Presented at the 46th IEEE Photovoltaic Specialist Conference, June 17 2019, Chicago

Mounting Rail Spacers for Improved Solar Panel Durability

Andrew M. Gabor[1], Rob Janoch[1], Andrew Anselmo[1], Jason Lincoln[2], Eric J. Schneller[2], Hubert Seigneur[2], Duncan J. Harwood[3], Michael W. Rowell[3]

[1]BrightSpot Automation LLC, Westford, MA, USA

[2]Florida Solar Energy Center, University of Central Florida, Cocoa FL, USA

[3]D2Solar, San Jose, CA, USA

Abstract **— Solar panels generally contact the mounting structure only along the surfaces of the aluminum frame surrounding the perimeter of the panel. With no support in the middle of the panel, front side mechanical loads from snow, wind, and human factors can cause significant deflection of the panel, resulting in tensile stress in the solar cells and cell cracking that can degrade system performance. This work examines an alternative approach whereby the mounting scheme is modified to place spacer elements between the rails of the support structure and the rear side of the panel. These spacers significantly reduce the panel deflection under load, and we have demonstrated a dramatic reduction in cell cracking at high load levels and in crack opening after cyclic loading. Such spacers can be applied to either the rear of the module or to the rails on the mounting structure and could be introduced for both new installations or as protective retrofits to existing systems. The spacers can also be of sufficient thickness to cause positive deflection of the panels to introduce some protective/restorative compressive stress into the cells.**

Index Terms **— Electroluminescence, Finite element analysis, Photovoltaic cells, Power system stability, Solar Panels, Stress**

I. Introduction

The traditional method of mounting solar panels involves clamping the extruded aluminum frame of the panels at 2 points along each long edge to 2 metal rails that span the width of the panels. To minimize module deflection under front side loads, the modules are often installed so that the rails intersect the long edges of the frame at around 1/5 to 1/4 of the total frame length from each corner as is seen in Fig. 1.

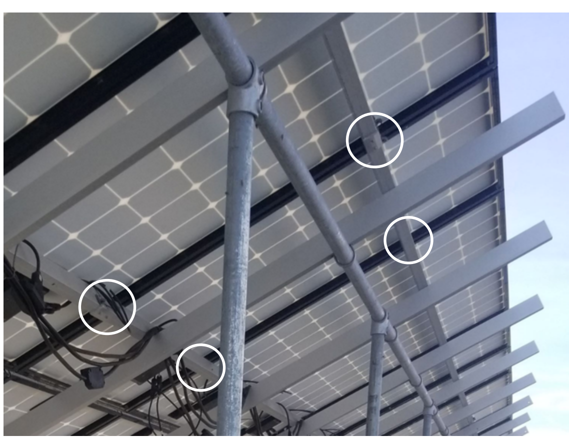


Fig. 1. The back side of a PV installation showing panels mounted on rails with the intersection between the black frame of the panels and the support rails circled in white.

Front-side wind and snow loads deflect the panels inward toward the rails, and this deflection results in tensile stress in the cells that can lead to cell cracking and higher than desired degradation rates [1-3]. This deflection and cell damage can be reduced by using glass/glass module construction, or by using thicker glass or sturdier frames, but the higher weight and higher materials costs are undesired by the industry. We have previously described methods of building compressive stress into a panel during the lamination stage or by applying a rear side brace to the panel that is held in place between the inside lip of the frame and the back side of the panel [4]. Such compressive stress and the limiting of deflection by the brace can reduce the cell cracking under loading events.

As a variation on the brace concept, we explore here the concept of supporting the rear side of the panel by introducing spacing elements (*RailPads*) between the rear support rails and the rear of the panels.

II. Design and Application of Rail Spacers

The *RailPads* could be fixed to the rails or the modules in the factory, or could be attached to the rails during installation. Fig. 2a shows a drawing of a *RailPad* attached to the rail such that when the panel is placed on the rail, the *RailPad* is flush against the backsheet of the panel. The top surface of the *RailPad* may be of a soft material to not damage the backsheet. Fig. 2b, shows a variation where the *RailPad* is thicker so that when the panel is clamped against the rails, the center of the panel is deflected outward. Such deflection may add some protective compressive stress to the panel to help keep any pre-existing cracks in a closed state with minimal associated power loss, or help prevent the cells from ever going beyond the critical tensile stress level where new cracks form. Additionally, such deflection, may prevent the back of the panel from lifting away from the *RailPad* during rear-side wind loads, and thus prevent a high frequency of rear side impacts that could lead to potential damage to the backsheet or cells.

