

Cracking Down on PV Module Design: Results from Independent Testing

Cracks in solar cells are typically so small that they cannot be detected by eye – yet they can reduce a project's energy yield and create safety issues over time. As climate change accelerates and weather patterns change, force majeure events such as wildfires, hail and other storms are more likely to affect solar power plants. **This white paper explains the problem of cell cracks and discusses how PV module buyers, investors and asset owners can mitigate risk by investing in durable PV modules.**

Understanding Cell Cracks

Cell cracks, also known as microcracks, are caused by excessive thermal and mechanical stress that can result from several different factors:

- **Manufacturing defects**, such as stresses during cell soldering, lamination pressures and production line handling.
- **Environmental conditions**, such as daily temperature fluctuations, freeze-thaw cycles, wind, snow accumulation and hail.
- **Physical damage**, such as mishandling during transportation and/or installation, maintenance and/or improper cleaning.



The PV module above was damaged by a tornado leading to cell cracks and inactive/dark areas. This EL image was taken by PVEL in the field.

Cell cracks appear as dark, discolored, broken lines or areas in electroluminescence (EL) images. The module could produce less energy if these cracks restrict the flow of current through the cell.

A local hotspot may eventually form in the damaged area of the cell, which can accelerate backsheet degradation and delamination, eventually increasing the risk that ground and arc faults will occur.

Cracking in the Field

A recent analysis of PV modules installed in various projects in Jordan found that **severe cell cracks caused power losses as high as 9%** in monocrystalline PERC modules after just four months of field exposure.¹

The study concluded that the number, size and shape of the cell cracks as well as busbar design all significantly influence the rate of power loss. It is important to note that, in many cases, power loss is realized over time, not in the space of a few months.

Technology Trends and Risks

Two recent trends in PV module design could significantly increase cell crack susceptibility, either alone or in combination. First, manufacturing shifts to larger format, higher-powered PV modules may increase cracking risks because:

- They contain larger silicon wafers that will be subjected to pressures over a larger surface area.
- The modules may be subject to more deflection during high wind and snow loads.
- To reduce the weight of these modules, some manufacturers are using thinner glass and/or thinner frames, which can reduce rigidity and durability.

Second, reductions in inter-cell spacing, which are achieved through shingling and other cell-to-cell interconnection techniques, could increase mechanical stress on solar cells.

Climate Change and Extreme Weather

In tandem with these PV manufacturing trends, the severity and frequency of extreme weather events are rising due to climate change, and more gigawatts of solar power are located within the likely paths of major storms. Hail, hurricanes, tornadoes and other high wind events are all known to cause glass and cell cracks in PV modules.

Asset owners can mitigate the risk of cell-level damage in their fleets by investing in more robust PV modules, especially for projects in storm-prone regions.

¹ Matthar Bdour et al, "A Comprehensive Evaluation on Types of Microcracks and Possible Effects on Power Degradation in Photovoltaic Solar Panels." Sustainability 12 (2020): 6416. <https://www.mdpi.com/2071-1050/12/16/6416/html>

The Mechanical Stress Sequence in PVEL's PV Module Product Qualification Program

Modules tested for PVEL's Product Qualification Program (PQP) undergo the mechanical stress sequence (MSS), as shown in the diagram below. The MSS test combines static and dynamic loading with thermal cycling and humidity freeze to create, articulate and propagate cracks in susceptible modules – as would occur in field conditions.

Testing at the Bill of Materials (BOM) Level

The PVEL PQP evaluates specific PV module BOMs. MSS is required following any BOM changes that can impact mechanical durability, including a change in cell, cell interconnects, glass, rear encapsulant, frame and/or frame attachment method, as well as increasing module size and/or cell count.

Qualifying new factory locations and new combinations of materials also triggers MSS testing, including new combinations of cell + glass, cell + frame, cell + encapsulant, glass + encapsulant, encapsulant + backsheet, and junction box attachment + backsheet.

Learn more about PVEL's PQPs at pvel.com/pqps.

