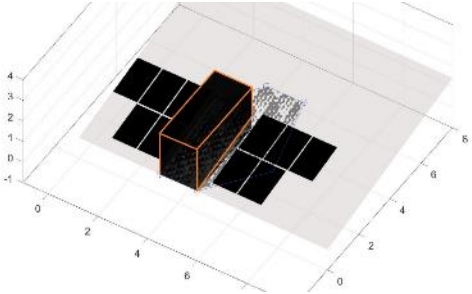


IEA PVPS

Performance Assessment of MLPE Equipped PV modules and Performance rating of shaded PV systems

Daniel Riley, Sandia National Laboratories, USA
Cyril Allenspach, ZHAW SOE IEFE, Switzerland

Intersolar 2021, Munich, 6th October 2021

Characterizing and Modeling AC PV Modules

Daniel Riley, Sandia National Laboratories, USA

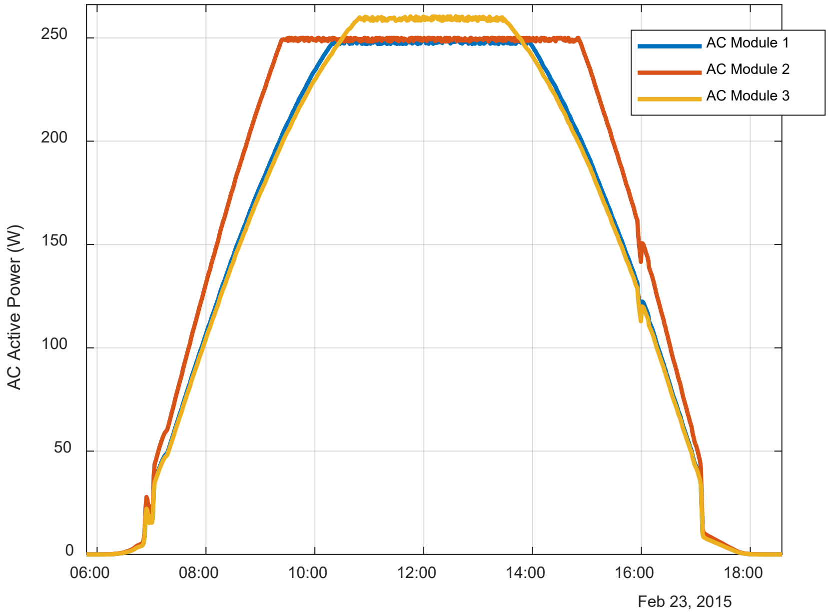
Intersolar 2021

AC Module Definition

- An AC photovoltaic module is created when a PV module and a microinverter are fully integrated
  - AC power is generated when exposed to sunlight
  - No access to the DC circuit
- Simplicity of an AC module is good, but requires new methods to describe and characterize performance.

The Question for AC Modules

- How do we compare and describe the performance of AC modules?
- These three modules have similarities in their performance characteristics, but would produce different amounts of energy.



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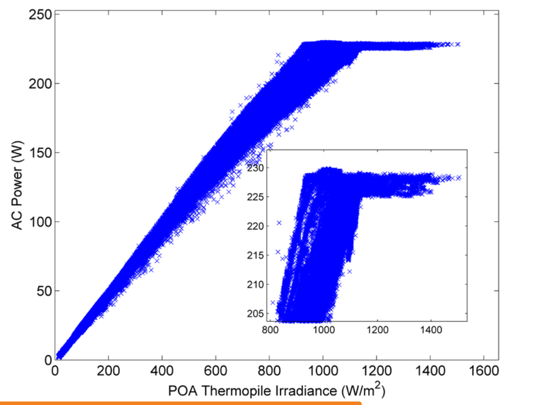
Sandia National Laboratories historical work

