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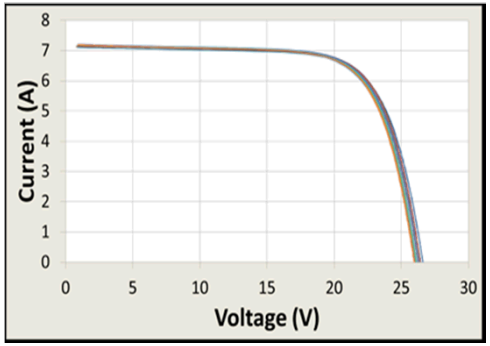

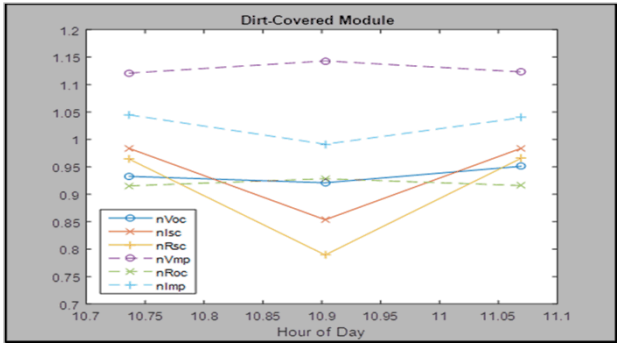

In-Situ Module-Level I-V Tracers for Novel PV Monitoring

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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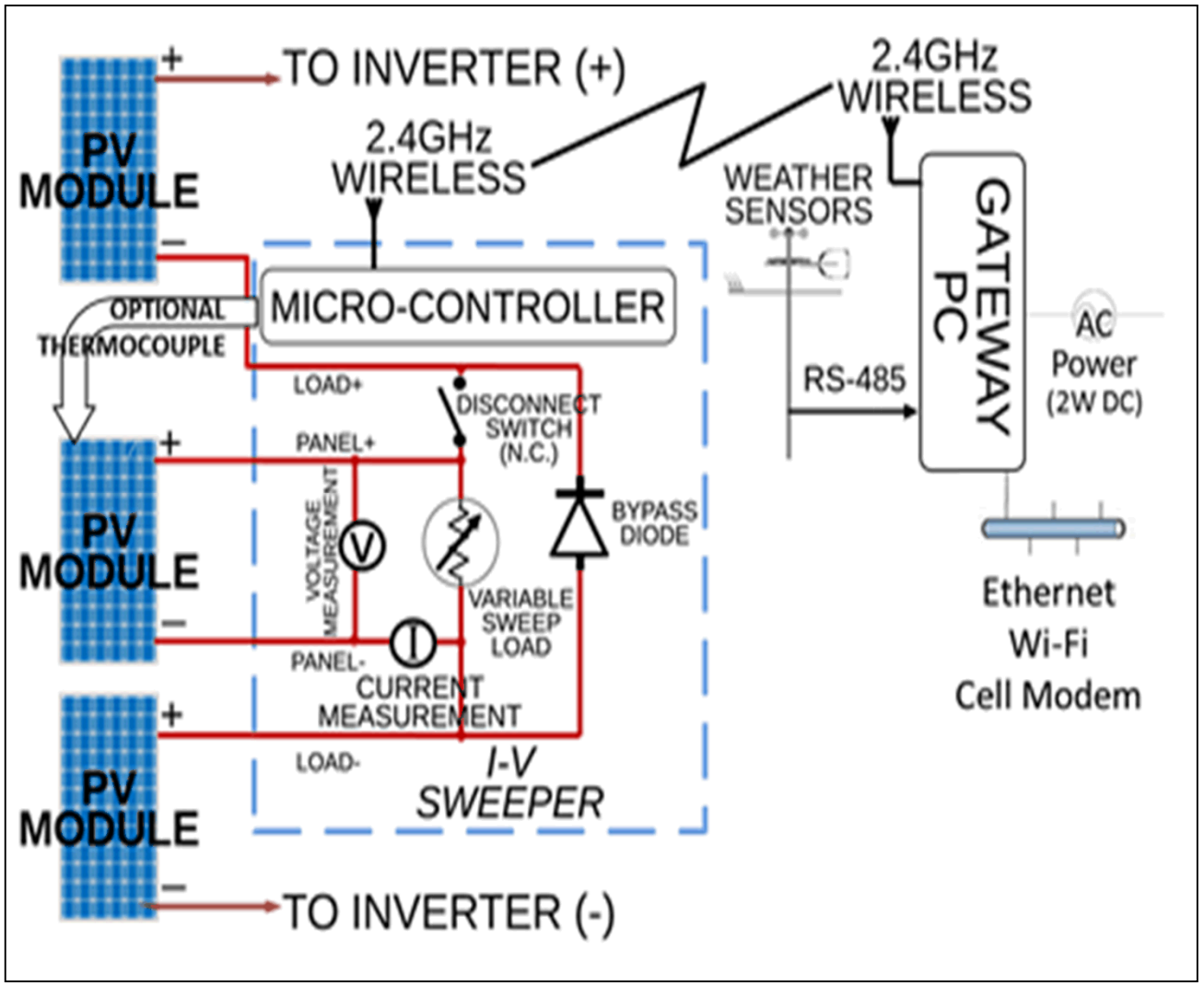
Overview

