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Real-time series resistance monitoring in PV systems

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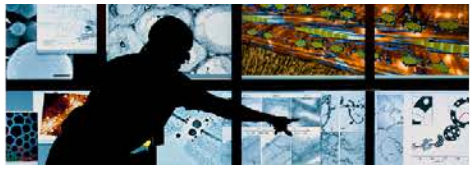
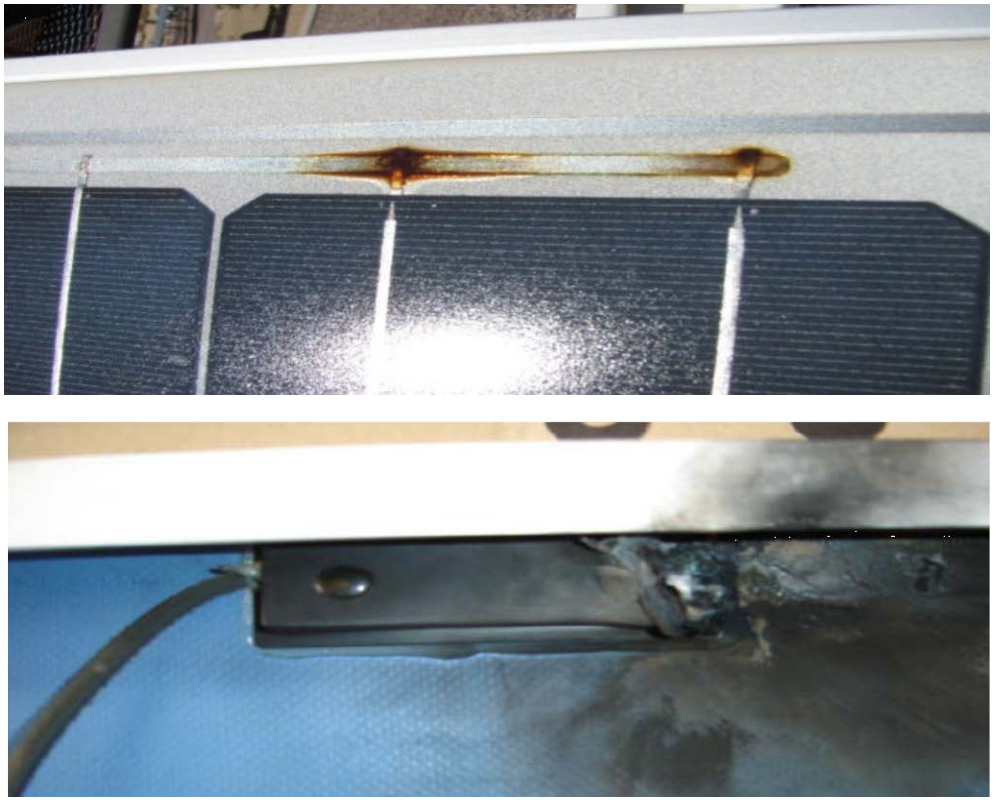


NREL/PR-5J00-63998

Benefits of R_s monitoring

- Beyond performance indices - automated diagnostic alerts
- Increases in R_s associated with fire risks