PVEL's PV Module PQP

Factory Witness							
Intake Characterizations							
Light Soaking for Light-Induced Degradation							
Post-Light Soaking Characterizations							
Thermal Cycling	Damp Heat	Backsheet Durability Sequence	Mechanical Stress Sequence	Potential-Induced Degradation	LeTID Sensitivity	PAN File & IAM Profile	Field Exposure
TC 200	DH 1000	DH 1000	Static Mechanical Load	85°C, 85%RH MSV (+ and/or -) 96 hrs	LeTID 162 hrs (75°C, Isc-Imp)	PAN File	Field Exposure 6 Months
Characterization	Characterization	Characterization			Characterization	IAM Profile	
TC 200	DH 1000	UV 65 kWh/m²	Characterization	Characterization	LeTID 162 hrs (75°C, Isc-Imp)		Characterization
Characterization	Characterization	Characterization	Dynamic Mechanical Load	85°C, 85%RH MSV (+ and/or -) 96 hrs	Characterization		Field Exposure 6 Months
TC 200	Stabilization 85°C, Isc, 48 hrs	TC 50 + HF 10	Characterization	Characterization	LeTID 162 hrs (75°C, Isc-Imp)		Characterization
Characterization	Characterization	Characterization	TC 50		Characterization		
		UV 65 kWh/m²	Characterization				
		Characterization	HF 10				
		TC 50 + HF 10	Characterization				
		Characterization					
		UV 65 kWh/m²					
		Characterization					
		TC 50 + HF 10					
		UV 6.5 kWh/m²					
		Characterization					

PVEL's MSS Step-by-Step

Step 1: Factory Witness and Intake

- As samples are manufactured, BOMs are witnessed in production from the opening of raw materials through every step of the production until they are palletized with tamper-proof tape and received at PVEL's labs.
- Once received, modules undergo flash testing and EL imaging to capture power output and physical condition before they are subjected to the test sequence.

Step 2: Static Mechanical Load (SML)

- Modules are mounted on two rails, secured to the module at typical ground mount clamping locations.
- Modules are then subjected to three cycles of one hour of downforce and one hour of upforce pressure of 2400 Pa, which is comparable to hurricane-force winds and heavy snow loads.
- This step creates cell cracks in susceptible modules.

Step 3: Dynamic Mechanical Load (DML)

- The mounted modules are subjected to 1000 cycles of alternating positive and negative loading at 1000 Pa, which simulates variable windspeeds and wind shear.
- This step articulates existing cracks, creating inactive areas or increased series resistance.

Step 4: Environmental Stress

- Modules are placed in environmental chambers and subjected to 50 thermal cycles from +85°C to -40°C, with current injected into the module as the temperature rises.
- Modules are then subjected to 10 cycles of humidity freeze - high heat and high humidity, followed by a rapid drop to freezing temperatures.
- This step simulates an acceleration of natural, daily temperature changes and other environmental conditions that cause cracks to propagate through cell metallization.

Characterizations after Every Step

- Power loss is measured with precision flash testing.
- Detailed visual inspection is conducted to identify damage.
- Wet leakage testing is performed to verify electrical safety.
- EL images are taken to reveal cell cracks, which are typically not visible by eye.

Cracks and Power Loss by Step

1

Pre-stress
0%

2

Post-SML
- 1.17%

3

Post-DML
- 1.71%

4

Post-TC50+HF10
- 3.55%

Advantages of PVEL's MSS

PVEL's MSS was carefully designed to replicate cell cracking observed in the field. The test sequence is aligned with the forthcoming IEC 63209 technical specification for extended reliability testing. In contrast, the IEC 61215 certification standard only requires static mechanical loading, and PV modules will pass if they exhibit no visible damage when evaluated by eye and have less than 5% power loss.

This evaluation criteria – and particularly the lack of EL images – prevents buyers from using IEC 61215 certification to effectively assess crack susceptibility. PVEL's test sequence extends beyond the IEC 61215 standard by including additional post-static mechanical load stresses as would occur in a typical field installation, thereby allowing the full potential power loss of the cracks to be quantified.

" Today's solar projects are often built with razor-thin margins, so power losses greater than 3% could easily eliminate profits.

Jenny Chase, Head of Solar Analysis, BloombergNEF

MSS Test Results: Key Findings from PVEL's PQP

As of December 2020, PVEL has completed MSS on over 40 modules, representing more than 20 unique bills of materials (BOMs). Results thus far range from no detectable power loss to a degradation rate of over 5%.