The drawing in Fig. 3a shows how a conventionally mounted panel may bend during the application of a front side load, with the backsheet even potentially touching the hard rail surfaces or other components (e.g. – microinverters) under very high loads that could damage the backsheet. Fig. 3b shows the proposed approach with *RailPads* limiting the panel deflection and limiting any impacts against other components.

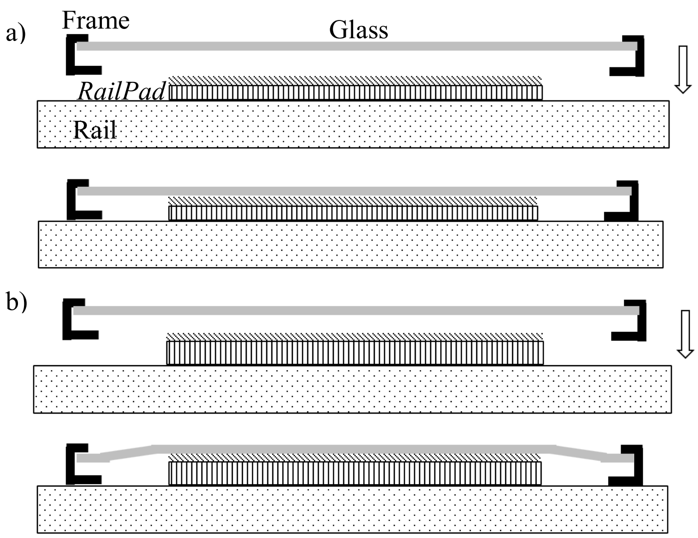


Fig. 2. Drawings showing the mounting of the *RailPads* for a) flush mounting and b) deflection mounting of the *RailPad* against the panel.

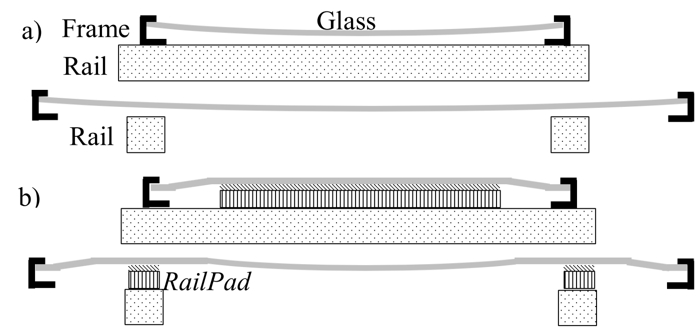


Fig. 3. Cross-section drawings along the center of the short and long axes of modules under a front side load for a) standard mounting, and b) *RailPad* deflection mounting.

III. Finite Element Analysis of Rail Spacers

We used the FEA program Abaqus to model the cell stresses vs applied loads as we have in prior publications [1,4,5]. Fig. 4a shows a simulation of cell deflection and first principal stress for a typical 72-cell panel with standard clamping at the 1/5 points (0.37m) from the corners. The peak deflection is above 7 cm and the peak cell tensile stress is above 225 MPa. In contrast, Figures 4b and 4c show the scenarios with *RailPad* mounting with no deflection and 8mm deflection, respectively, of the panel prior to loading. Here the peak deflection is significantly reduced, and the peak tensile cell stress reduced by around a factor of 2. Fig. 4d is similar to the case in Fig 4c, except the clamping points have been moved inward to 0.61m from the corners. This is not a common mounting point for rack-mounted modules, but it is closer to the clamping case of many tracker-mounted modules. Here the peak deflection has been further reduced and the stress reduced to < 75MPa, below the threshold where cells crack on high quality panels. Clearly these simulations suggest that this approach should significantly reduce cell cracking under high load conditions.

For these simulations, the glass thickness and frame mass were identical in both cases. In future simulations we will demonstrate the potential for reducing panel mass and cost by reducing the glass thickness and frame mass. Additionally, we will explore other mounting schemes such as running the rails parallel to the long axis of the frame and adding *RailPads* closer to the center of the panel for tracker applications.

