Experimental Methods to Replicate Power Loss of PV Modules in the Field for the Purpose of Fault Detection Algorithm Development

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LCOE Reduction Through Proactively Optimized PV System Monitoring

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Collaboration

Project Highlights

- Goal –
  - Quantify the contribution PV monitoring systems have in terms of LCOE
- Method-
  - Two PV systems in geographical different areas will be used to investigate power loss events and validate algorithms that can detect those losses
  - Implement those algorithms into a supervisory monitoring system
  - Propagate those algorithms to a utility scale field and determine their success rate in that arena
- Outcome –
  - Comparative results between new algorithms and existing algorithms
  - Improved understanding and contribution to PV's body of knowledge
  - Provide meaningful inputs to the LCOE models that account for PV system monitoring costs

Today’s topic – Experimental Methods

- Method-
  - Two PV systems in geographical different areas will be used to investigate power loss events and validate algorithms that can detect those losses
    - Soiling
    - Cell cracks
    - Within module interconnection failures
    - Between module interconnection failures
    - Shading
- Creating the data set
  - Developing experimental methods to create the defects that will generate the fault

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Experimental Methods

- Developing experimental methods to create the defects that will generate the fault
  - Soiling
  - Cell cracks
  - Within module interconnection failures

Soiling Experimental Method

Soiling Experimental Method

- Objective
  - Develop a simple, quick method to emulate soiling signature
    - Provide data set characteristic of soiling
      - Reduced current
      - Change in Vmp, Imp, Pmp, Isc
  - Use soiling method to generate data sets
    - Power loss detection
    - Root cause based on PV characteristics

- Not characterizing soil, types of soil, etc.

Soiling Characteristics

- Typical characteristics of soiling
  - As reported in literature
    - Reduced current (Isc, Imp)
    - Reduced power (soiling ratio)

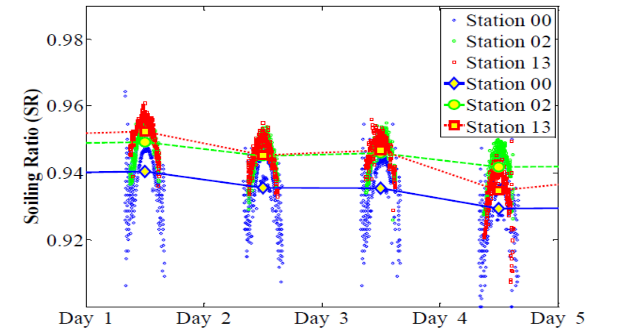


Fig. 2. Soiling ratio measurements from three measurement stations at site A over a four day period. Small symbols show instantaneous readings, taken once per minute, which vary throughout the day due as discussed in the text. Large symbols show daily averaged values.

Ref: M. Gostein, J. R. Caron and B. Littmann, "Measuring soiling losses at utility-scale PV power plants," *2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*, Denver, CO, 2014, pp. 0885-0890.

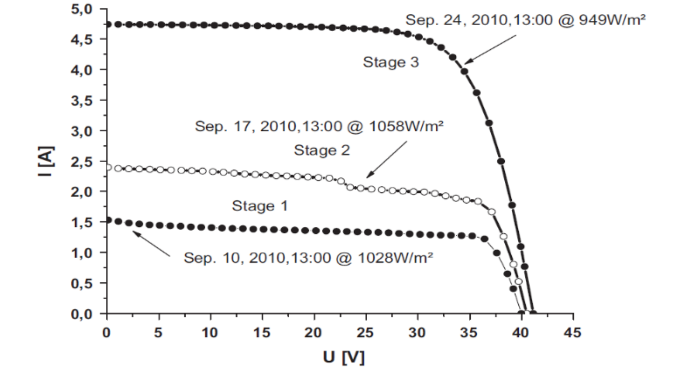
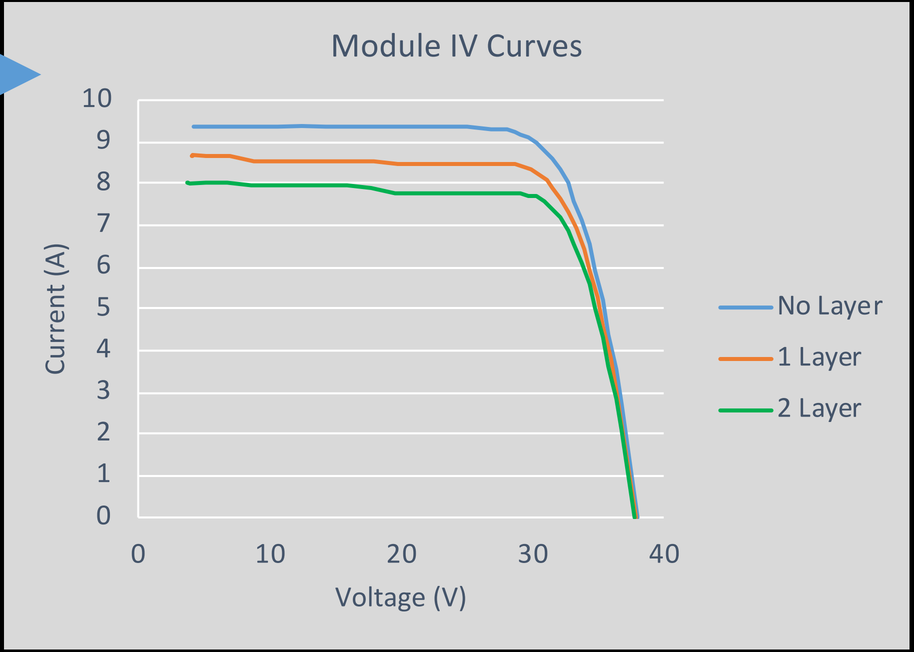


Fig. 5. Typical *IV* curve showing effects of soiling (September 10), partial shading after a minor rainfall event (open circles, September 17) and removing of the soil (September 24).