- Introduce the Stratasense in-situ module-level I-V tracers and SNL testbed.
- Describe field testing and I-V data analysis including:
  - Opaque square shading
  - Dirt soiling
  - Pole shading
  - Series resistance
- Examples of data analysis using the Loss Factors Model (LFM) parameters.
- Conclusions

Connection Diagram

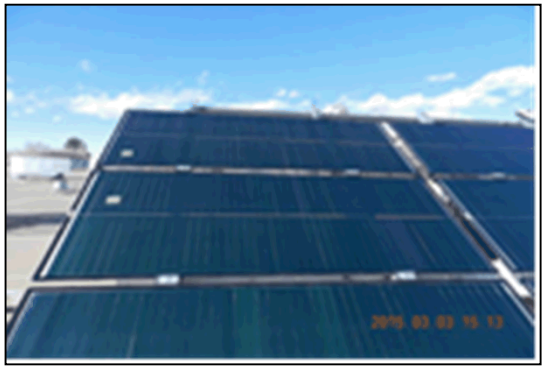


- Nearly uninterrupted power production (<2 sec/trace).
- Wireless Gateway (up to 100 tracers per gateway)
- Analog inputs (pyranometer, reference cell, and thermocouple)
- Raspberry Pi PC

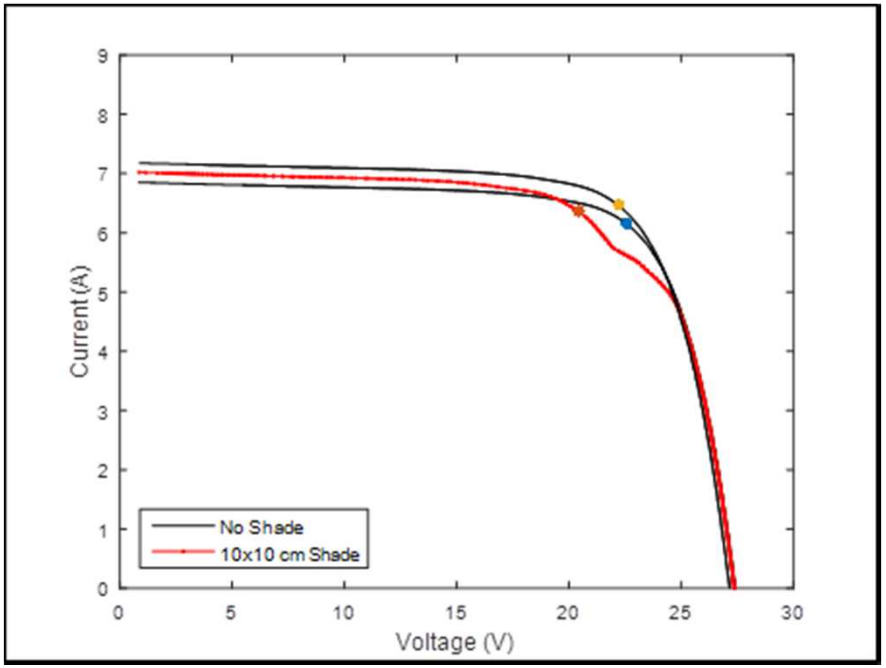
SNL Testbed

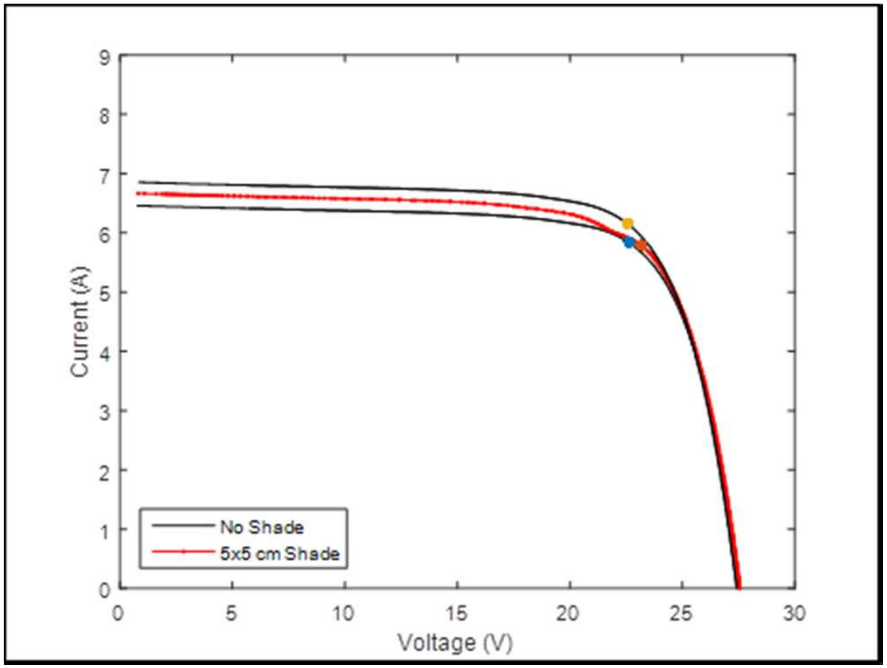
- 15 I-V tracers in 16 fixed-tilt module string connected to grid-tied inverter.
- Modules
  - CIGS thin-film
  - 145 W
  - I_{MP} = 6.3 A
  - V_{MP} = 23 V
  - I_{SC} = 7.12 A
  - V_{OC} = 29 V
- 3000 W inverter
  - MPP voltage range: 230-500 V

Opaque Squares Tests



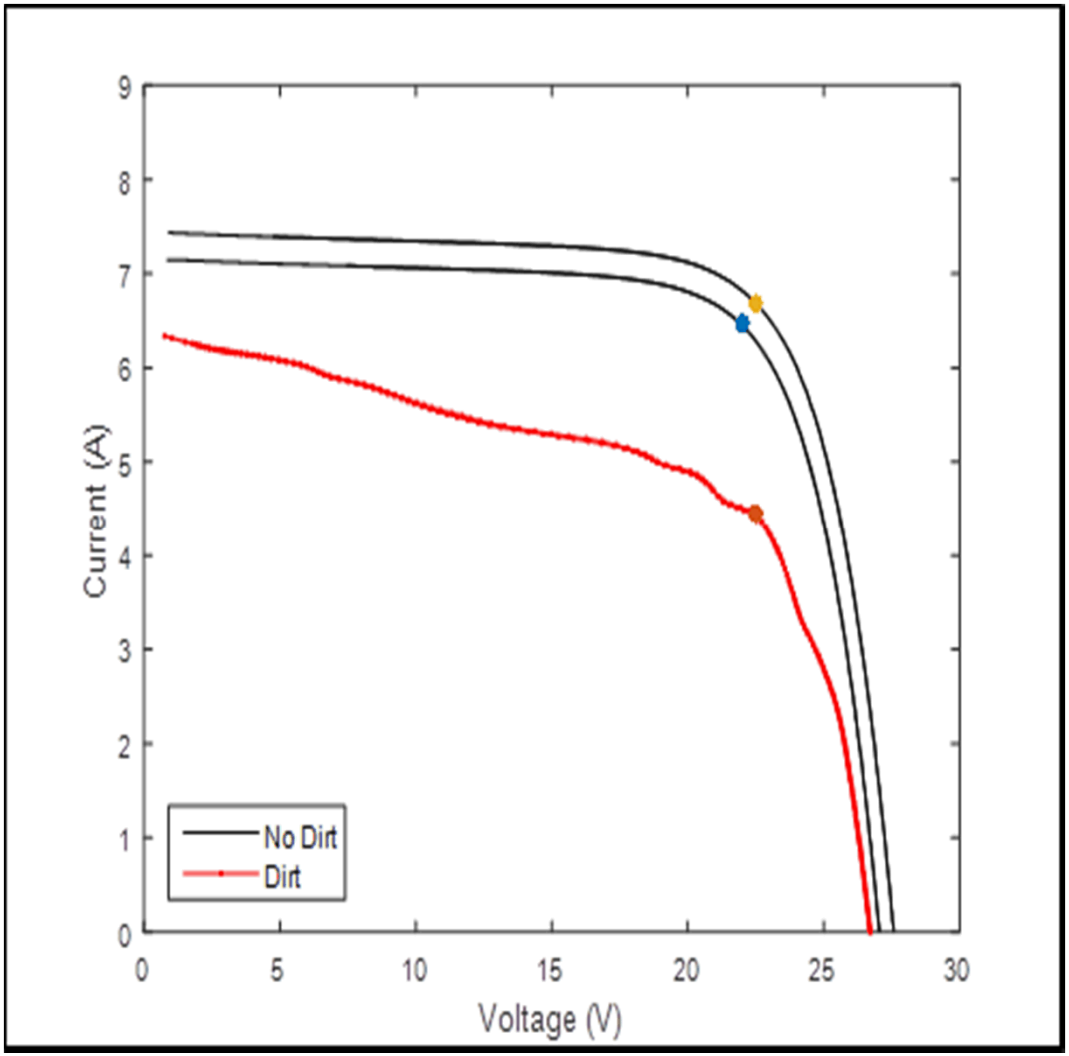
- 5x5 and 10x10 cm squares
- I-V curve during test (red), before and after (black).
- Cell mismatch indentation (affects I_{MP} or V_{MP})





