Utrecht University

EU PVSEC 2023

Shading Tolerant PV Modules Measurements and Simulation

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40th European Photovoltaic Solar Energy

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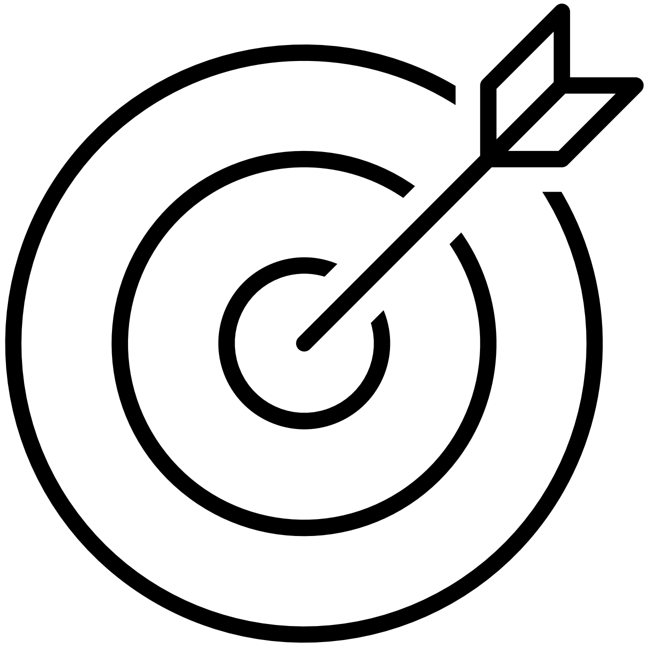
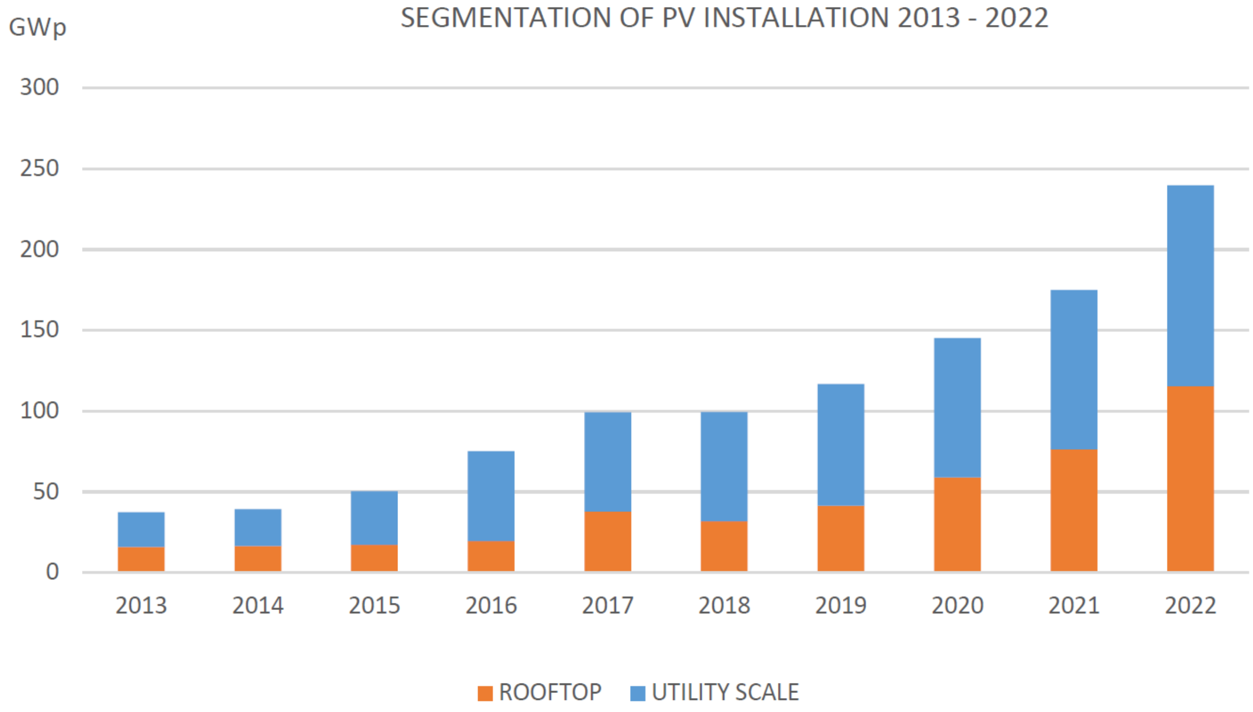
Related research and publications