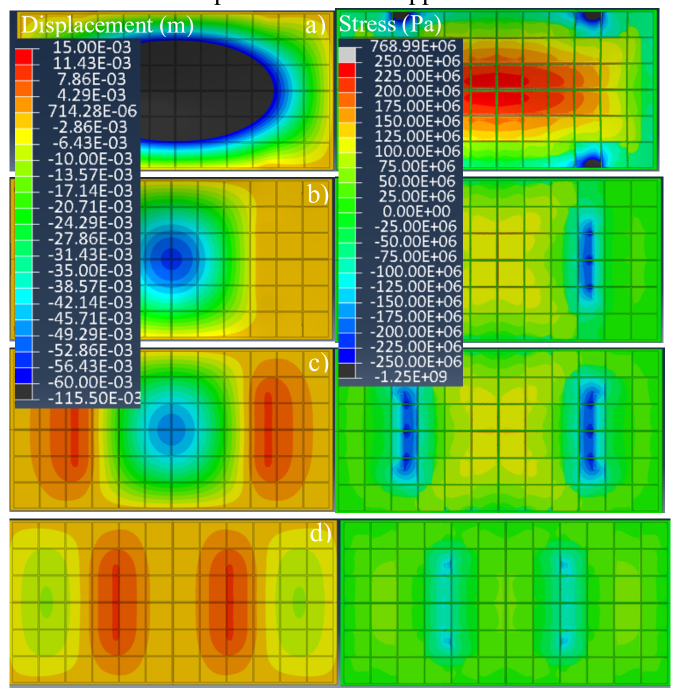


Fig. 4. Simulated maps of panel deflection (m) on the left and cell first principal stress (Pa) on the right under a front side load of 5400 Pa with clamps placed 0.37m from the corners for a) standard mounting, b) mounting with *RailPads* flush with the backsheet, c) with *RailPads* that deflect the glass outward by 8 mm; d) with *RailPads* that deflect the glass outward by 8 mm but with the clamps placed 0.61m from the corners.

IV. Load Testing of Rail Spacers

BrightSpot Automation's mechanical load tester, the *LoadSpot*, was designed to allow insight into crack formation, crack opening, and power degradation by leaving the front side open for electroluminescence (EL) and IV measurement. We have published results on how closed cracks can open up as front side loads are applied with vacuum behind the panels and the cells are placed into tensile stress [1-2]. As cracks open up, dark inactive areas appear in the EL images and the panel power decreases.

Fig. 5 shows a photo of the *LoadSpot* with *RailPad*-like structures mounted to the backplane. Silicone rubber strips were adhered to rectangular Al extrusions, and these extrusions were supported against the backplane with additional extrusions rotated 90 degrees and fixed in place with brackets bolted to holes in the backplane. The photo also shows an array of 9 distance sensors arranged in the upper left quadrant. Short blocks mimic mounting rails to support the frame against the backplane in the usual four locations. After loading, top side clamps press against the top lip of the frame to push the bottom of the frame against the rear support blocks. In so doing, the RailPad pushes against the module backsheet to deflect it outward.

Fig. 6a shows photos of a 60-cell multi panel under a load of 4000 Pa for convention mounting, while Fig. 6b shows the case for *RailPad* mounting with a 2-mm deflection after mounting. The *RailPad* mounting reduced the deflection in the center by over a factor of 2 from 38.4 mm to 17.2 mm as measured by the sensors. Near the middle of the short edge close to the frame, the deflection was reduced by a much larger percentage: from 24.4 mm to 1.6 mm.

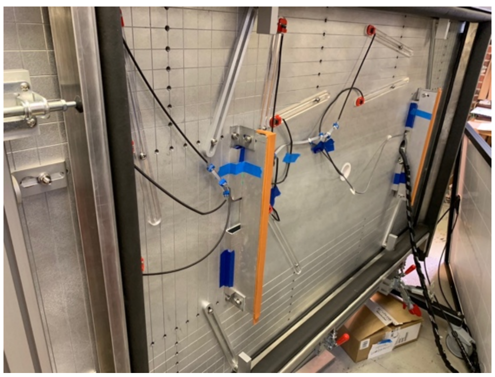
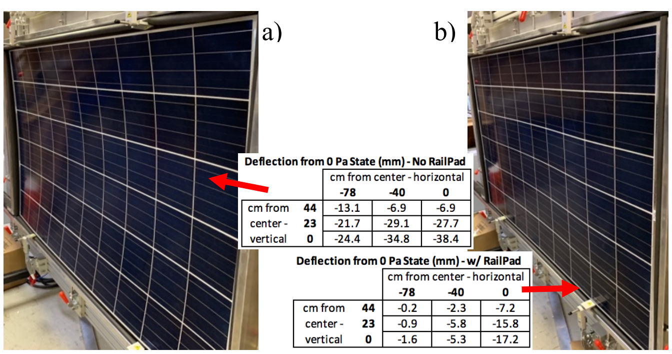


Fig. 5. Photo showing the prototype *RailPad* mounting mockup for load testing on the *LoadSpot* tool.



