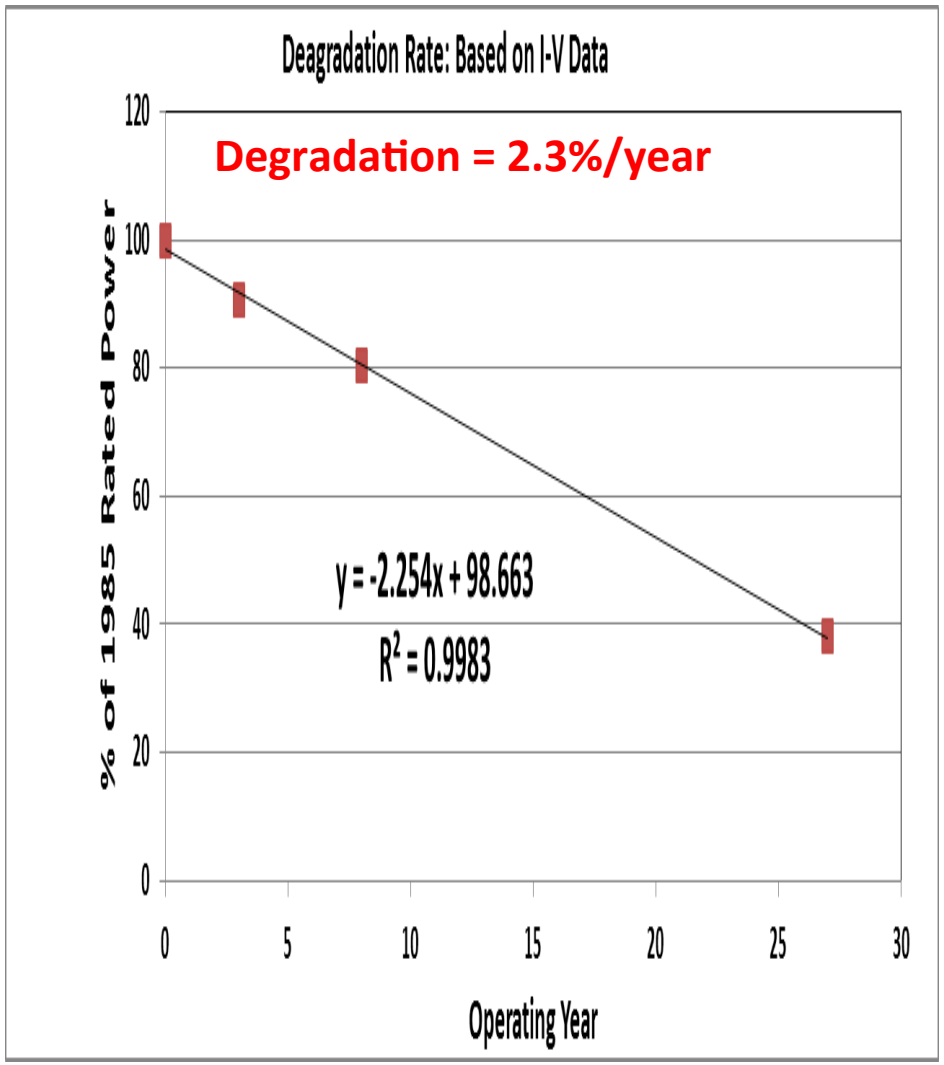




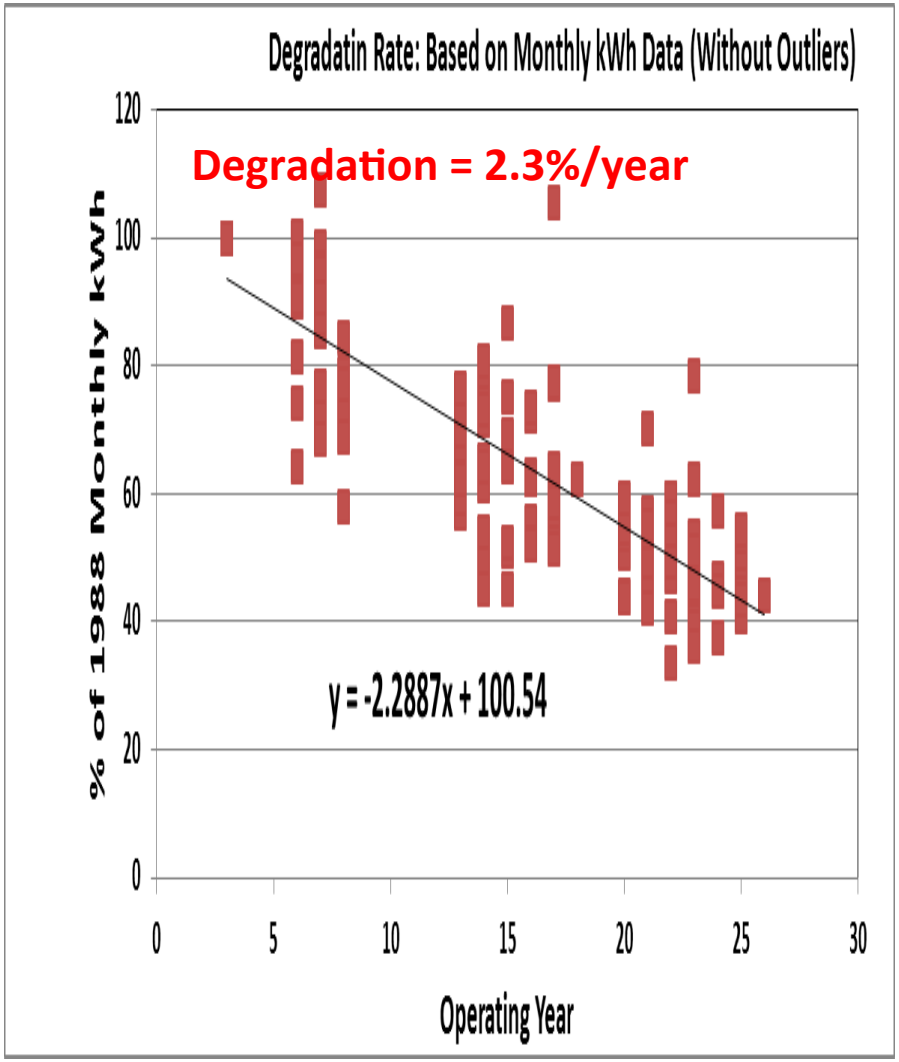


