

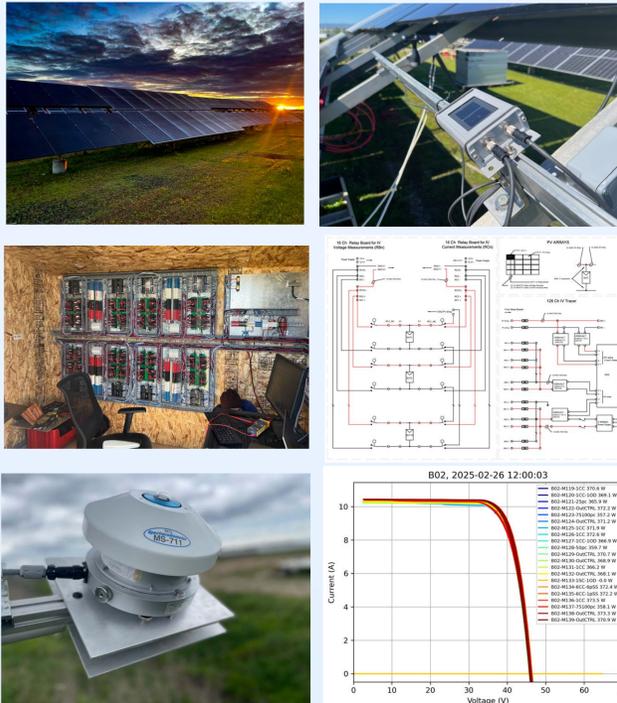
INTRODUCTION

- Goal:
 - How much underperformance occurs for PV modules varying numbers of cell cracks.
 - How do the latest batch of industrial PV modules perform outdoors?
- We present 1.7 years of outdoor testing data on PV modules with and without cell cracks.
- Samples received a variety of cracking stress, from 0% to 100% cracked cells.
- 104 modules deployed outdoors, starting in April 2024, ending in November 2025

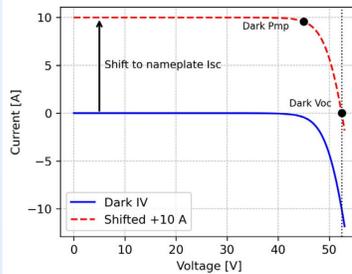
BOM	Cell Technology	Back glass (BG) Back sheet (BS)	Number of Busbars	Number of Cells	Nameplate Pmp W	Number of Samples
B01	n-HJT	BS	20	80	410	19
B02	n-TOPCon	BS	6	144	415	22
B03	n-TOPCon	BG	6	144	565	15
B04	n-TOPCon	BG	16	144	570	15
B05	p-PERC	BS	12	132	400	17
B06	n-TOPCon	BS	6	144	445	8
B07	n-TOPCon	BS	10	144	535	8
B08	p-PERC	BS	6	144	545	8

INSTALLATION AND DATA COLLECTION

- Giant 128 → 1 switchboard uses a single IV tracer to cycle through and trace each module individually.

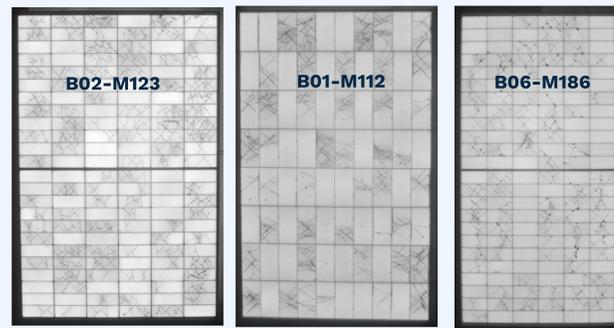


- **Dark IV analysis:** shift the Dark IV curve up to the nameplate Isc, then find Pmp and Voc.
- Allows investigation of series resistance, shunt resistance and voltage loss.

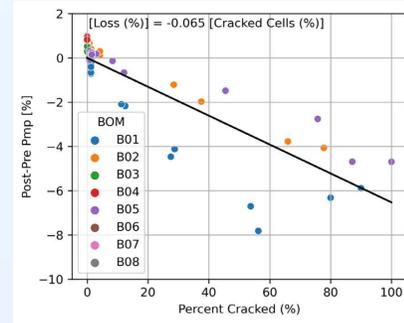


Cracks don't cause much power loss

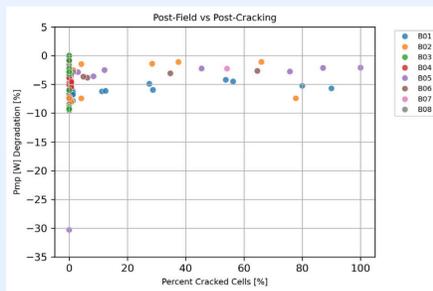
- Do cracks cause underperformance? *Yes, but it's smaller than you'd think!*
- Worst case: ~8% under-performance in Pmp for a single module (does not take into account effect on large arrays). Most cracked modules under-perform by less than 4%.
- Examples of highly cracked modules:



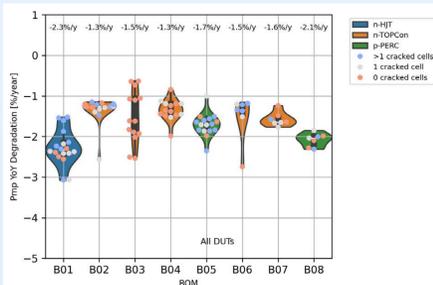
- From before to after cracking, modules "look worse than they are": lots of cracks cause <10% power loss.