Reference: Christian Schill, Stefan Brachmann, Michael Koehl, Impact of soiling on IV-curves and efficiency of PV-modules, Solar Energy, Volume 112, 2015, Pages 259-262.

Soiling Characteristics – our method

- Indoor flash tester



Soiling Characteristics – our method

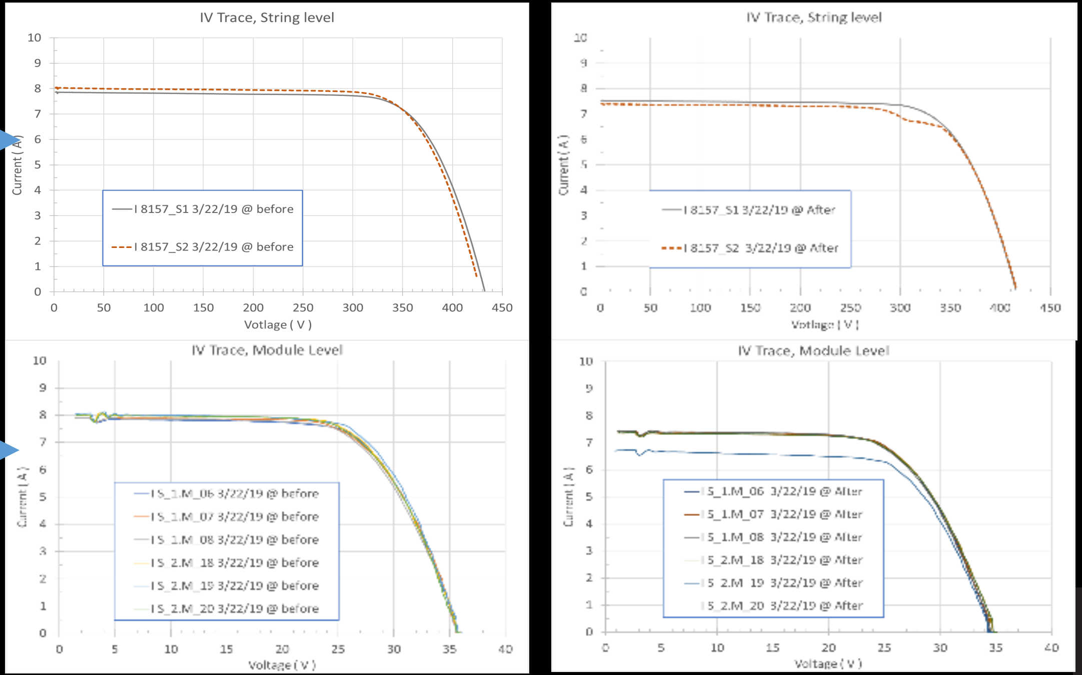
- Outdoor IV tracer
  - *In situ* configuration

String level tracer
string 1
string 2

Module level tracer
4 of 24 modules

Before 'Soiling'

After 'Soiling'



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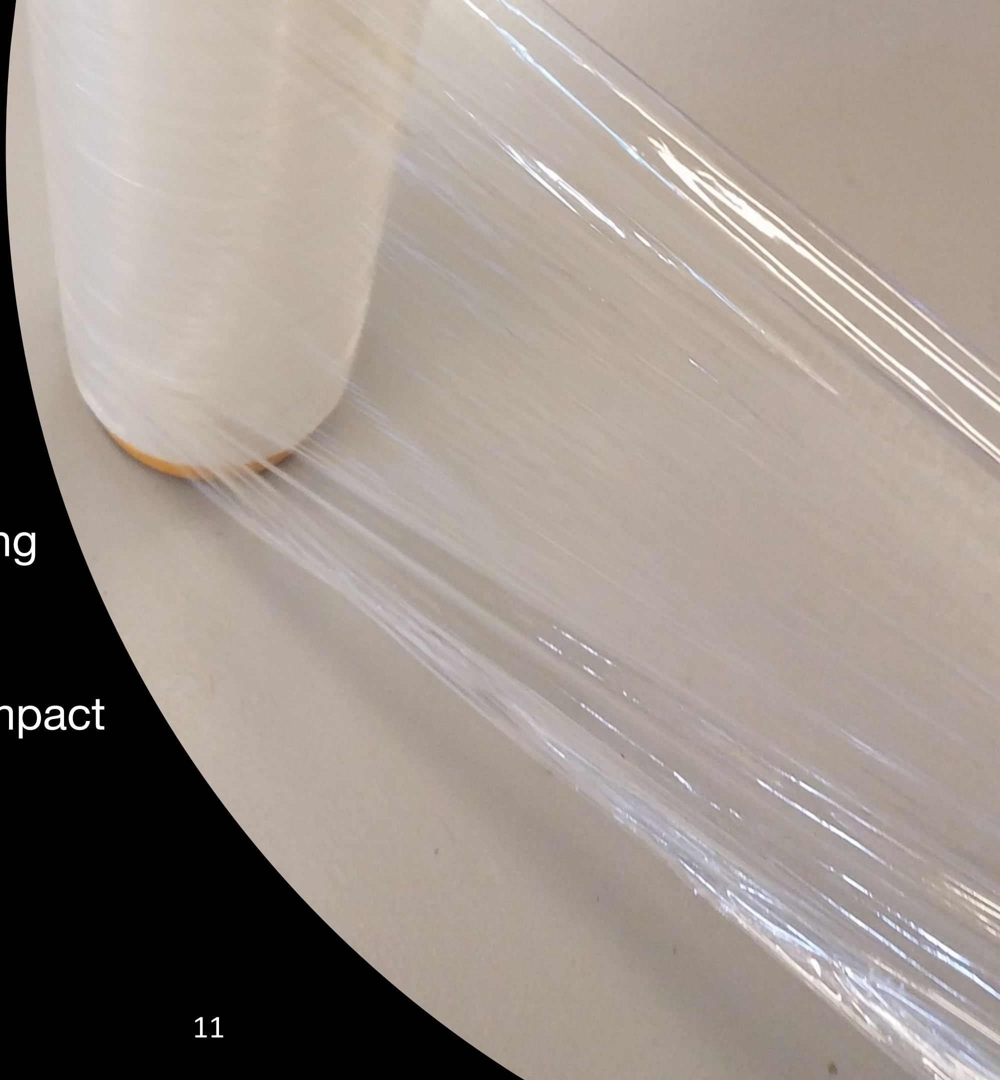
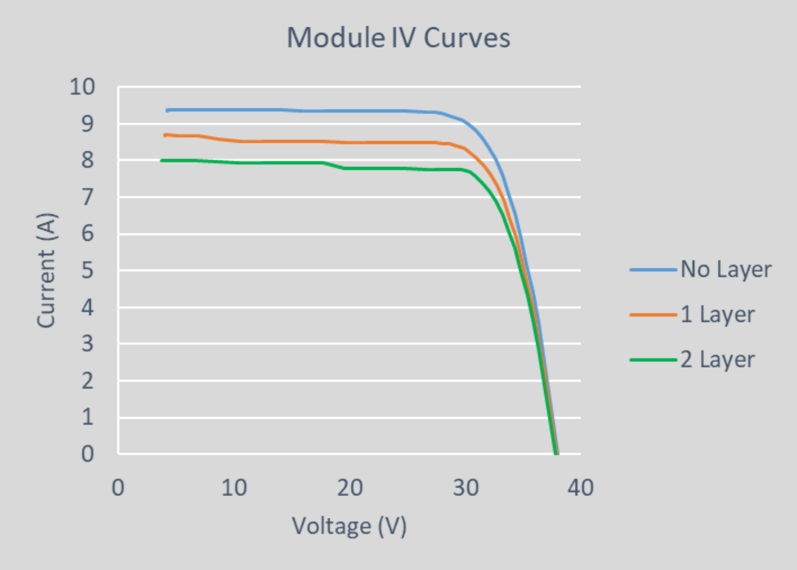
‘Soil’ = Transparent film

