DuraMAT
Durable Module Materials Consortium

Accelerating a sustainable, just, and equitable transition to zero-carbon electricity generation by 2035.

Bifacial photovoltaic module degradation dynamics

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Fielded Module Forensics

Awarded FY23 Core Modelling Call

Period of Performance: 6-mo FY23, 6-mo FY24
Funding: 50k + 20k

Contributing to DuraMAT Consortium Goals

https://datahub.duramat.org/dataset/best-field-data

How does your research contributes to 50-year Modules and Duramat

1. This study highlights potential degradation modes unique to bifacial PV since this technology is just starting to take significant market share
2. Additional relevance with DuraMAT includes existing connection with the DuraMAT Data Hub to disseminate NREL bifacial array field data and tie-in with glass-glass module durability studies

Project Overview

In a comprehensive study conducted at NREL's 75 kW bifacial single-axis-tracked field, accelerated degradation was observed in four out of five bifacial silicon photovoltaic (PV) module technologies when compared to their monofacial counterparts. Root cause analysis of accelerated bifacial degradation involved various analytical tools and techniques. This included employing RdTools to identify rates of power loss, conducting measurements on fielded and control modules using infrared imaging, electroluminescence (EL) and photoluminescence (PL), quantum efficiency (QE) analysis, IV-curves assessment, as well as utilizing handheld Raman and handheld reflectance measurements.

RdTools

$$Rd_n = \frac{PR_{n+365} - PR_n}{PR_{yr1}}$$

$$PR_n = daily\ perf.ratio \qquad \frac{\sum_{365}^{1095} Rd_{n:(n+365)}}{365}$$

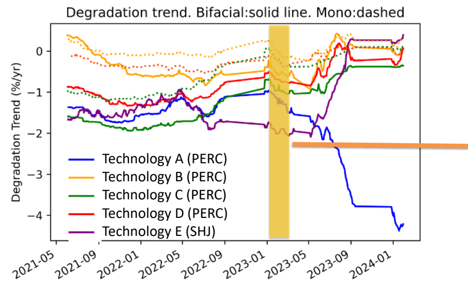
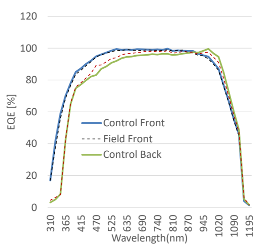


Fig. 1 - Year-on year degradation trend, 12-month rolling average calculated with RdTools. Initial Bifacial energy gain has a slight downward trend over 2.5 years, but then some of the technologies degradation has started to stabilize and improve. On average, bifacial PERC and Si-HJT are degrading faster than monofacial counterpart

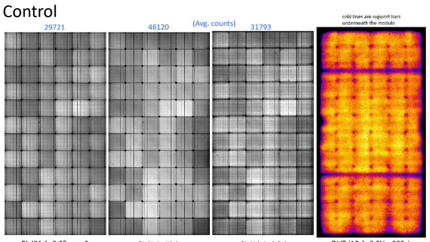
	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D	Manufacturer E
Technology	pPERC	pPERC	pPERC	mc-pPERC	HJT
Back Surface			Glass		
Half or Full Cell	Full	Full	Half	Half	Half
JB Location	Top	Top	Center	Center	Center
Encapsulant*	EVA	"PE / EBA"	EVA	" PE / EBA"	"PE / EBA"
Control module available	Yes	Yes	Yes	No	Yes
Performance changes as of 02/23 measurements					
ΔISC Front	-0.35%	-0.46%	-1.86%	-2.7%	-6.43%
ΔISC Back	2.15%		-2.93%	0.6%	-3.22%
ΔVoc Front	-1.39%	-0.09%	-2.70%	-1.3%	-1.19%
ΔVoc Back	-1.41%		-2.81%	-0.9%	-0.89%
ΔFF Front	-0.45%	-0.10%	-1.00%	0.4%	-0.02%
ΔFF Back	-0.88%		-2.27%	-0.8%	-0.93%
ΔPmp Front	-2.17%	-0.62%	-5.45%	-3.6%	-7.53%
ΔPmp Back	-0.13%		-7.82%	-1.1%	-4.96%
Monofacial counterpart results					
ISC Loss	No monofacial counterpart	-0.04%	-0.30%	-0.8%	No monofacial counterpart
Voc Loss		-0.11%	-1.92%	-0.9%	
FF Loss		-0.06%	-0.34%	-0.1%	
Pmp Loss		-0.23%	-2.54%	-1.7%	

Technology A

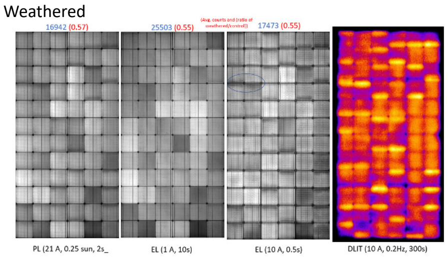
IV Curves Results	% Change
ISC Loss Front	-0.35%
ISC Loss Back	2.15%
Voc Loss Mono	
Voc Loss Front	-1.39%
Voc Loss Back	-1.41%
FF Loss Mono	
FF Loss Front	-0.45%
FF Loss Back	-0.88%
Pmp loss Mono	
Pmp Loss Front	-2.17%
Pmp Loss Back	-0.13%