Deflection from 0 Pa State (mm) - No RailPad

		cm from center - horizontal		
		-78	-40	0
cm from	44	-13.1	-6.9	-6.9
center -	23	-21.7	-29.1	-27.7
vertical	0	-24.4	-34.8	-38.4

Deflection from 0 Pa State (mm) - w/ RailPad

		cm from center - horizontal		
		-78	-40	0
cm from	44	-0.2	-2.3	-7.2
center -	23	-0.9	-5.8	-15.8
vertical	0	-1.6	-5.3	-17.2

Fig. 6. Photos and deflection data at a front side load of -4000 Pa for a) standard mounting, and b) *RailPad* mounting.

We took EL images of the panel at different pressures first mounted with the *RailPads*, and then later with convention mounting after removing the *RailPads*. This panel had some pre-existing damage, and the cracks seen at 5400 Pa in Fig. 7a were not new. In contrast a large number of new cracks formed when tested at 5400 Pa without the *RailPads* as is seen in Fig. 7b.

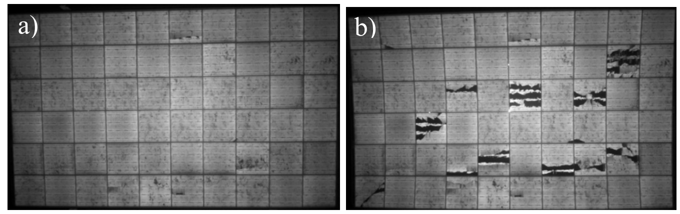


Fig. 7. EL images of a single multi panel with some pre-existing cracks taken during a frontside load of -5400 Pa first for a) *RailPad* mounting, and b) later during standard mounting.

Similarly, Fig. 8a shows a 60-cell mono panel of higher than average resistance to cracking at a load of 4000 Pa with standard mounting showing 7 cracked cells, while a sister module in Fig. 8b shows only 1 small crack when testing with *RailPad* mounting.

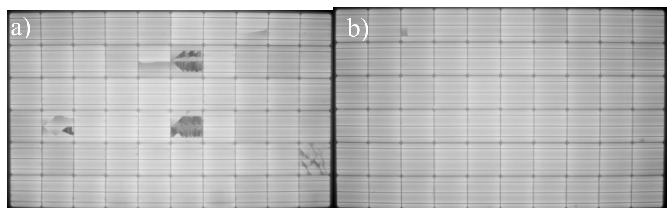


Fig. 8. EL images of 2 different mono panels taken during a frontside load of 4000 Pa for a) standard mounting, and b) *RailPad* mounting.

We also took a series of EL images (see Fig. 9) on the *LoadSpot* for a 72-cell module at different pressures first mounted with the *RailPads*, and then later with convention mounting after removing the *RailPads*. Few new cracks are seen with the *RailPads*, but upon removing them, new cracks form at relatively low pressures. Fig. 10 shows the *LoadSpot* at -5400 Pa for both cases, and Fig. 11 shows the module deflection across the array of 9 distance sensors placed behind 1 quadrant of the module for each cases across the entire range of pressures, showing a large decrease in deflection when using the *RailPads*. We later reinserted the *RailPads* and performed cyclic loading at +/-1000 Pa for 200 cycles, and this created relatively little crack opening (few darker regions). However upon removing the *RailPads*, and repeating the cyclic loading, significant crack opening occurred. Thus, the *RailPads* both prevent the creation of new cracks upon front side loading, as well as prevent the opening up pre-existing cracks from cyclic loading events. Still, it is a testament to the durability of Si PV panels that a module with so many cracks performs as well as it does during such an EL test, tested at an injection level similar to standard testing conditions (~10 Amps). However, it is important to note the modules operate far from standard testing conditions (STC) during much of the day, and EL performed at a low injection level of 1 Amp shows dramatic differences between heavily cracked and uncracked cells [6], as is shown in Fig. 9j. Such a difference can be explained by shunting that is proportional to the total length of cracks within a cell, since shunting effects are stronger at low current levels. Thus, cracking may have much more of an effect on the energy delivery of a system rather than the performance at STC. Since most field inspections of PV modules is geared toward getting as close to STC as possible, this important effect may be often overlooked.

