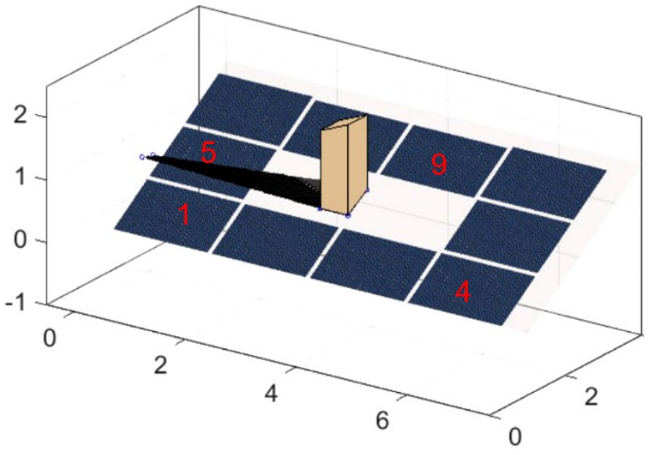
Zürcher Hochschule
für Angewandte Wissenschaften

School of Engineering
IEFE Institut für Energiesysteme und Fluid-Engineering

IEA PVPS



Wann sind Optimzer effektiv?

Franz Baumgartner, ZHAW Winterthur, Switzerland

See EU PVSolar Energy Conf. talk 2022, 2023 & 2024

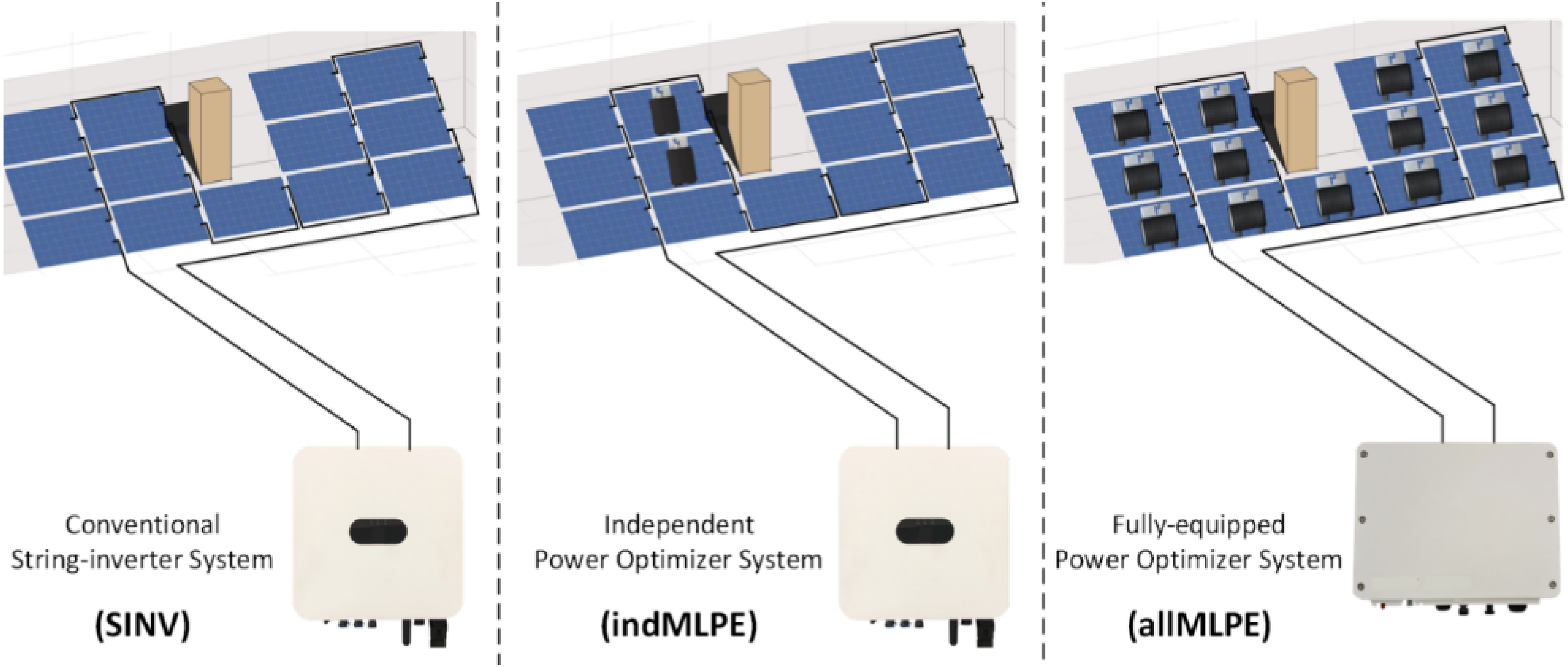
Quantifying Losses due to Shading

- About **200 million power optimizer (MLPE)** are mounted worldwide behind each PV module to increase performance
- **Do** these **high-tech components** on the roof **really always lead to more yield**?
- Do the **independent studies** back up the double-digit yield increases promised by power optimiser manufacturers?

"**Up to 30% more energy**!"
Marketing at Intersolar Munich 2021,

PVPS

PV Module Wiring – 3 Types of DC/AC Systems



PVPS

IV curve at typical shading situation half cut cell cr- Si module

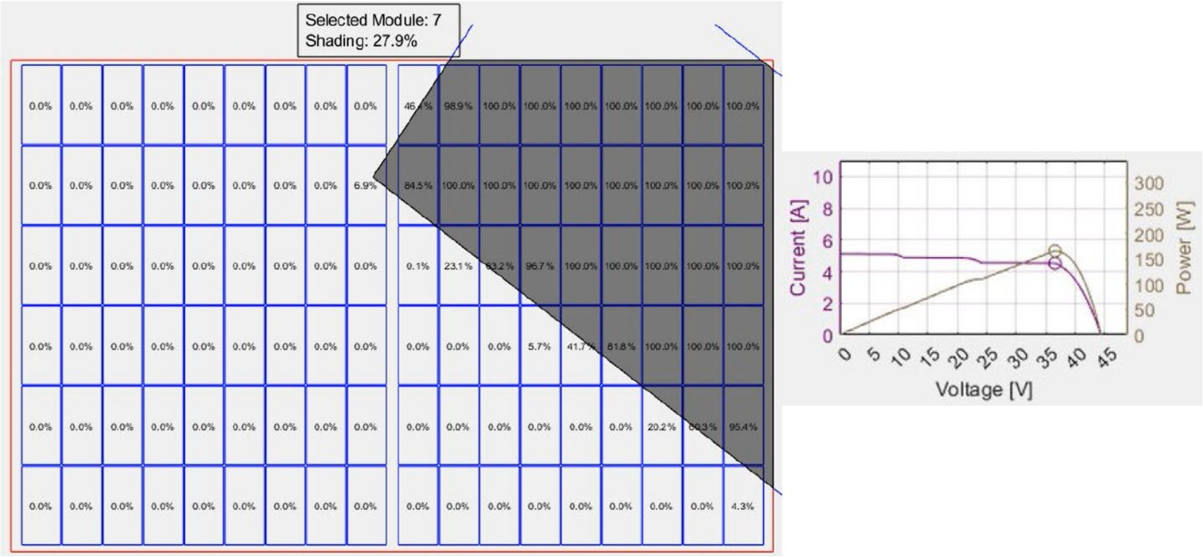


Figure 4.1 – Cell shading percentage of a half-cut PV module with partial shading by a chimney and corresponding IU- and PU-curves.

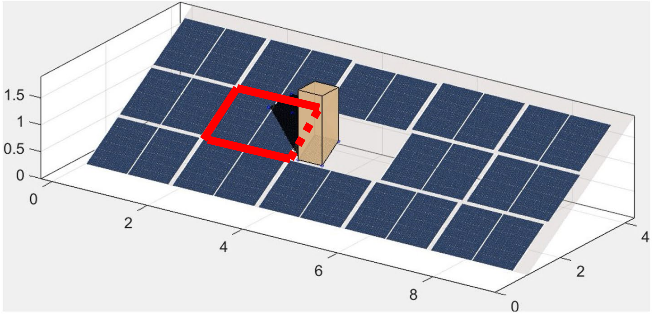
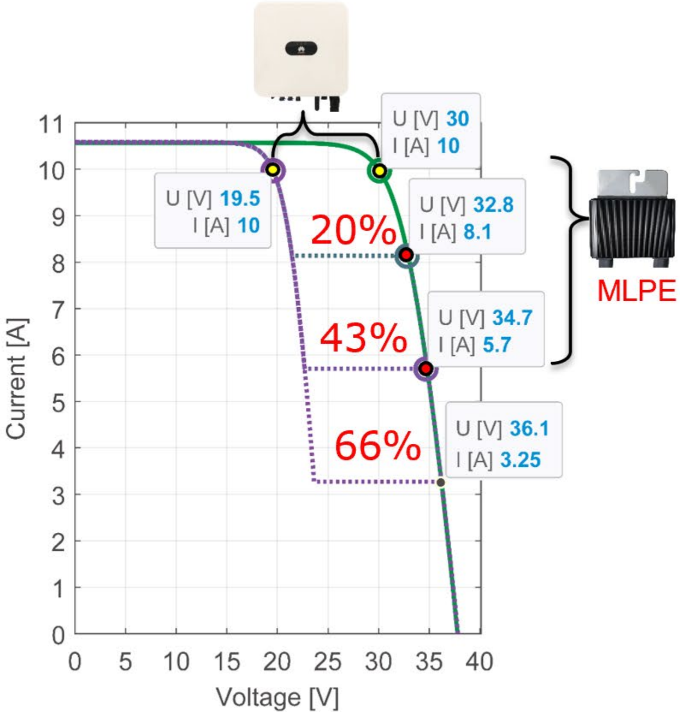


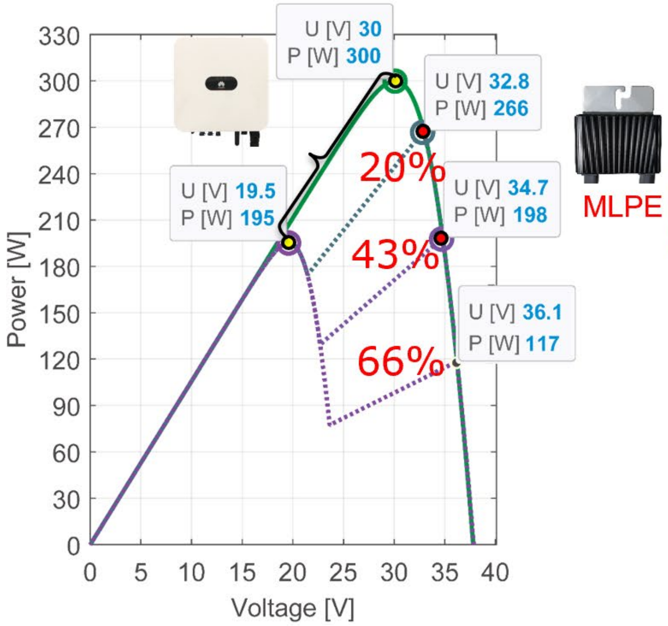
Figure 4.2 – 3D model of the 14-module rooftop PV system consisting of half-cut modules, which are affected by the partial shading of a chimney.

