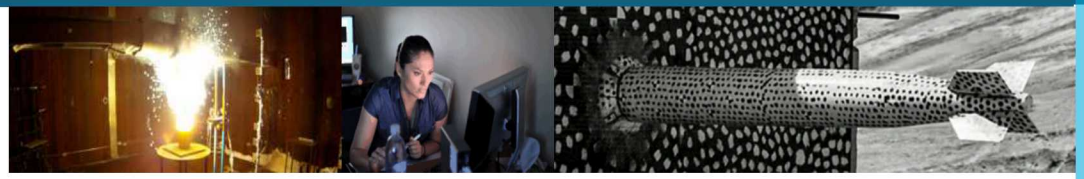
SAND2019-7024C

Predicting Photovoltaic Module Series Resistance based on Indoor-Aging Tests & Thermal Cycling Cumulative Exposure Estimates



PRESENTED BY

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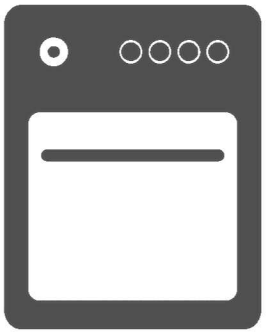
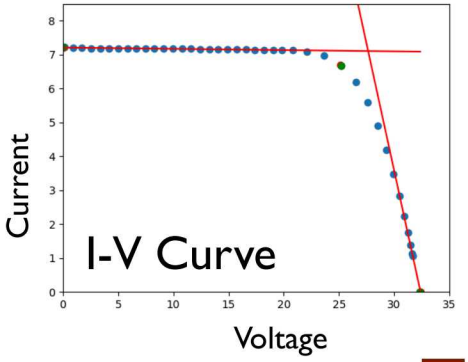
Presentation Overview

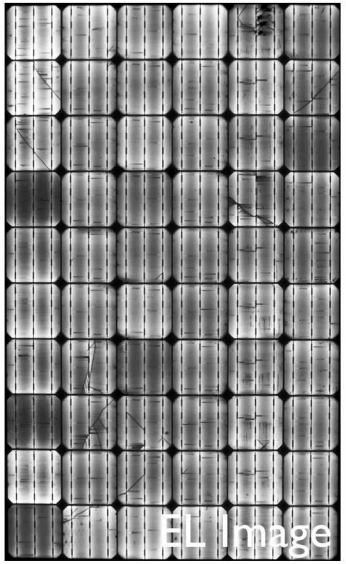
Accelerated-aging of PV modules



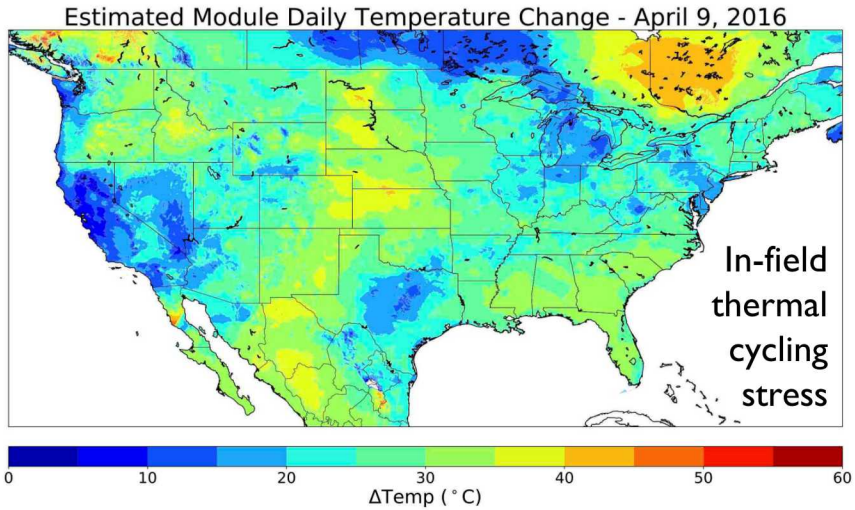
Stress: Indoor Test Chamber

Measure performance using EL images & I-V curve scans





Predict in-field performance



Stress: Outdoor Environmental

PV array exposed to outdoor environment

Introduction

1. Hypothesis
   - The IEC 61215 and Qualification Plus thermal cycling test procedures provide the necessary data to predict Rs
2. Why does this matter?
   - Accurate predictions of in-field performance will lower uncertainty, inform module manufacturing, etc.
3. Contribution - Explore relationship between Rs changes and the cumulative exposure to thermal cycling.
   - Provide evidence not proof
   - Motivate future work