- Developed characterization tests for AC modules
- Developed a performance model
  - Combines a PV module performance model with an inverter performance model without requiring testing of either component individually
- Funded by the United States Department of Energy, Solar Energy Technologies Office

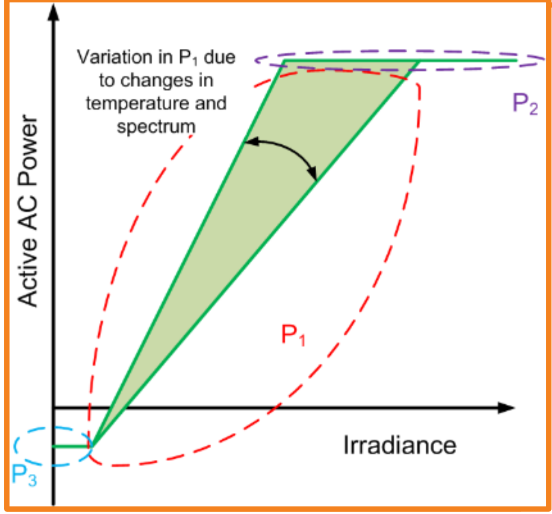
Basic AC Module Model Description

- Active AC power is controlled by the microinverter and has three principle operating states
  - P_3 – Low irradiance self-consumption
  - P_2 – Maximum power self-limiting
  - P_1 – Typical operating state



- The performance model is a piecewise function with three subdomains

$$P_{AC} = \begin{cases} P_1 & P_3 \le P_1 \le P_2 \\ P_2 & P_1 > P_2 \\ P_3 & P_1 < P_3 \end{cases}$$



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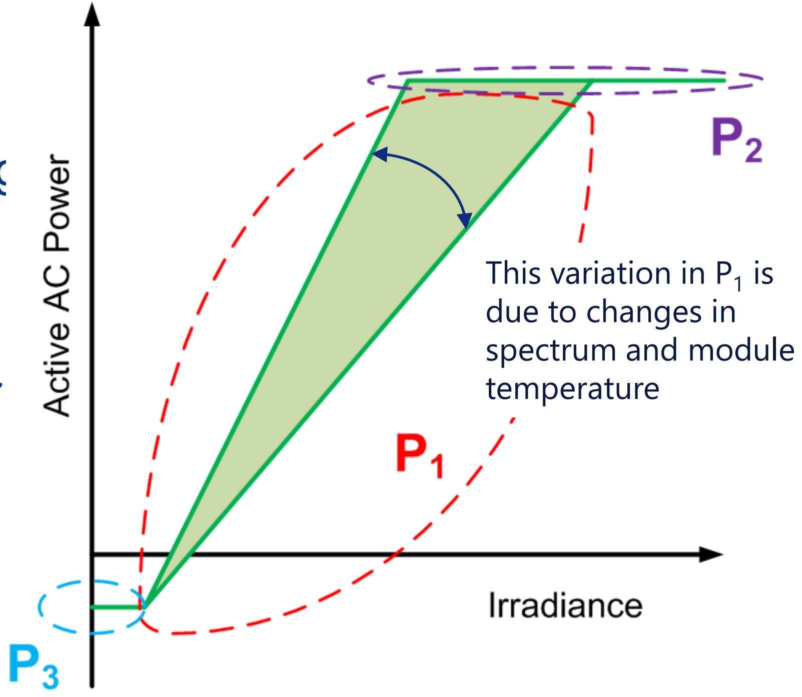
Equation Subdomains

- P_3 is the operating mode when there is too little irradiance for the AC module to begin inverting, and the module may be consuming a little power.
- P_2 is the operating mode when the PV module is producing too much DC power for the inverter.
- P_1 is the typical operating mode of an AC module, where the AC power changes as a function of irradiance, spectrum, and temperature.



