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

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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



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 (lsc, 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).

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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





Soiling Characteristics – our method



'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

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- Aging characteristics
- Field Test

Viable

- Flash test
 - Sinton FMT-350
- Apply film to module
 - 1st layer
 - Indoor flash test
 - 7.7 % drop in lsc
 - 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 lsc
 - 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 \pm 60° (30° to 150° with 90° being normal)
 - Influence of outdoor exposure
 - 4.67 kWh/m² of UV (295 nm to 385 nm)





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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

% transmission of 65 micron plastic wrap (unweathered)





% 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





% 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





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





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					



Crack Initiation

Insulated box with Dry Ice

• Expose PV modules to extremely cold temperatures

• (-40°C per IEC standard) to create microcracks / weaknesses



Cover until -40°C



Mechanical load after crack initiation

- Load modules @ 2400Pa
 - Applied to 4 modules

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Mechanical load after crack initiation

Load modules @ 2400Pa

• Applied to 4 modules





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			

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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®



Light table to see interconnection

Dremel® with cutting wheel fixture



Cover opening with Kapton® tape, double layer



Interconnection break visible at front





Module - Electroluminescence



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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