Background

1. Indoor test procedures
   - IEC 61215 TC200[1]
   - Qualification Plus TC500
2. Compare IEC indoor vs outdoor performance
   - Pass tests w/out significant degradation[2]
   - TC200 vs 5 years in-field[3]
     - Voltage close; Current not close
3. Thermal cycling damage model
   1. Solder bond degradation[4]
   2. PV solder bond[5]

1 "IEC 61215-1:2016," 2016. [Online]. Available: https://webstore.iec.ch/ publication/24312

2 J. H. Wohlgemuth and S. Kurtz, "Using accelerated testing to predict module reliability," in *2011 37th IEEE Photovoltaic Specialists Confer- ence*, Jun. 2011, pp. 003 601–003 605.

3 C.B.Jones,B.Hamzavy,W.B.Hobbs,C.Libby,andO.Lavrova,"IEC 61215 Qualification Tests vs Outdoor Performance using Module Level In Situ I-V Curve Tracing Devices," in *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC)*, Jun. 2018, pp. 1286– 1291.

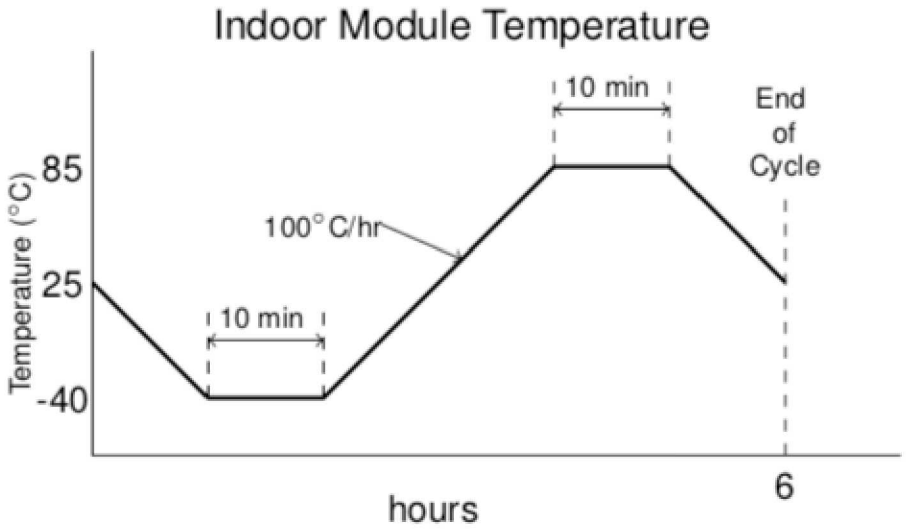
4 K. C. Norris and A. H. Landzberg, "Reliability of Controlled Collapse Interconnections," *IBM Journal of Research and Development*, vol. 13, no. 3, pp. 266–271, May 1969.