- M. Littwin, F. Baumgartner, M. Green, W. van Sark, Performance of New Photovoltaic System Designs, IEA-PVPS, Report number IEA-PVPS T13-15: 2021, April 2021, ISBN: 978-3-907281-04-8.
- S. M. Golroodbari, A. de Waal, and W. van Sark, “Improvement of Shade Resilience in Photovoltaic Modules Using Buck Converters in a Smart Module Architecture,” Energies, vol. 11, no. 1, p. 250, Jan. 2018.
- S. Mirbagheri Golroodbari, A.C. de Waal, W.G.J.H.M. van Sark, "Proof of concept for a novel and smart shade resilient photovoltaic module," IET-Renewable Power Generation, vol. 13, pp. 2184-2194, 2019.
- Mark Sprenger, Field testing of smart shade resilient photovoltaic module under partial shading and fouling conditions, Natural science research Project, 2022.
- Boyd Beerling, Hotspot testing of a shade resilient smart photovoltaic panel, M.Sc. Thesis Energy Science, 2022.
- Marnix Remming, Niels van der Zijden, Silas Witmond, Teun Drijfhout, Smart Module Design, B.Sc. Project HU, 2022.



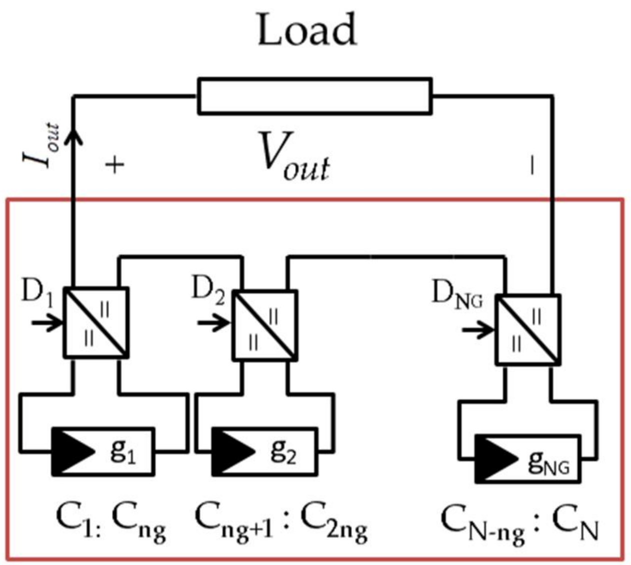
Introduction

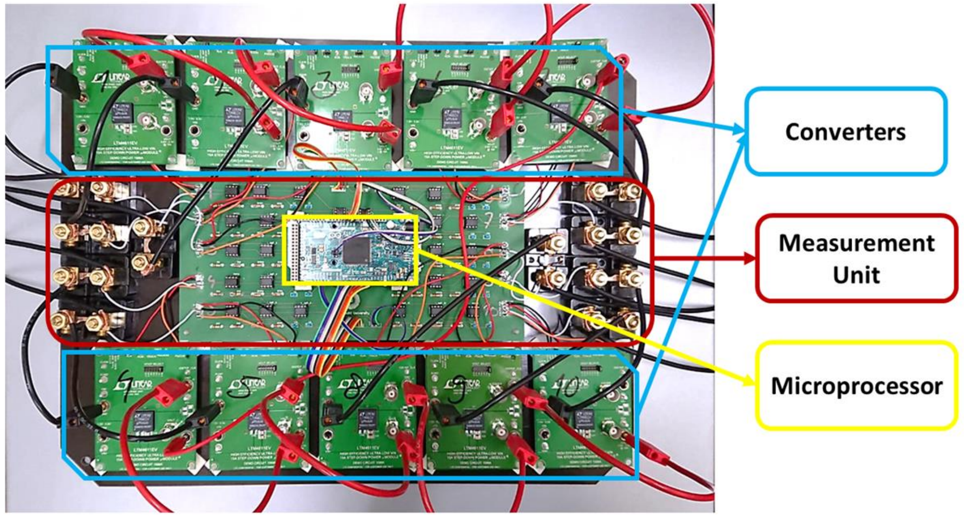
- PV systems are increasingly used for power generation in residential and large-scale setups.
- Energy harvesting from PV modules is achieved by connecting them to inverters with maximum power point tracking (MPPT) algorithms.
- Partial shading (PS) conditions can lead to module mismatches, particularly in urban PV installations due to obstacles in buildings.
- PS has a significant non-linear impact on PV system outputs, especially in building-integrated PV, like façade-based systems.



