DuraMAT
Durable Module Materials Consortium

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New materials and designs for photovoltaic modules providing low-cost energy

Using electrical circuit tool pvspice for potential induced degradation simulations on a string level

Multi-Scale, Multi-Physics Model

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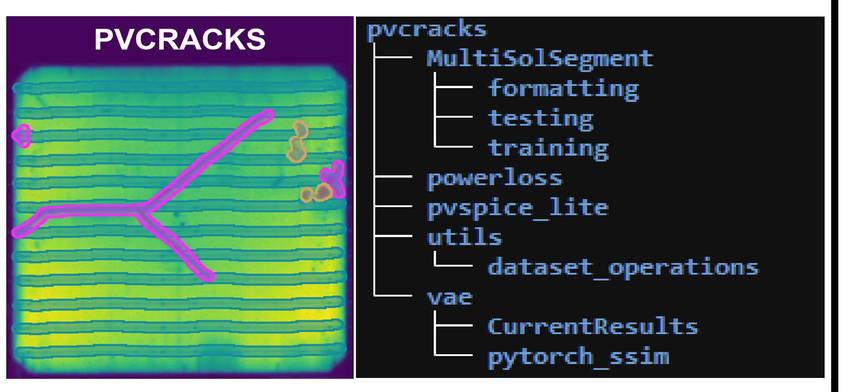
Contributing to DuraMAT Consortium Goals

This work will develop **modular, open-source model and analysis** components including crack detection workflow and parameterization for **quantitative inspection of large EL large datasets**. These tools will allow users to quickly and accurately assess the **extent and types of cracking** in their modules. In addition to, estimate the **power loss of cracks and other degradation modes**.

pvcracks: github.com/sandialabs/pvcracks

Project Overview

This repository [1] is for cell electroluminescence (EL) image segmentation, rapid EL image classification according to severity of the damage and a model to predict power loss from the cell image. Additionally, it includes an electrical simulation tool (pvspice) that uses single cell diode parameters to replicate a module current-voltage (IV) curve. These results can then be used for a whole string simulation. This is a new feature that is being presented here for potential induced degradation (PID) losses.

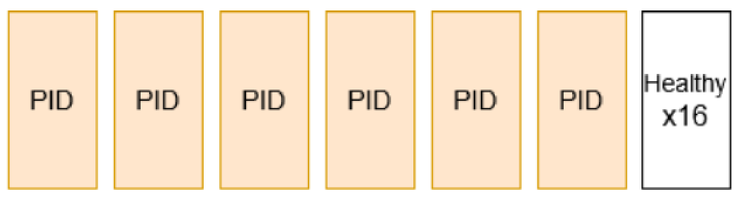


pvcracks logo and tree of the repository, pvspice is part of this repo with the full version being included soon

Experimental set-up from DTU

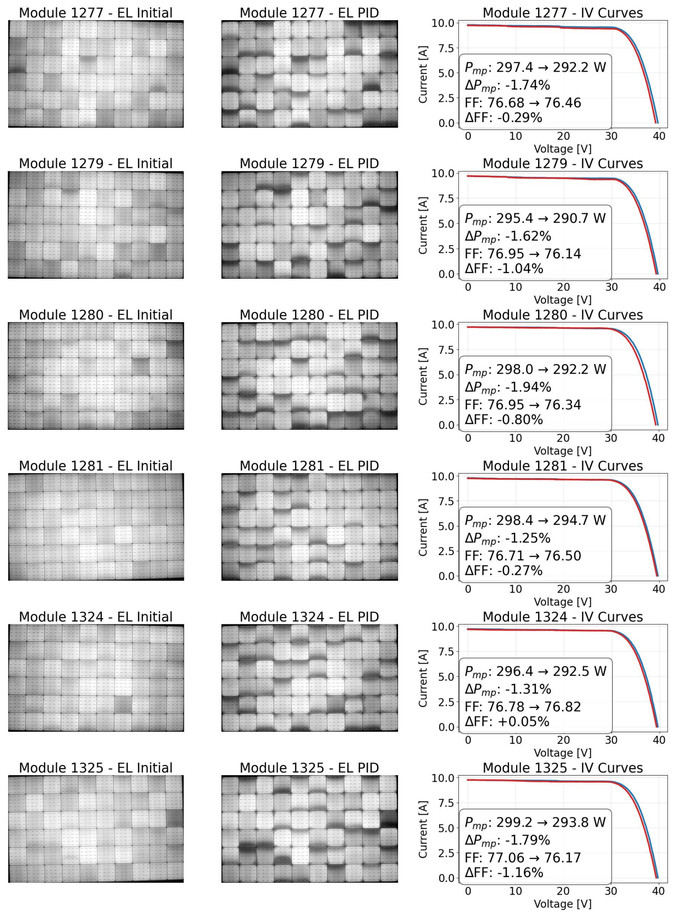
- In Risø, Denmark (lat 55.696, long 12.105) [2]
- 22 Trina TSM-305 60 cell modules
- Six modules with artificially accelerated PID by applying 1500V for 504 h
- Remaining 16 modules are pristine