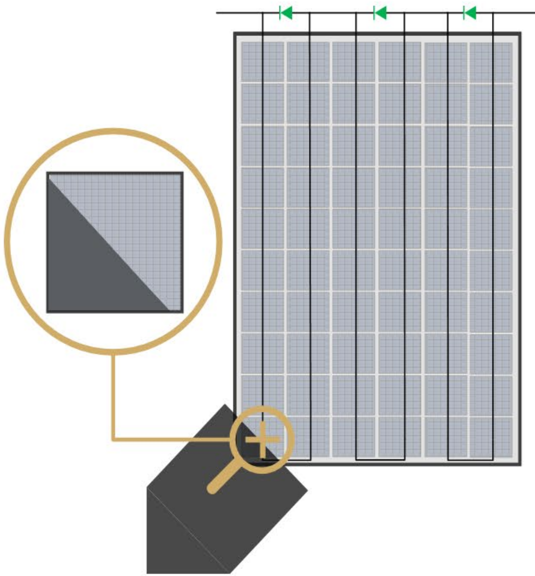
Butterfly PV module 2x9x6=108 half solar cells

C. Allenspach
ZHAW IEFE
Master Thesis 2023

PV Module Under Partial Shading







Theoretical available Max DC Power

at 11:05 the string inverter and MLPE find max. power

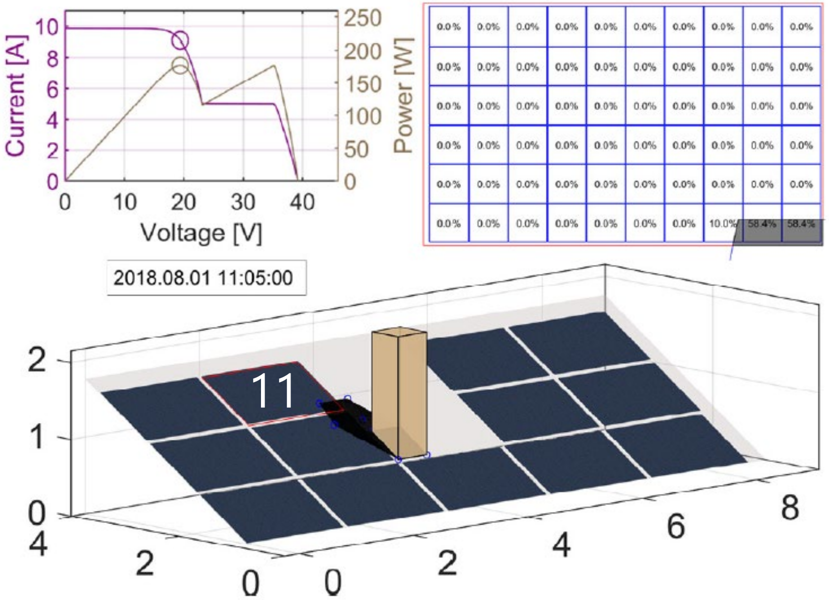


Figure 6. Second time step of the simulated PV system at 11:05 of August 1, 2018 (same shading scenario as described in the caption of Figure 5).

at 11:50 only the MLPE find max. Power

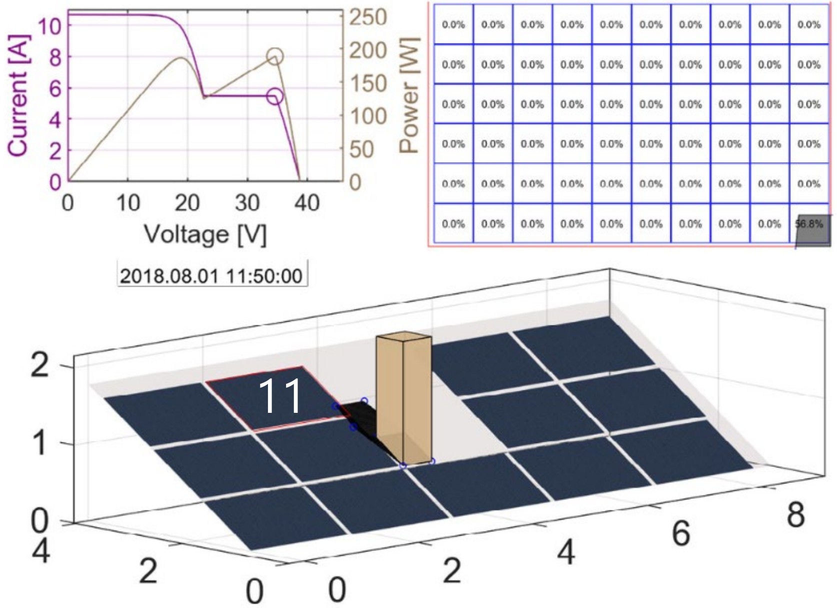
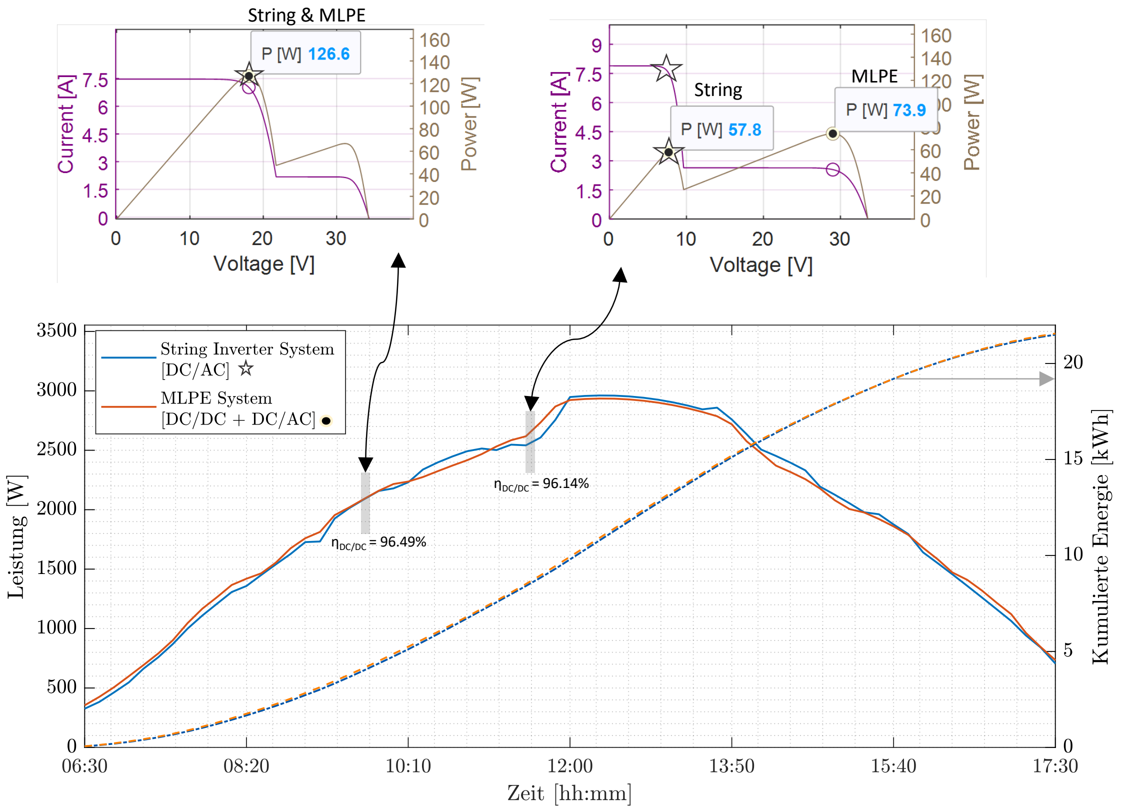
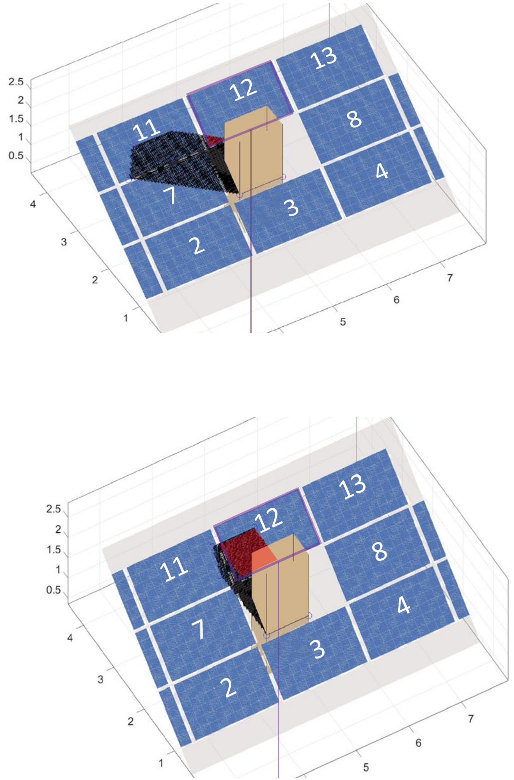


Figure 7. Third time step of the simulated PV system at 11:50 of August 1, 2018 (same shading scenario as described in the caption of Figure 5).

Clear Sky Day – MLPE versus SINV Performance



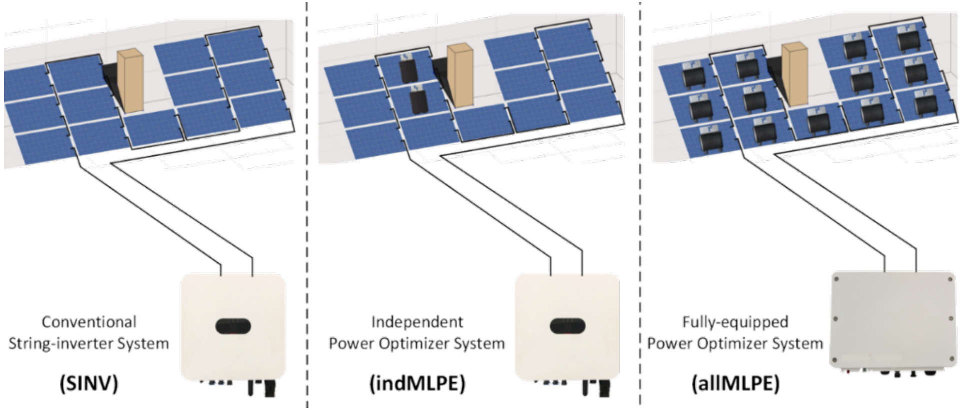


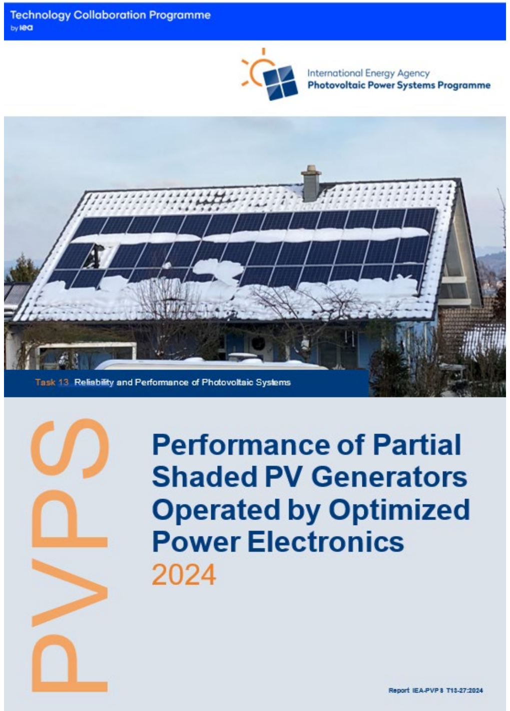
PVPS

Power Electronics of Partial Shaded PV Systems

Introduction

- The Evolution of PV Technology from String Inverter – Optimiser – Hotspot-free PV Module
- Fair Manufactures Data Sheet Values missing
- Challenges in PV Planning and recommending the most efficient System Power Electronic Topology