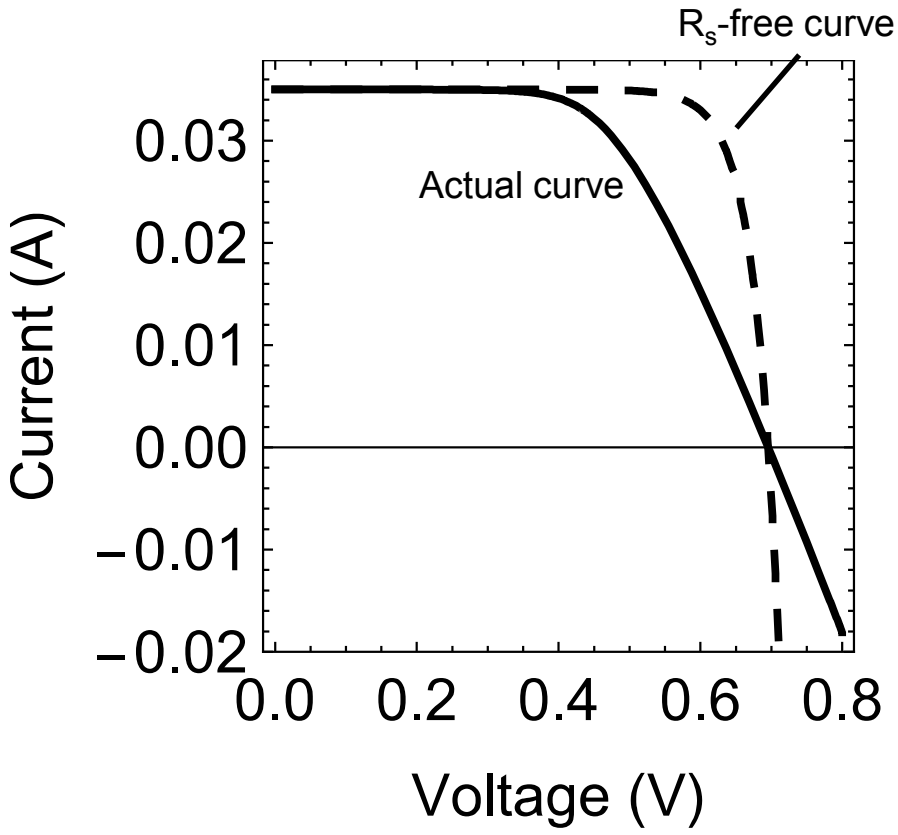
Wohlgemuth and Kurtz, PVSC 2012

Automated R_s monitoring

- Avoid hands-on, equipment-intensive measurements
- Automatically adapt to other changes in the module
  - e.g. change in shunt resistance

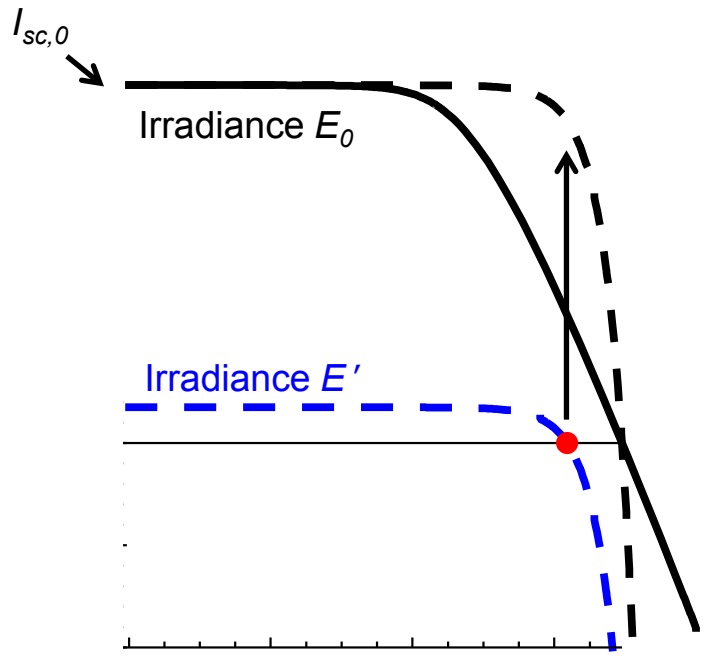
Background: Suns-V_{oc}

- Measure intensity dependent V_{oc} values
- Construct an R_s free IV curve
- R_s from Ohm's law
- Most often used for measuring cells
- Recently demonstrated outdoors on modules and systems[1]