Method

- Bypass diodes (BPDs) are used to mitigate partial shading effects, but increasing the number of BPDs complicates MPPT algorithms and leads to efficiency losses.
- Active BPDs, can replace conventional BPDs.
- In the smart module architecture, a buck converter is paired with each group of cells to control shaded groups' current by reducing the output voltage of the converter, ensuring equal current flow in all converters for efficient shading performance.



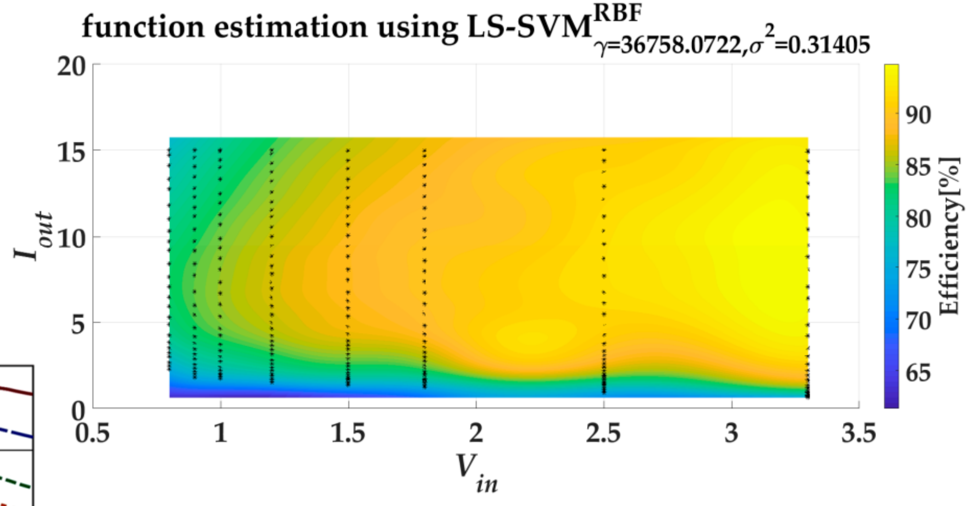


Method

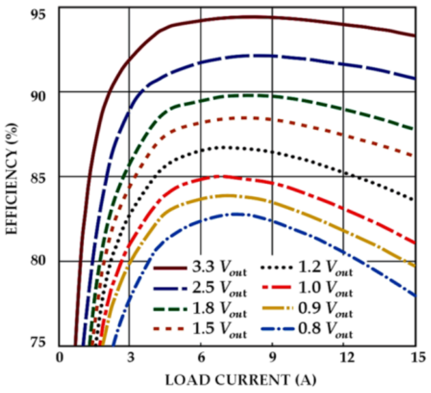
- LTM4611 from Linear Technology Corporation chosen because:
  - Voltage and current specifications matching the small groups of cells,
  - Higher switching frequency for improved MPPT algorithm performance,
  - No need for extra elements besides the chip itself.

- To maximize efficiency, LS-SVM technique is used for the generalization of data.

$$X_j = [V_{in}(j), V_{out}(j), I_{out}(j)]^T \xrightarrow{\hat{f}} Y_j = \eta(j)$$