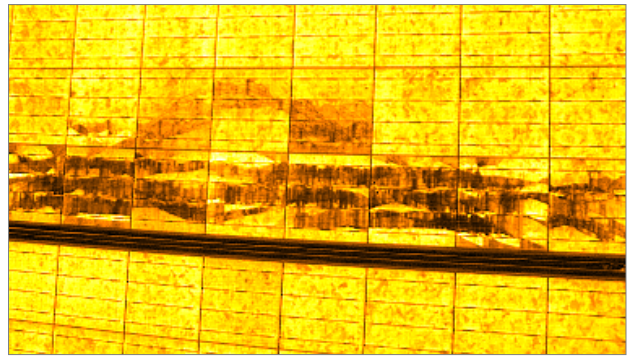
Different shapes, sizes and types of cracks affect PV modules in different ways, although in PVEL's lab and field testing experience, branching cracks (also known as dendritic cracks) that spread through cells as modules age in the field are usually the most destructive. As shown in the PVEL test results that follow, BOMs can experience significant cell cracking when they are installed according to the structurally-optimal mounting method employed for MSS testing. **In PVEL's experience, the use of alternative mounting configurations – which are common in the field – can subject modules to additional stresses and thereby increase the potential for cracks to occur.**

Crack Susceptibility Depends on Many Factors

As there are many factors that impact a module's mechanical durability, the topic of crack susceptibility is nuanced. **Results to date indicate that the specific BOM and production process used to manufacture a PV module will affect crack susceptibility more than any single design choice.**

For example, some full cell modules exhibit multiple cracks and power loss following MSS while others perform very well. It is vital to test specific BOMs intended for procurement to ensure they perform as expected.

With that in mind, the following sections outline several observations regarding crack susceptibility that can be gleaned from PVEL's PQP results.

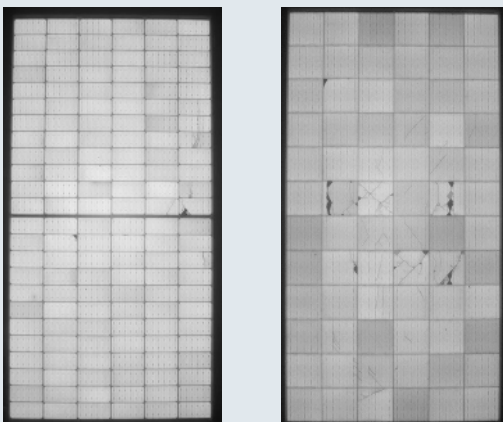


The magnified EL image above shows multiple branching cracks in a fielded PV module.

Half-Cut vs. Full Cell

In some cases full cell modules are more susceptible to cell cracking than modules made with half-cut cells. This is likely because they have a larger cell surface area that needs to withstand the mechanical pressure during static mechanical load.

This is a nuanced finding, as cutting cells can actually create microcracks if done improperly.

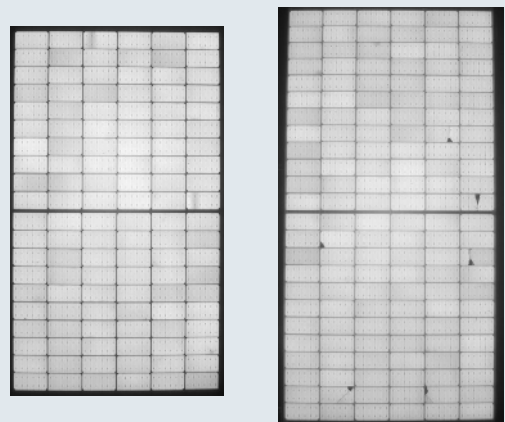


The EL images above compare a full cell module (right) and half-cell module (left) after MSS. The half-cell module shows very few cracks in comparison to the full cell module.

120 Cell vs. 144 Cell

The BOMs for the EL images pictured below are nearly identical – but one is a 144-cell design and the other is the same manufacturer's 120-cell design.

While both performed relatively well, the 144-cell version experienced more cell cracks than the 120-cell version. **A larger surface area can result in more deflection during mechanical loading, which may generate cracks.**

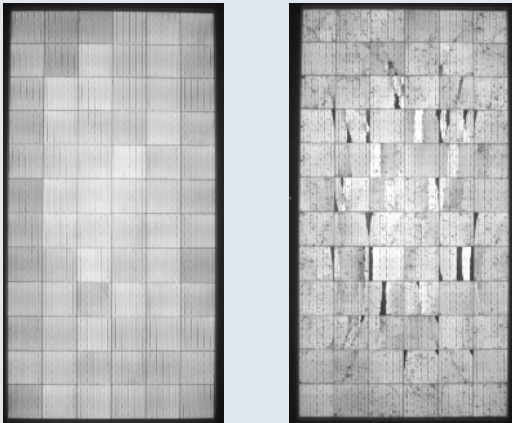


The PV modules pictured above have nearly identical BOMs. However, the 144-cell version of this BOM (right) proved more susceptible to microcracks than the 120-cell version (left).