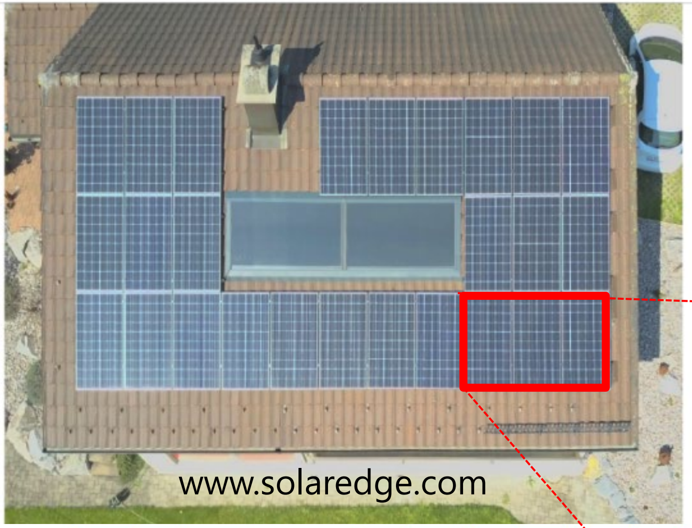


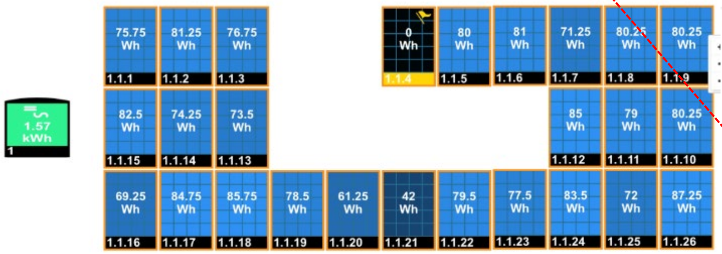
Report IEA-PVPS T13-27:2024, Nov 2024

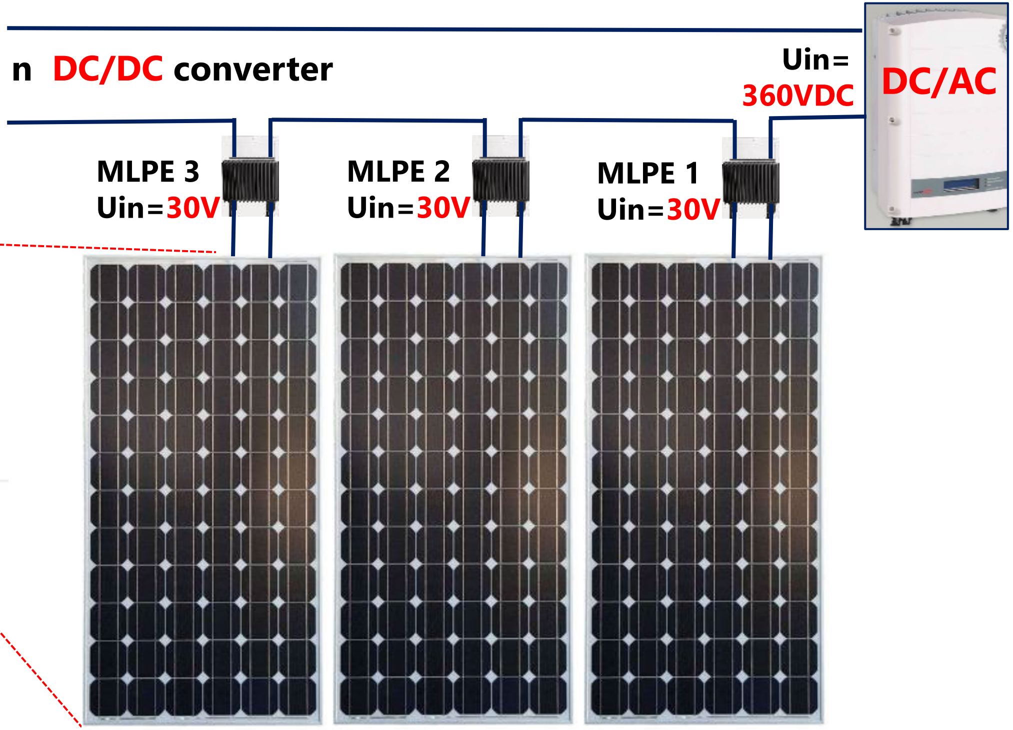
Module Level Power Electronics (MLPE)

Zürcher Hochschule für Angewandte Wissenschaften
zhaw School of Engineering
IEFE Institut für Energiesysteme und Fluid-Engineering