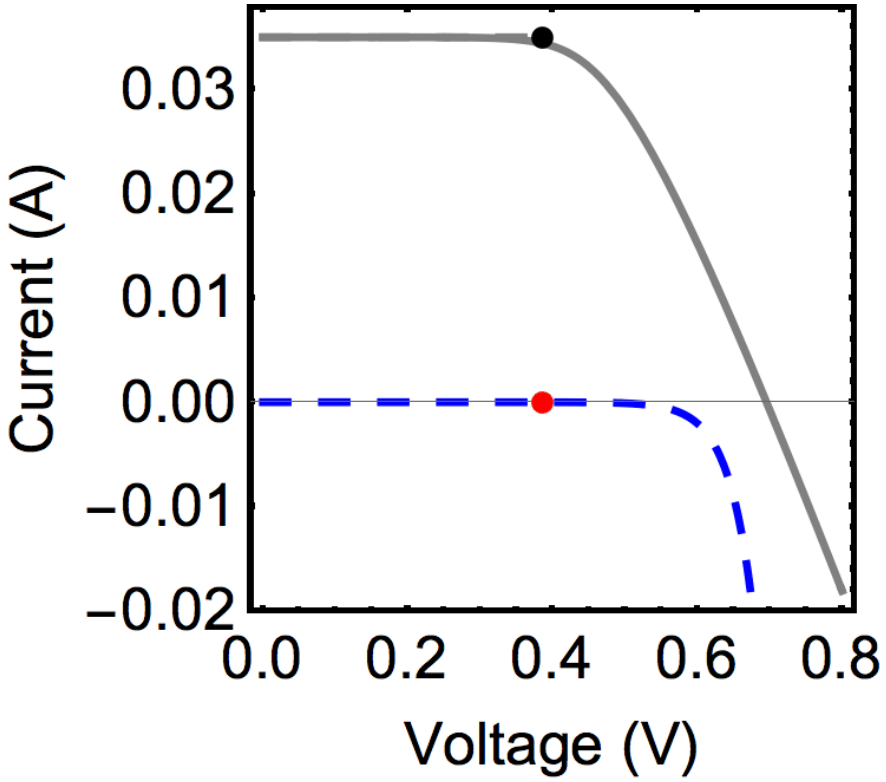
[1]*Forsyth et al. PVSC 2014 p1928*

Operating principles



Translate V_{oc} from low irradiance to: $I_{sc,0}\left(1-\frac{E'}{E_0}\right)$

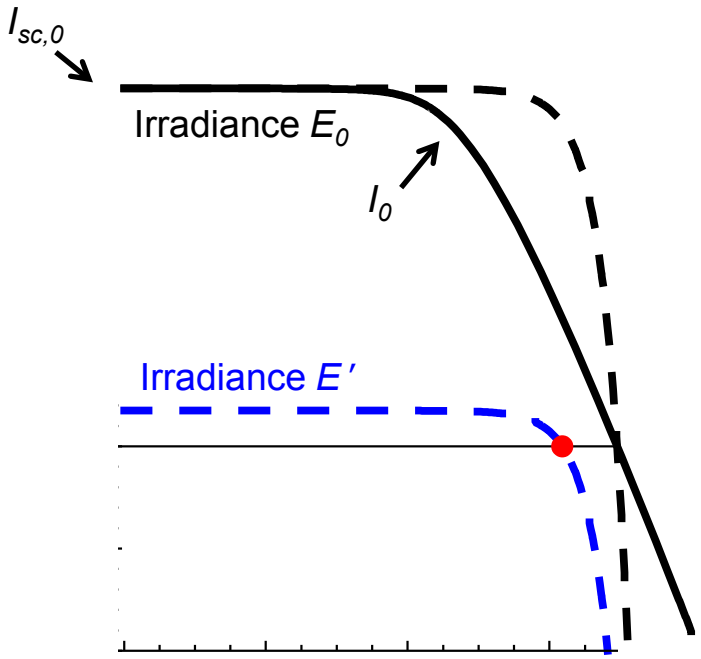
Operating principles



Translate V_{oc} from low irradiance to: $I_{sc,0}\left(1-\frac{E'}{E_0}\right)$

Real-time series resistance (RTSR)

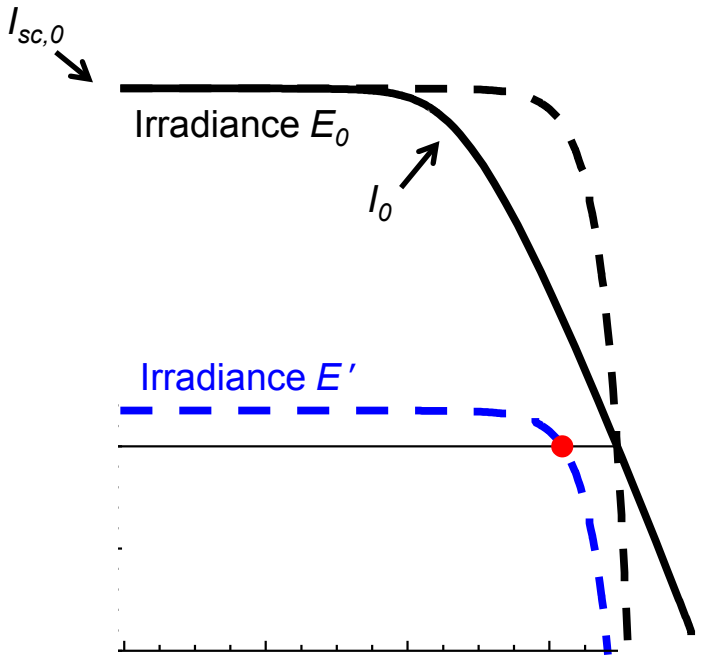
- Record operating I and V
- Record V_{oc} at low irradiances
- Compare operating V to recent V_{oc} at target irradiance:



$$I_0 = I_{sc,0}\left(1 - \frac{E'}{E_0}\right) \longrightarrow E' = E_0\left(1 - \frac{I_0}{I_{sc,0}}\right)$$

Handling temperature

- Module will generally be cooler at E'
- Temperature coefficient depends on irradiance
- Goal: adaptive, calibration-free