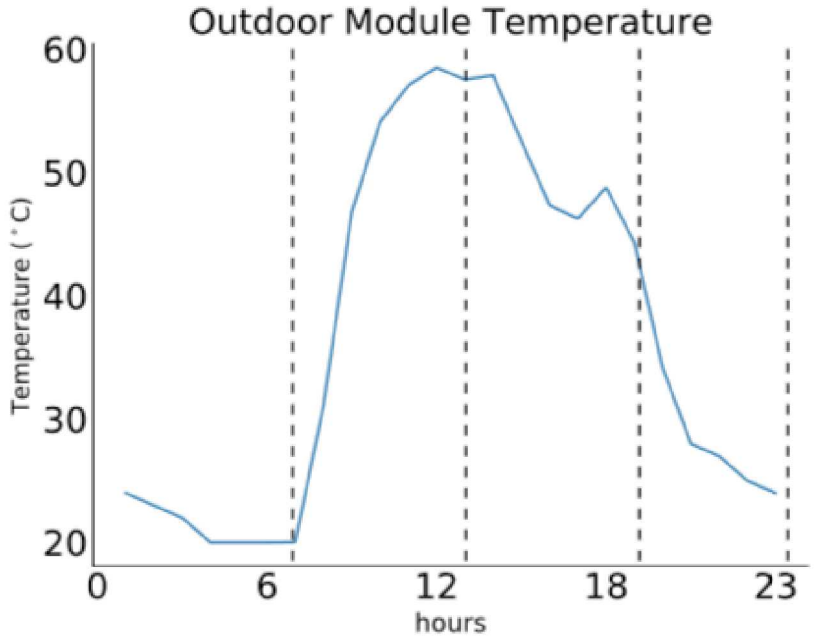
5 N. Bosco, T. J. Silverman, and S. Kurtz, "Climate specific thermo- mechanical fatigue of flat plate photovoltaic module solder joints," *Microelectronics Reliability*, vol. 62, pp. 124–129, Jul. 2016.

Methodology

Thermal Cycling Exposure Indoor & Outdoor

1. Indoor
   a. IEC 61215 TC200
      - 200 6-hour cycles
   b. QP TC500
      - 500 6-hour cycles
2. Outdoor
   a. Single Day
      - (4) 6-hour cycles
      - 1 hour data





Thermal Cycling Exposure Estimates

1. Implemented two exposure calculations
2. Exposure Type 1:
   - Norris-Landzberg Equation
3. Exposure Type 2:
   - N. Bosco et al "Climate Specific Solder Thermal Fatigue Damage in PV Modules"

$$\text{Exposure}_1 = \sum_{t=0}^{q} (f)^m (\Delta \text{Tm})^n \exp\left[\frac{-Q_a}{k_b \text{Tm}_{max}}\right](t) \quad (1)$$

freq. = 6-hour

max delta & temp w/in 6-hour period

$$\text{Exposure}_2 = \sum_{t=0}^{q} (\text{rev}(\text{Tm}))^a (\Delta \text{Tm}_{day})^n \exp\left[\frac{-Q_a}{k_b \text{Tm}_{max}}\right](t) \quad (2)$$

rev at 54.8C

Performance Predictions & Validations

1. Predict in-field Rs

- Rs - Dependent Variable
- Exposure - Independent Variable

$$Rs = f(Exposure)$$

2. Validate indoor Rs changes

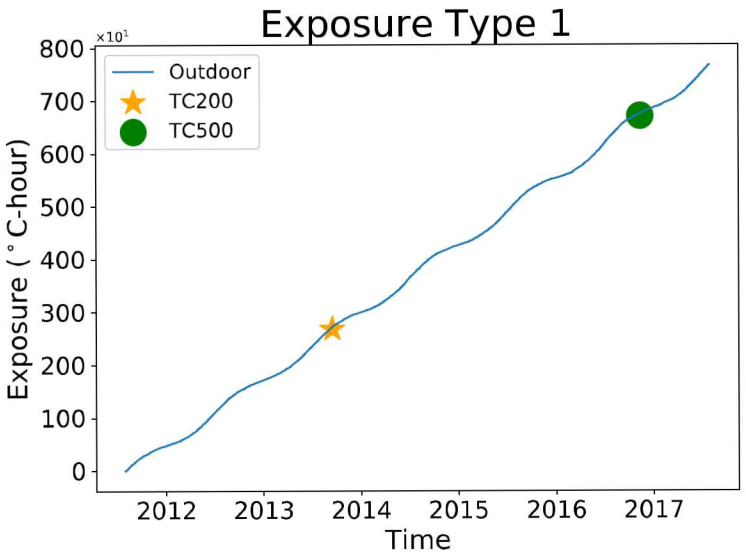
- Compare pre & post EL
  - Busbar defects
  - Overall Pixel changes