PVA Schneider, Turbenthal





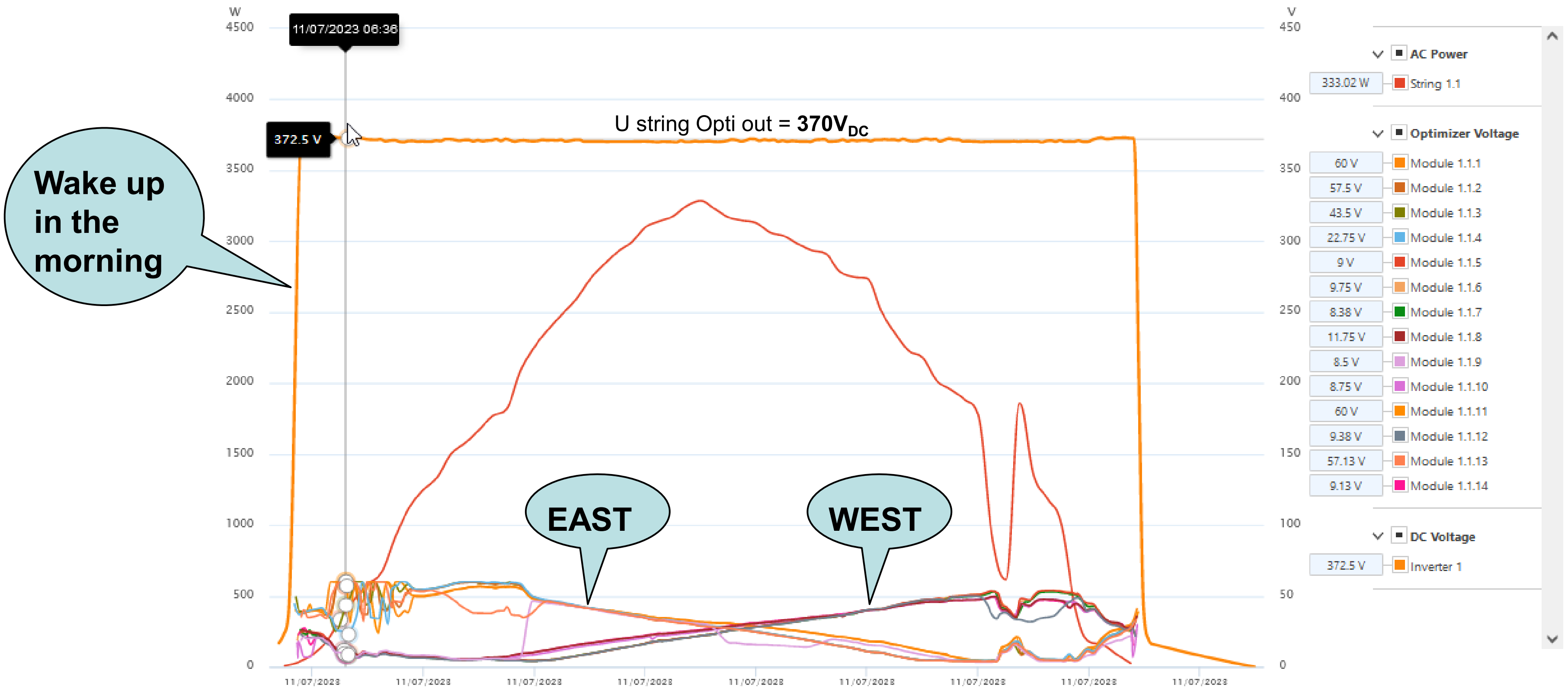


PVPS

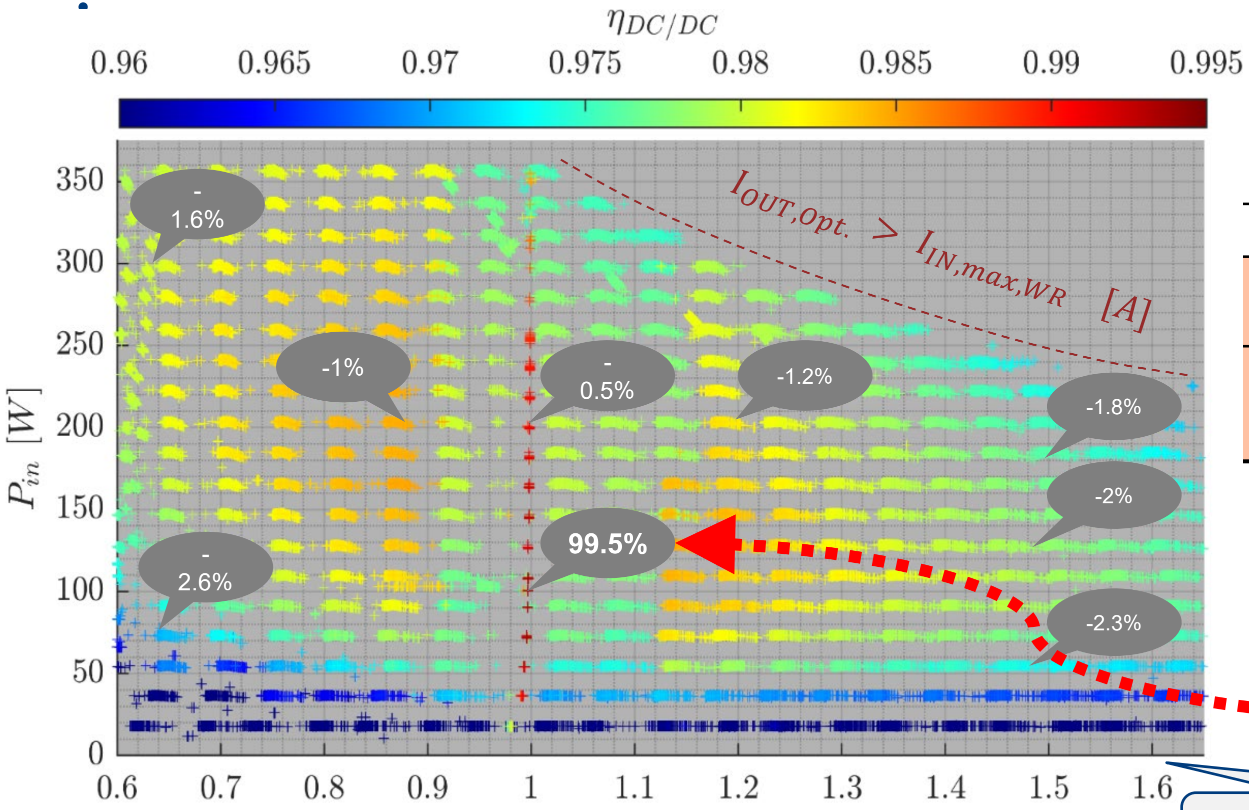
On Top of East West Dormer

Solaredge Monitoring 2023-07-15 Clear Sky Day

Optimizer Output Voltage & String Voltage



MLPE Real Efficiency ZHAW Measurement



$U_{out} < U_{in}$ $U_{out} < U_{in}$

Optimizer P370

P370	0.85	0.95	k = 1	1.05	1.2	1.5
	ZHAW IEFE Measurement results					
EURO Eff.	97.7 %	97.3 %	98.9 %	97.4 %	97.6 %	96.6 %
No. Optimizer	9	10	11	12	13	17

-2%

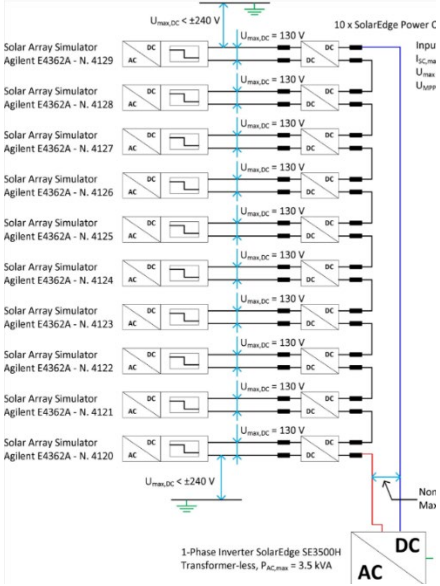
Manufacturer	
Max	Weighted
99.5%	98.8%

High number of optimizer in the string

PVshade – Simulation Based on Real Losses

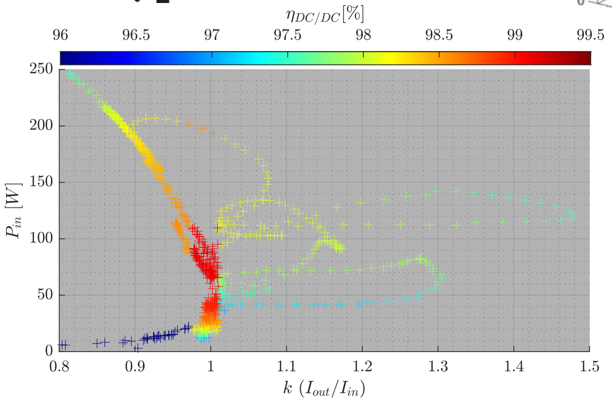
Indoor ZHAW Lab measurements

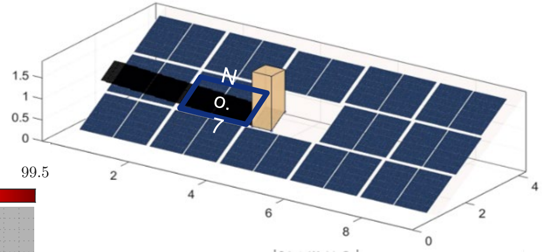
of power electronic components in the relevant operation area

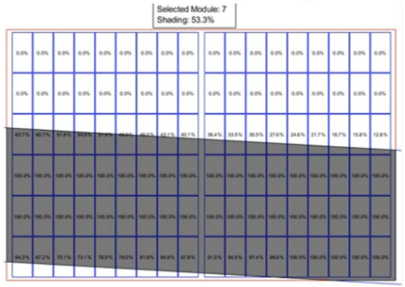


Annual ZHAW PVshade Simulation

of shadow propagation & losses for each power electronic component / optimizer



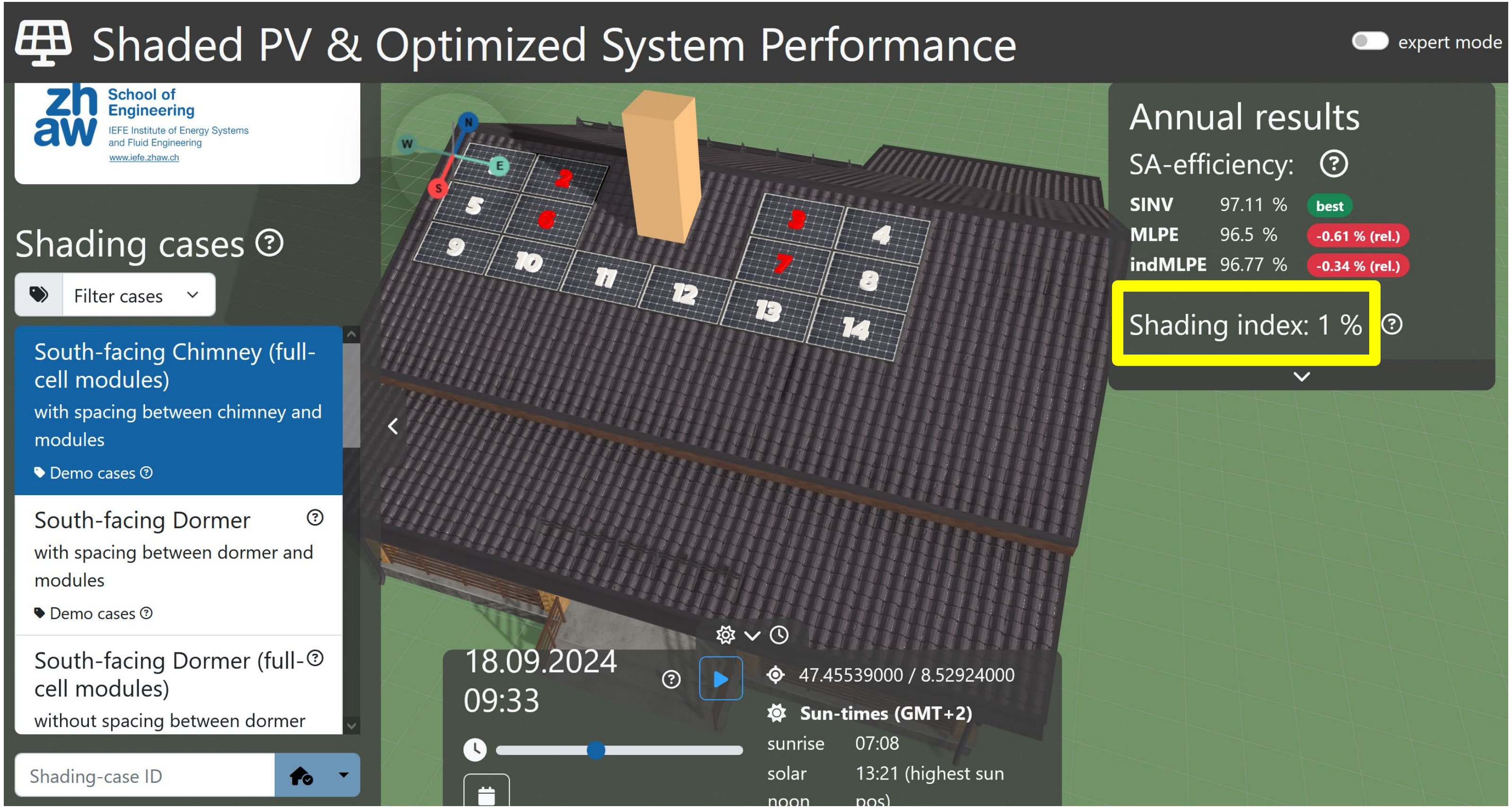




PVPS

C. Allenspach, F. Baumgartner, et al. Sol. RRL 2022, 2200596

Light Shading SI 1% - ZHAW Webtool Simulation



PVPS

Light Shading SI 1% - ZHAW Webtool Simulation

System definition

description

	SINV	independent MLPE	all MLPE
Inverter type	Huawei, 3.68KTL-L1	Huawei, 3.68KTL-L1	Solaredge, SE3500H
Optimizer system	-	Huawei, SUN2000-450W-P2	Solaredge, P370
Module type ⓘ	**14** x LG NEON2 LG350N1C		

Inclination: 25.2° ⓘ
Rotation: 180° ⓘ
Plant size: 25.5 m² ⓘ
Peak power: 4.9 kW ⓘ
Theoretical DC-max: 3,142.9 kWh ⓘ

Environment

Pos.: 8.52924 / 47.45539 (lon/lat) ⓘ
Albedo: 0.18 ⓘ
Shading index: 1.003 ⓘ

Simulation

Time-period: 2018-01-01 / 2018-07-01 ⓘ
Sim-steps: 30 min ⓘ

Annual results ⓘ

analyse single PV-modules

Performance ratio: 0.97 ⓘ

	SINV	independent MLPE	all MLPE
AC-out	3,052 kWh	3,041.4 kWh (-0.35%)	3,033 kWh (-0.62%)
DC-out	3,130.4 kWh	3,118.5 kWh	3,070.4 kWh
AC-out (specific) ⓘ	622.9 kWh/kWp	620.7 kWh/kWp	619 kWh/kWp
SA-efficiency (AC) ⓘ	97.11 %	96.77 %	96.5 %
SA-efficiency (DC) ⓘ	99.6 %	99.22 %	97.69 %
Total energy loss (to DC max.) ⓘ	-2.89 %	-3.23 %	-3.5 %