Control



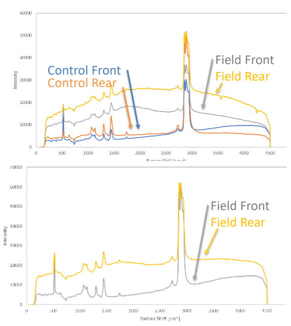
Weathered



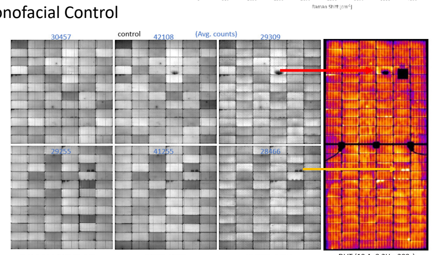
For weathered module compared to control, overall luminescence intensity is down to about 55% of the control, suggesting a loss in voltage. There are dark edge patterns (either top or bottom of cells) in high-current EL and PL, and hotter DLIT, suggesting these are areas with increased carrier recombination, perhaps loss of passivation.

Technology C

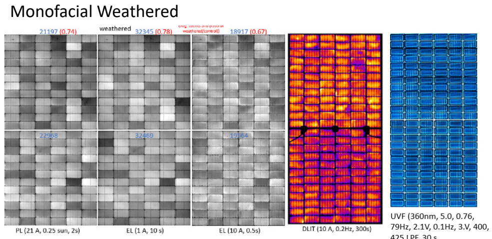
IV Curves Results	% Change
ISC Loss Front	-0.30%
ISC Loss Back	-1.86%
Voc Loss Mono	-2.93%
Voc Loss Front	-1.92%
Voc Loss Back	-2.70%
FF Loss Mono	-2.81%
FF Loss Front	-0.34%
FF Loss Back	-1.00%
Pmp loss Mono	-2.27%
Pmp Loss Front	-2.54%
Pmp Loss Back	-5.45%



Monofacial Control

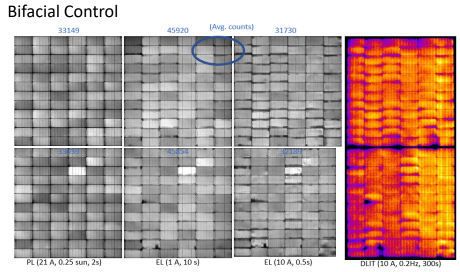


Monofacial Weathered

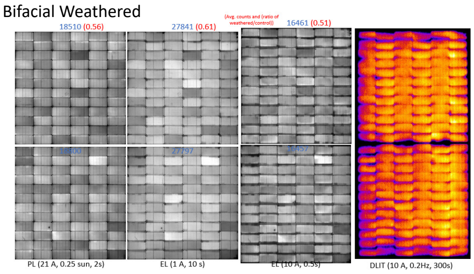


For weathered module compared to control, overall luminescence intensity is down to about ~¾ of the control, suggesting a loss in voltage. There are a few patterns in high-current EL showing dark areas of higher resistance. DLIT dark areas here too, suggesting lower current density or broken grid fingers – possibly leading to reduced fill factor.

Bifacial Control

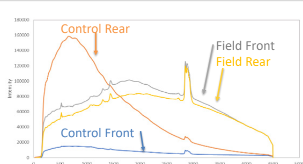


Bifacial Weathered

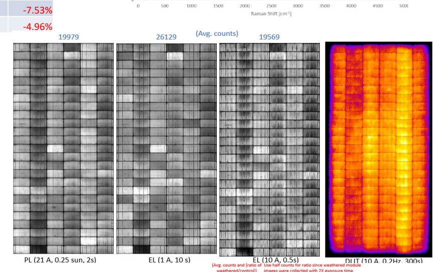


Technology E

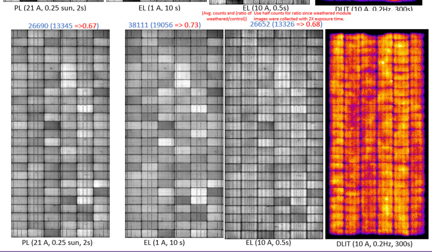
IV Curves Results	% Change
ISC Loss Front	-6.43%
ISC Loss Back	-3.22%
Voc Loss Front	-1.19%
Voc Loss Back	-0.89%
FF Loss Front	-0.02%
FF Loss Back	-0.93%
Pmp Loss Front	-7.53%
Pmp Loss Back	-4.96%



Bifacial Control



Bifacial Weathered



For weathered module compared to control, overall luminescence intensity is down to about ~¾ of the control, suggesting a loss in voltage. No other obvious patterns or observations when comparing weathered to control.

Conclusions. Most cases point to carrier lifetime degradation causing Voc loss and simultaneous Isc loss. In some cases, Isc further recreases likely due to optical effects from encapsulant degradation. This study is a small sample of degradation seen, and needs to be placed in perspective of broader degradation analysis. The changes in degradation rate seen after taking IV measurements indicate that **we need multiple years to validate degradation rate and mechanisms.**

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Photovoltaic Reliability Workshop (PVRW)
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