Results

Comparison of Indoor and Outdoor Exposure

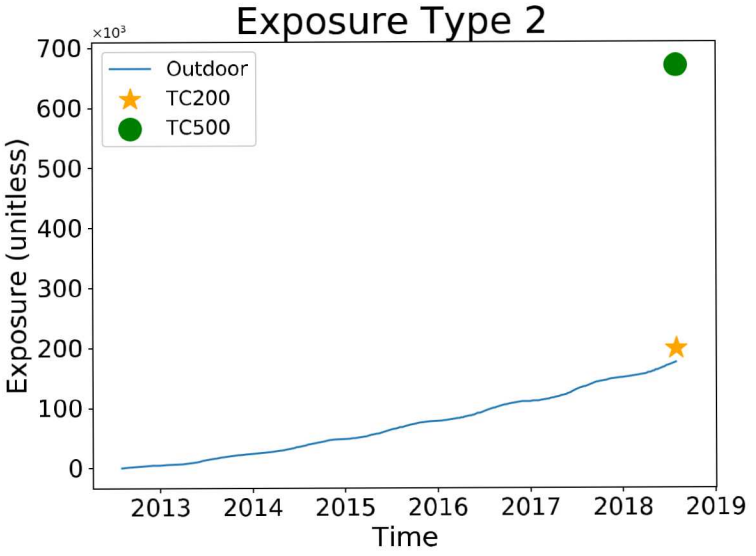
1. Exposure Type 1:

- TC200 ~ 2 years
- TC500 ~ 5 years



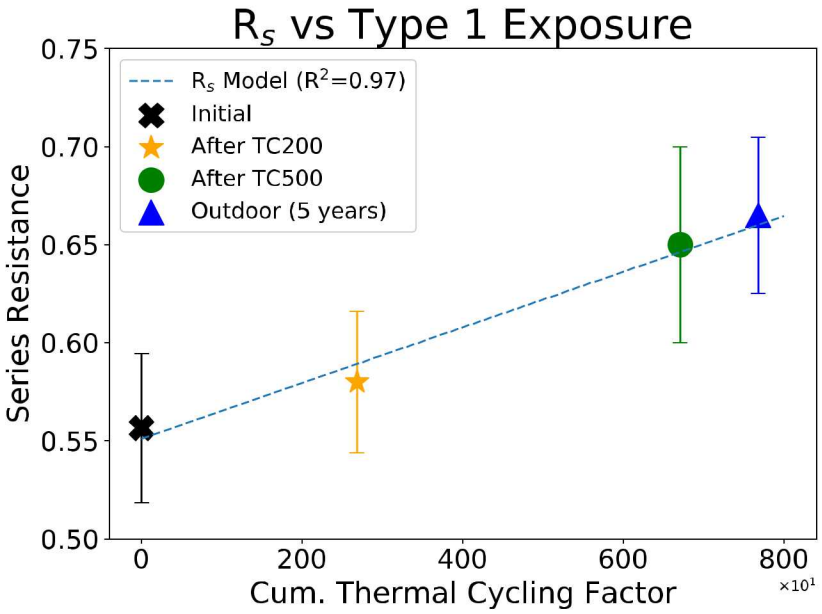
2. Exposure Type 2:

