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Cyclic Mechanical Loading of Solar Panels – A Field Experiment

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***Abstract* — Cracks were created in a PV module by static mechanical loading before installation in the field to quantify the power degradation due to cracks propagating and opening as a result of cyclic wind loading over a large number of cycles. The magnitude and frequency of the displacement at the center of a PV module were monitored during a convenient wind loading event (nearby passing hurricane Irma). Despite circumstances being significantly different from cyclic loading conditions of the IEC 61215 and IEC 62782 standards, we observed clear evidence of cracks opening. Furthermore, we attempted to reproduce this result in the laboratory using the *LoadSpot* tool on similarly prepared modules (Static mechanical loading at 2400Pa followed by 50 Thermal Cycles or TC50 and 10 Humidity-Freeze cycles or HF10). We found a comparable trend in power degradation in the laboratory corresponding to approximately 2% power loss over 10,000 cycles.**

***Index Terms* — cracks, cyclic load testing, mechanical load testing, photovoltaic modules, reliability, silicon.**

I. Introduction

Because of the potential for high wind loads, the East coast of Florida, and most notably Miami Dade County, are known for stringent code requirements for PV installation. Nevertheless, it is not uncommon in the aftermath of a hurricane to observe damaged racking components and partially detached or even missing solar panels. Additionally, for the remaining "unaffected" panels, it is unclear whether these cyclic wind loading events can form new cracks or, perhaps more reasonably, cause existing cracks to propagate or open resulting in power degradation. If so, it would be useful to understand how the magnitude, frequency, and duration of the out of plane displacement, which is a function of wind direction and velocity, affects power degradation over a large number of cycles. Such a study has the advantage of looking degradation on a similar timescale between the laboratory and the field.

Today, design qualification testing seeks to demonstrate PV module robustness against known failure modes or wear mechanisms formed as a result of standardized accelerated testing protocols; failures which would otherwise occur only over a very long period of time in the field. Cyclic loading is an integral part of standardized accelerated testing. For example, IEC 62782, which is a standard for cyclic mechanical load testing for PV modules, requires ± 1000 Pa at a rate of 3 to 7 cycles/min for 1000 cycles with current flow.

We have recently observed in the lab that conditions used in the IEC 62782 (without current flow) were able to consistently open cracks created after a static mechanical loading step followed by a TC50 and HF10 steps [1]. This leads us to believe that a module in the field that has several existing cracks and that has undergone temperature cycling throughout the years would be susceptible to power degradation as a result of cyclic wind loading. Therefore, in this work, we investigate a cyclic mechanical loading event in the field in order to further validate the expected effect on modules containing cracked cells.

II. Experiment

We installed a custom-built glass/backsheet (clear) module on our ground mounted racking system at the Florida Solar Energy Center located in Cocoa, Florida. Other than using only 30 cells, the module dimensions and materials are standard for a 60 cell module. The thickness of the glass is 3.2 mm. The aluminum frame area is 1.5 m by 1 m with 3.7 cm height. Based

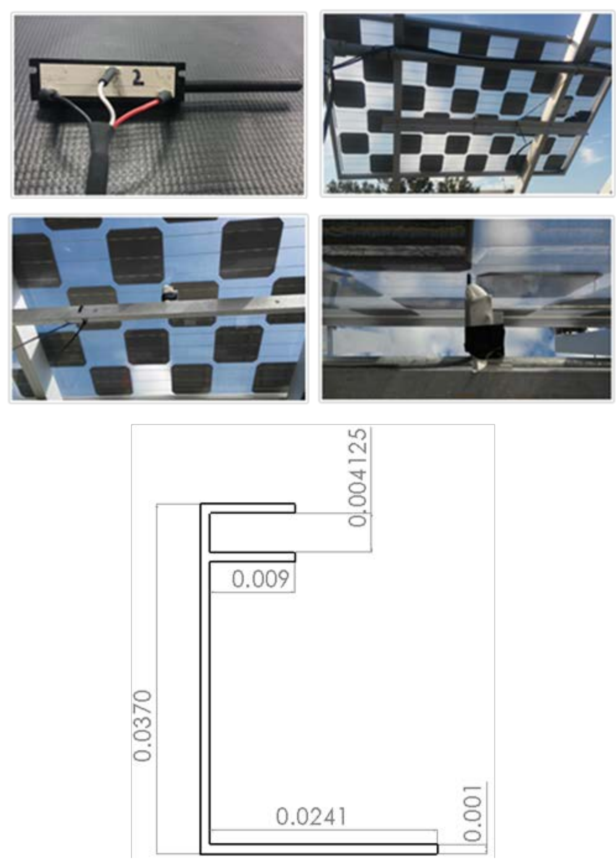

Fig. 1. (Top) Module containing cracks installed with a position sensor mounted at the center of the module. (Bottom) Drawing of the frame cross-section