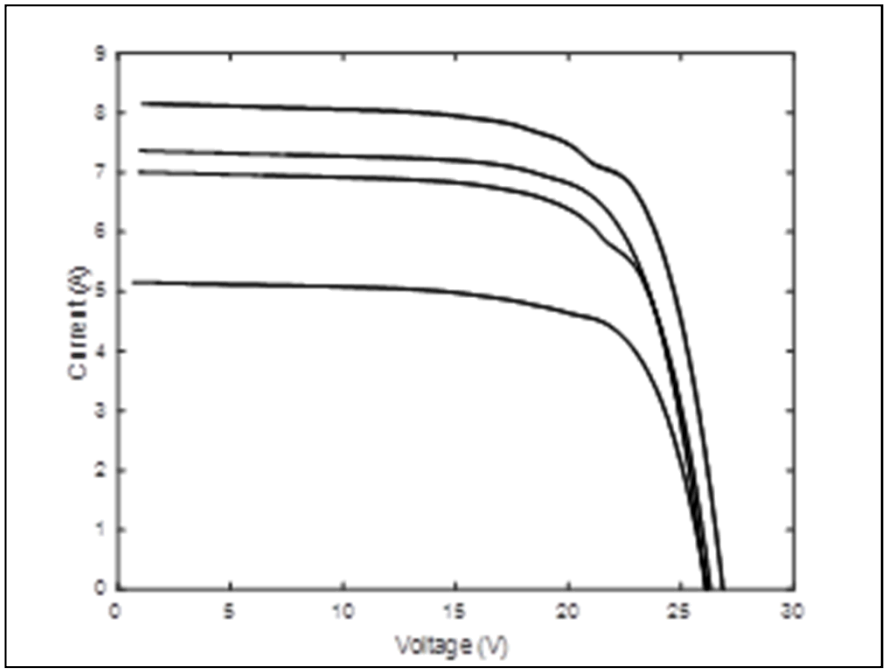
Dirt Soiling Tests

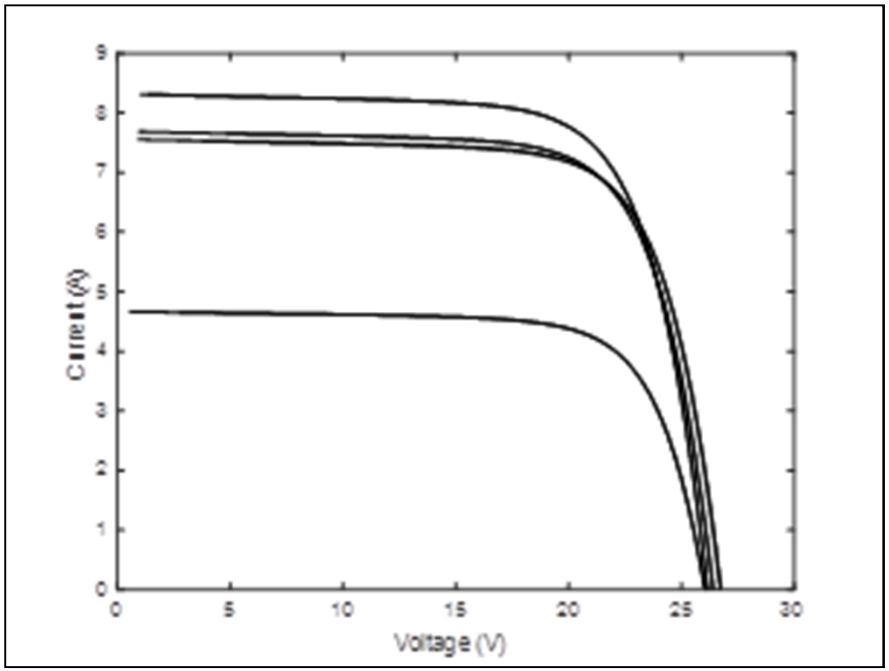
- I-V curve during test (red), before and after (black).
- Mainly affects current (I_{SC} or I_{MP}).
- Non-uniformity causes cell mismatch.