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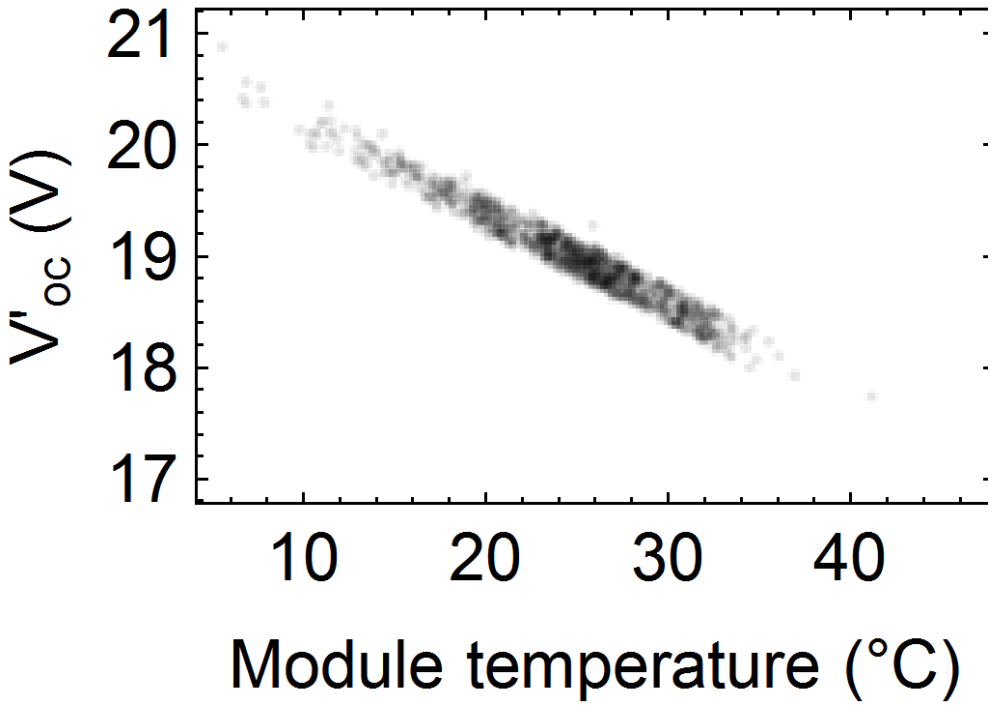
Handling temperature

- Look at recent V_{oc} measurements near E'
  - Recent = 1 week
  - E' ± 10%,
- Regress V_{oc} vs. T
- Extrapolate



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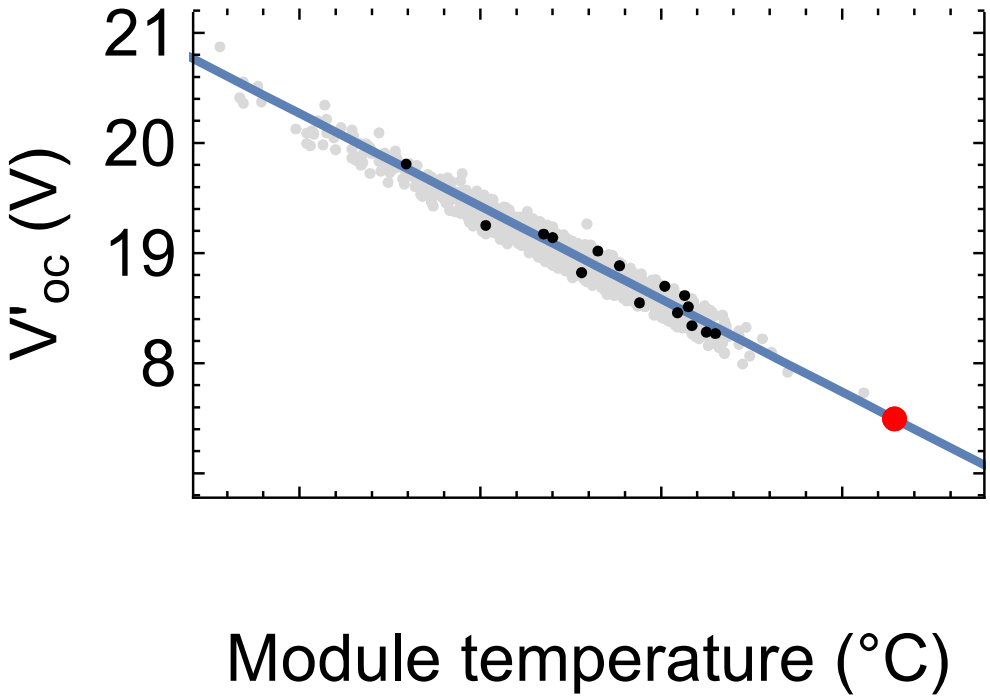

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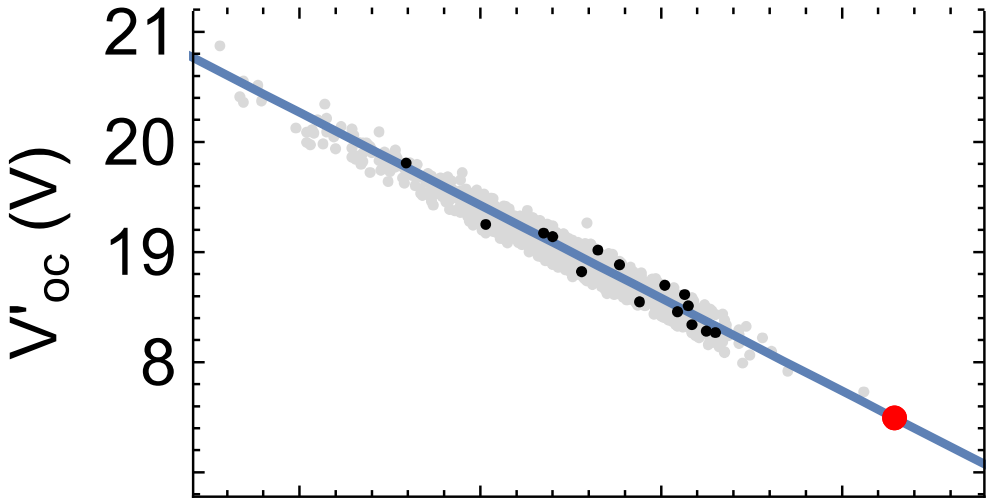