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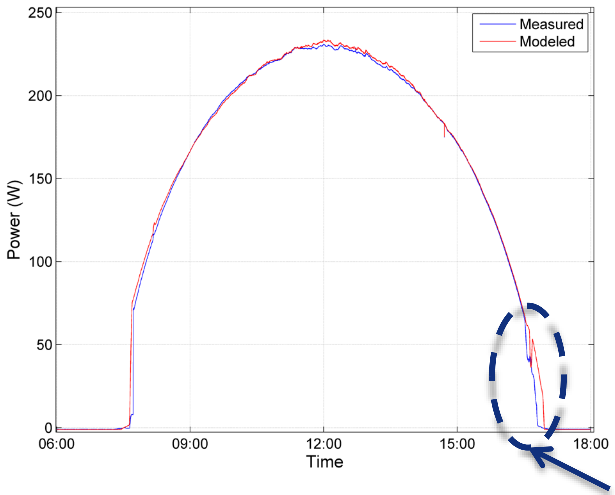
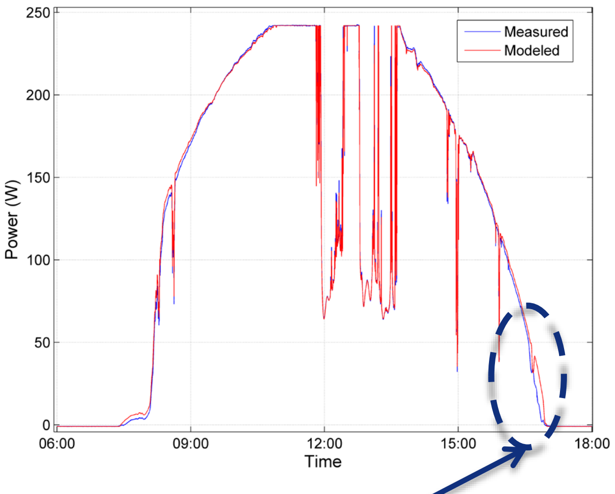
Validating the AC Module Model

- For the AC Modules Sandia characterized, the model estimated AC power to within 2% of the reference power for the AC module.

- A warm, calm, sunny day



- A cool, partly-cloudy day
- Good transition to power limiting



Shading of the module but not the irradiance sensor. Data omitted from subsequent analyses.

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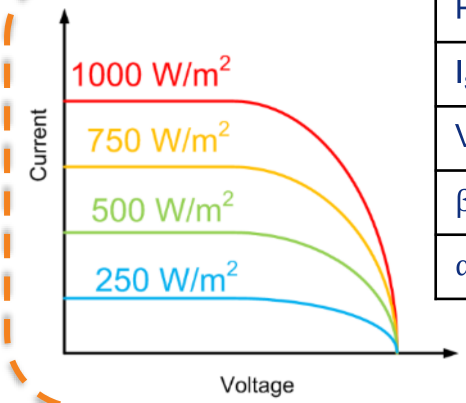
Conclusion

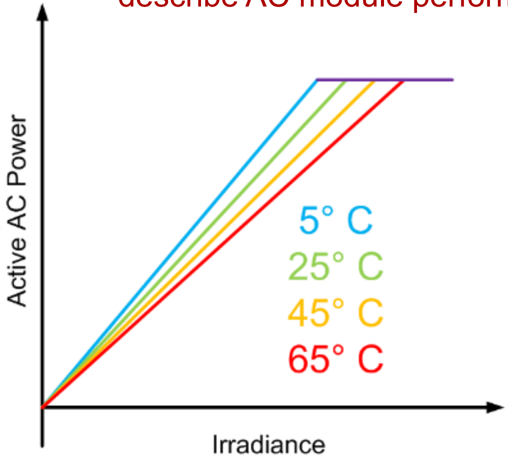
- When PV modules and inverters are fully coupled, new test and characterization methods are required to describe the performance of these AC modules.
- Sandia's work with AC modules allows for empirical testing, performance description, and performance modeling.

