Cracked Up: how should we classify and respond to various electroluminescence defects in silicon PV modules?

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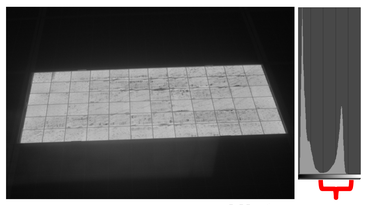
1. Problems

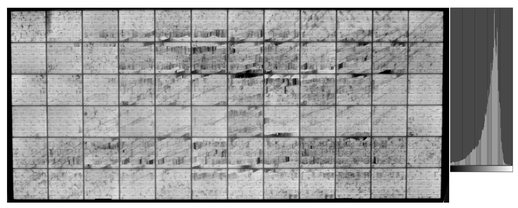
- Module degradation rates are strongly correlated to the number of cracked cells[1]
- IEC 61215 is lenient regarding cracked cells
  - The static load test creates cracks, but there is no subsequent cyclic loading to open up the cracks
  - Cold explosure[2] in the chamber tests creates tiny microcracks in many modules but there is no subsequent mechanical loading to propagate them into full cracks
- Few modules are tested for cracks in the field by electroluminescence (EL); just in factory
- No clear agreement on how to interpret EL images or how to react to cracked cells
- Without wider testing and consequences, module manufacturers have little incentive to improve designs and may not even be aware that they should
  - There is immense difference in the crack resistance of different module designs, but most module buyers are clueless

2. How enhance & interpret EL images?

Enhance example

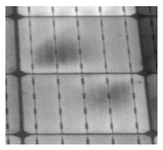


Perspective-
Stretch
Rotate
Crop

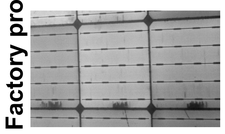


Histogram-stretch

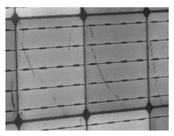
Factory problems



Blotches in repeating pattern - Si growth or cell processing contamination. Not cracks.

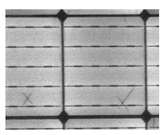


Repeating pattern: poor screen printing. Not cracks.



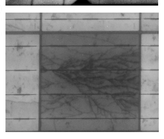
Curved and non-continuous lines on mono cells: Cell processing contamination. Not cracks. Many mono cracks are at 45º

Field problems

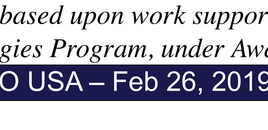


"X" cracks: Rear side point impact, likely post shipping, sometimes from cable connectors swinging against back

Line of "X" cracks: Rear side dragging impact, possibly from dragging a corner of another module across backsheet when unpacking pallet



Dense dendritic crack pattern. Likely cracked at high load level with high release of energy. Shunting makes image dark. Worse low-light performance.



"Crow's feet" V cracks at wire tips: poor soldering

Dark finger regions consistently going up to busbars: Likely cracks in fingers but not in Si; poor metallization and/or tabbing process/design

Dark regions around 1 or more busbars: poor soldering or cracked wire

Closed cracks – no power loss. Yet.

Open cracks – possible power loss and hot spots

3. How quantify EL images?

# of modules	322
# of modules with cracks	258
% of modules with cracks	80%
# of cracked cells	1147
% of cracked cells	4.9%

- Keep track of cracks in key categories: Closed, Open, Rear Impact
- Important to automate detection and quantifications

3. How and when test panels?

Systems	Throughput (modules/hr with 2 workers)	Pros	Cons
Tripod systems	20-60	Lowest cost Easy to transport	Focusing challenges Poor reproducibility
Trailer systems	40-120	Best quality images Reproducible conditions Can do IV and other tests Can test during daytime	More expensive Undesirable to de-mount modules Difficult to move far
Drone systems	>120	Fastest Best for difficult to access installations	Focusing challenges More expensive? Dangerous high-voltage power supplies to bias many modules at once

Who?	When?	Why?
Distributors	Sample incoming shipments	Ensure quality of modules Differentiate from competitors
EPCs/Installers	Sample incoming shipments Sample	Because investors or insurance companies require it Ensure quality of modules and work Differentiate from competitors
Independent Testing Services	Sample new installation and low-performing systems	Hired to verify system quality
O&M Groups	Test low performing strings or modules with hot cells from thermal imaging	Replace or "repair" high risk modules
Investors and insurance companies	At all stages through above groups	Maximize revenue and minimize risk Establish baselines in case of warranty claims

Parameter	Baseline	Crack Free
Degradation rate (%/year)	0.75	0.45
Service life (years)	25	30
LCOE % change from baseline	0.0%	**-7.8%**

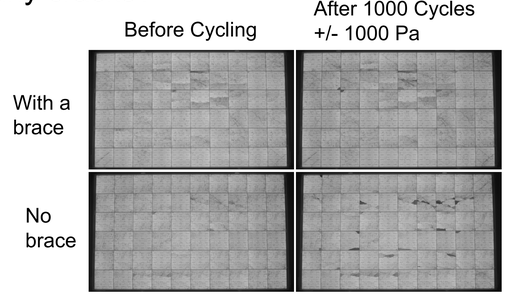
Improving the degradation rate or service lifetime has huge impact on LCOE (*NREL Comparative LCOE calculator*)

4. How to respond to EL images?

Testing after shipping:
- Why accept any cracks?
- How much higher $/W to demand replacement from module supplier of panels with any cracks?

Testing right after installation:
- Why accept any cracks?
- How much higher $/W to demand replacement from installer of panels with any cracks?

Testing of older systems:
- Is it acceptable to add a "band-aid" to badly designed or compromised modules?
- What damage can be ignored
- What damage requires further testing?
- What damage requires replacement?



Adding a brace can limit deflection vs load and prevent crack opening or even close opened cracks[3]

Criteria	No action	Thermal image and IV test within 2 years	Thermal image and IV test in place within 3 months	Replace Module
# of closed and rear impact cracks	3 or less	4-6	7-10	>10
# of open cracks	0	1	2-4	>4

Example of possible responses to cracks

Example of a brace that presses on back side

5. References

[1] S. Chattopadhyay et. al., "All-India Survey of Photovoltaic Module Reliability: 2016," IIT Bombay and NISE.
[2] M.W. Rowell, S.G. Daroczi, D.W.J. Harwood, and A.M. Gabor, " The Effect of Encapsulant Properties and Temperature Cycling on the Fracture Strength and Performance of Encapsulated Solar Cells," in WCPEC-7, 2018.
[3] A. M. Gabor, J. Lincoln, E. J. Schneller, H. Seigneur, R. Janoch, A. Anselmo, D. W. J. Harwood, M. W. Rowell, Compressive Stress Strategies for Reduction of Cracked Cell Related Degradation Rates in New Solar Panels and Power Recovery in Damaged Solar Panels," in WCPEC-7, 2018.

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