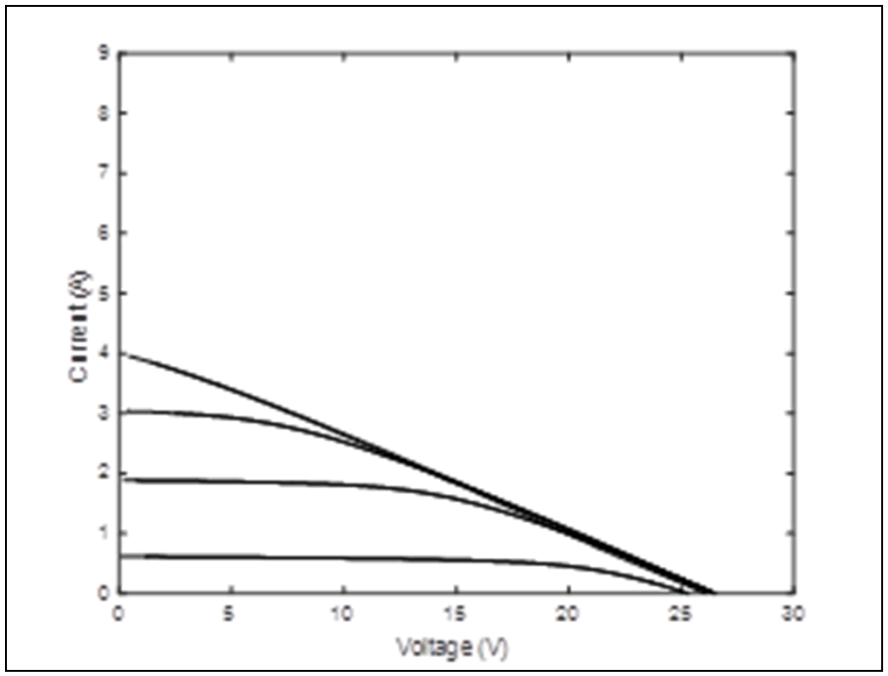
Pole Shading Tests

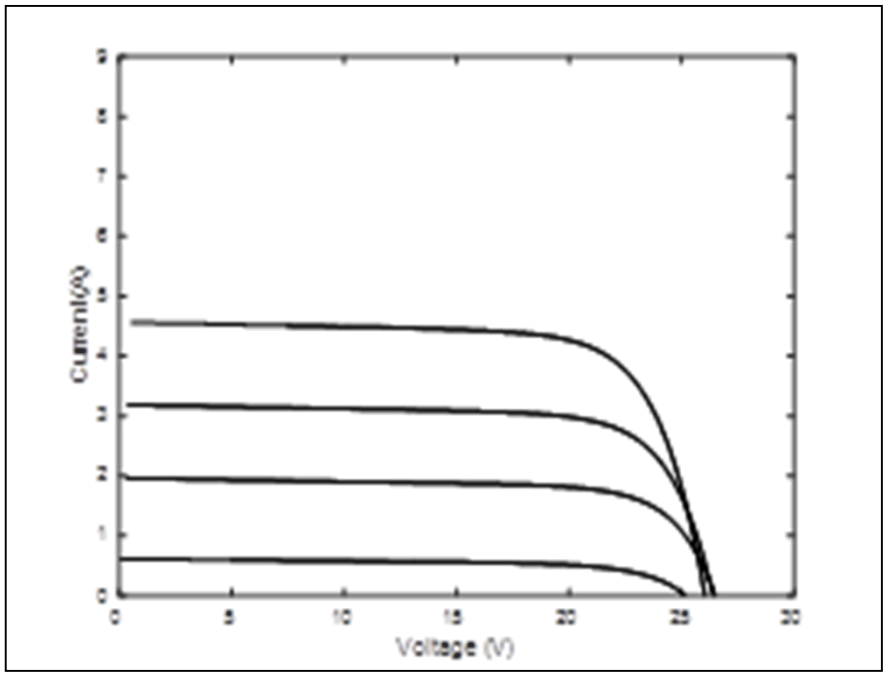
- Four I-V curves in 60-minute period (20-minute intervals).
- Shaded module curves on left, unshaded module curves on right.
- Cell mismatch indentation (affects I_{MP} or V_{MP})





Series Resistance





- 5 ohm series resistance applied to single module.
- Extreme impact on "V_{OC} slope", extends to I_{SC} by the time irradiance ~600 W/m^2.