These common descriptions aren't useful for AC modules



P_{max}	250 W_{DC}
I_{SC}	9 A_{DC}
V_{OC}	36 V_{DC}
β_{Voc}	-0.45 %/°C
α_{Isc}	0.05 %/°C

We need new ways to best describe AC module performance



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More information

- A complete white paper (SAND2015-0179) with test processes, analysis techniques, more discussion, and model validation is available at

  http://1.usa.gov/1B3sxum

  - Or just search for SAND2015-0179 in your favorite search engine

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PV Output Estimation with Partial Shading

- Shading by obstacles in Switzerland
- Estimation by simulation with 3D PV-modell

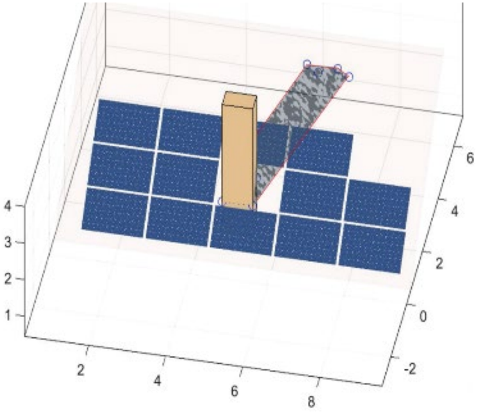
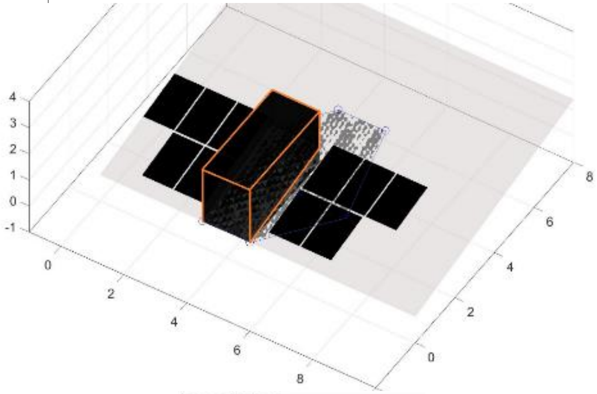


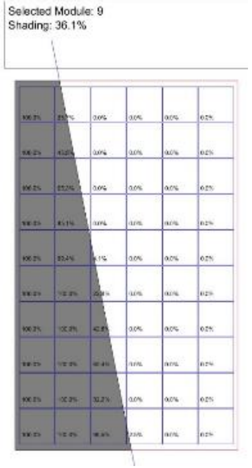
Figure 2 – ZHAW SOE ShadingTool

Figure 1 – SFH 13kWp by PV installer,
«Alsona AG» - Webpage: https://www.alsona.ch/

Figure 3a-3c – Various rooftops in Zurich City, by Juliet Haller (AfS),
Office for Urban Development – City of Zurich, «Leitfaden Dachlandschaften»