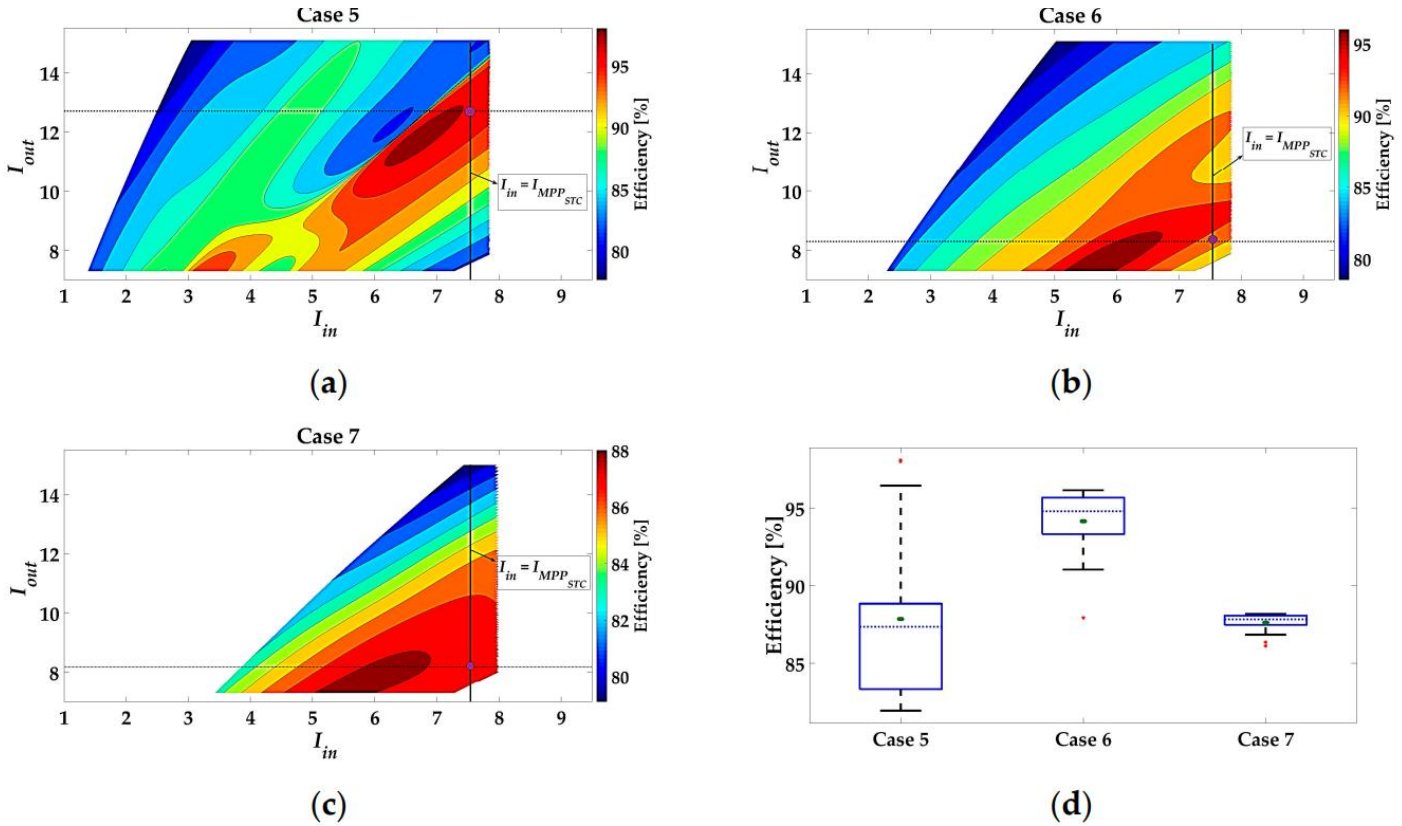
Efficiency for all values of V_{in} and I_{out} at V_{out} = 5 V.



Efficiency vs Load Current at V_{in} = 5 V.

Method

- Irradiance variation mainly affects the output current at the MPP in a linear fashion, while the voltage at MPP is only slightly affected.
- For simplification, it is assumed that the input voltage for the buck converter remains constant.