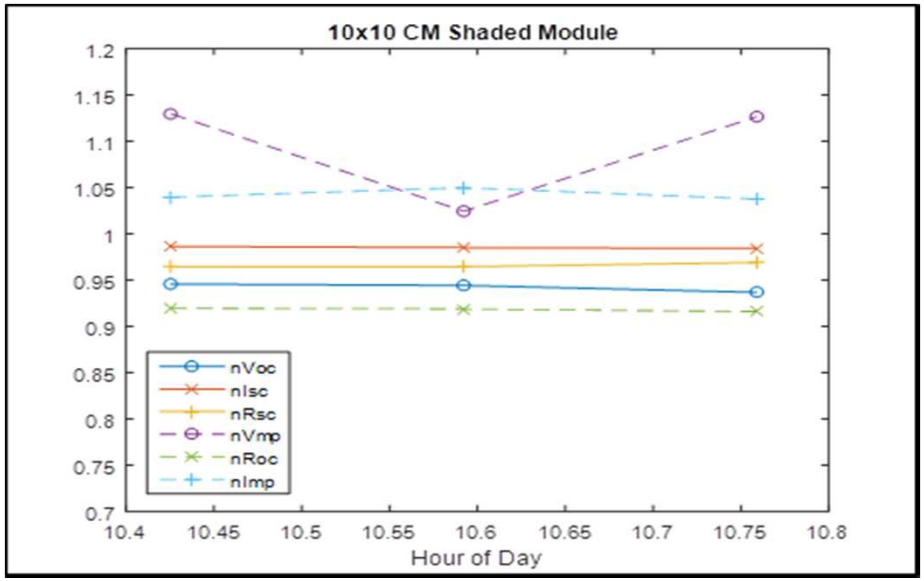
The Loss Factors Model (LFM)

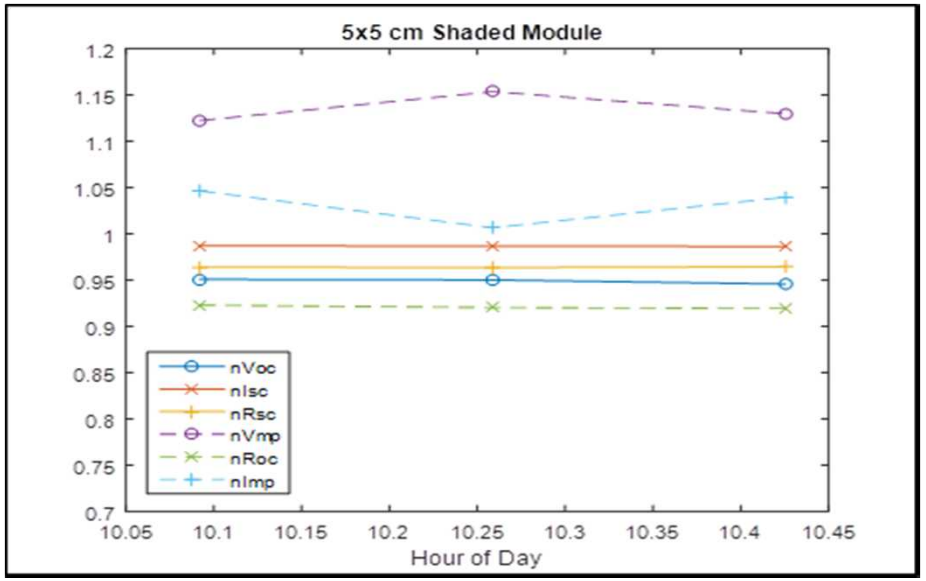
- Developed for interpretation and monitoring of continuous module I-V curves.
- Based on six normalized parameters describing I-V curves independent of POA irradiance.
- Given measured I-V curve (prefix “m”) and reference I-V curve at STC (prefix “r”) can derive normalized parameters (prefix “n”).