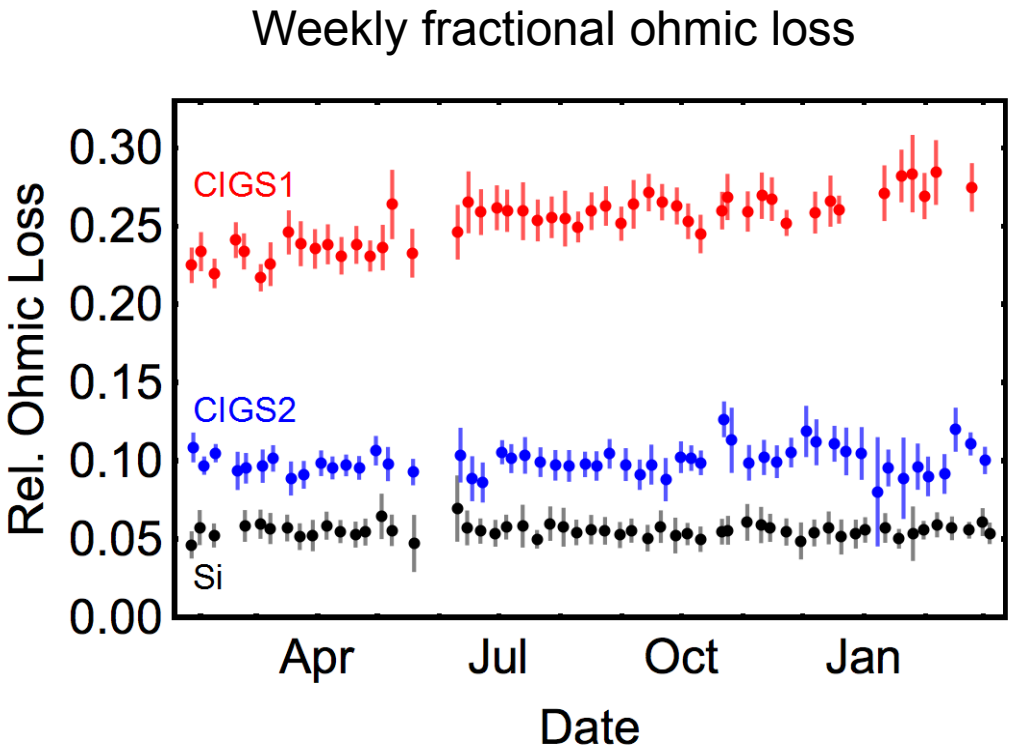
- Capture V_{oc} vs. T at relevant irradiance
- Automatically adapt to changes in the module

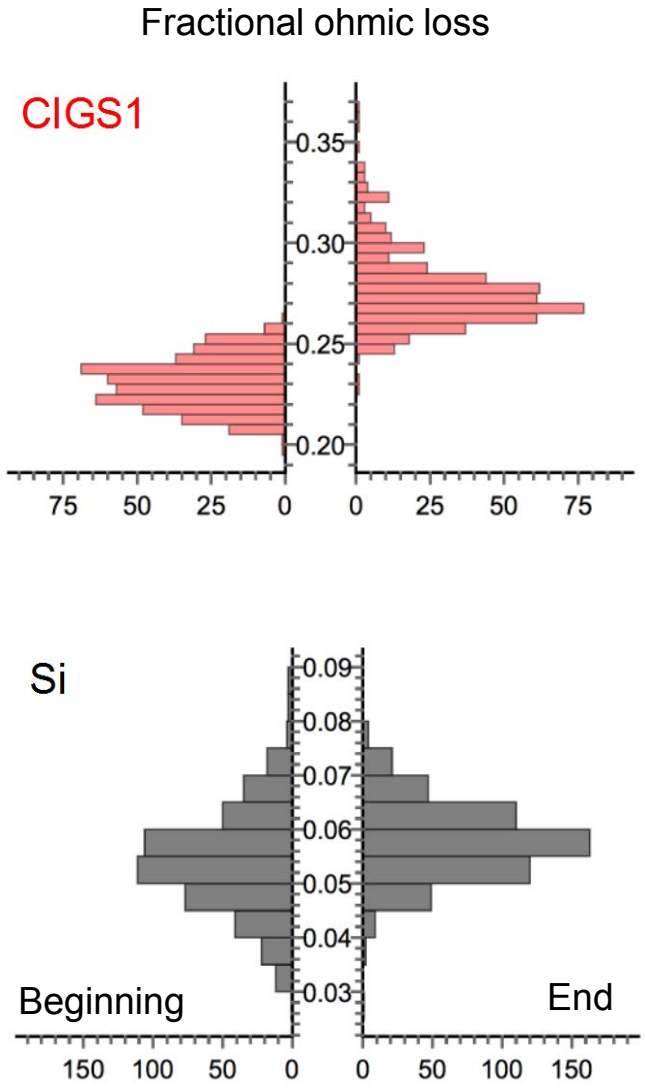
Example application

- Various modules deployed in **Cocoa FL**, Eugene OR, and Golden CO
- IV curves measured at 5-minute intervals
- Meteorological monitoring
- Publically available dataset
- RTSR: **Use subset of data, not full IV curve**