- Nearly transparent film
    - Linear low-density polyethylene
    - Apply over module to emulate soiling
- Characterize properties
    - Viability test
        - Indoor electrical performance impact
    - Optical properties
        - Transmittance
            - Various angles of incidence
        - Aging characteristics
- Field Test



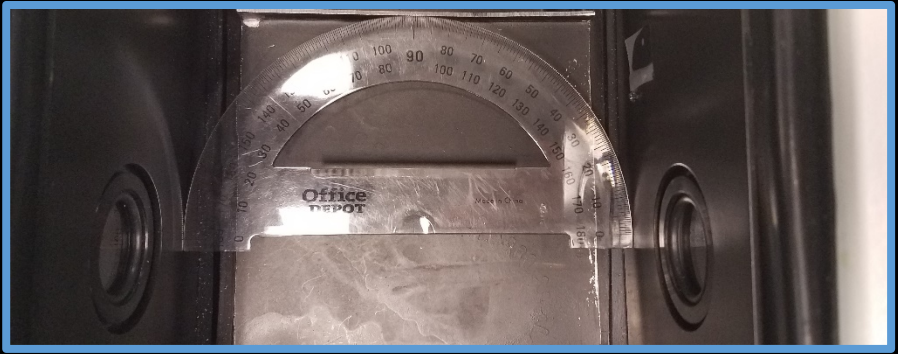
Viable

- Flash test
  - Sinton FMT-350
- Apply film to module
  - 1st layer
    - Indoor flash test
      - 7.7 % drop in Isc
        - 9.39 A to 8.67 A
      - 8.1 % Power loss
        - 272 W to 250 W
  - 2nd layer
    - Indoor flash test
      - 15.0 % drop in Isc
        - 9.39 A to 7.98 A
      - 15.4 % Power loss
        - 272 W to 230 W