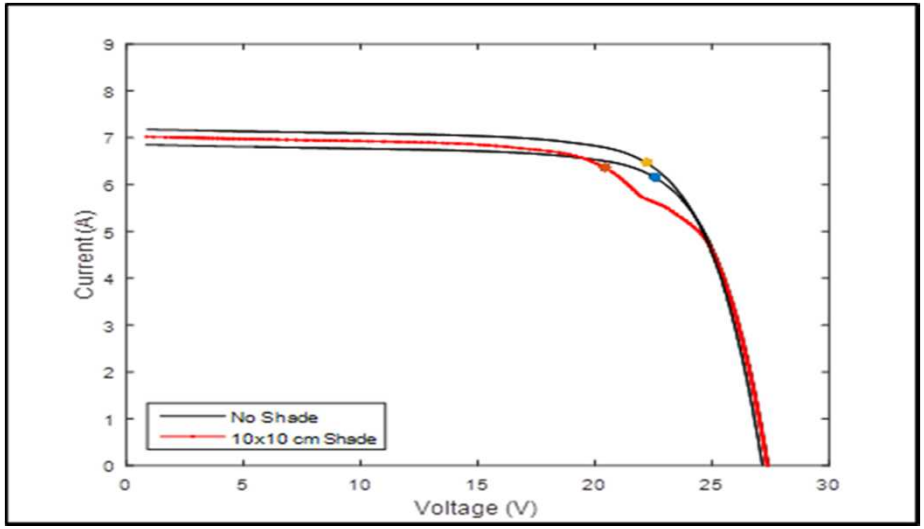
1. $nIsc = \frac{mIsc}{rIsc} / G_i$
2. $nRsc = \frac{mIr}{mIsc}$
3. $nImp = \frac{mImp}{mIr} \times \frac{rIsc}{rImp}$
4. $nVmp = \frac{mVmp}{mVr} \times \frac{rVoc}{rVmp}$
5. $nRoc = \frac{mVr}{mVoc}$
6. $nVoc = \frac{mVoc}{rVoc}$

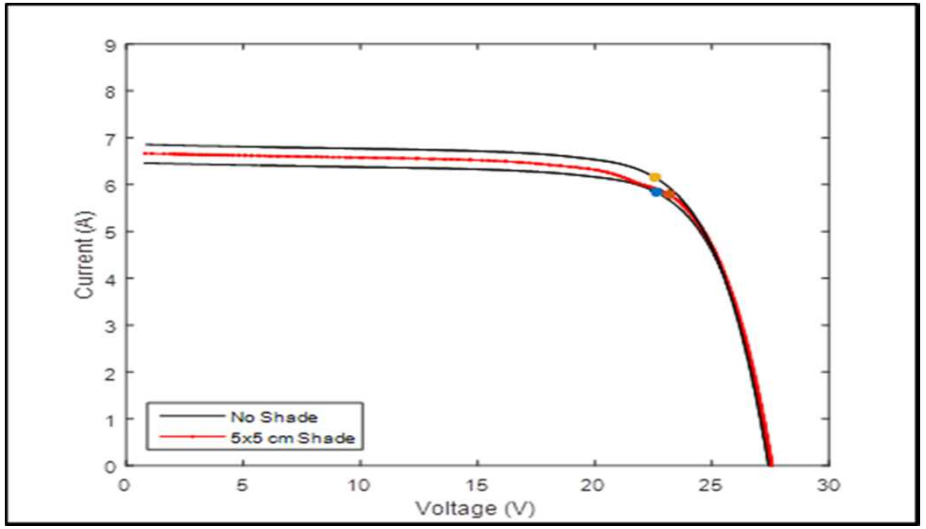
J. S. Stein, J. Sutterlueti, S. Ransome, C.W. Hansen, and B. H. King, "Outdoor PV Performance Evaluation of Three Different Models: Single-Diode, SAPM and Loss Factor Model,” 28th EU PVSEC, Paris, France, October, 2013.