Monocrystalline vs. Multicrystalline

The speed of the industry's transition from multicrystalline to monocrystalline silicon solar cells has surprised many analysts who foresaw that multicrystalline would have a larger market share than its current share of about ten percent. The obvious benefit of this transition is higher efficiency modules. PVEL's MSS test results point to another benefit: **multicrystalline cells are often more susceptible to cracks than monocrystalline cells.**

However, this observation comes with an important caveat: if monocrystalline modules are produced using substandard components or poor quality controls, they may be significantly more susceptible to cell cracking than is shown in the example below.



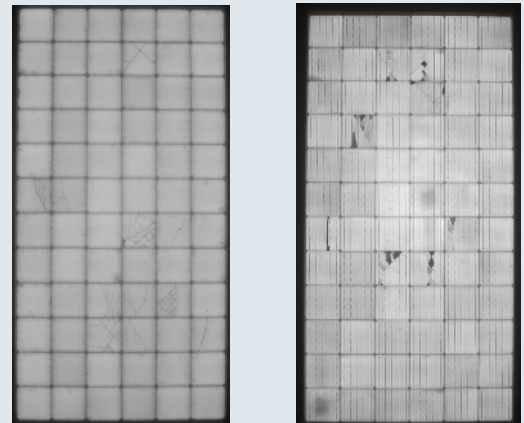
The multicrystalline PV module above (right) showed significant cell cracking and inactive areas following MSS, whereas the monocrystalline module (left) is unaffected.

Number of Busbars

Cell cracking can become a safety and performance issue when it creates inactive areas in the cells. PVEL has seen that there is a significant difference in inactive areas due to cell cracks for five busbar cells and 12 busbar cells.

In the five busbar example, the cell cracks have clearly created inactive zones where they have separated portions of the cells from the busbars. For the 12 busbar example, similar cell cracks have occurred, but due to the higher number of busbars spanning the cells, very few inactive areas can be seen.

While **resistance to power loss from cracking is an innate advantage for multi-busbar modules**, it is important to note that there are five and six busbar modules that have performed well in PVEL's MSS testing.



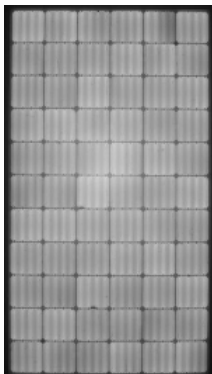
Both the 12 busbar (left) and five busbar (right) PV modules above suffered cracks during MSS testing, but the five busbar PV module has significantly more inactive areas.

Distinct Technologies

A handful of distinct module technologies have shown strong results in MSS testing:

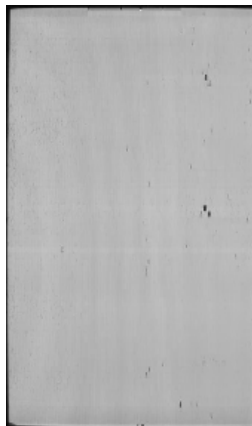
Interdigitated Back Contact (IBC)

Back contact technologies such as IBC have performed well during MSS testing. The image below shows no significant changes post-MSS.



