Characterizing Cell Level Behaviour: Integrating Thermal, Electrical and Optical Models under Different Operating Conditions and Breakdown Voltages

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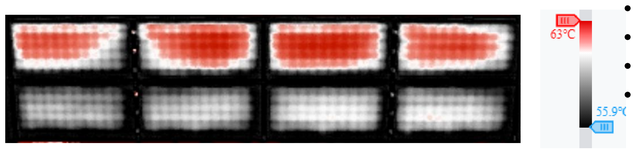
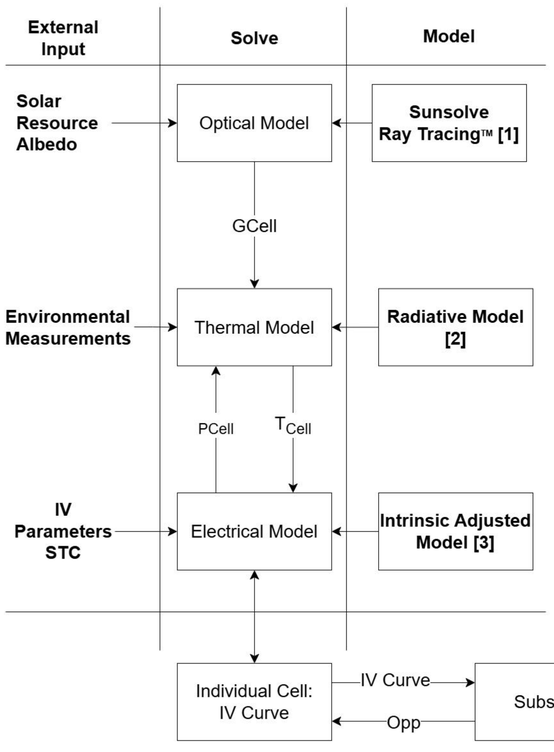
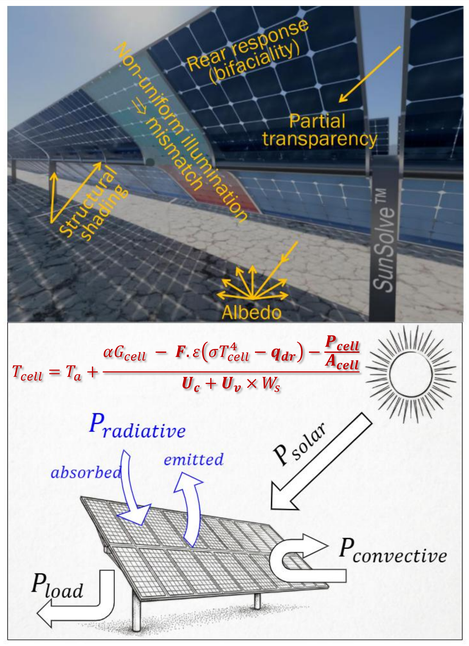
Study Background and Impact



- The impacts of inhomogeneous irradiance and temperature conditions in PV systems can range from localized accelerated degradation and mismatch losses to hotspots.
- Current Yield Assessment and Digital Twin tools often consider homogeneous irradiance and temperature distribution across the whole module.
- Breakdown Voltage is a key component to understand hotspot formation and mismatch consequences.
- This work proposes a framework to simulate full PV systems by modelling individual cells to then scale them to the system level, highlighting the linked relationship between thermal and electrical models and their impact on I-V curves while preserving mismatch awareness.