Marion et al. NREL Report: TP-5200-61610
Contact: bill.marion@nrel.gov

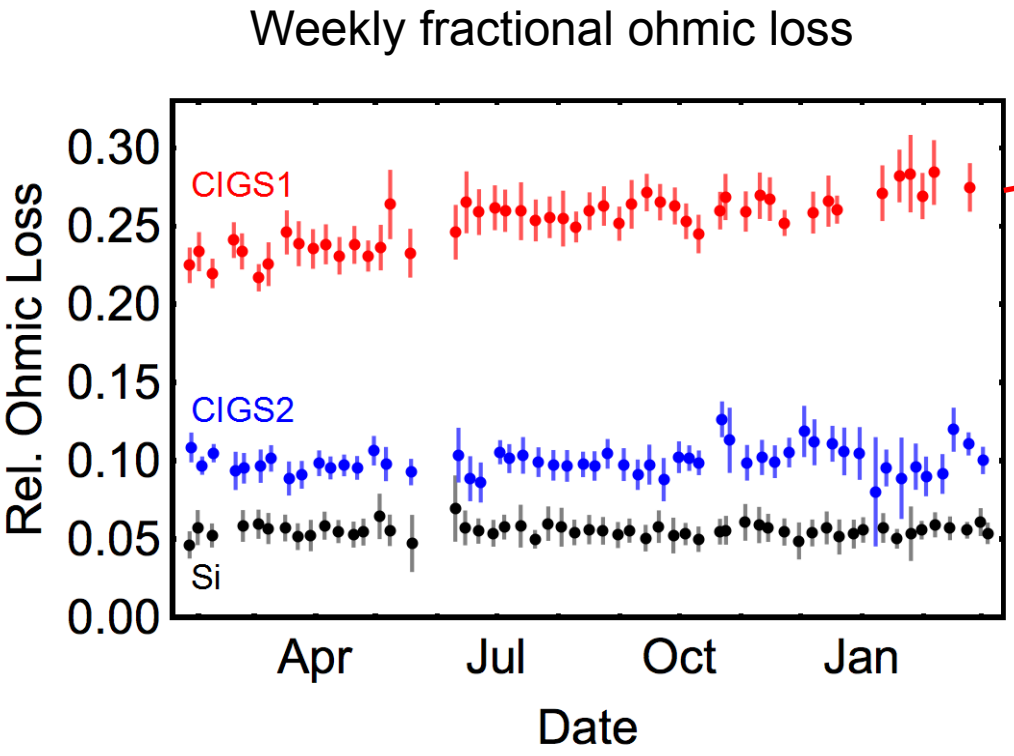
R_s time series

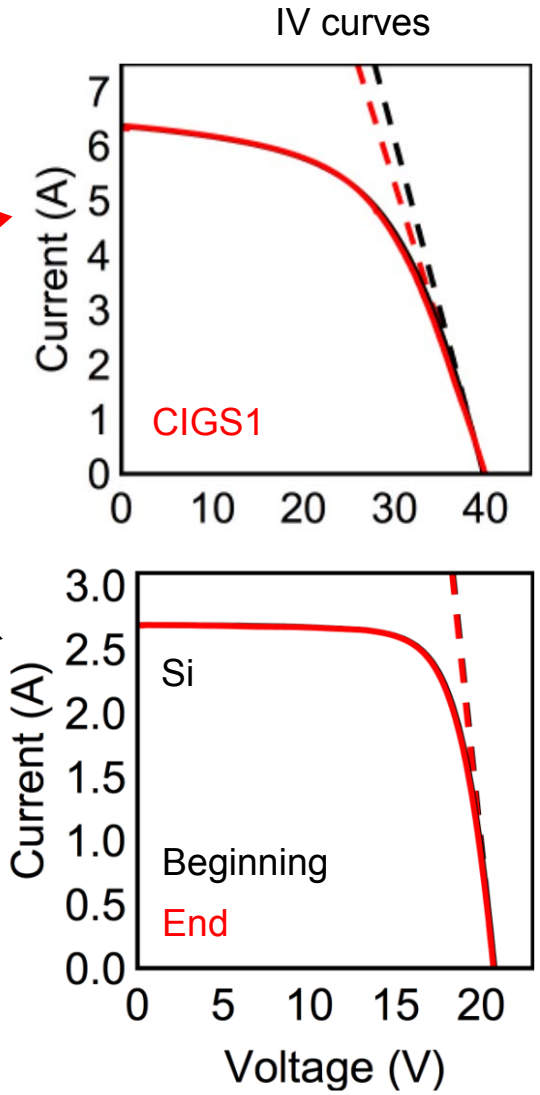




Can identify increases in R_s