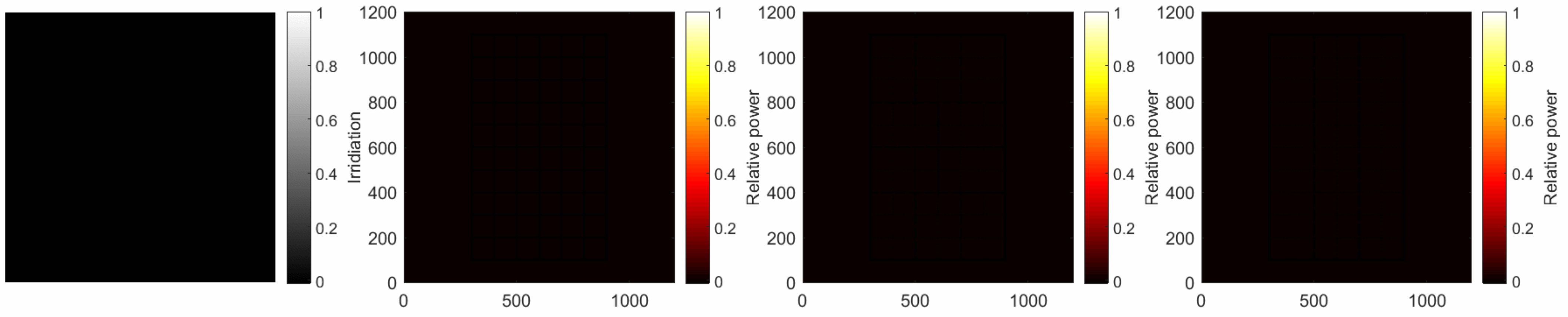
Case Number	1	2	3	4	5	6	7	8	9	10
# Cells (n_g)	60	30	20	15	10	6	4	3	2	1
# Groups (N_G)	1	2	3	4	6	10	15	20	30	60
Vmpp (mV) *	29,412	14,706	9804	7356	4902	2941.2	1961.6	1471.2	980.8	490.4
Feasibility	No	No	No	No	Yes	Yes	Yes	No	No	No

* STC is considered as the highest reference.

Method

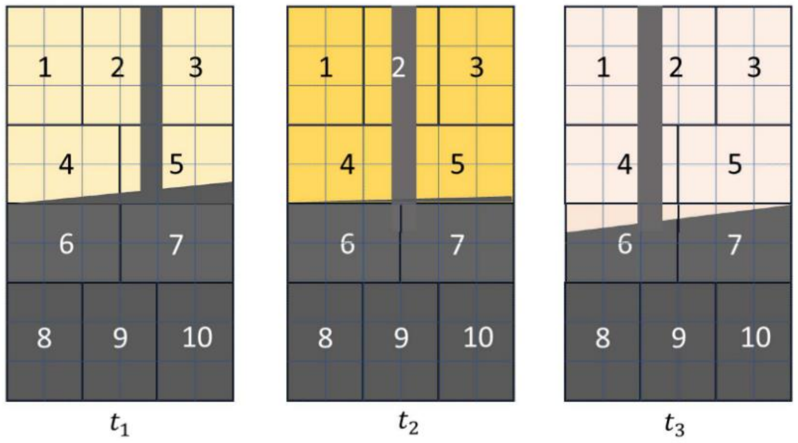
The study focuses on two types of shading, random and pole shading.