String configuration:



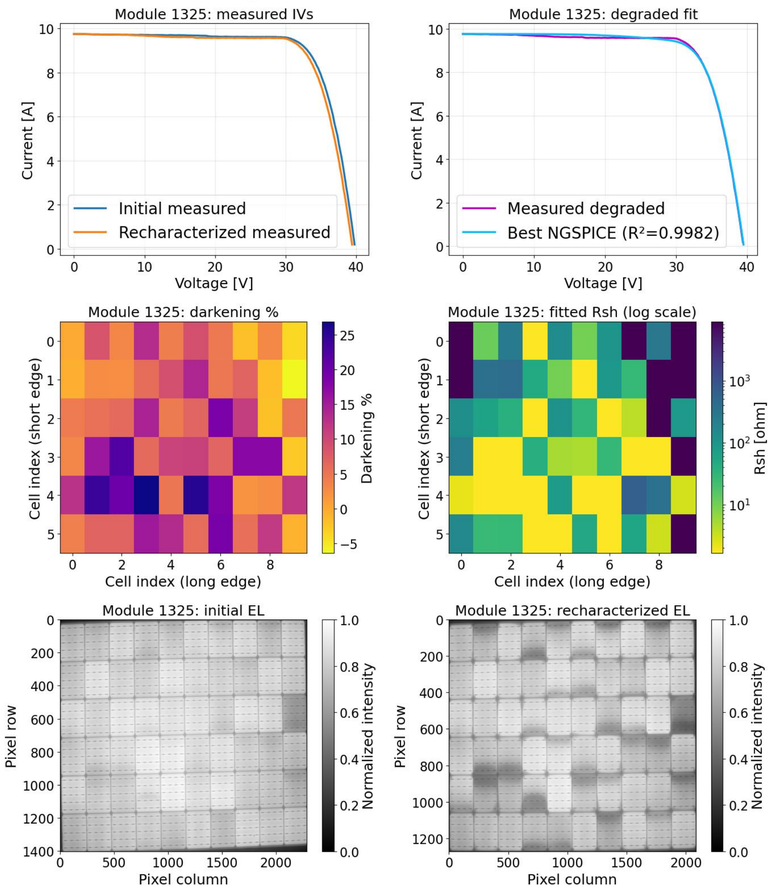
Outdoor IV curves taken with a Pordis 321 series IV tracer from April 2024.

Indoor lab data includes electroluminescence images, thermal images, and STC IV curves of the stressed modules before and after PID.



