Is Your Array Healthy?
Monitoring DC Field Health

James Rand, Mason Reed, Michael Hendricks

Core Energy Works, Newark, DE

INTRODUCTION

It can be a very difficult task to understand exactly how your PV array is performing. Monitoring energy output is certainly necessary, but is it sufficient to answer the following:

A. Are all your modules performing above the level guaranteed by the warranty?

B. Is your field wiring and/or field connections limiting your performance?

C. Are there subtle degradation mechanisms operating to lower performance faster than you modeled?

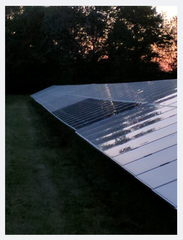
Motivation

Many system owners have used the industry standard 0.5% degradation year-over-year in their financial modules. Our field experience is that 0.5% is too optimistic in many (perhaps most) cases. Further we have found that energy monitoring alone is not enough to understand the array health.

Field Testing

To fully understand performance, and more importantly, degradation rates over time, Core Energy Works has developed a field-testing protocol that utilizes the following tests:

1. Infrared imaging via drone
2. Detailed visual inspection
3. IV testing of the modules
4. IV testing of the strings
5. Measurement of Soiling
6. Electroluminescence imaging



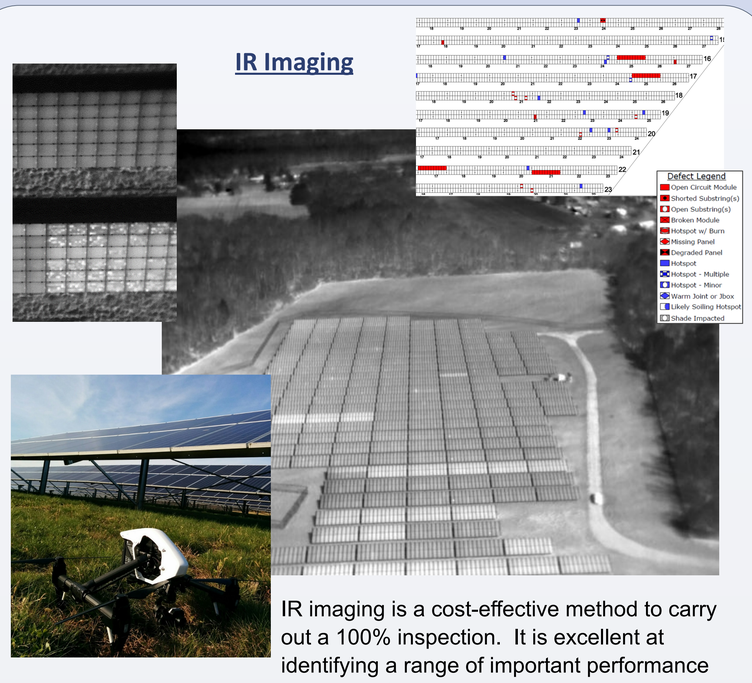
These methods, taken as a group, can deliver a full report card on the health of a solar array. This testing can be completed in the field in as little as two days with very little disruption of energy generation and requires no modules to be dismounted.

Examples of issues found impacting performance are presented, including solar cell degradation, defects in module manufacturing, and wiring failures (both inside the module and with connectors). In addition, Core Energy Works has extensive experience with cracked silicon wafers within modules resulting from both: 1) rough handling during transportation and installation as well as; 2) operation and maintenance activities in the field. Utilizing these many test methods as a group will capture virtually all degradation mechanisms.

Core Field Test Protocol

Test	Sample Size	Key Result
IR Imaging	100%	Thermal non-uniformities at the module level
Visual Inspection	2% (+/-)	Detect module package defects such as bubbling, burn marks, delamination, and overheated Jboxes.
Module Level IV	2% (+/-)	Establishes baseline performance of the modules (degradation mechanisms impacting all modules)
String Level IV	Small Sample	Measures mismatch losses
Impact of Soiling	Small Sample	Measures soiling loss
EL	Small Sample	Determines solar cell level defects impacting performance

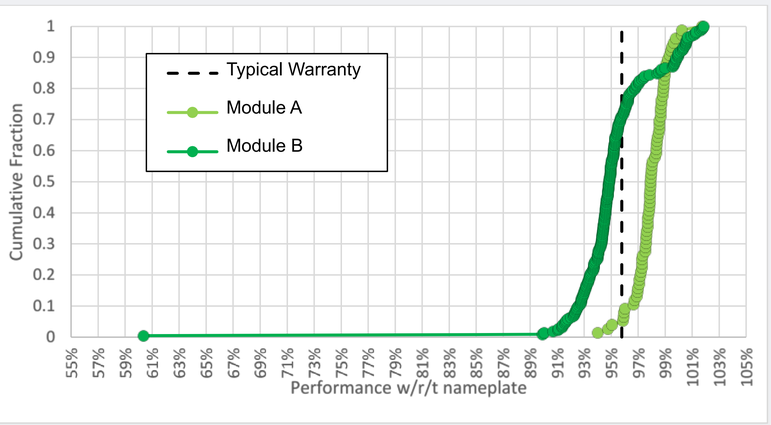
IR Imaging



IR imaging is a cost-effective method to carry out a 100% inspection. It is excellent at identifying a range of important performance detractors (but not all!).