SINV
eta_{EURO}=97.3%

PVPS

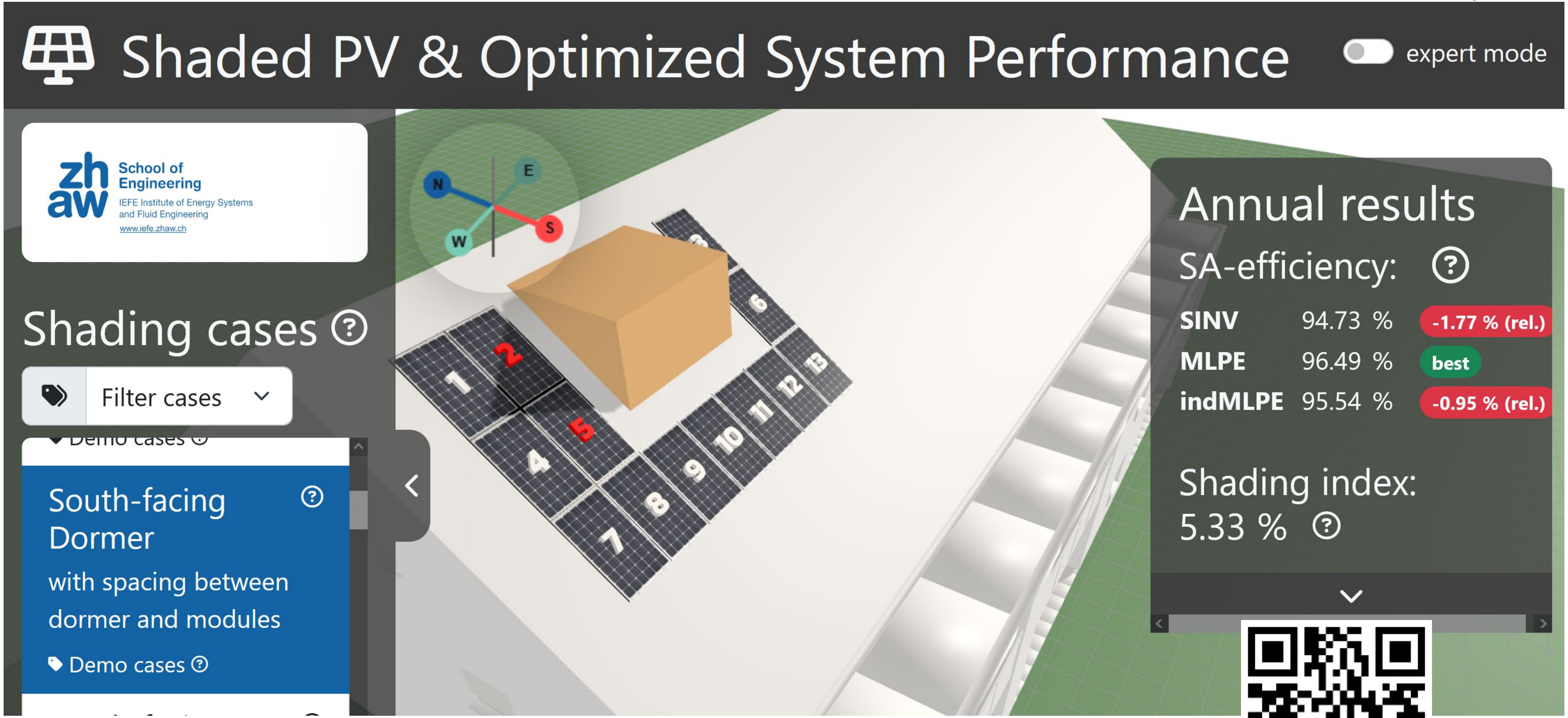
Light Shading SI 1% - ZHAW Webtool Simulation

Module-results

PV-module	Annual result	Delta to max.
#1	214 kWh	-2.05% (-4.49 kWh)
#2	209 kWh	-4.65% (-10.17 kWh)
#3	210 kWh	-3.97% (-8.69 kWh)
#4	215 kWh	-1.76% (-3.86 kWh)
#5	218 kWh	-0.52% (-1.14 kWh)
#6	218 kWh	-0.28% (-0.62 kWh)
#7	218 kWh	-0.40% (-0.87 kWh)
#8	218 kWh	-0.56% (-1.22 kWh)
#9	219 kWh	-0.04% (-0.09 kWh)
#10	219 kWh	-0.00% (-0.00 kWh)
#11	219 kWh	-
#12	219 kWh	-
#13	219 kWh	-
#14	219 kWh	-0.05% (-0.12 kWh)

-4.7%
Module No 4

Medium Shading SI 5% - ZHAW Webtool Simulation



PVPS

Heavy Shading SI 9% - ZHAW Webtool Simulation

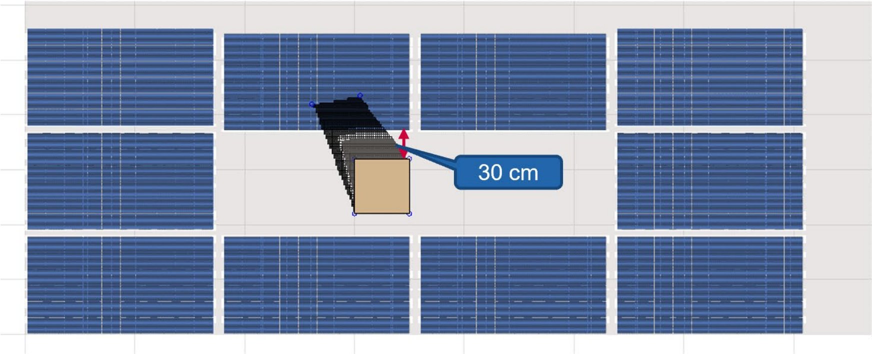
PV-module	Annual result	Delta to max.
#1	305 kWh	-15.64% (-56.64 kWh)
#2	272 kWh	-24.96% (-90.38 kWh)
#3	275 kWh	-23.97% (-86.80 kWh)
#4	336 kWh	-7.20% (-26.09 kWh)
#5	289 kWh	-20.33% (-73.60 kWh)
#6	309 kWh	-14.71% (-53.25 kWh)
#7	361 kWh	-0.18% (-0.65 kWh)
#8	362 kWh	-0.12% (-0.43 kWh)

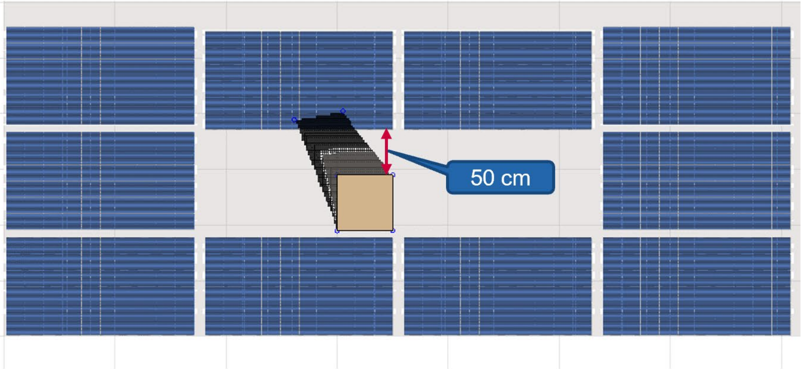
PVPS

Annual Simulation Results 1 with real Eff.

System A : **MLPE @ Chimney - near**
Optimizer Solaredge SE3500H (HD-wave)+P370

System B : **SINV @ Chimney - far**
Stringinverter Huawei SUN2000-3.68KTL-L1





	Chimney «near»
MLPE	**100%**
SINV	99.5%

	Chimey «far»
MLPE	102.8%
SINV	**103%**

PVPS

Annual Simulation Results 2 with real Eff.

System A : **MLPE**
Optimizer Solaredge SE3500H (HD-wave)+P370

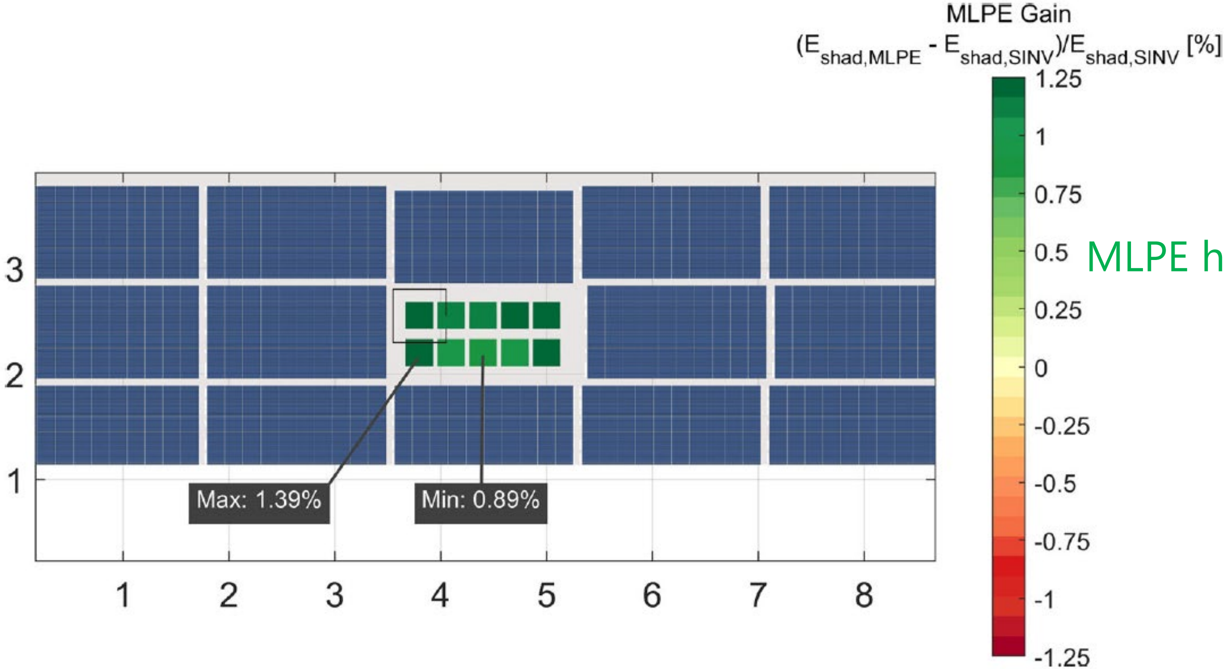
System B : **SINV**
Stringinverter Huawei SUN2000-3.68KTL-L1

	MLPE – new–	MLPE – old–	SINV -new-
Chimney «near»	**96.2%**	94.4%	95.7%
Chimney «far»	96.2%	94.4%	96.6%
Manufacturer	$98.8\% \cdot 98.8\% = 97.6\%$	$98.8\% \cdot 97.5\% = 96.3\%$	97.3%

PV Plan Designer will find OPTIMUM

Zürcher Hochschule für Angewandte Wissenschaften
zh aw School of Engineering
IEFE Institut für Energiesysteme und Fluid-Engineering

System of 14 PV modules: Percentage Performance Benefit of **MLPE (new DC/AC)** versus **SINV**