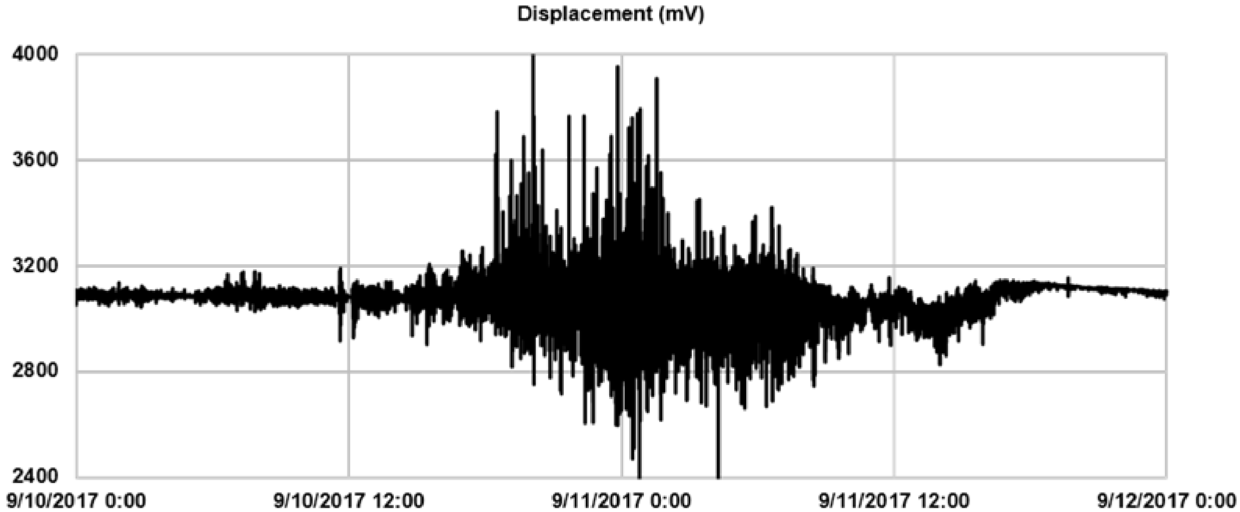

Fig. 2. Displacement at the center of a module during a wind loading event producing several thousands of cycles

on the frame design with an average embedment depth of the laminate in the frame, we expect deflection results to be larger than the average industry module using 3.2mm glass [2]. The module was left in open-circuit. We installed a linear position sensor model 9615 from BEI at the center of the module as depicted in the figure to measure the displacement during wind loading.

Measurements were collected during a brief period that included the weather of Hurricane Irma that impacted the area starting on the afternoon of September 10, 2017 and continuing through the following morning. Hurricane Irma made landfall on the Florida peninsula as a category 3 storm and quickly weakened in intensity as it moved across land. At the storms closest approach to the test site, the storm was a category 1 and was approximately 90 miles to the west. The impacts of the storm in the local area were moderate included downed power line, damaged roofs and widespread damage to signs and other upright structures. It should be noted that impacts from this storm were much more severe in regions of the Caribbean that experienced direct impacts while Irma was at its maximum strength as a category 5 hurricane.

III. Results

The meteorological station data at the site includes irradiance, wind speed, barometric pressure, ambient and module temperature. The wind speed sensor was installed on the top of same rack as the modules. This is considerably lower than the standard 10-meter height that is required for typical meteorological stations. Because of this, observations during the storm indicated maximum wind gusts of 16 m/s or 35mph. These readings are substantially lower than nearby meteorological stations, but are more indicative of the conditions experienced by the modules. The ground mounted racking system for this experiment is south facing and is relatively protected on its north side (building), east side (building), and south side (trees). Winds from the East and South were effectively blocked throughout the event and had largely subsided by the time they were coming from the West. Also, because the wind data was collected every minute, it is possible that stronger gusts of wind were not recorded.