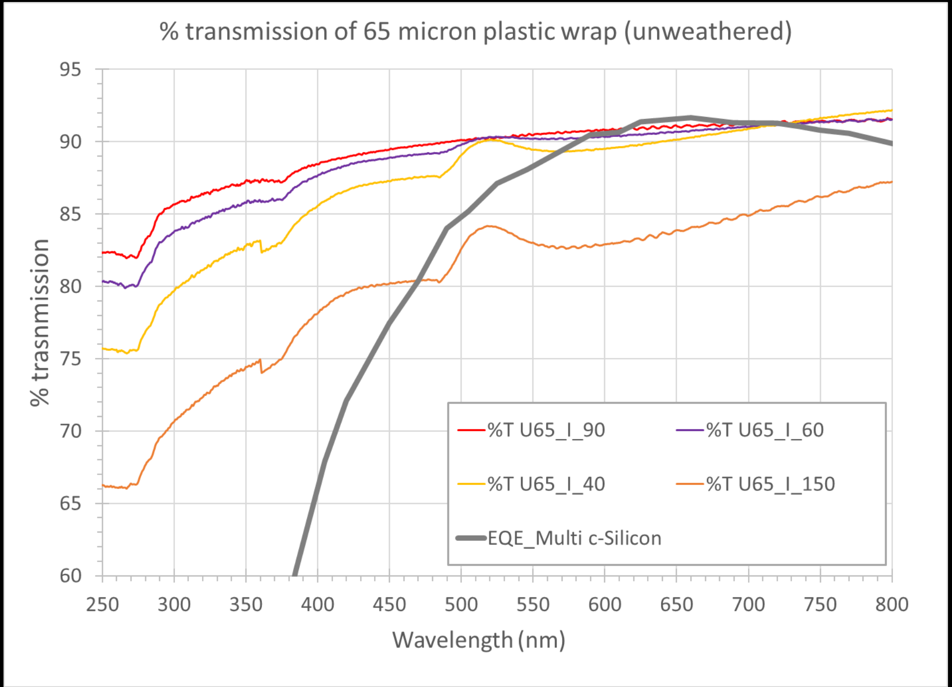
Optical properties

- Characterization
  - Shimadzu UV-2401PC
    - IV-VIS recording spectrophotometer
- Investigated two film thicknesses
  - 39 micrometer (μm)
  - 65 micrometer (μm)
- Transmittance (%T)
  - Wide range of incident angles
    - Normal ± 60° (30° to 150° with 90° being normal)
  - Influence of outdoor exposure
    - 4.67 kWh/m^2 of UV (295 nm to 385 nm)



Transmission characteristics

- % Transmission
  - Wavelength scan
    - 250 nm to 1000 nm
  - Shows drop in %T
    - Range of incident angles
      - (90 ° = normal)
    - Drops significantly >40° from normal
- External Quantum Efficiency (EQE)
  - Included as reference to wavelengths of interest



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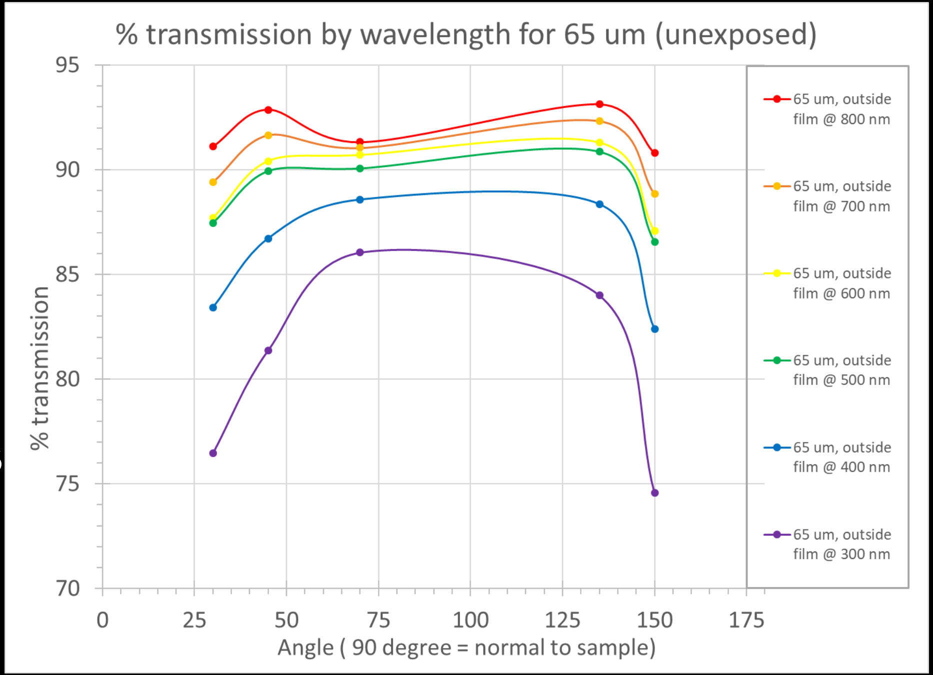
% Transmission – Wavelength and Incident Angle

- Shows the %T by
  - Incident angle (x axis)
  - Wavelength (family of curves)
- Shorter wavelength, %T drops
  - < 400 nm
- Larger incident angle, %T drops
  - > 40° from normal



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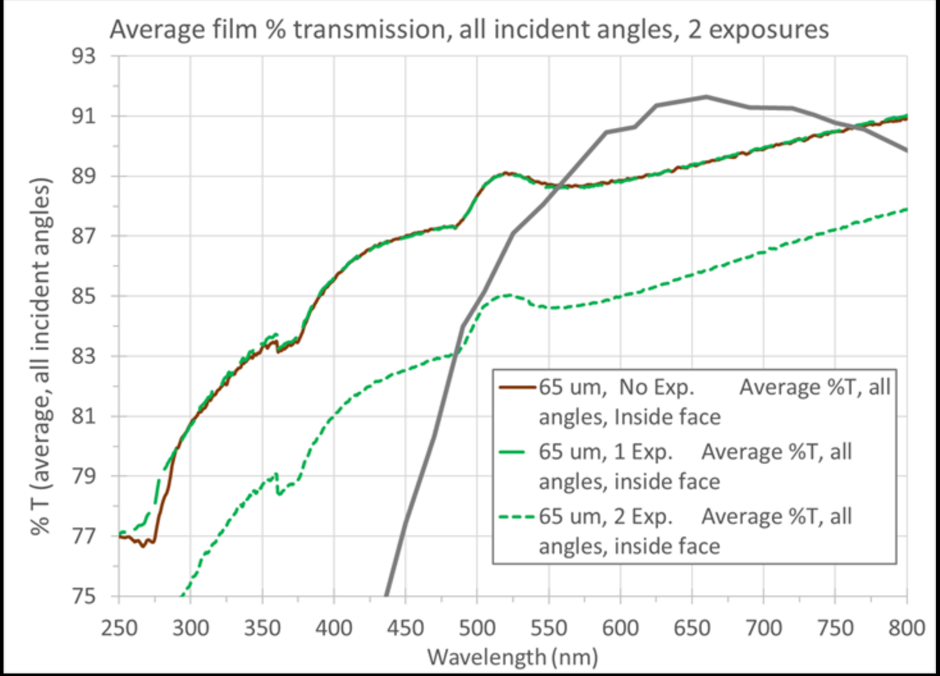
% Transmission, Outdoor exposure