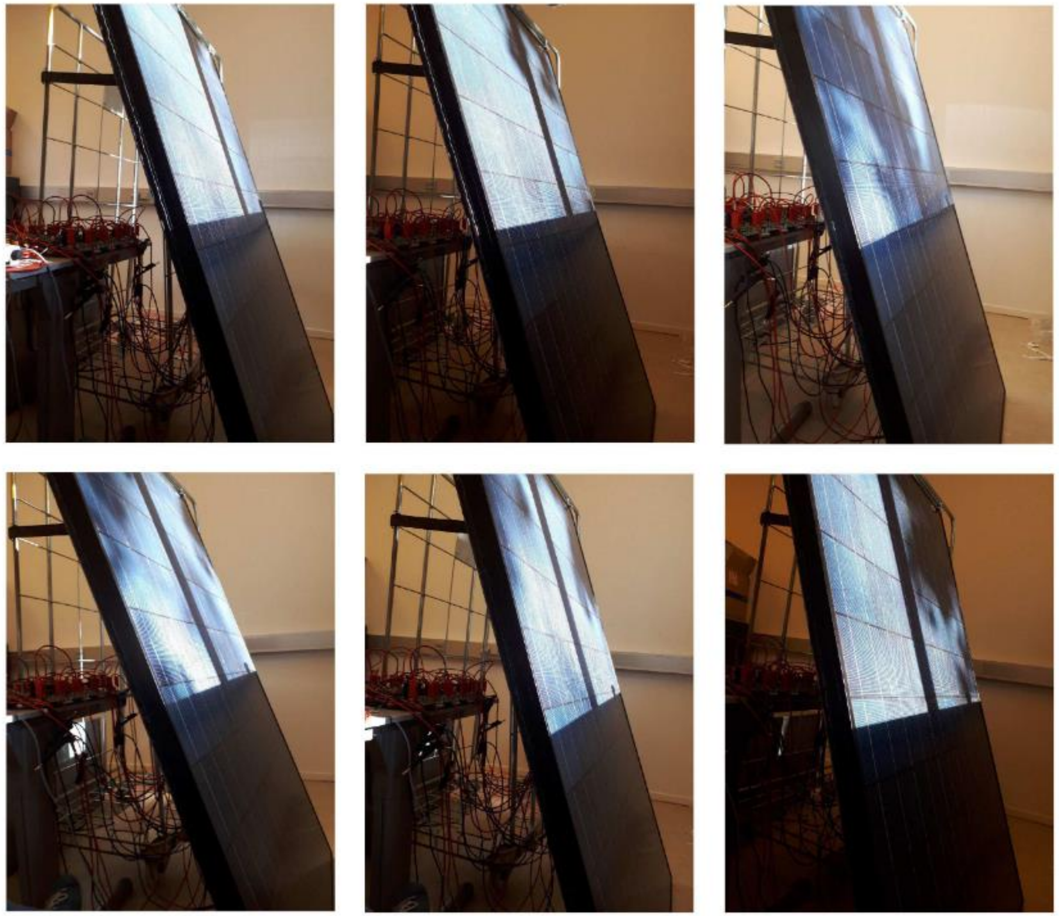
- Random shadow
- Pole shading



Concept Image Ideal Module Smart Module Conventional Module

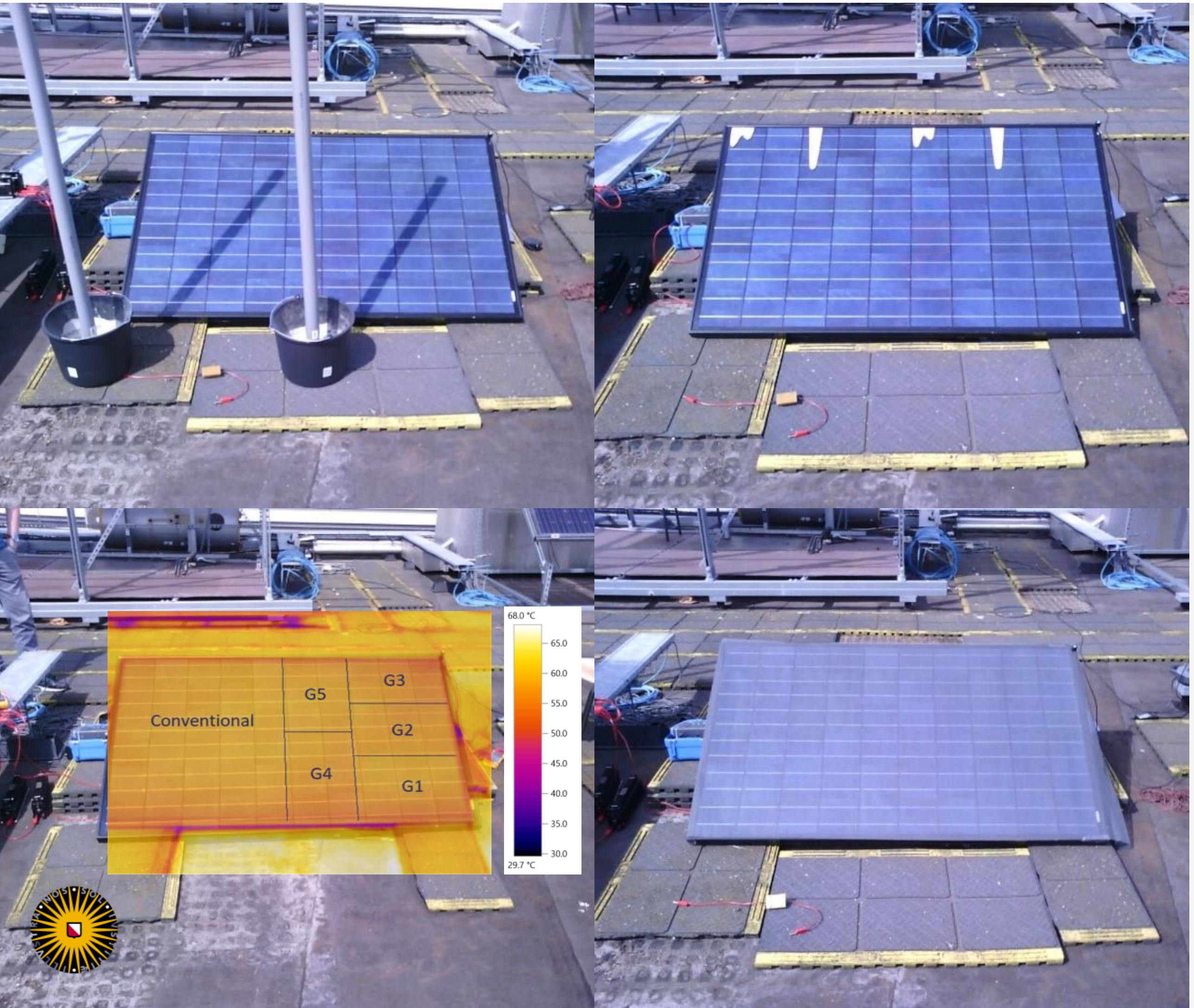
Prototyping





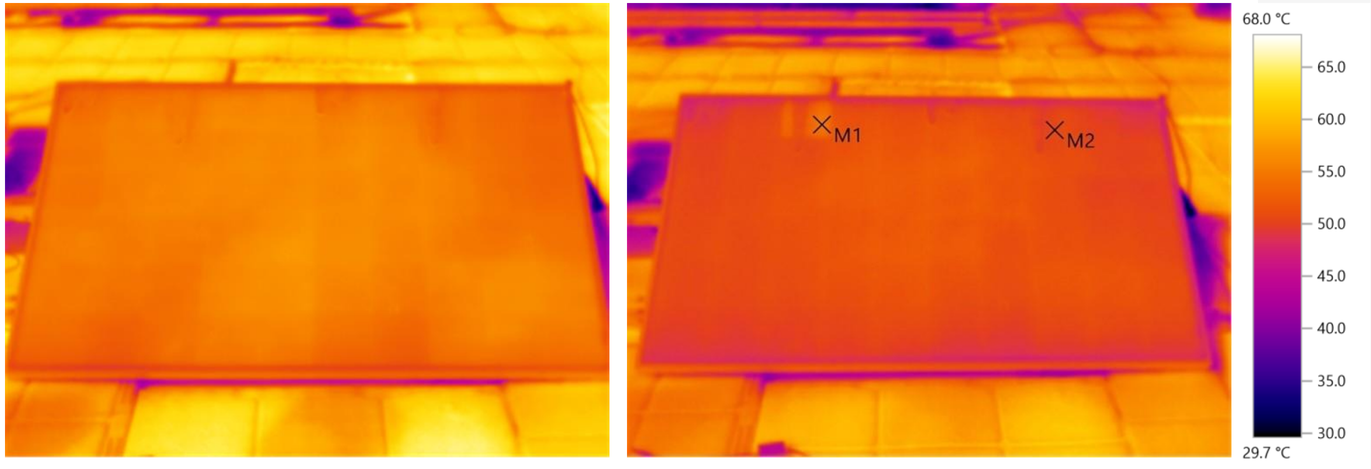
- The smart panel effectively responded to rapid changes in shading patterns, response time of < 0.2 seconds.
- The smart module can extract approximately 5.1 times more power compared to a conventional module equipped with three Bypass Diodes under the tested conditions.