MLPE higher Performance

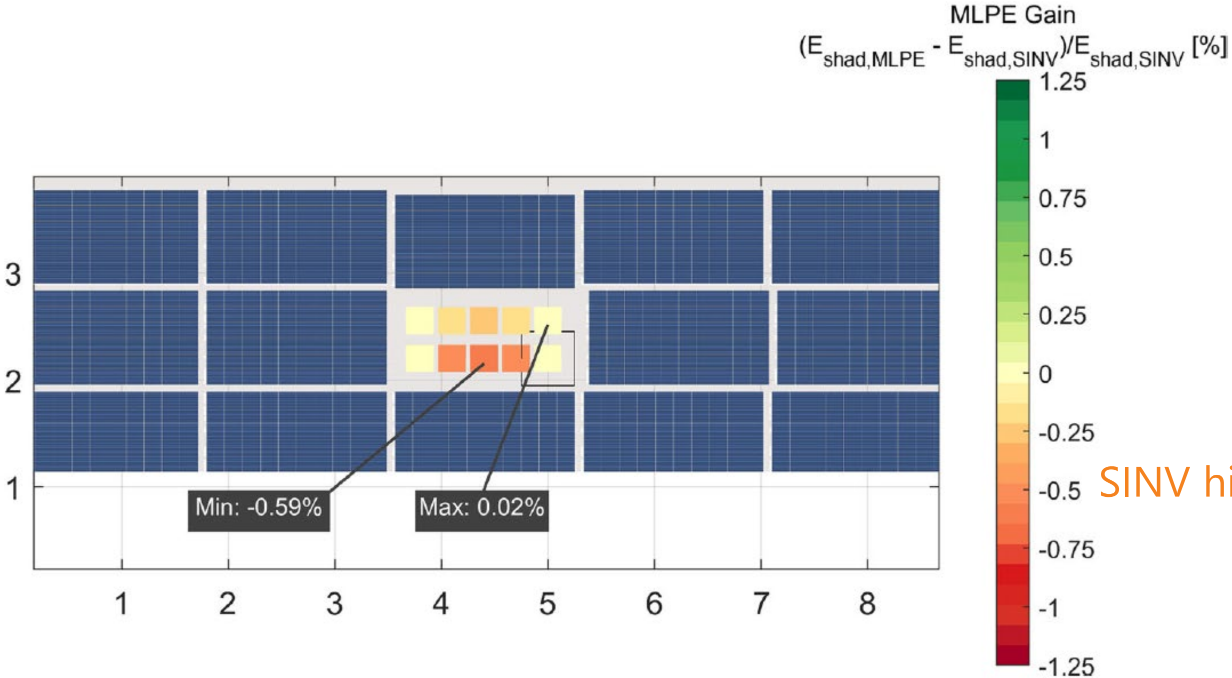
Figure 12. Comparison of the SINV: SUN2000-3.68KTL-L1 and MLPE: SE3500H with P370 power optimizer for a 14-module residential PV plant. Annual MLPE yield gain for 10 chimney positions visualized as boxes and their magnitude indicated by color bar. Minimum 0.9% and maximum MLPE yield gain 1.4% are denoted by gray text boxes

C. Allenspach, A. Bänziger, A. Schneider, F. Carigiet, F. Baumgartner , Conference Paper at 8th WCPEC 2022, Milano and published as Journal Paper in www.solar-rrl.com

PV Plan Designer will find OPTIMUM

Zürcher Hochschule für Angewandte Wissenschaften
zh aw School of Engineering
IEFE Institut für Energiesysteme und Fluid-Engineering

System of 14 PV modules: Percentage Performance Benefit of **MLPE** (old DC/AC) versus **SINV**



SINV higher Performance

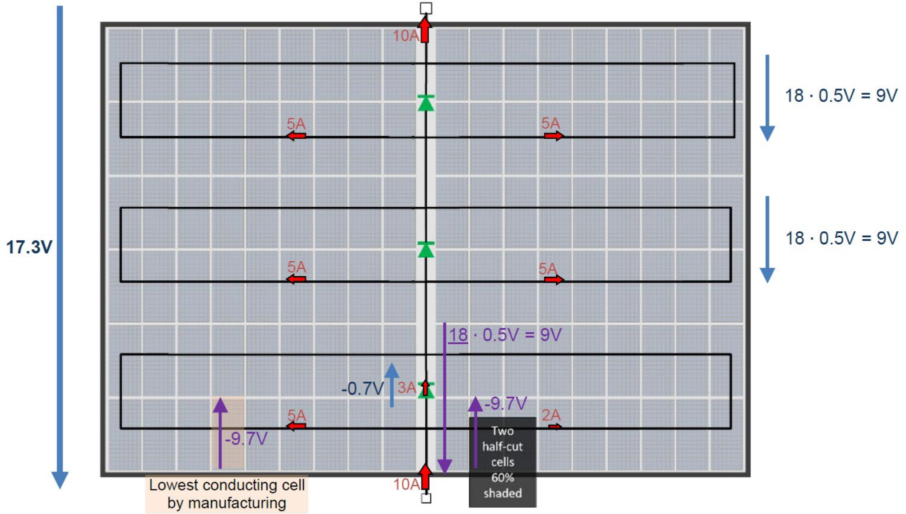
Figure 13. Comparison of the SINV: SB3.6-1AV-41 and MLPE: SE3500 (**non-HD-wave**) with P370 power optimizer for a 14-module residential PV plant. Annual MLPE yield gain for 10 chimney positions visualized as boxes and their magnitude indicated by color bar. Minimum 0.6% and maximum MLPE yield gain 0.02% are denoted by gray text boxes

PVPS

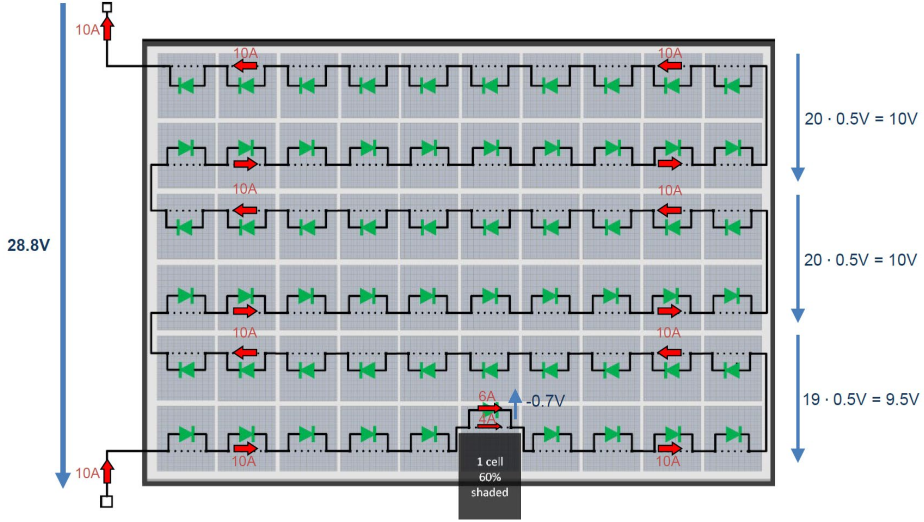
C. Allenspach, A. Bänziger, A. Schneider, F. Carigiet, F. Baumgartner , Conference Paper at 8th WCPEC 2022, Milano and published as Journal Paper in www.solar-rrl.com

PV Module and Bypass Diodes

Three Bypass Diode Standard



More Bypass Diodes Partial Shading Optimisation



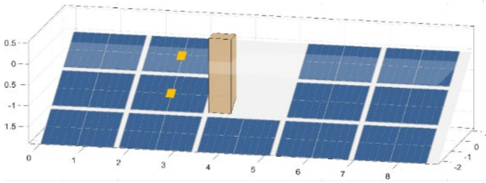
Manufactures like AESOLAR, Aiko, Maxeon ...

Report IEA-PVPS T13-27:2024, Nov 2024

see also manufacturing IBC cells e.g. ISC Konstanz, PV-magazine 2023/03/18

PVPS

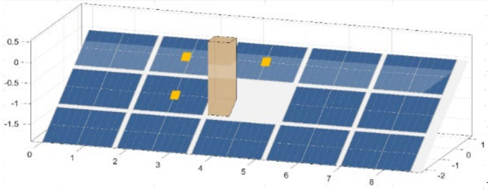
Shading tolerant PV modules are effective 1



#13 PV modules
SI about 2%

Relative Annual Energy		Full Cell PV Module	Half-cut cell PV Module	Third-cut cell PV Module	4 quadrant shingled	Shading-resistant All Cells + Diode	
Unshaded + no losses				100			%
shaded + no losses		96.8	96.8	96.8	98.4	97.8	%
SINV	Relative Energy	93.0	92.9	92.7	94.0	93.9	%
indMLPE	Relative Energy	93.8	93.6	93.1	94.6	94.8	%
	MLPE Gain	0.9	0.8	1.1	0.6	0.4	%
allMLPE	Relative Energy	93.3	92.8	93.7	94.4	94.2	%
	MLPE Gain	0.3	-0.2	0.4	0.3	-0.1	%
Average Rel. Energy		93.3	93.1	93.2	94.4	94.3	%

Max. SINV diff.: 1.4%
Max. indMLPE diff.: 1.8%
Max. allMLPE diff.: 1.2%
Max. Difference Tot: 2.1%



#14 PV modules
SI about 3%

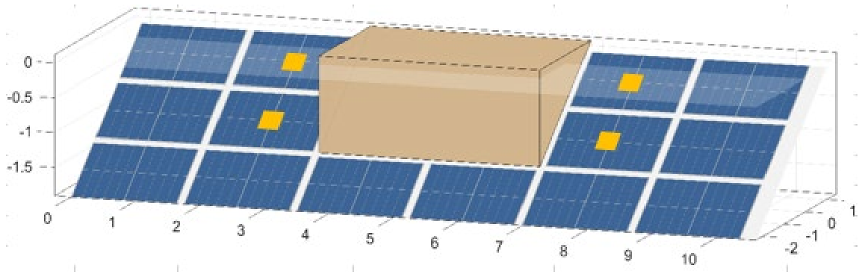
		Full Cell PV Module	Half-cut cell PV Module	Third-cut cell PV Module	Shading-resistant 4 quadrant	Shading-resistant All Cells + Diode	
Unshaded + no losses				100			%
shaded + no losses		95.3	96.0	95.8	98.0	97.0	%
SINV	Relative Energy	90.7	91.7	91.2	93.0	92.9	%
indMLPE	Relative Energy	92.1	92.7	92.1	93.8	93.4	%
	MLPE Gain	1.4	1.1	1.6	0.8	0.5	%
allMLPE	Relative Energy	91.6	91.9	92.6	93.9	93.0	%
	MLPE Gain	0.9	0.3	1.1	0.9	0.1	%
Average Rel. Energy		91.5	92.1	92.0	93.6	93.1	%

Max. SINV diff.: 1.9%
Max. indMLPE diff.: 1.3%
Max. allMLPE diff.: 2.3%
Max. Difference Tot: 2.2%