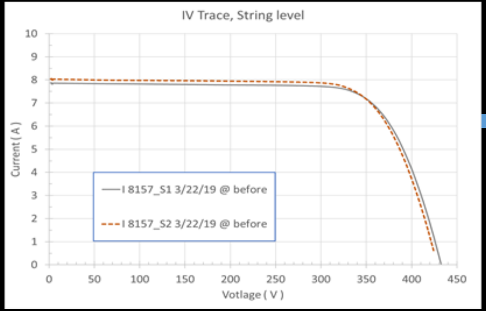
- Polymer films susceptible to UV
  - Measure UV with Eppley TUV
    - Wavelength range:
      - 295 nm to 385 nm
- Exposure
  - None
  - 1st Exposure (September, 2018)
    - 1.53 kWh/m² (7 days, Cocoa, FL)
  - 2nd Exposure (September+, 2018)
    - 4.65 kWh/m² (33 days, Cocoa, FL)
- %T drops with exposure
  - 4% less transmission after a month



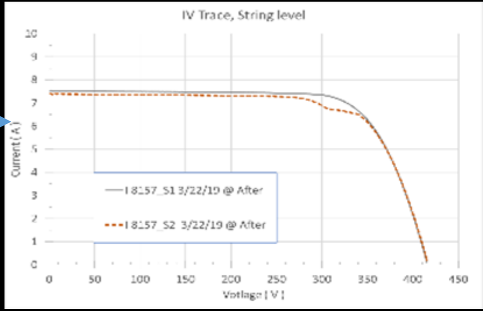
‘Soiling’ Take away

- Linear low-density polyethylene
- Provides characteristic signature of soiling
  - Single layer covering shifts PV performance ~8%
- Relatively fast degradation could be used as advantage when testing algorithms

Before ‘Soiling’



After ‘Soiling’



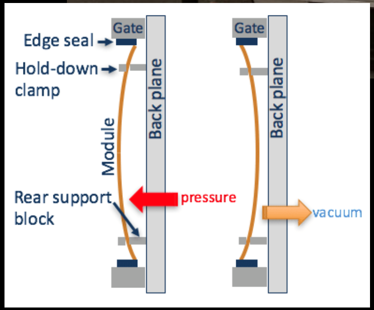
Cell Cracks Experimental Method

Cell Cracks Experimental Method

- Objective
  - Develop a simple, quick method to generate cell cracks in modules
    - Provide data set characteristic of cell cracks in modules
    - Power loss, voltage change
  - Use modules with cracks to generate data sets
    - Power loss detection
    - Root cause based on PV characteristics

LoadSpot mechanical load test

- Mechanical load test
  - Open face allows
    - Flash test under load
    - EL under load
  - Chamber behind module
    - Pressurized
    - Vacuum
  - Programmatically apply load
    - IEC standard
    - Develop new methods



Schneller, Gabor, Lincoln, et al (2017). Evaluating Solar Cell Fracture as a Function of Module Mechanical Loading Conditions.

Experimental plan

Time period	Activity
Week 1-3	Light soak 4 modules, EL/IV before & after
Week 4	Crack initiation, Load modules @ 2400Pa (1 day) Add the modules to the string and monitor
Week 5	Remove and return modules to the lab Load modules @ 5400Pa, EL/IV before & after. (1 day) Add the modules to the string and monitor
Week 6	Remove and return modules to the lab 1000 Cycles @±1000Pa on same 4 modules (4 ½ days)
Week 7	Add the modules to the string and monitor
Week 8	Remove and return modules to the lab 1000 Cycles @±2400Pa on same 4 modules (4 ½ days)
Week 9	Add the modules to the string and monitor
Week 10	Remove and return the modules to the lab

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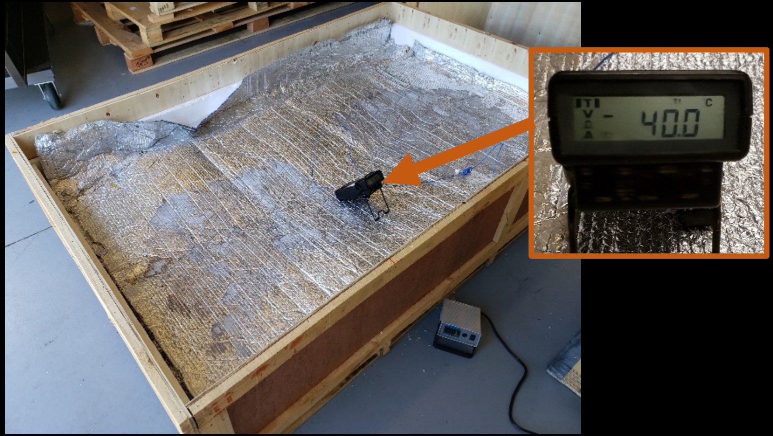
Crack Initiation

- Expose PV modules to extremely cold temperatures
  - (–40°C per IEC standard) to create microcracks / weaknesses