Site 2: Results – Average Annual Degradation Rate

Measured DC Power Data

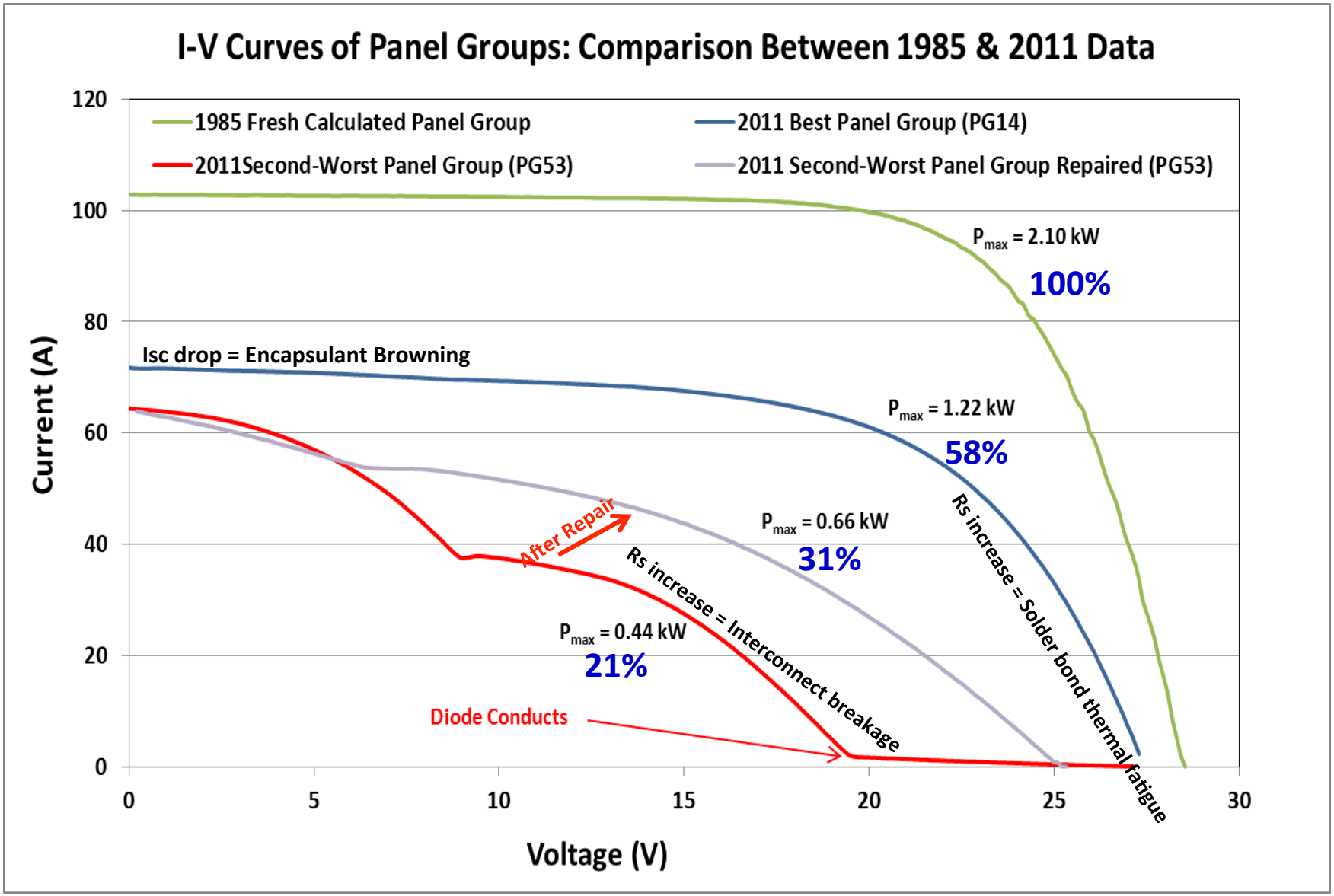