R_s time series





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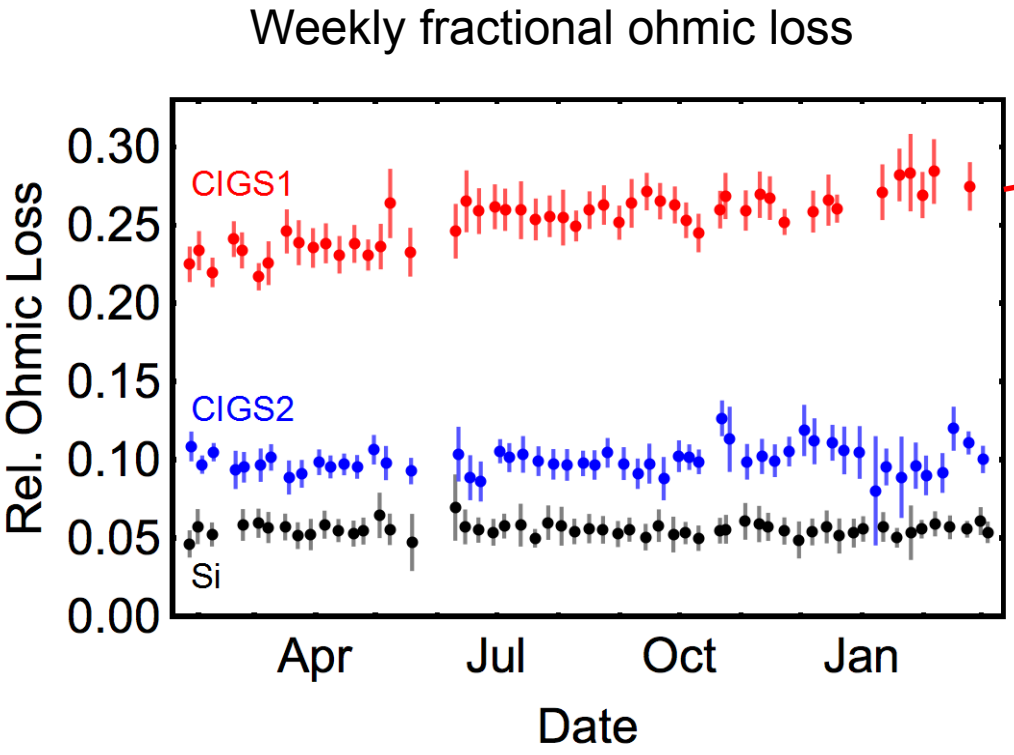
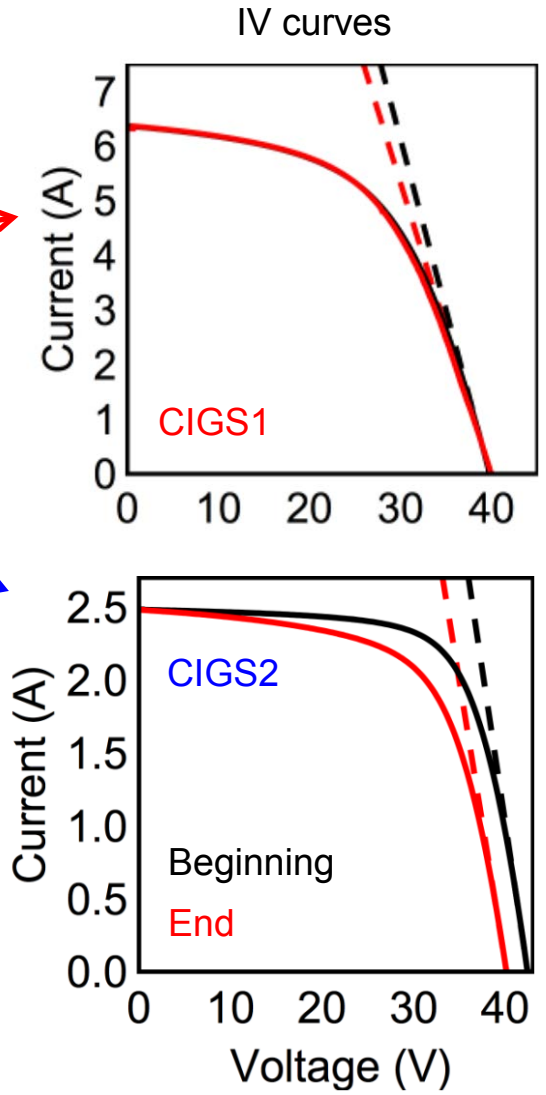
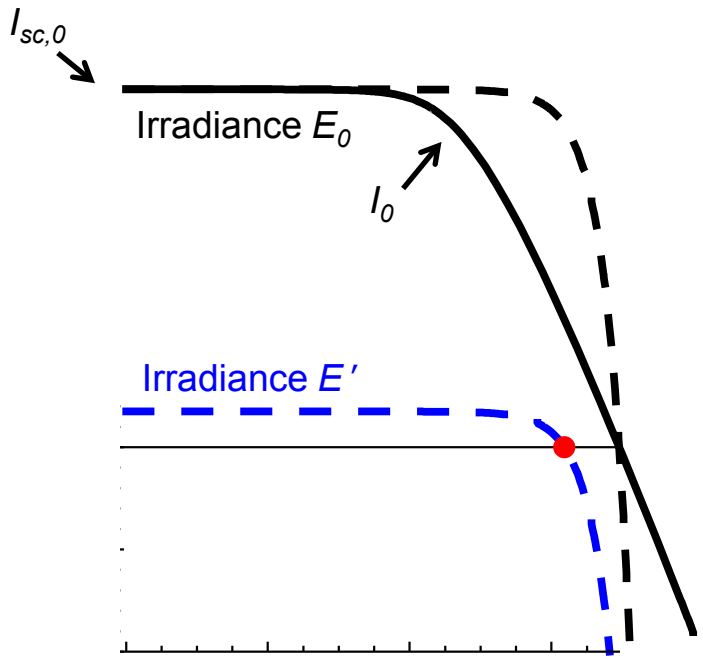