The displacement data is shown in Fig. 2. The largest peak to peak displacement signal observed during that period was 1676 mV (4005 mV – 2329 mV), which corresponds to 1.6 cm. The displacement is initially centered at 3100 mV, so the maximum displacement in the positive direction (up) was approximately 900 mV or 0.9 cm while -770 mV or -0.77 cm in the negative direction (down). This data was collected every second, and the entire displacement cycle was approximately 2 to 4 seconds, which is significantly faster than the IEC 62782 recommendation of 3 to 7 cycles per min. Furthermore, in the field, displacement occurs randomly in time, which is not the case in the lab where displacement takes place according to a period established by the standards. Another random feature observed in the field has to do with the sequence of positive and negative displacements. A positive pressure can be followed by another or multiple other positive ones without any occurrence of a negative pressure. In the lab, the dynamic loading test is systematically alternating between a positive and a negative pressure. It is unclear whether the random nature of displacement cycles in the field further accentuates power degradation or rather abates it with respect to the uniform cyclic loading in the lab.

Additionally, we report a daily recurring displacement between day time and night time in the absence of wind. These oscillations were measured to be about 170 mV peak to peak or 0.17 cm, or about 10% of the displacement due to winds. We compared the displacement with the ambient temperature and we can clearly see that the observed daily fluctuation follows the temperature. To verify that the measured displacement is real and not just an artifact of the displacement sensor itself, we

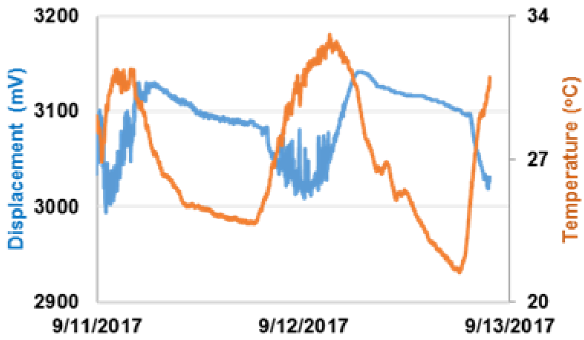

Fig. 3. Daily displacement and temperature with the position sensor mounted at the center of the module.

mounted the displacement sensor against a fixed racking support after the module was removed.

Fig 4 confirms that the sensor did not experience any displacement, only temperature changes. Therefore, the daily displacement at the center of the module in the absence of wind is real introducing both compressive and tensile stresses.

The table below indicates a 2.4% loss in the maximum power following the wind loading event. The EL images support the IV data, as we see partially closed cracks in the original image that have opened up as a result of the cyclic wind loading.

TABLE I
POWER LOSS BEFORE AND AFTER WIND LOAD

Load during IV Measurement (Pa)	0	600	1000
Max Power **Before** Wind Load (W)	112.4		
Max Power **After** Wind Load (W)	109.7	108.9	106.5

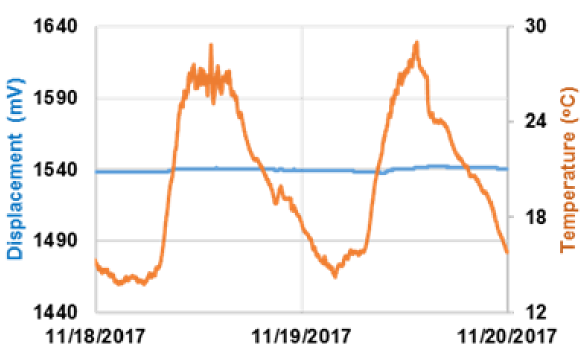

Fig. 4. Daily displacement and temperature with the position sensor mounted against the racking support.

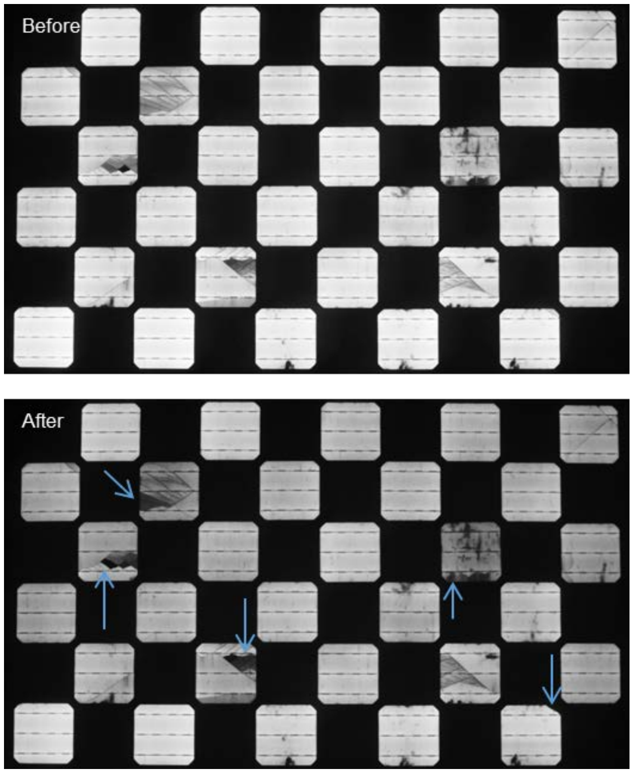

Fig. 5. EL images of the cracked module before and after the wind loading event.