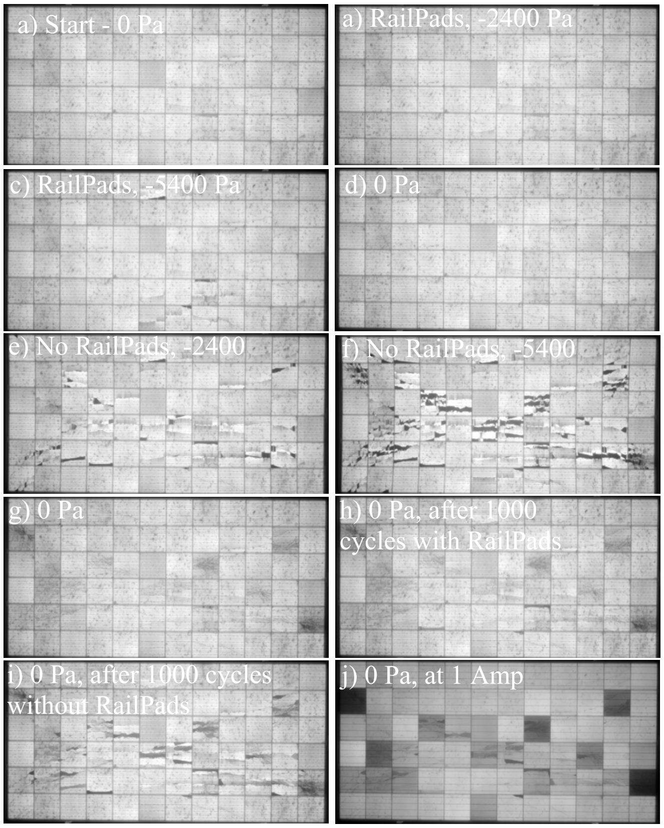


Fig. 9. EL images at 10 Amps for a) As received module 0 Pa with some pre-existing cracks; with *RailPads* at b) -2400 Pa; c) -5400 Pa; d) back to 0 Pa; without *RailPads* at e) -2400 Pa; f) -5400 Pa; g) back to 0 Pa; after 200 load cycles at +/-1000 Pa performed h) with *RailPads* and i) without *RailPads* and j) at the end of testing with an injection current of 1 Amp.

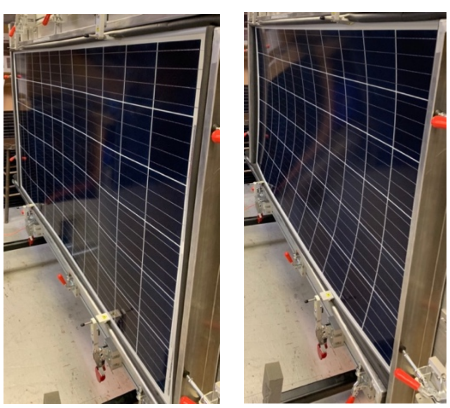


Fig. 10. Photos of a 72-cell module under a front side load of -5400 Pa for (left) *RailPad* mounting and (right) standard mounting.