LFM Factors – Opaque Squares

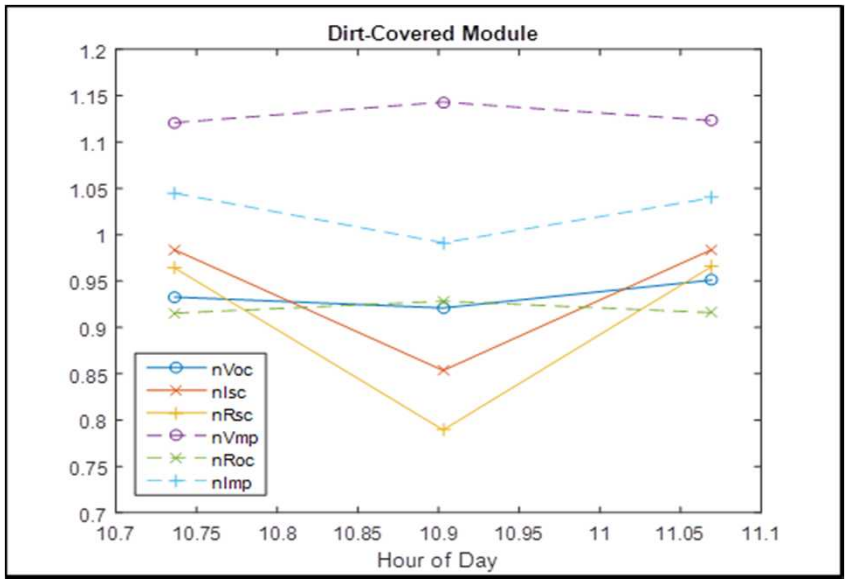


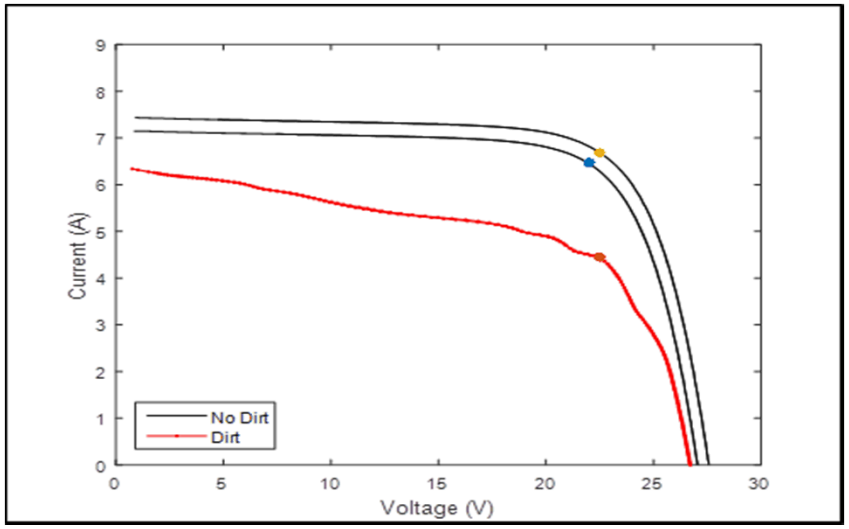






LFM Factors – Dirt Soiling





- Reductions in nI_{SC} and nI_{MP} can be correlated to I-V curve MPP.
- Reduction in nR_{SC} correlated to increase in the negative slope at I_{SC} in the I-V curve.

Conclusions

- Product offers benefits of I-V curves at the module-level with easy implementation.
- Provides more sensitive diagnostics than string-level I-V tracers with module-specific information.
- Research applications as an automated solution for continuous I-V curves.
- Challenges:
  - Economic feasibility
  - Reliability
  - Data consistency
  - Storage and computation of massive dataset

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Thank you!

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