kWh_{ac} Metered Data

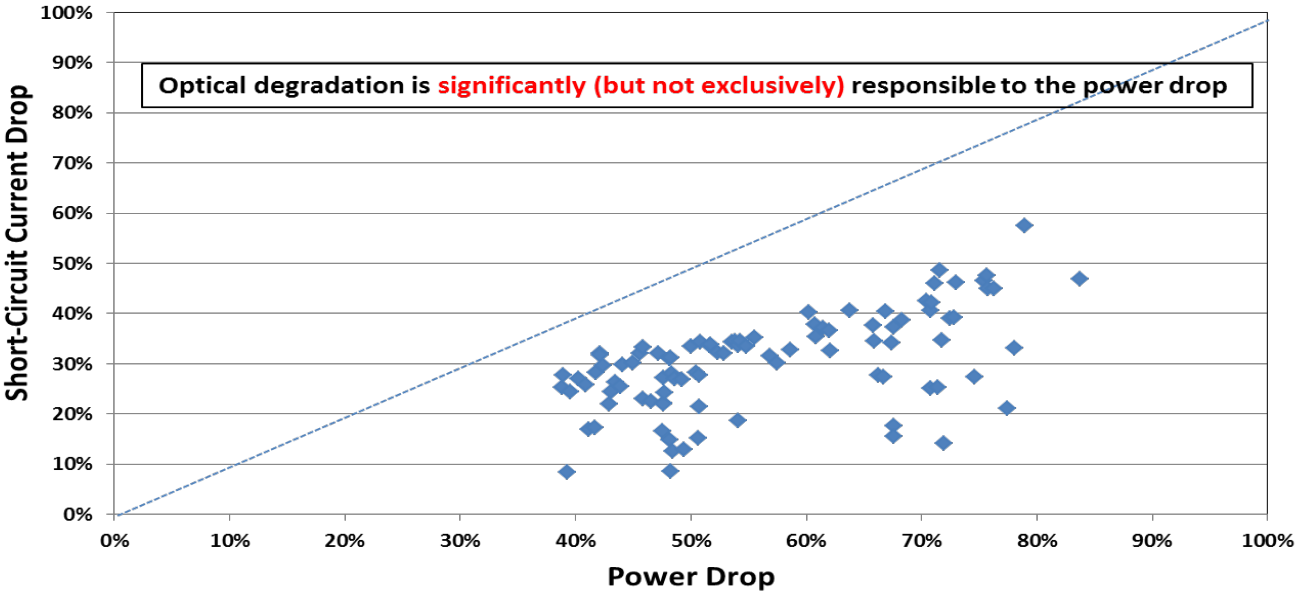