Shading simulation overview





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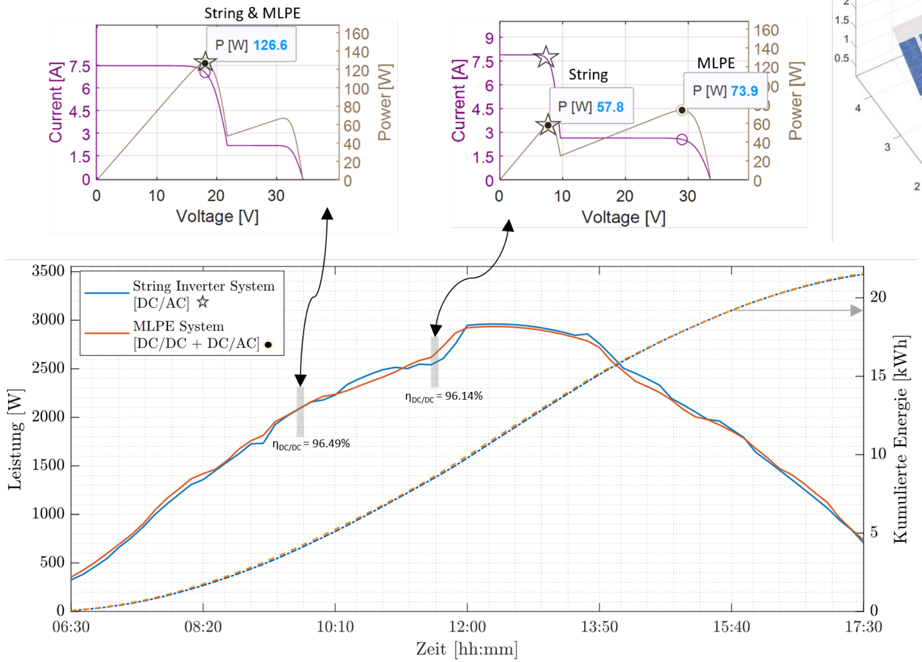
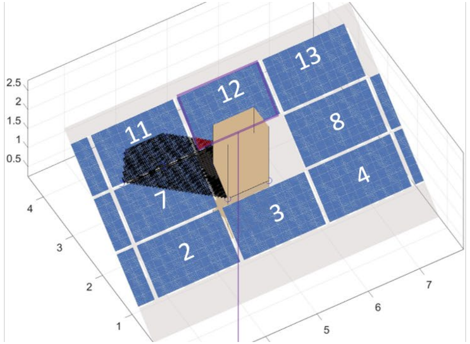
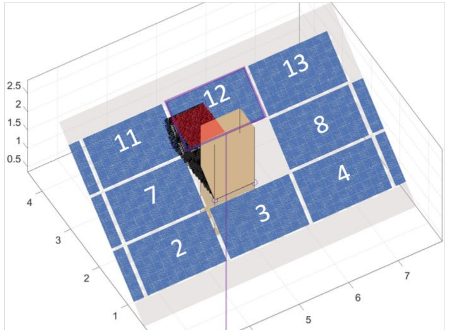
Performance of two different setups

- Simulation of a plant with string inverter setup (SINV) and same installation with Power Optimizers (MLPE)







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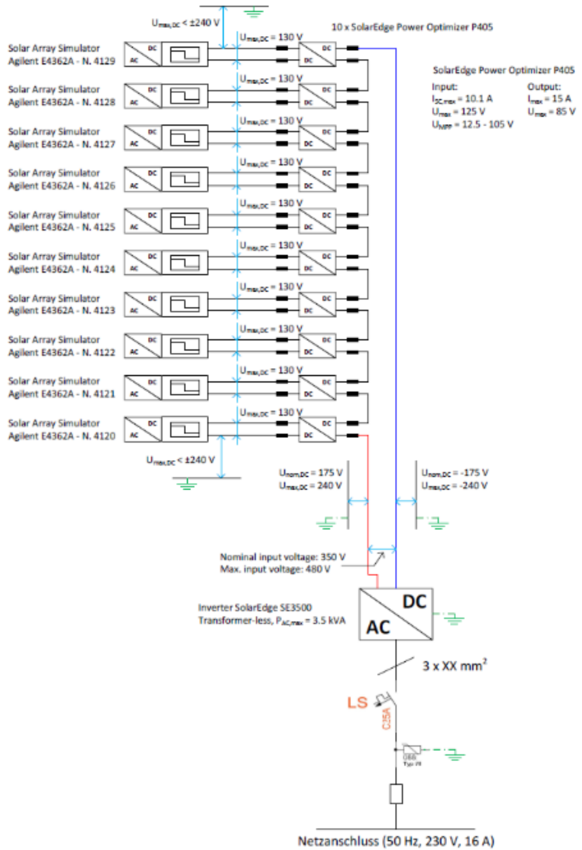
Measurement in ZHAW indoor Laboratory