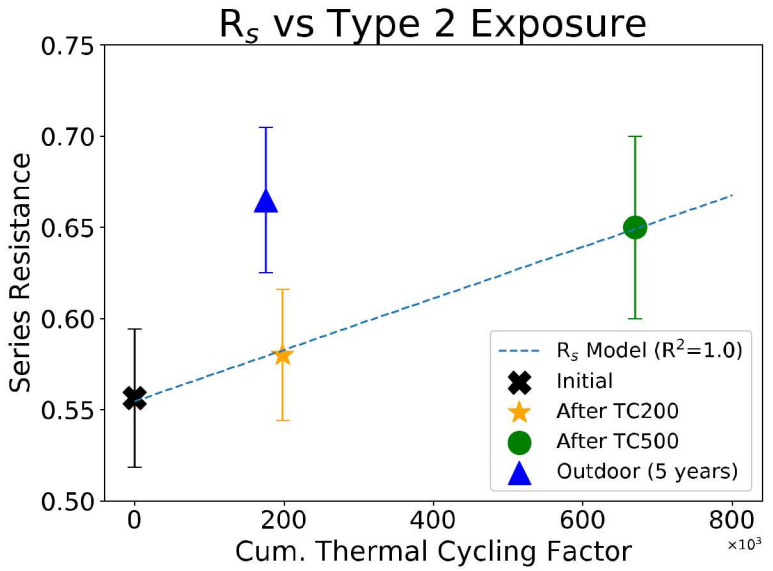
- TC200 > 5 years
- TC500 >> 5 years



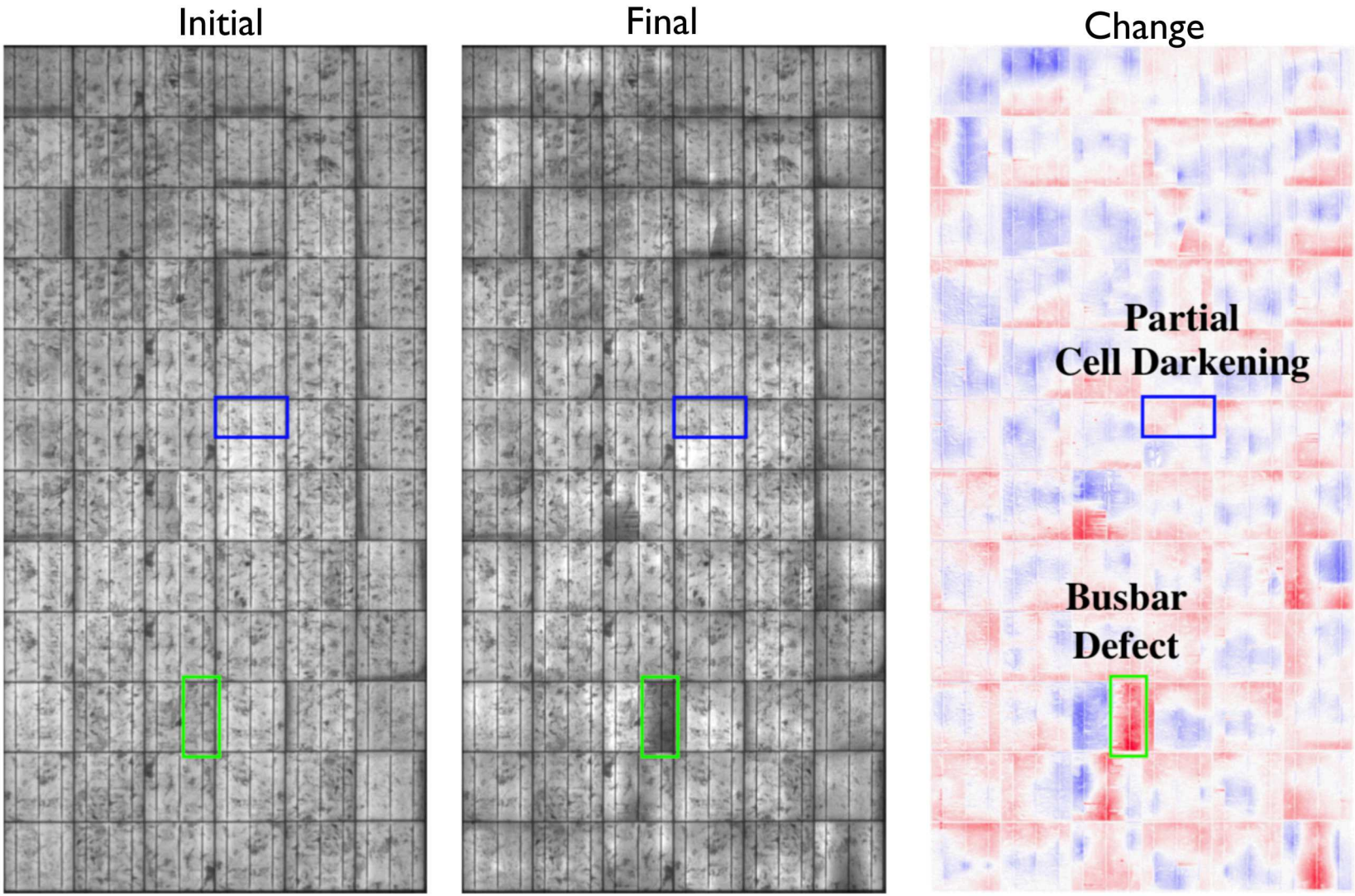
Degradation Models Based on Indoor Tests