PVPS

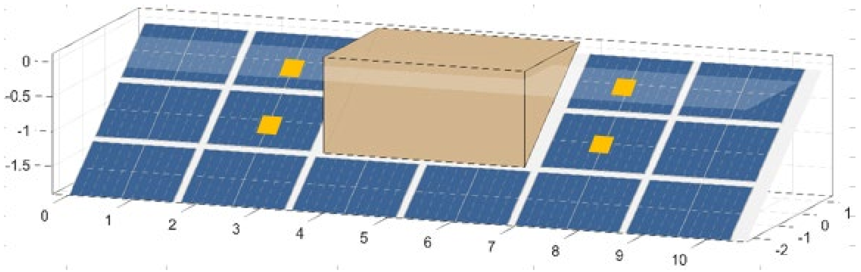
Distance PV Module to the Shading Object

no distance



Shading Adapiton Efficiency in %		Full cell module	Shading-resistant 4 diode	Shading-resistant all diodes
Unshaded + no losses			100	
Shaded + no power electronic losses		94.3	96.5	96.6
SINV	Relative Energy	88.4	90.8	92.3
indMLPE	Relative Energy	90.6	91.6	92.7
	MLPE Gain	1.4	0.8	0.3
allMLPE	Relative Energy	89.6	92.5	92.7
	MLPE Gain	2.4	1.8	0.4

more space



Shading Adapiton Efficiency in %		Full cell module	Shading-resistant 4 diode	Shading-resistant all diodes
Unshaded + no losses			100	
Shaded + no power electronic losses		95.2	97.3	97.1
SINV	Relative Energy	90.1	92.1	92.9
indMLPE	Relative Energy	91.0	92.6	93.1
	MLPE Gain	1.0	0.6	0.3
allMLPE	Relative Energy	91.4	93.2	93.1
	MLPE Gain	1.5	1.2	0.3

Report IEA-PVPS T13-27:2024, Nov 2024

Markets: Shading Tolerant Modules

2. Generation

NEOSTAR 2S Einzelglas 440W-470W

Teilverschattungs-Optimierung | Besserer Temperaturkoeffizient | Geringere Zelltemperatur bei Verschattung | Widerstandsfähigkeit gegen Mikrorisse | Höhere Leistung | Niedrigere BOS | Höhere Ästhetik

IBC solar cell cross section
ISFH Germany 2020
www.nature.com/scientificreports

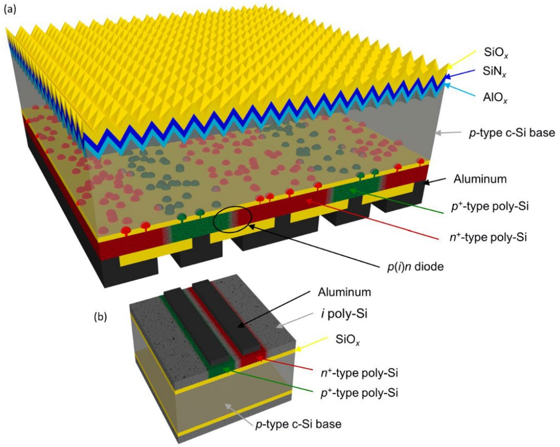
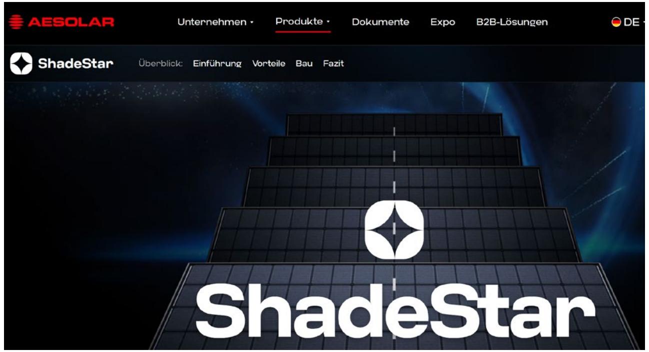


Figure 1. (**a**) Schematic drawing of the structure of an IBC solar cell with n^+- and p^+-type poly-Si contact fingers separated by an initially intrinsic poly-Si region. (**b**) Sketch of a $p(i)n$ test structure.

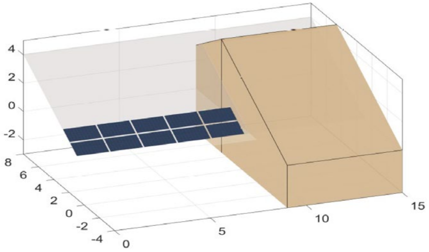


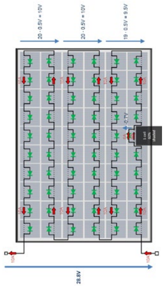
https://ae-solar.com/de/products/ShadeStar

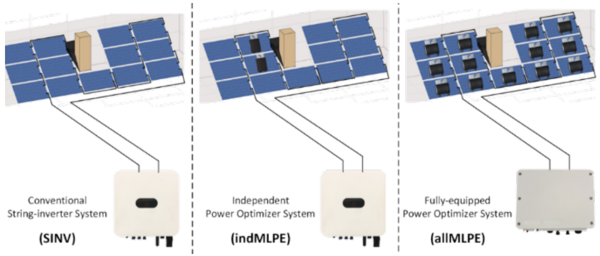
PVPS

z.B. Hersteller AIKO
Aiko ABC Module Erläuterungen dazu von AIKO
e.g. Distributor **Energy Depot** Schweiz & DACH
https://www.energydepot.ch/

Conclusion – Recommendations – PV Rooftop







Shading Scenarios			PV Module	Power Electronic Systems		
Shading degree	Objects	Modules affected	Type	SINV	indMLPE	allMLPE
Weak		<10%	Standard	+	+	-
			4+ Bypass diode	+	+	-
Medium		>10% and <40%	Standard	0	+	+
			4+ Bypass diode	+	+	+
Strong	Buildings, trees	>40%	Standard	-	0	+
			4+ Bypass diode	0	+	+

Report IEA-PVPS T13-27:2024, Nov 2024

Call for Improvements

The IEA study has identified several key areas where improvements are needed:

- Urgent call to optimiser **manufacturers** to finally provide **realistic efficiency data**, **standards**
- **Cost analysis of replacement** of optimiser **including craftsman** compared to string inverter

Optimizing PV Plant Design

- **Collaborative efforts for improved PV planning**:
  website **information of typical shading cases** and annual exact performance, transfer research findings to **commercial PV design software**

- **Extension of the recommendations** in the IEA report to improve performance such as for the efficient power electronic system choice together with new **hotspot-free PV modules** and **optimum distance from module** to shading objects based on exact annual performance simulations

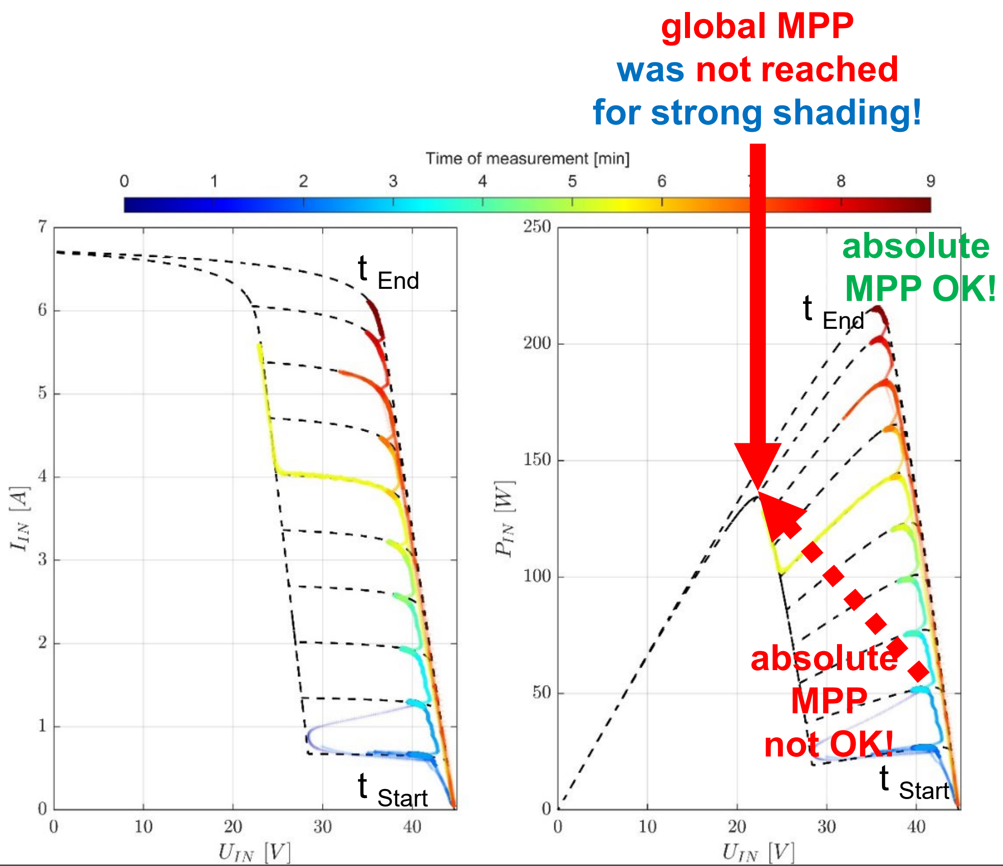
Shading Scenarios			PV Module	Power Electronic Systems		
Shading degree	Objects	Modules affected	Type	SINV	indMLPE	allMLPE
Weak		<10%	Standard	+	+	-
			4+ Bypass diode	+	+	-
Medium		>10% and <40%	Standard	0	+	+
			4+ Bypass diode	+	+	+
Strong	Buildings, trees	>40%	Standard	-	0	+
			4+ Bypass diode	0	+	+

Report IEA-PVPS T13-27:2024, September 2024

Indoor Labtest - Commercial MPP Tracking Failed

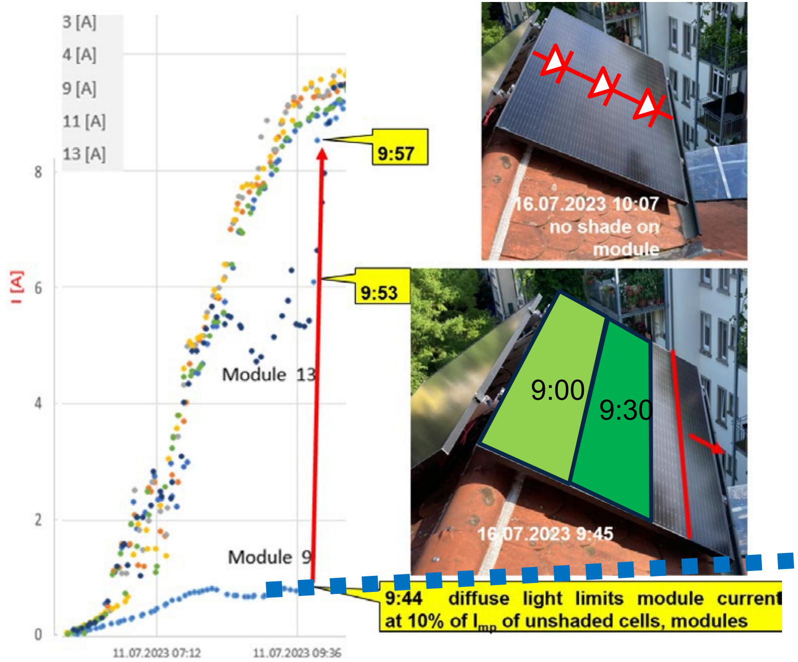
zh aw School of Engineering
IEFE Institute of Energy Systems and Fluid-Engineering