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Efficiency values of MLPE in data sheet

P320 / P340 / P370 / P400 / P401 / P405 / P485 / P505 www.solaredge.com

Optimizer model (typical module compatibility)	P320 (for 60-cell modules)	P340 (for high-power 60-cell modules)	P370 (for higher-power 60 and 72-cell modules)	P400 (for 72 & 96-cell modules)	P401 (for high power 60 and 72 cell modules)	P405 (for high-voltage modules)	P485 (for high-voltage modules)	P505 (for higher current modules)	
INPUT									
Rated Input DC Power[1]	320	340	370	400		405	485	505	W
Absolute Maximum Input Voltage (Voc at lowest temperature)	48		60	80	60	125[2]		83[2]	Vdc
MPPT Operating Range	8 -			8 - 80	8-60	12.5 - 105		12.5 - 83	Vdc
Maximum Short Circuit Current (Isc)				10.1	11.75	11		14	Adc
Maximum Efficiency	99.5								%
Weighted Efficiency	98.8							98.6	%

max eff 99.5%

weight. eff 98.8%

Table 1 Overview of Power Optimizers and Micro Inverter products: Overview of performance related information provided by the manufacturers in the datasheets (non exhaustive list).

Product Category*	Manufacturer and Model	Performance figures according to datasheet		Datasheet information acc. to EN 50524
		Conversion efficiency	MPPT efficiency	
Products available on the market today				
DC.UP.S	Solar Edge PB250-AOB [9]	Maximum 98.6 % European/CEC 97.8/97.7%	No information	No
DC.DN.S	TIGO Energy MM-ES [10]	No information	No information	No
DC.UP.S	ST Microelectronics SPV1020 [11]	"Up to 98% efficiency"	No information	N/A (only chipset, no final product)