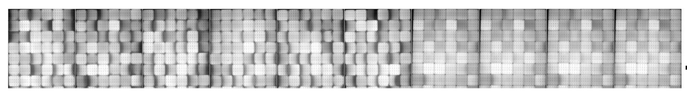
pvspice: single module

- We use pvimage to crop out cells [3].
- Segmentation tool in pvcracks does not feature darkness detection caused by PID yet.
- Custom code is used that compares the intensity of the cell ELs in a certain range and outputs darkening maps.
- pvspice is used to simulate the single modules
  1. Use pvlib to fit CEC parameters.
  2. Fit the initial STC IV curve with pvlib single diode then convert them to single cell. parameters by comparing to the pvspice fit
  3. From S. Pingel et al. [4] we know that the shunt resistance (Rsh) is affected by PID. We use the darkness maps to modify Rsh of these cells using and optimization code to replicate the degraded IV curve.
  4. The resulting parameters are collected for the string level simulations.

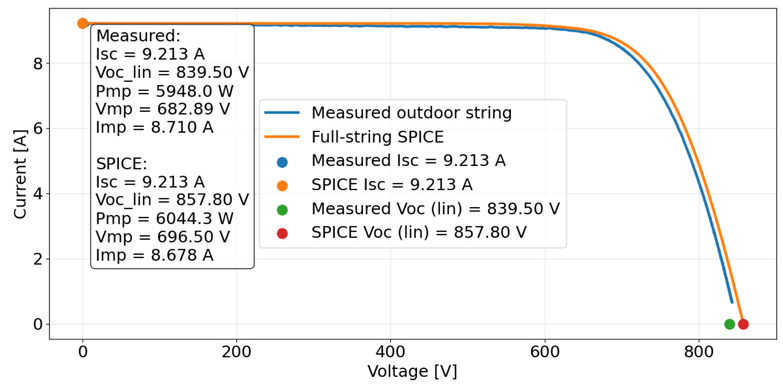


pvspice: string level

- The 22 module string would look like this in EL:

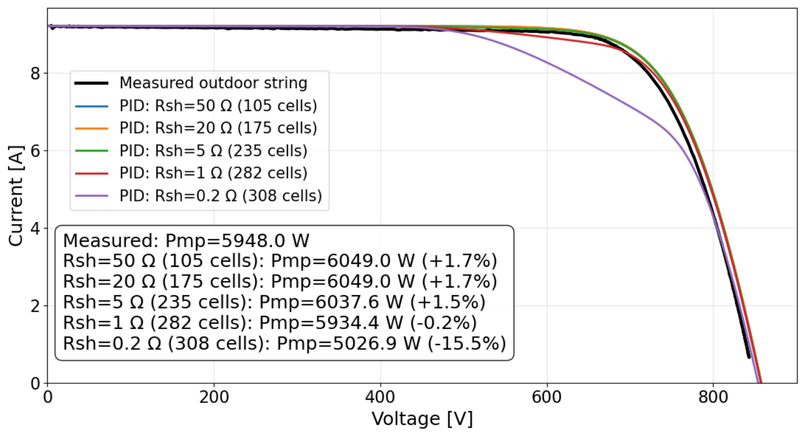


- We use the spice parameter maps fitted before.
- A function is added to pvspice to simulate whole module strings passing parameters for each cell.
- We simulate one specific timestamp of the outdoor data that was measured under 1017W/m2 and a cell temperature of 49ºC.
- Resistances had to be increased to account for interconnection.



Severe PID simulations

- Rsh increase simulating PID severity [3].
- Affected cells are the same as from the darkening map.
- PID spillage, neighboring cells are affected by severity [3].
- The total number of cells in the strings are 1320, simulation scenarios increase the number of affected cells and decrease Rsh of these
- We can see affects of up to 15.5% power loss for the string in DC.



- Future work:
  1. Better PID spillage simulations.
  2. Inverter model for lower clipping.

References

[1] N. Jost, et al. (Mar. 12, 2024). Python. Sandia National Lab. (SNL-NM), doi: 10.11578/dc.20240606.4
[2] M. Bartholomäus (2025) 10.4229/EUPVSEC2024/4BV.3.18
[3] B. Pierce et al. (2020) 10.1109/JPHOTOV.2020.2973448
[4] S. Pingel et al. (2010) 10.1109/PVSC.2010.5616823