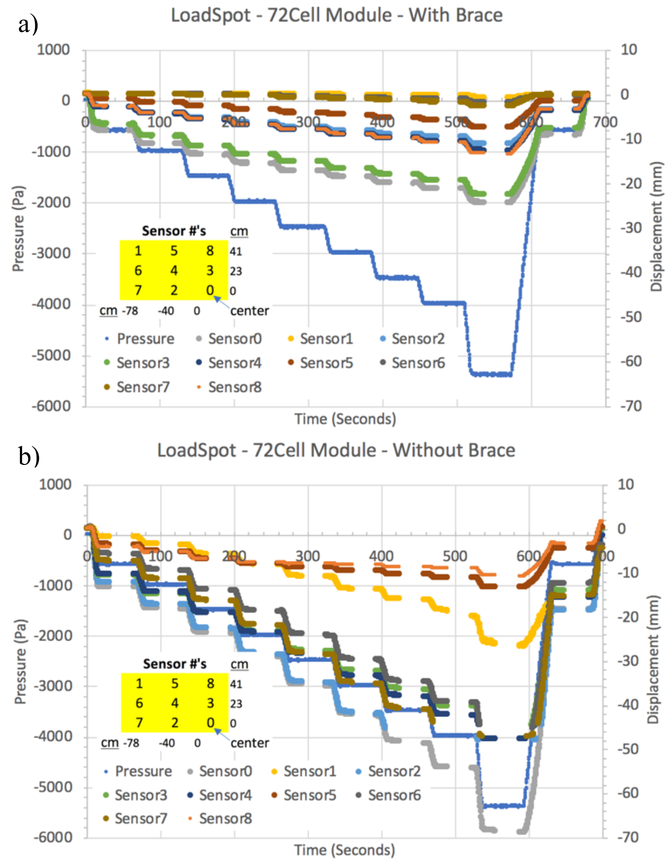


Fig. 11. Deflection data for a 72-cell module ramped from 0 to -5400 Pa for a) *RailPad* mounting and b) standard mounting showing far greater deflection without the *RailPads*.

V. RailPad Design and Field Testing

We designed protype *RailPads* with considerations of low-mass, low-cost, and ease of installation. We also designed for 2 different scenarios: 1) use in a new installation, and 2) application to an existing installation without the need for removal of the modules from the rack. Shown below in Fig. 12 are some 'new-construction' *RailPads* connected to rails and after a module was clamped in place. We are presently in the process of mounting modules at an FSEC outdoor test facility with and without *RailPads*. This experiment will examine both how the *RailPads* may prevent the creation of new cracks on undamaged module, as well as how they may slow the opening of pre-existing cracks on pre-damaged modules. The installation includes monitoring of the module performance to allow us to explore other potential effects for example related to module temperature. Visual examination of the modules will allow us to see any physical wearing effects due to rear side contact regions, and IR thermography will allow us to see any spatial temperature variations.

Fig. 12. Photos of (top) *RailPads* connected to the rails prior to module mounting, and (bottom) the underside of 2 mounted modules one of which has a *RailPad* pressing against the backside.

VI. Conclusions

We have demonstrated a potentially low-cost modification to the panel mounting hardware that could greatly reduce the sensitivity of solar cells to cracking under front side panel static loading and to crack opening under cyclic loading. This could enable improved panel degradation rates, higher system performance, lighter panels, and cost savings in the glass and frame that outweigh the cost of the new spacing elements and associated labor. The use of spacers that deflect the glass surface outwards could build protective compressive stress in to the cells. These spacers could be applied to both new panels as well as a retrofit to old panels to lengthen the system lifetime and increase performance.

Future work will involve the testing of spacing elements mounted to actual rails in the field and in environmental chambers to explore any negative effects related to the touching of the spacing elements against the panel backsheet.

Acknowledgements

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number DE-EE0008152.

References

[1] A. M. Gabor, R. Janoch, A. Anselmo, J. L. Lincoln, H. Seigneur, and C. Honeker, "Mechanical load testing of solar panels - Beyond certification testing," in *IEEE 43rd Photovoltaic Specialists Conference (PVSC)*, 2016, pp. 3574-3579.

[2] E. J. Schneller, A. M. Gabor, J. L. Lincoln, R. Janoch, A. Anselmo, J. Walters, and H. Seigneur, "Evaluating Solar Cell Fracture as a Function of Module Mechanical Loading Conditions" in *IEEE 44th Photovoltaic Specialists Conference (PVSC)*, 2017.

[3] M. Koentges, I. Kunze, S. Kajari-Schröder, X. Breitenmoser and B. Bjørneklett, "Quantifying the Risk of Power Loss in PV Modules Due to Micro Cracks," in *25th European Photovoltaic Solar Energy Conference and Exhibition*, 2010, 3745 – 3752.

[4] A. M. Gabor, et. al., "Compressive Stress Strategies for Reduction of Cracked Cell Related Degradation Rates in New Solar Panels and Power Recovery in Damaged Solar Panels" in *The 7th World Conference on Photovoltaic Energy Conversion (WCPEC-7)*, 2018.

[5] H. Seigneur, et. al., "Microcrack Formation in Silicon Solar Cells Exposed to Cold Temperatures" in *IEEE 46th Photovoltaic Specialists Conference (PVSC)*, 2019.

[6] M. Koentges, et. al., "Review of Failures of Photovoltaic Modules" Report IEA-PVPS T13-01:2014, last accessed 17Jun2019 at www.iea-pvps.org/fileadmin/dam/intranet/ExCo/IEA-PVPS_T13-01_2014_Review_of_Failures_of_Photovoltaic_Modules_Final.pdf