R. Bründlinger, N. Henze, et. al.; Module Integrated Power Converters, 25th EUPVSEC Valencia, 2011

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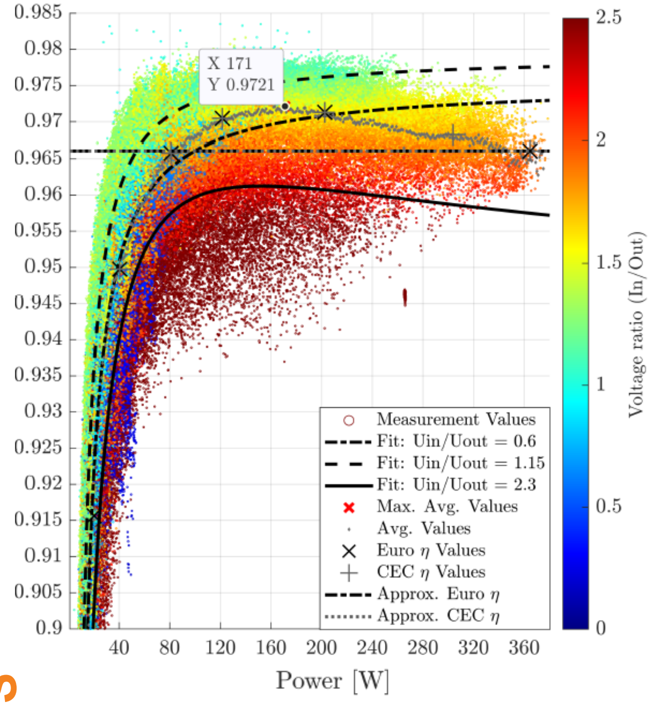
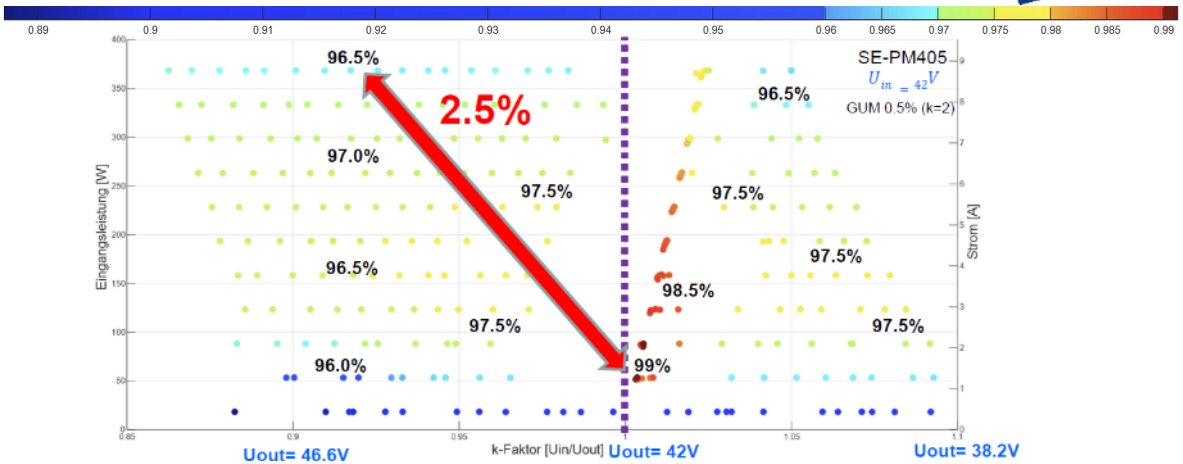
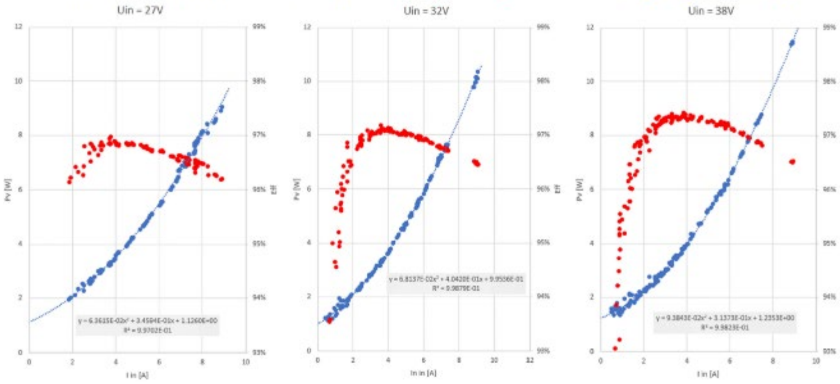
Performance 1: Static efficiency





Static efficiency , losses $P_l = c_0 + c_1 \cdot I + c_2 \cdot I^2$ with c_i polynom in U_{in}



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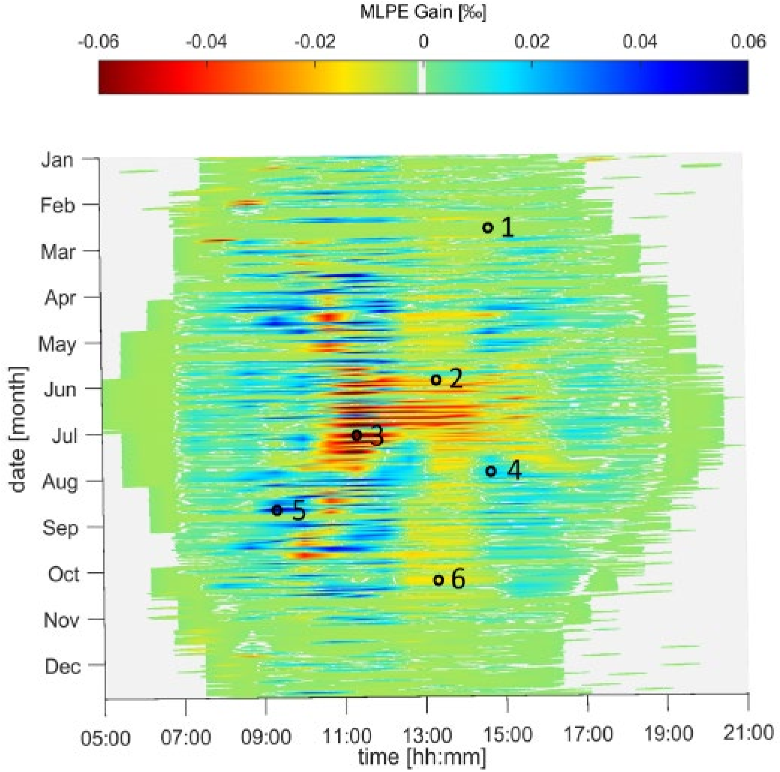
Performance 2: Shading adoption Efficiency