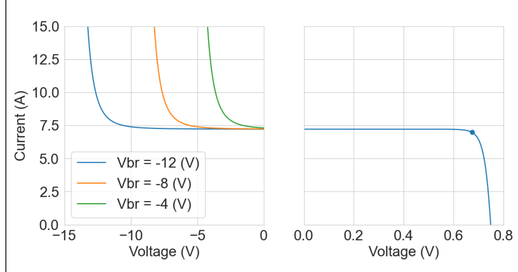
Methodology

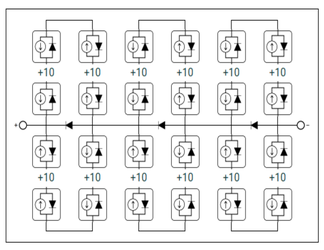


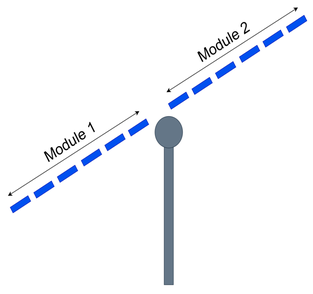


Experimental Setup

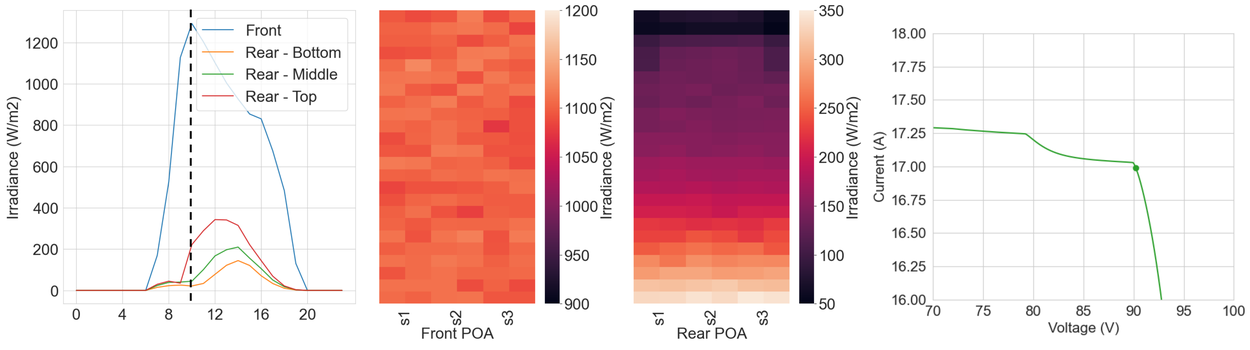
Cell and Module Configuration







Baseline System Performance

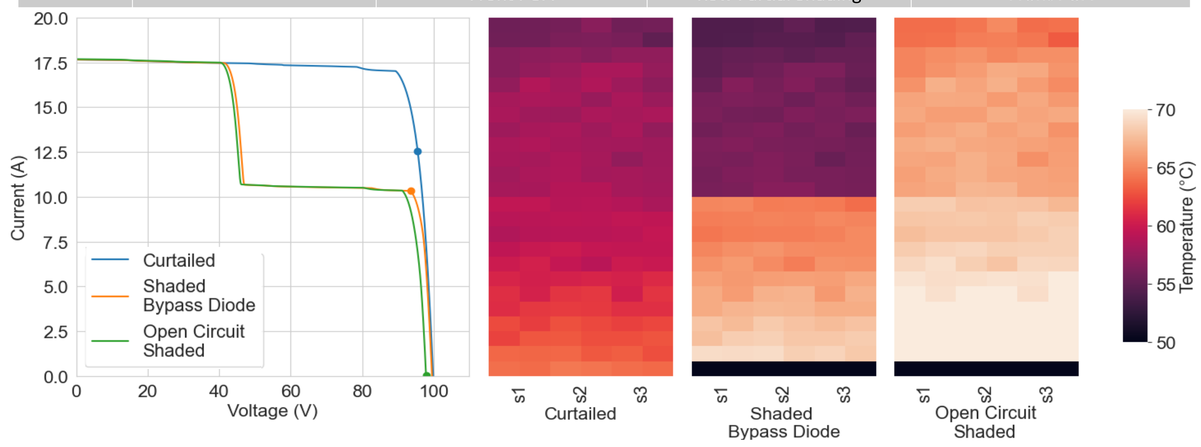


- Electrical Output of – Strings of 2 Modules

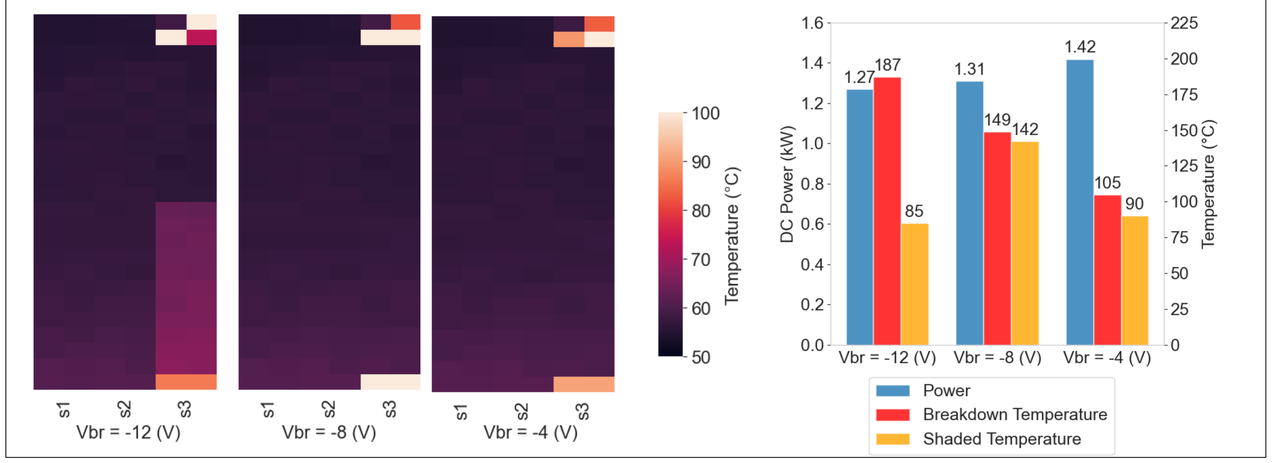
Results

Different Operating Conditions

	Curtailment		Partial Shading on Module 2 Bypass Diode		Partial Shading on Module 2 Open Circuit		Partial Shading on Module 2 Reverse Bias (V_{BR} = -8 V)	
	P_{cell} Correction	Change from Homogeneous	P_{cell} Correction	Change from Homogeneous	P_{cell} Correction	Change from Homogeneous	P_{cell} Correction	Change from Homogeneous
T_{max} (°C)	64.22	+8.39	69.1	+13.2	72.5	+16.7	145	+106
T_{avg} (°C)	59.36	+3.53	59.6	+3.78	66.3	+10.5	59.6	+5.81
V_{opp} (V)	95.52	-0.98	93.5	-0.76	97.9	-2.9	77.1	+0.53
I_{opp} (A)	12.56	+0.13	10.33	-0.01	0	0	17.0	-0.02
P_{opp} (W)	1199.73	0	966	-8.78	0	0	1315	-7.38
Notes	30% Curtailment		Bottom Row Shaded to 30% of Front POA		100% Curtailment and Bottom Row Partial Shading		Bottom Cells Shaded to 30% of Front POA	



Breakdown Voltage – Module 2 Shading Analysis



Conclusion

- Under normal conditions, temperature differences between module cells can reach up to 5 °C
- By considering real operation under curtailment, corrected temperature increases by 8 °C
- Partial shading scenarios can increase temperature up to 14 °C if the bypass diode protection activates; and hotspots of up to 150°C are simulated under reverse bias operations
- Mismatch in cell conditions in Open Circuit operation can lead to self-consumption scenarios
- Lower Breakdown Voltages in solar cells significantly affect hotspot formation under partial shading
- Understanding temperature distribution across the module is key to assessing cell-level degradation and technology lifetime performance

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Acknowledgements

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