Outdoor testing

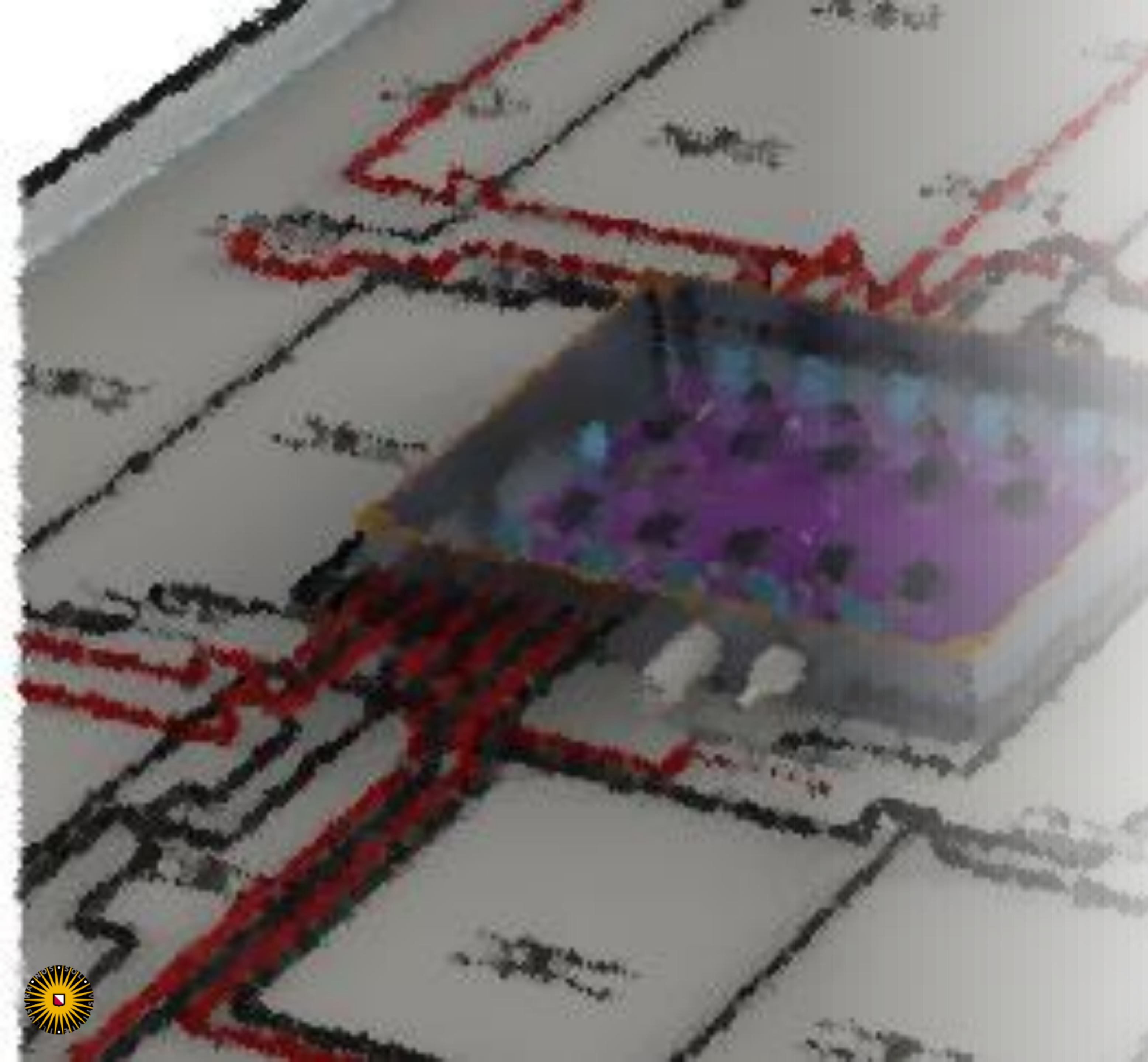


- The module is divided into two sections: a smart and a conventional section.
- The following shading patterns are tested in this research:
  - Pole shadow
  - Heterogeneous non-transparent pattern: representing the effects of bird droppings
  - Homogeneous semi-transparent pattern: to simulate the effects of homogeneous fouling like dust and pollen.

Outdoor testing



- During the bird dropping test, measurement point M1 has a temperature of 53.1°C, while M2 has a temperature of 49.0°C.
- This results in a temperature difference of 4.1°C between the hotspot and the corresponding location on the smart half.



New Design

- SMD elements is proposed.
- Current sensing options are Hall effect sensors with good EMI filtering.
- Voltage sensing can be achieved using analog-to-digital converters .
- Effective PCB design can minimize emissions by strategically placing copper layers in a smart stack-up.
- Heat dissipation strategies involve using a heat sink and an insulating layer to prevent heat flow to the back sheet.

Acknowledgments:

- This work is partly financially supported by the Netherlands Enterprise Agency (RVO) within the framework of the Dutch Top sector Energy (project Scalable Shade Tolerant Modules, SSTM).
- supported with a subsidy from the Dutch Ministry of Economic Affairs, National EZ subsidies, Topsector Energie, performed by the Rijksdienst voor Ondernemend Nederland (RVO), based on Customized Smart Mismatch-Tolerant Module (CSMTM) project.

Sharing science,
shaping tomorrow

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