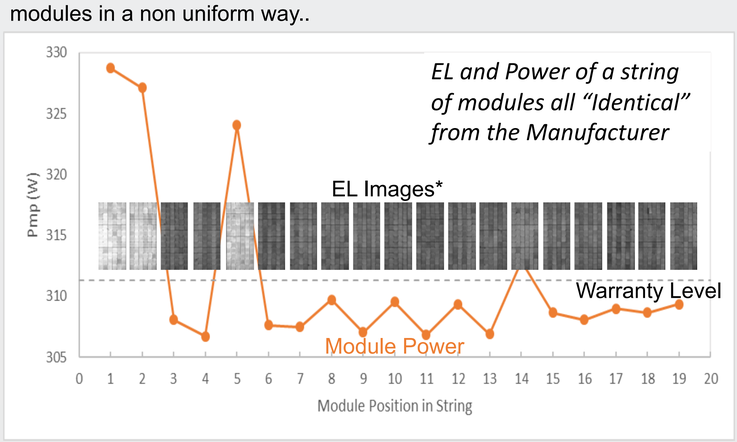
Larger IV Samples Are Needed To Reveal Issues Not Found in Averages Alone

The module data shown below is from a single field and was part of typical Core Energy Works test sequence. In this case we found module performance varied greatly between the two module manufacturers represented on this utility scale site. Further, one manufacturer had a multi-modal distribution included at least two distinct defect modes.



How EL Images Support IV Test Data

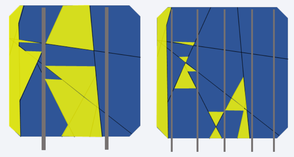
Our testing has been able to find definitive issues with modules identified as low power by IV testing. As IV testing in the field can be prone to wide error bars, confirmation by root cause determination is needed make sure the conclusions are valid. In the case shown below, EL was able to confirm the wide spread in IV power, and uncovered LeTID (or HID) [1] impacting the modules in a non uniform way..



* EL must be done under very similar conditions to allow for a meaningful comparison of contrast.

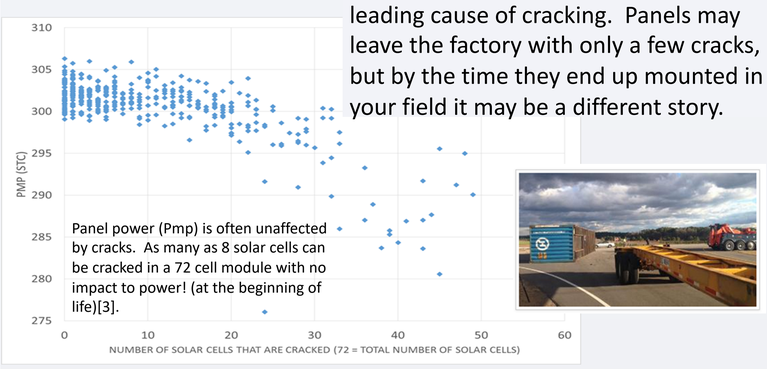
SOLAR CELL CRACKS

Cracked solar cells are present in virtually all silicon based PV panels. Cracking can result in potentially isolatable areas of the wafer. Increasing the number of busbars can limit the overall impact to power [2]. Thick plated metallization can also offer fault tolerance.



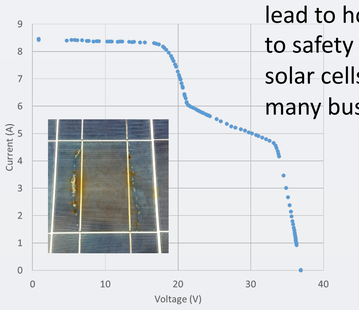
Transportation and Handling Damage

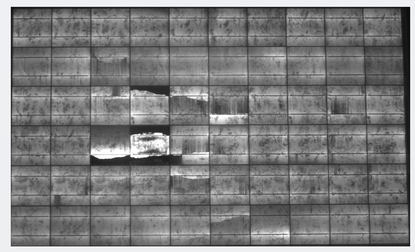
Transportation and rough handling are a leading cause of cracking. Panels may leave the factory with only a few cracks, but by the time they end up mounted in your field it may be a different story.



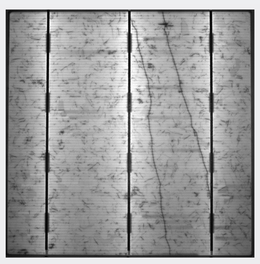
Hot Spots Due to Cracking

Under certain worst case conditions, cracking can lead to hot spots of 100C or more. These can lead to safety and performance issues. Often cracked solar cells are benign, especially in modules with many busbars or full back metallization.





Conclusions



- Monitoring the energy output of your array is a necessary part of O&M, but its not sufficient to safeguard your long-term performance.
- An aggressive mix of field testing, preventative work, and energy monitoring should be part of your overall O&M strategy.
- Cracked solar cells might not be bad, but they can't be good.
- The *Effective Degradation Rate* of cracked solar cells is still largely unknown.

Core Energy Works

Core Energy Works is a small engineering services company. The principal engineers have deep experience in the field performance of silicon-based modules, as well as direct experience with manufacturing, testing, and certifying solar cells and modules. Core Energy Works has visited over 50 commercial and utility scale sites in the past 2 years and fully assessed the performance of over 200 MW of product in the field.

References

[1] Alison Ciesla née Wenham, Stuart Wenham, et al, "Hydrogen-Induced Degradation", 7th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, 2018

[2] M.Kontges et al,"UV Fluorescence method to detect cell cracks and safety issues of cell cracks", Presented at the 2017 NREL PV Module Reliability Workshop, Denver, CO USA - 28Feb2017

[3] James Rand, Mason Reed, "Rough Handling of Silicon Modules", Presented at the 2018 NREL PV Module Reliability Workshop, Denver, CO USA.