ANALYSIS

Comparing the observed magnitude of the displacement in the field with those in the lab using the *LoadSpot* tool, we determined that the maximum pressure experienced in the field was around 250 Pa. Moreover, this single event is estimated to

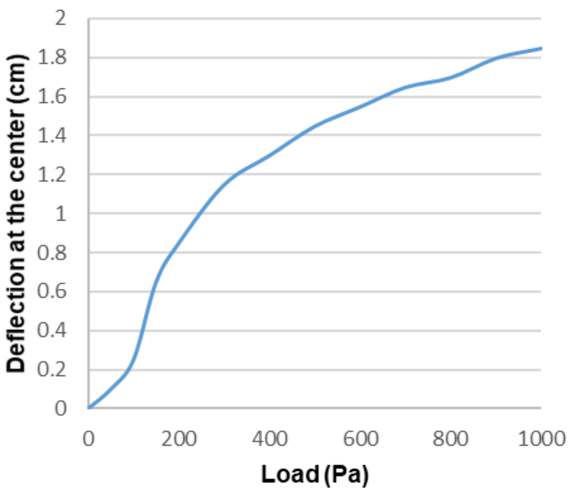

Fig. 6. Displacement vs load curve on the *LoadSpot*

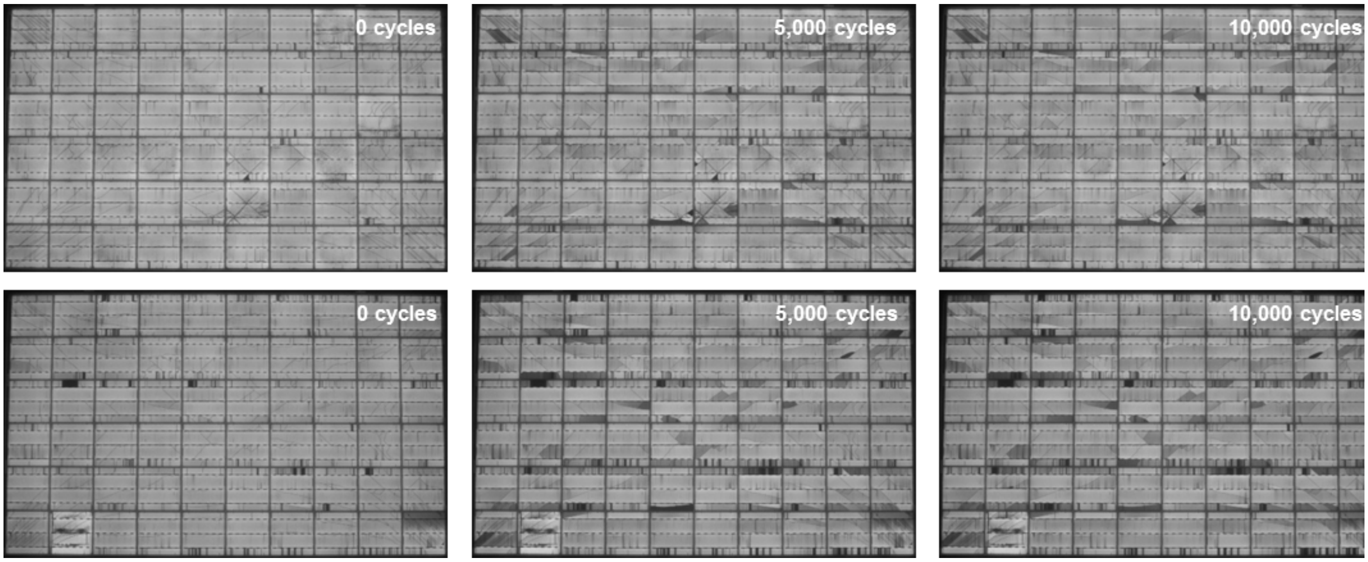

Fig. 8. EL images of two modules undergoing 10,000 cycles at ± 250 Pa using the LoadSpot tool

have produced approximately 10,000 “cycles” during a 24-hour period. This is also much different than IEC 62782 conditions.

