LCOE Reduction Through Proactively Optimized PV System Monitoring

Collaboration

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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 (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.


Fig. 5. Typical I-V 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).

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’
‘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

Module IV Curves
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/m² 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
% 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

<table>
<thead>
<tr>
<th>Time period</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-3</td>
<td>Light soak 4 modules, EL/IV before &amp; after</td>
</tr>
</tbody>
</table>
| 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

- 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

• 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

<table>
<thead>
<tr>
<th>String 2 (west), module ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
</tr>
<tr>
<td>18</td>
</tr>
</tbody>
</table>
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

Interconnection failure using mechanical load

• Mechanical load test
  • Sequence intended to
    • stress ribbon
    • not the cell
  • $\pm 2000\text{Pa} @ 8.6\text{ sec/cycle}$
    • 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

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

Dremel® with cutting wheel fixture

Cover opening with Kapton® tape, double layer

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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