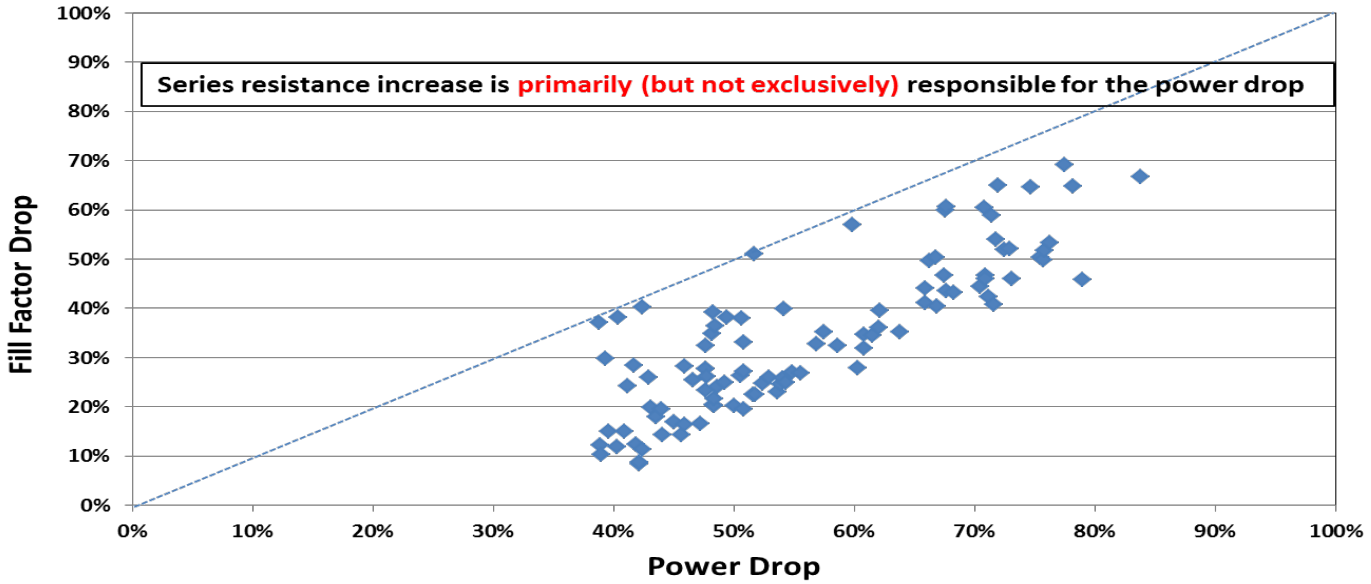
Currently, the plant is operating at about 40% of its rated capacity!