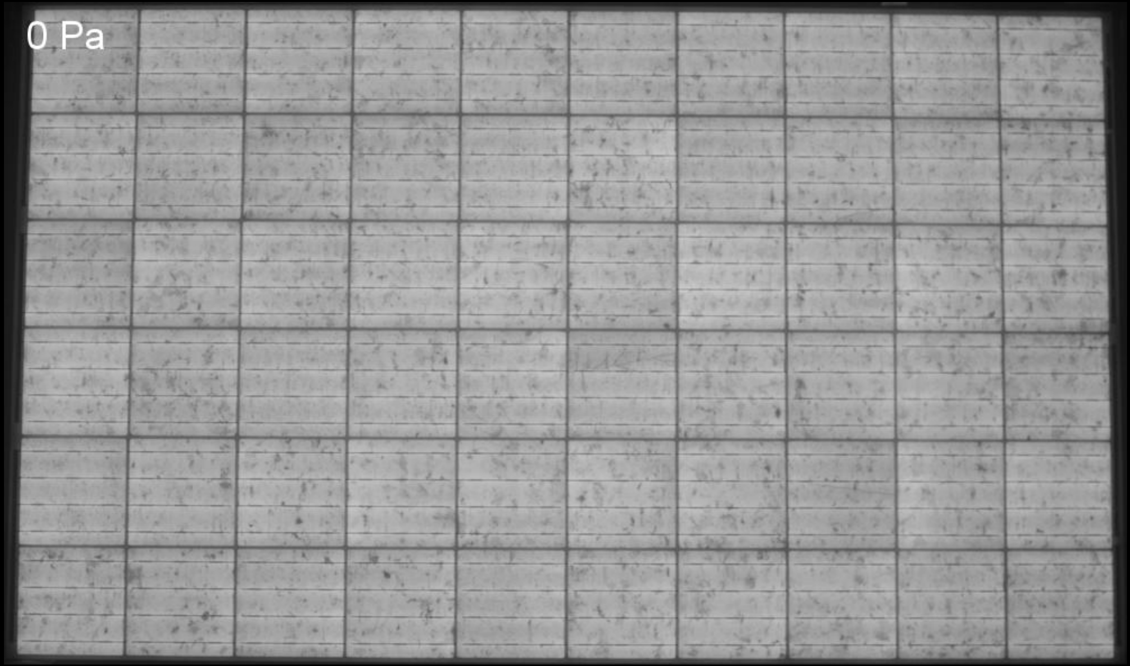
Insulated box with Dry Ice



Cover until -40°C

Mechanical load after crack initiation

- Load modules @ 2400Pa
  - Applied to 4 modules



Mechanical load after crack initiation

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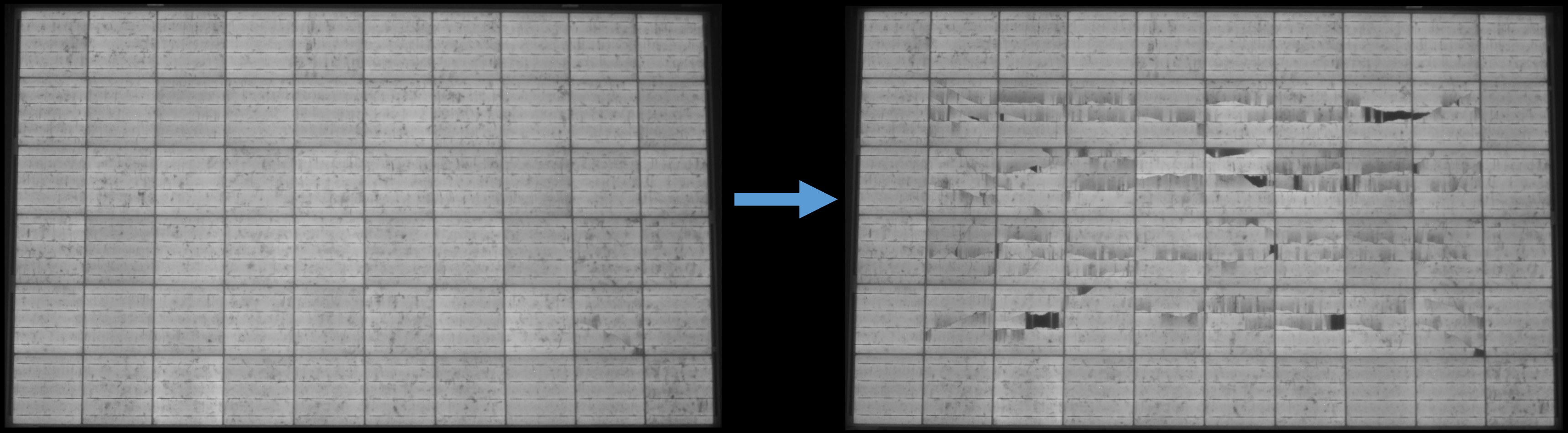

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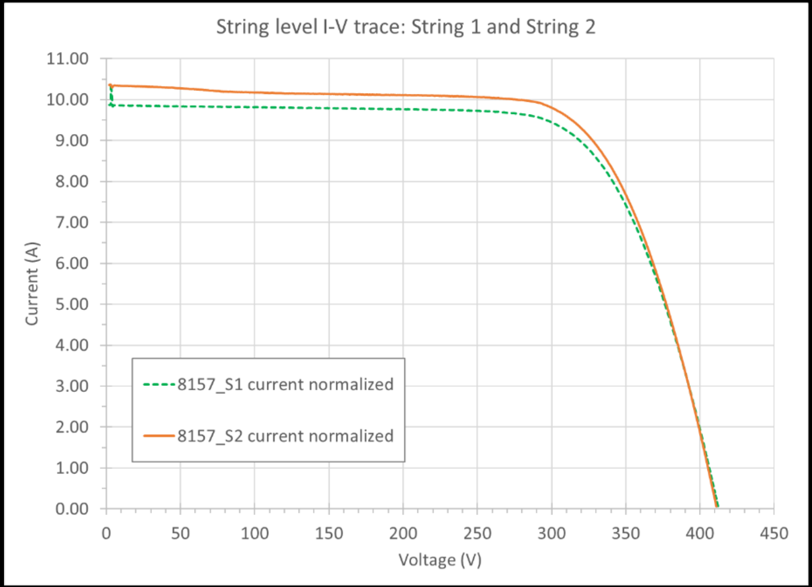
Install Cracked Modules in PV system