- Shading adoption efficiency based on yearly performance, representative operating points and coefficients

$$\eta_{shad,a} = \frac{P_{ac}}{\sum_{i=0}^{k} P_{mod,i}}$$	(2)
$$\eta_{shad,a} = \sum_{n=1}^{N} a_{shad,a,n} \cdot \eta_{shad,a,n}$$	(3)

Shading Adaption Eff. Coefficients $a_{shad,a,n}$



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Results and Outlook

Results:

- Indoor lab measurements showed MLPE efficiency values 2% lower at nominal power than data sheet max efficiency
- Max. efficiency stated in data sheet was reached at $U_{in}=U_{out}$
- A concept for comparing the efficiency of different MLPE systems and conv. string inverter systems (SINV) is presented by the annual shading adaption efficiency
- 1.2% gain in annual efficiency was calculated using MLPE I component (P405) relative to String Inverter, SINV II (Fronius Symo), with an EURO EFF of 97.5%

Shading cases of PV Systems	Shading objects a	I MLPE	II SINV
Single roof tilted - chimney	1	96.6%	95.8%
Single roof tilted - dormer	2	x	x
Single roof tilted - tree	3	x	x
Flat roof - ventilation pipe	4	x	x

Outlook:

- Economics:
  A gain of 1% in annual output allows for 10% higher prices of the respective power electronic components
  (Today: MLPE total power of 20 GW – 1% would equal 200 Mio. US$)
- Best practice system design:
  $U_{in}=U_{out}$ should be reached for no shading conditions
- Costs of individual fine planning at the installer level are too high:
  Need of 3D geometry capture of shading obstacles, lack of software solutions with MLPE loss calculation and manpower
- Objective:
  Manufactures datasheet include shading adaption efficiency for typical shading cases, (see Euro. Inverter efficiency)
- Standard must be developed to measure MLPE and SINV for the shading adaption efficiency (IEC TC82 is interested), collaboration within Task 13 will be started

Sources & more information

- Work was initiated by Franz Baumgartner and realised with the support of Fabian Carigiet, Roman Vogt, Samuel Richter, Victor Gonzalez de Echavarri Castro and Christoph Meier.

Main sources:

- F. Baumgartner, C. Allenspach, et al.; Performance Analysis of shaded PV Module Power Electronic Systems (2021), IEA Task 13 (ST 1.3), Online: Video-MLPE-Presentation-21 (English), EUPVSEC 2021.
- F. Baumgartner, Optimizer: Nur ein Hype oder die Zukunft (German), Electrosuisse Bulletin, May 2021.
- C. Allenspach, F. Baumgartner, et al.; Module-Level Power Electronics under Indoor Performance Tests (2020), IEA Task 13 (ST 1.3), Online: , EUPVSEC 2020.

Addititional information:

- Links to papers, presentations and videos of our work: www.zhaw.ch/=bauf
- Video-Channel for presentations by Franz Baumgartner: www.youtube.com/channel/bauf

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