Site 2: Results – Degradation due to encapsulant browning and Rs increase



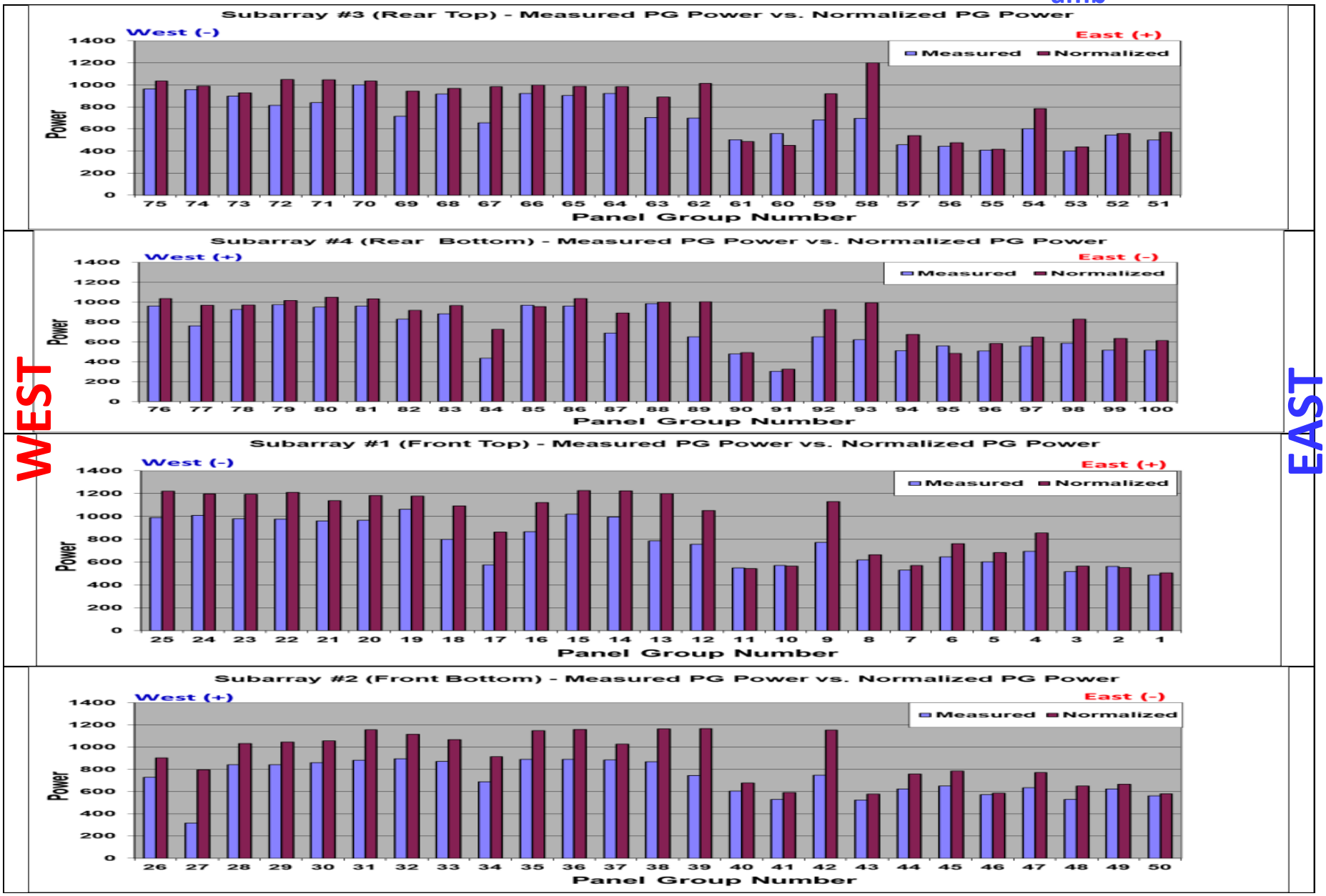
Site 2: Results – Power loss is significantly due to current loss (encapsulant browning) and primarily due to FF loss (solder bond fatigue)





Site 2: Results – East array degrades at much higher rate than west array!!

Wind direction effect?? (S-W wind direction when T_{amb} > 40°C)



Site 2: Conclusions

- The degradation rate of these 26 years old modules is determined to be 2.3%/ year

- Primary degradation modes in this hot-dry climate site also appear to be encapsulant browning and (thermo-mechanical) fatigue of solder bonds. Encapsulant browning leads to current drop and solder bonds fatigue leads to fill factor drop

- Currently, the plan operates at about 40% of its rated capacity

- East side modules have degraded at higher rate than the west side modules. The reasons are unknown (wind direction effect?)

Overall Conclusions

Primary degradation modes in hot-dry climatic sites appear to be encapsulant browning and solder bond fatigue. These degradation modes turn to become failure modes when the performance degradation exceeds the warranty limit, e.g., > 20%.

Contact

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