- Modules location in String
  - 13, 18, 19, 24
- Module voltages (low to high)
  - 13 < 18 < 19 < 24

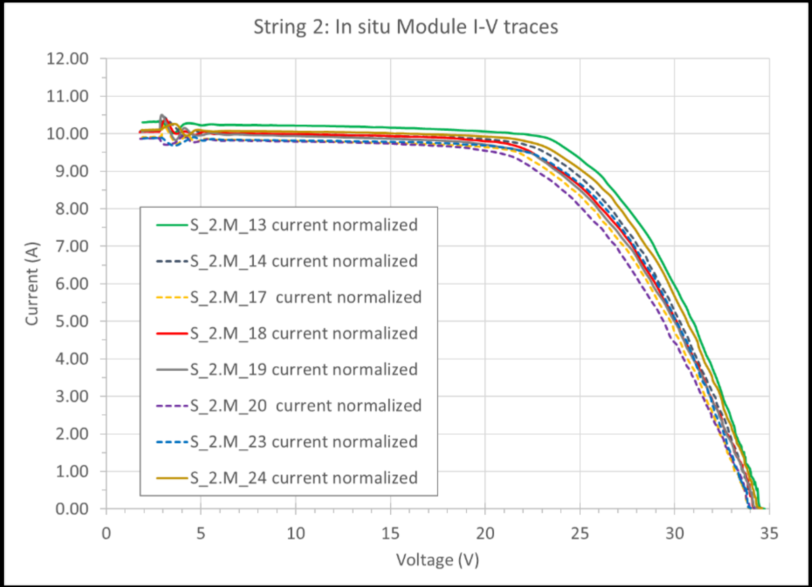
String 2 (west), module ID					
19	20	21	22	23	24
18	17	16	15	14	13

IV traces

- String 1 and String 2



- Modules in String 2



- Too early to tell, more analysis, more cracks

Cell Crack Take away

- Method developed to provide cell cracks in modules
- Study will test impact of cracks on PV parameters
  - Sequential mechanical loading experiment
  - Provide PV parameter changes with crack severity
- First round just completed
  - Nothing conclusive
  - More cracks, more testing

Interconnection Failure Experimental Method

Interconnection Failure Experimental Method

- Objective
  - Develop a simple, quick method to generate interconnection fault within the modules
    - Provide data set characteristic of modules interconnection failures
  - Use modules with interconnection fault to generate data sets
    - Power loss detection
    - Root cause based on PV characteristics

Interconnection failure

- Open path at busbar
  - Examples in literature

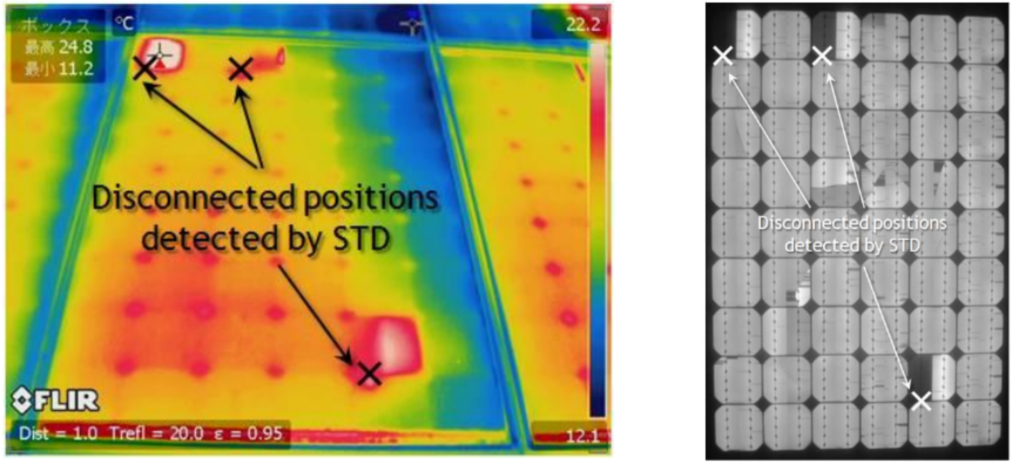
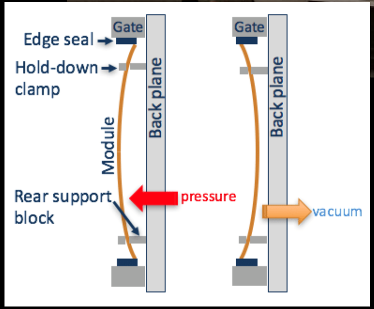


Fig. 6.2.14: Left: An example of disconnected cell interconnections found in the field (IR image). Right: The corresponding EL image of the same PV module.

Reference: [1] M. Köntges, S. Kurtz, C. Packard, U. Jahn, K. A. Berger, and K. Kato, *Performance and reliability of photovoltaic systems: subtask 3.2: Review of failures of photovoltaic modules: IEA PVPS task 13: external final report IEA-PVPS*. Sankt Ursen: International Energy Agency, Photovoltaic Power Systems Programme, 2014.