- No additional field degradation observed in indoor characterization for highly cracked modules.

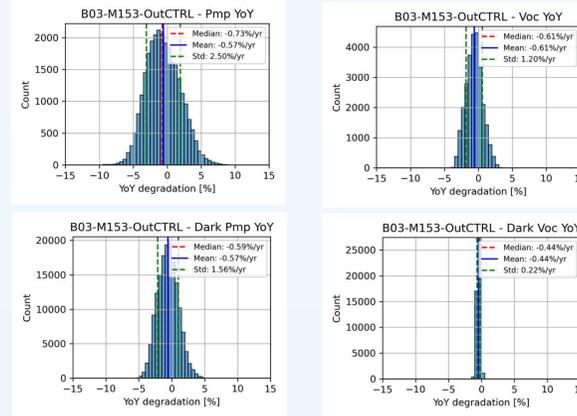


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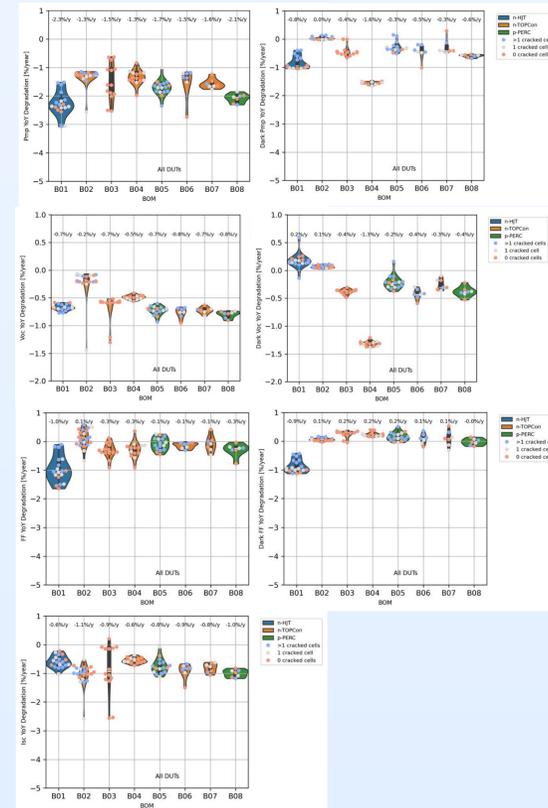
YOY Analysis

- Calculate change in IV parameters using year-on-year analysis¹, Year on year analysis is more robust than regression against artifacts caused by seasons, like temperature offsets, spectral changes, incidence angle changes.
- Dark parameter analysis has more certainty



Degradation Measured with Outdoor IV

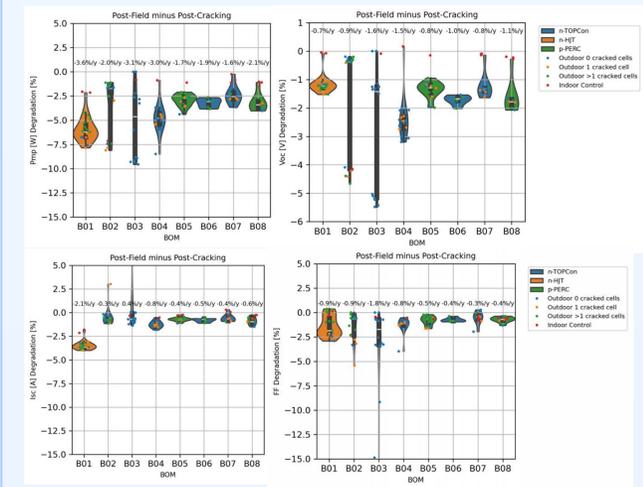
- YOY analysis shows significant degradation occurring in many different BOMs, ranging from -1.3%/yr to -2.3%/yr
- Pmp and Voc degradation is significant, implying cell changes are occurring.



1. Deceglie, Michael G., et al. "Perspective: Performance Loss Rate in Photovoltaic Systems." Solar RRL, vol. 7, no. 15, 28 June 2023, <https://doi.org/10.1002/solr.202300196>.

Degradation Measured with Indoor IV

- Outdoor exposure time: 1.7 years.
- No higher degradation observed for cracked modules. Very high degradation values observed, up to -3.6%/yr over 1.7 years.
- Modules were stabilized with 1 hour light soak before final characterization.
- Significant Voc degradation for many BOMs.
- Measurements span multiple calibration cycles: some indoor control modules stable in power to around 1% level.



SUMMARY & FUTURE WORK

- Even highly cracked modules typically have less than 5% power loss.
- Yearly degradation rates are outside warranty bounds on many modules (even without cracks).
- **DO NOT REWORK MODULES FOR CRACKS!** Module manufacturers are performing expensive and manual rework in order to remove a few microcracks from a substrate in a module. *This can cause more problems than it solves.*
- **IF IT AINT' BROKE DON'T FIX IT.** Modules with high numbers of cracked cells typically underperform by less than 5%. This underperformance does not justify the cost of replacing modules. If the glass isn't broken, don't fix it.
- Data collection is complete, remaining: anonymization, analysis and upload to Datahub.

ACKNOWLEDGMENT

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