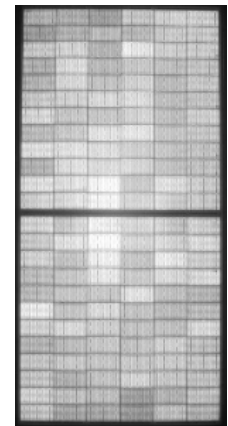
Thin Film

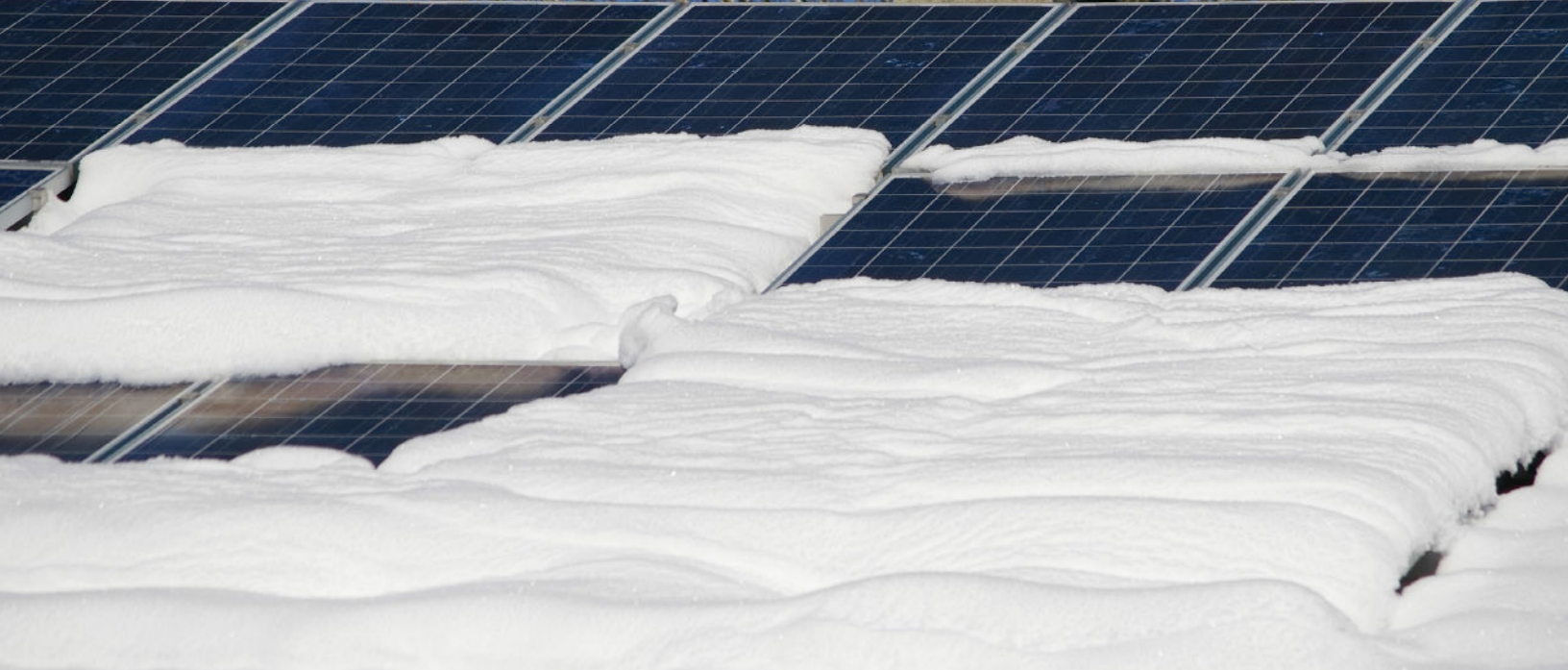
CdTe thin film modules are manufactured with cells that are not susceptible to cracking as shown in this post-MSS EL image.



Glass//Glass

PVEL has observed strong results from glass//glass modules. The module below shows no cracking post-MSS.





Conclusions

PVEL's MSS findings illustrate that crack susceptibility is nuanced. Several new technologies are inherently less susceptible to cracking, but some older technologies may perform better than their newer counterparts. Crack susceptibility ultimately depends on the specific components and manufacturing techniques employed in PV module production. **Selecting BOMs that have undergone and performed well in independent testing is the key to avoiding procurement of PV modules that are likely to experience cell cracks in the field.**

Next Steps

PVEL's PQPs are dynamic and responsive as the technical due diligence needs of PV module buyers change. Test programs are updated regularly as technology advances and as the market evolves – our MSS, introduced in 2019, is just one example of the many advances in the PQP since it was first established in 2012. PVEL's PV Module PQP will continue to evolve over time as new field data emerges and as new insights are shared by downstream buyers, independent engineers, manufacturers and research institutes.

As demand for PV modules that can withstand extreme weather events grows and the push for higher power classes brings larger and larger PV modules to market, crack susceptibility is an increasingly important factor for PV module buyers to consider. PVEL's research continues, with nearly 100 additional BOMs that are queued for or currently undergoing MSS testing. We look forward to sharing these results in our 2021 PV Module Reliability Scorecard.

Based on PVEL's test results to date, available field data and current market conditions, independent testing is an important and imperative risk mitigation tool for investors and asset owners.

To learn more about MSS or to sign up as a downstream partner and gain complimentary access to PQP reports contact:
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Are you concerned about cracks or damage in an operating asset?

PVEL provides in-field EL imaging to help asset owners, O&M providers and insurers fully quantify damage at project sites. Our services guide repairs and support insurance claim resolution. Contact us at info@pvel.com to learn more.