Interconnection failure using mechanical load

- Mechanical load test
    - Sequence intended to
        - stress ribbon
        - not the cell
    - : ± 2000Pa @ 8.6 sec/cycle
        - Periodically capture EL
        - Test to interconnection failure detected
- Today's modules are robust
    - 1 interconnection failure detected after 50,000 cycles
    - A few cracked cells introduced



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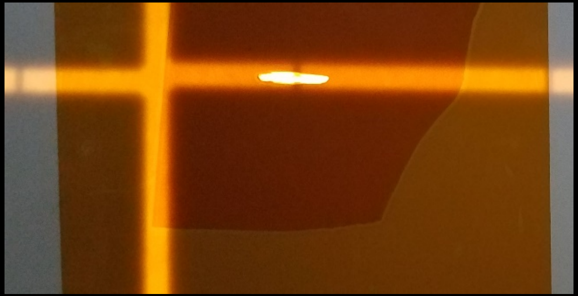
Interconnection fault

- Stepped back and looked at objective
  - Develop a **simple, quick method** to generate interconnection fault within the modules

Interconnection fault

- Stepped back and looked at objective
  - Develop a **simple, quick method** to generate interconnection fault within the modules

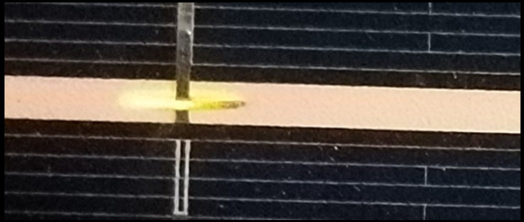
Cover opening with Kapton® tape, double layer



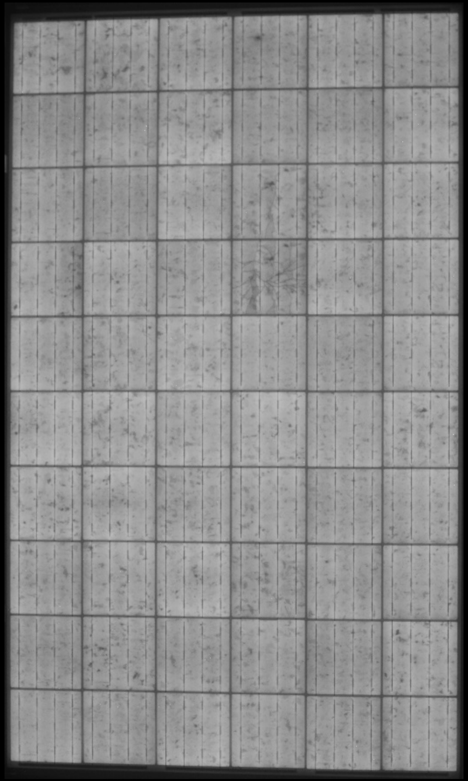
Dremel® with cutting wheel fixture

Light table to see interconnection

Interconnection break visible at front

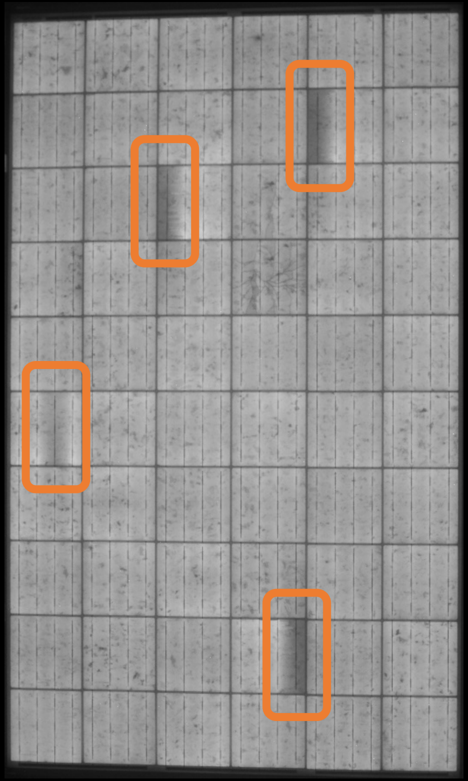


Module - Electroluminescence



Prior cut

Post cuts



Dark regions align with interconnection break

- 4 interconnections cut
- 1 bus bar per location

Charging forward –

Experimental Methods

- Developed experimental methods to create the defects that will generate the fault

Soiling

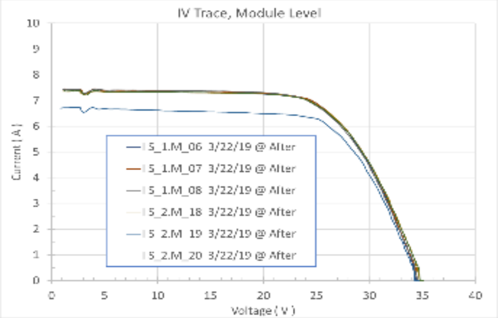
- Polymer cover

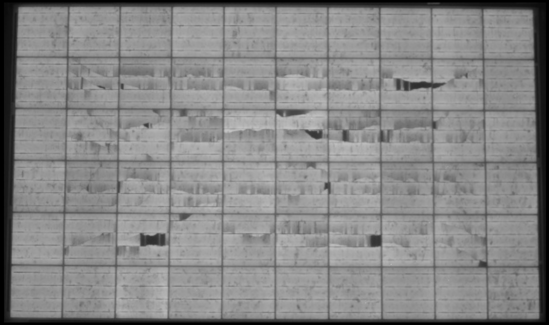
Cell cracks

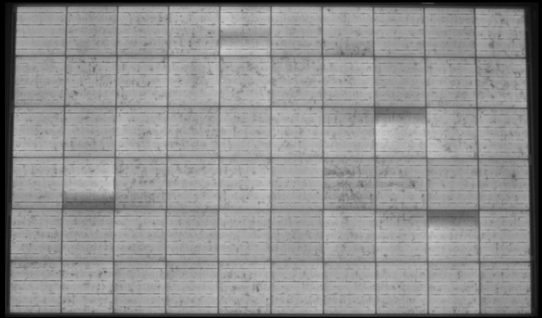
- Mechanical load

Interconnection failures

- Mechanical abrasion







Collaboration

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