Adapts to other changes in module

Implementation - review

- Collect:
  - Operating I, V
  - Low irradiance V_{oc}
  - Irradiance and temperature
- Regress recent low irradiance V_{oc} vs. T
- Calculate R_s from Ohm's law

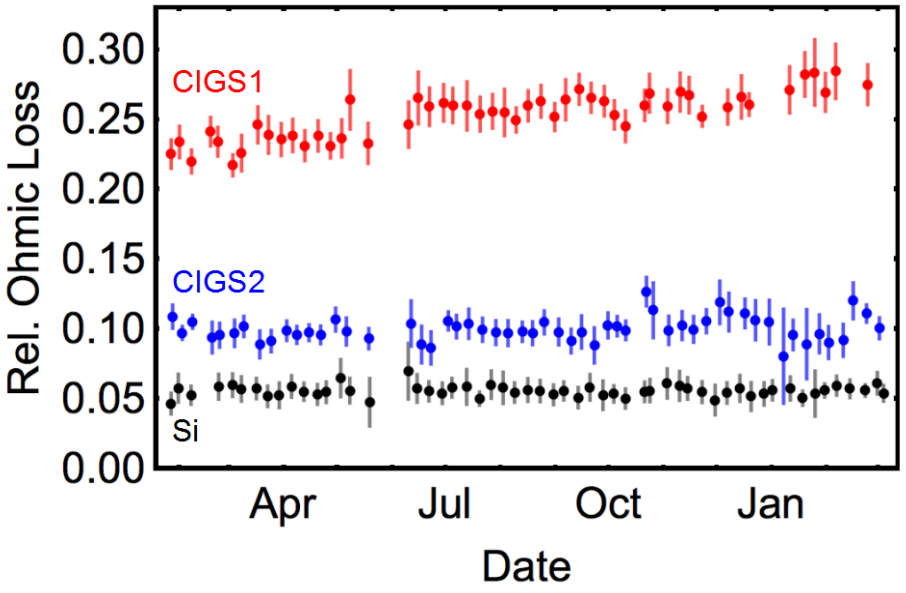


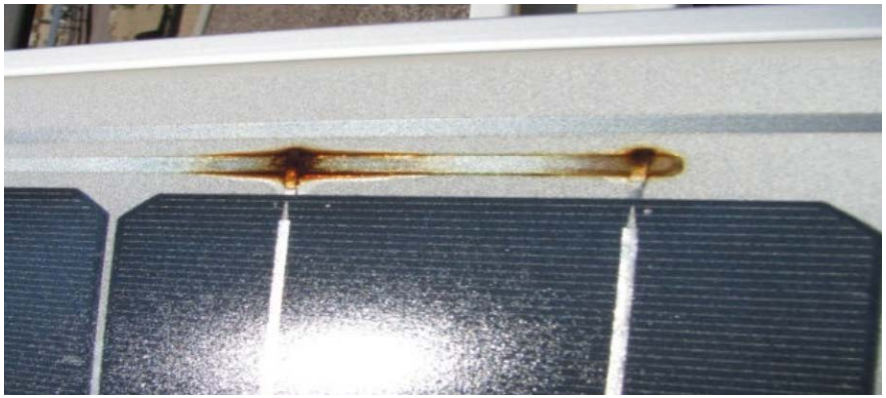
Implementation

- Readily applicable at module level
  - Integrated electronics
  - Power optimizers
- Possible at string-level
  - Challenges:
    - Variation in mounting angle
    - Partial shading

Conclusion – real time series resistance

- Automated, module/array integrated
- Adaptive, calibration-free
- Benefits
  - Beyond performance indices
  - Diagnostic
  - Early alert for fire risks





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