1. Type 1 exposure
   - Indoor tests have linear relationship
   - Can predict outdoor Rs performance
2. Type 2 exposure
   - Indoor test show linear relationship
   - Not able to predict outdoor Rs performance





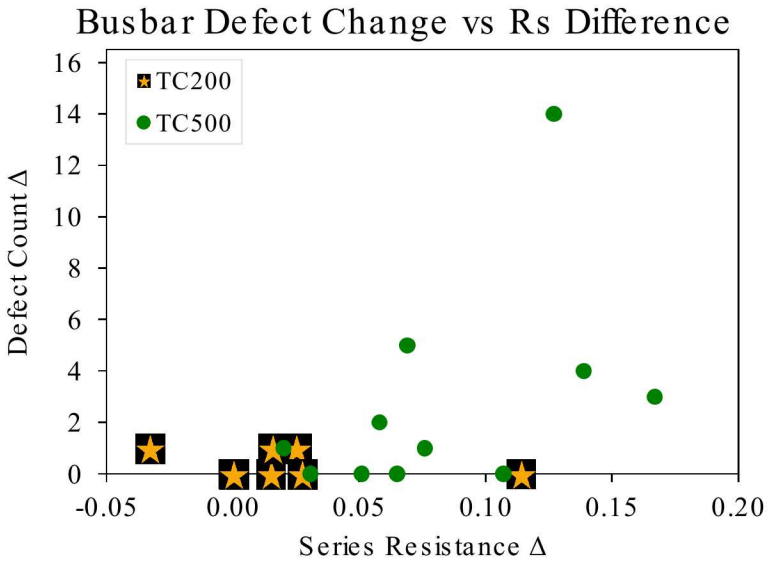
EL Image Analysis

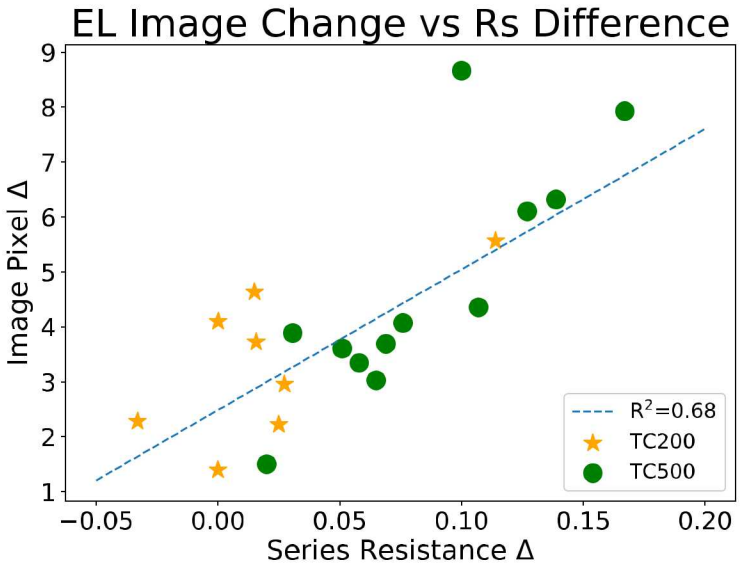


Red – darkening
Blue - brightening

EL Image Validation

1. Number of Busbar Defects
   - Change in count did not correlate with the change in Rs
2. Pixel Changes
   - TC200 & TC500 tended to increase with the change in Rs





I hope that you remember the following

1. Hypothesis was correct – can predict Rs using the indoor test produces (one example)
2. Evidence that EL images coincide with Rs changes
3. Encourage future work that evaluates the relationship between performance and cumulative exposure to stressors

Questions

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