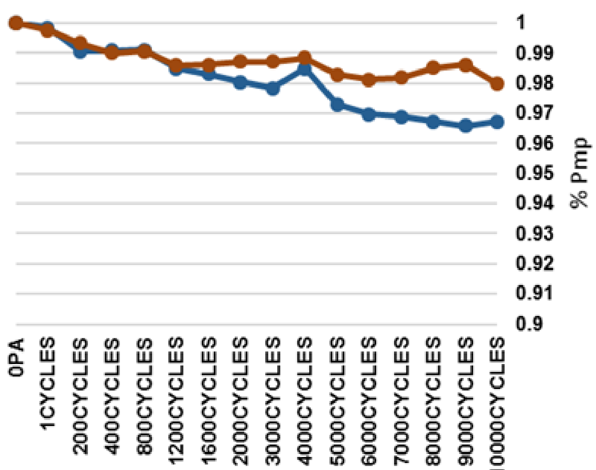

Fig. 7. Percent maximum power degradation after 10,000 cycles using the LoadSpot tool

We performed cyclic load testing on two modules of a different make and model that have first undergone static loading then TC50 and HF10 steps. The subsequent cyclic load tests were done under conditions similar to those observed in the field during this specific wind loading event (10,000 cycles at ± 250 Pa) to see if we would be able to observe any noticeable power degradation in the maximum power. As shown in Fig 7, we found about 1% degradation for 5,000 cycles and around 2% for 10,000 cycles.

Similar cyclic load results performed in the lab were recently presented [3.4]. The EL data presented in Fig 8 in general correlates well the results in the field for they also show that cracks are opening as the number of cycles are increasing. One significant difference is the prevalence of the finger darkening in the EL for the modules measured in the lab, which can be attributed to the TC50 and HF10 steps. The IV curves before and after 10,000 cycles in the lab also look very similar to the ones before and after wind loading in the field. Although the

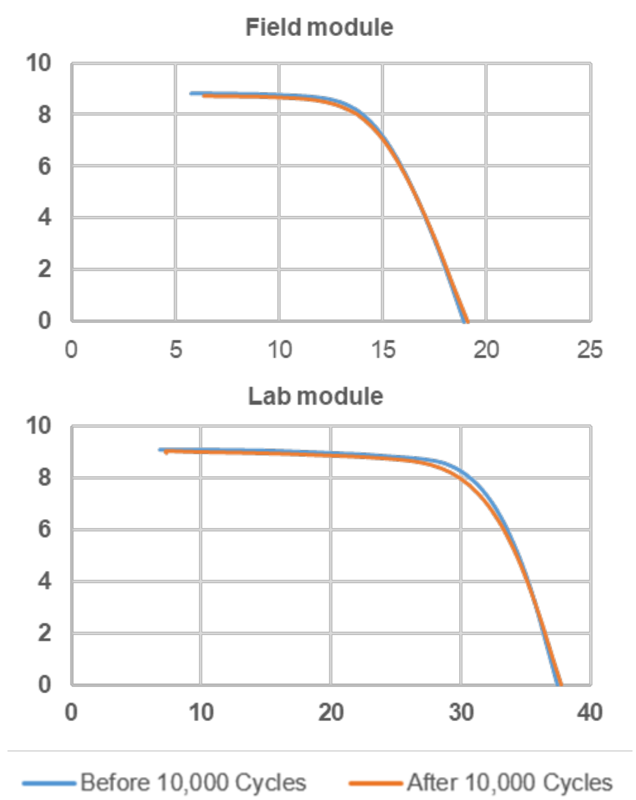

Fig. 9. IV curves before and after cyclic loading

fielded module voltage is lower because of having 30 cells, there is a noticeable similar increase in the series resistance.

IV. Conclusion

During the nearby passing of Hurricane Irma, measurements of displacement at the center of a module revealed rapid cyclic loading of a module at an outdoor test site in Cocoa, Fl. This event saw over 10,000 cycles in a roughly 24-hour period with amplitudes reaching a maximum of 0.9 cm or the equivalent of 250Pa load. This experiment confirmed that wind loading events can result in power degradation in the field over time as a result of cracks opening up. We were able to reproduce similar power degradation levels under comparable conditions in the laboratory using the *LoadSpot* tool. This further highlights how critical it is not to create cracks in the first place prior to or during module installation. Furthermore, crack resistant module designs that can effectively prevent cracks from being created in the field (e.g. due a snow load) would also be desirable. Last, we observed a very small daily displacement at the center of the module due to temperature. It is worth studying to see the range of such displacements for various systems since a daily displacement corresponds to about 10,000 cycles over 30 years.

References

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