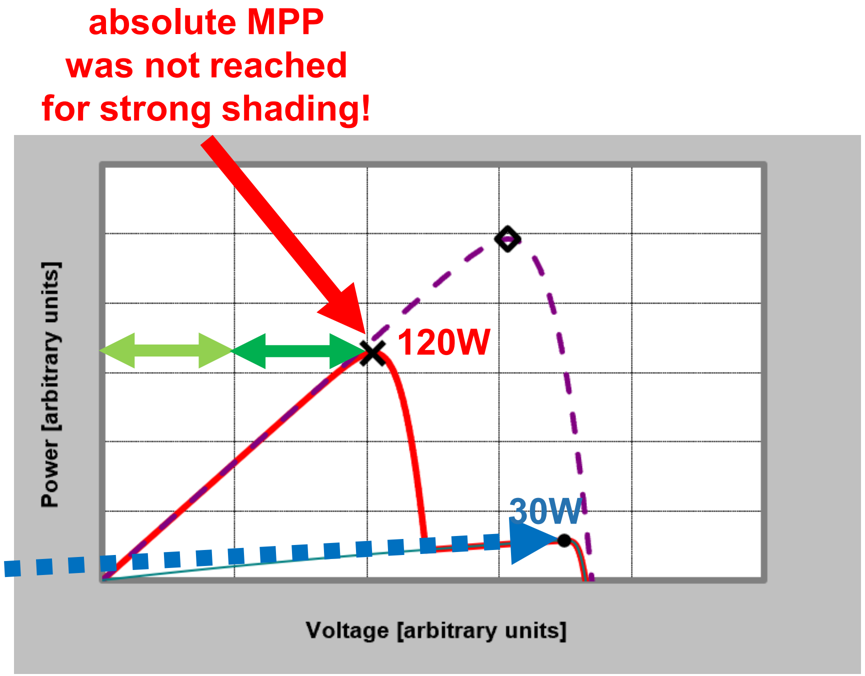
- MPP Tracking works in the morning
- MPP failures occurred at the beginning to find the global MPP by switching from about 40V to about 22V, for strong shading of a single solar cell! Device under Test Huawei 450W-P
  (Ref.: C. Allenspach Masterthesis ZHAW 2023)
- MPP works for lower shading at higher voltages 42V to 35V here after the first five minutes



Outdoor Test - Commercial MPP Tracking Failed

School of Engineering
IEFE Institute of Energy Systems and Fluid-Engineering



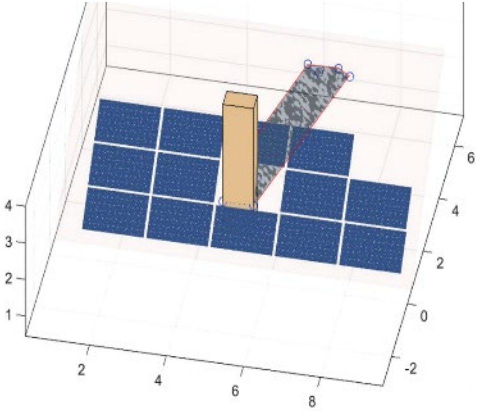


- Result: MPP tracking failed in outdoor operation toward low PV module voltage and high current as demonstrated in indoor tests

PV Output Estimation with Partial Shading

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

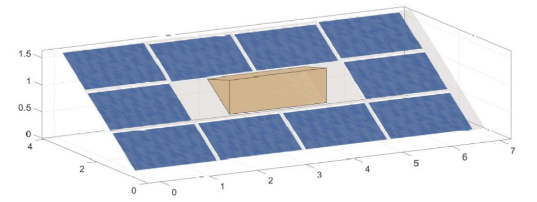
SFH 13kWp by PV installer,
«Alsona AG» - Webpage: https://www.alsona.ch/

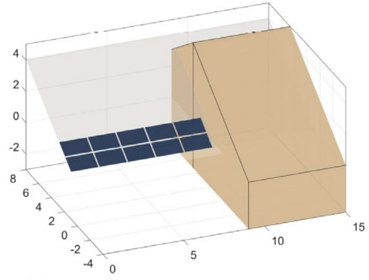


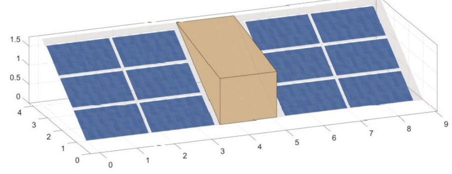
ZHAW SOE ShadingTool

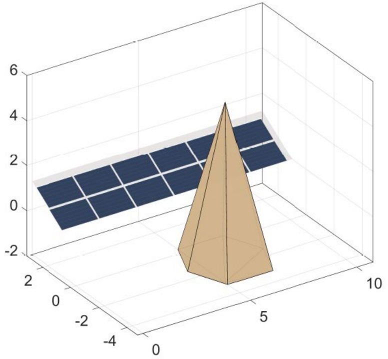
Various rooftops in Zurich City, by Juliet Haller (AfS),
Office for Urban Development – City of Zurich, «Leitfaden Dachlandschaften»

Performance at Light and Heavy Shading







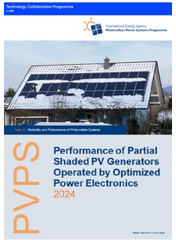


Cases	No:	Shading Severity	Shading index $SI_{DC,Max}$ [%]	Simulated annual yield [kWh] no shading & no loss [kWh]	no losses [kWh]	allMLPE [kWh]	SINV [kWh]	MLPE Gain [%]
Dormer (s)	1	Low	0.9	4410	4368	4207	4247	-1.0
Vent. Pipe	2	Low	2.9	4410	4282	4122	4129	-0.2
Chimney	3	Low	3.6	6337	6109	5904	5858	0.8
Tree 1	4	Medium	5.0	5295	5029	4862	4802	1.3
Tree 2	5	Medium	6.0	4410	4145	3987	3926	1.5
Building	6	Medium	7.9	4410	4062	3905	3802	2.7
Dormer (L)	7	Heavy	9.1	5295	4812	4643	4435	4.7
Roof Edge	8	Heavy	12.7	4410	3847	3693	3621	2.0

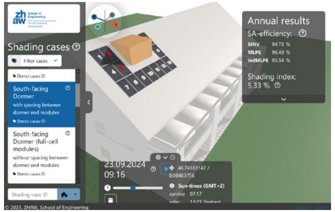
Report IEA-PVPS T13-27:2024, September 2024

Thank you for your Attention

IEA PVPS T13 Report Online: Nov 2024, IEA Website



Website PV Shading Cases: ZHAW WebPVshade

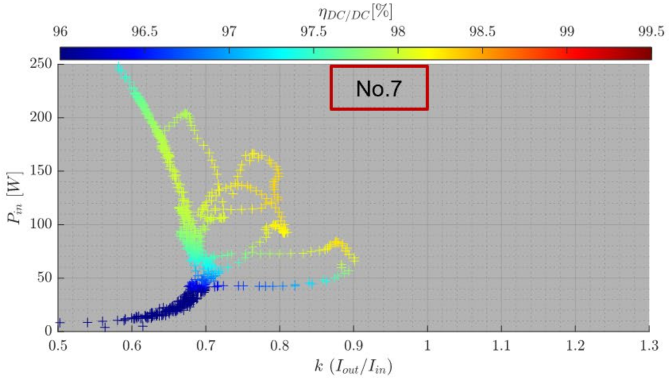


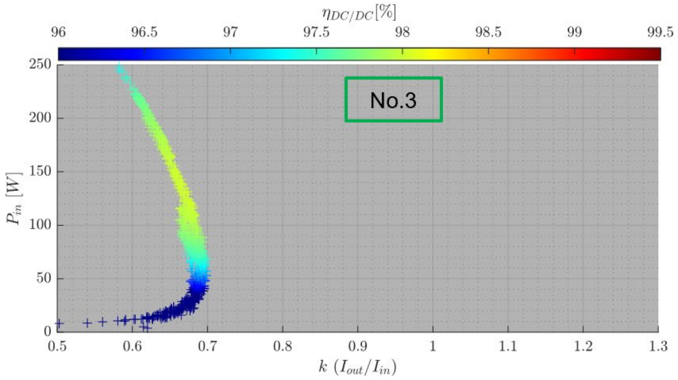
PV shading talks via youtube

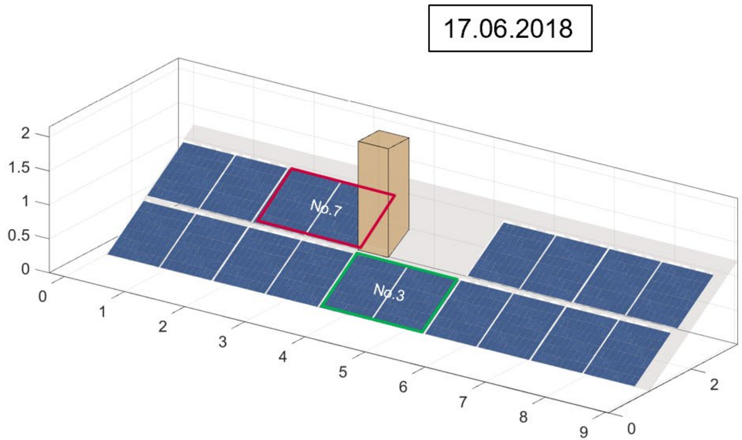
Franz Baumgartner, University ZHAW Webpage, ResearchGate

PVPS

9 Optimizer im String



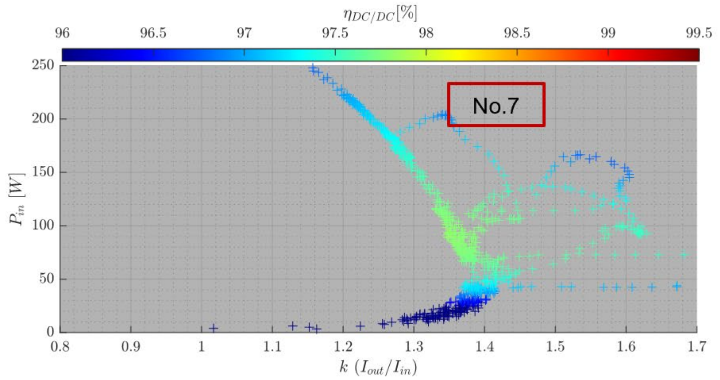


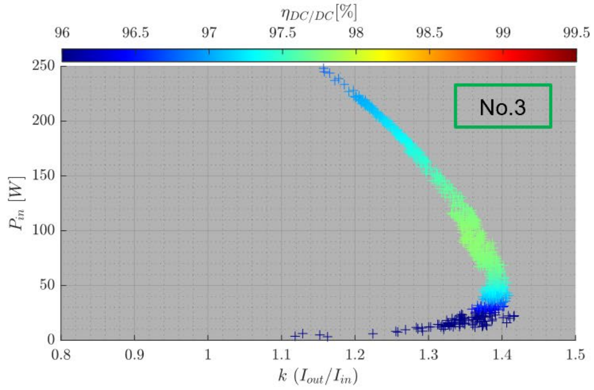


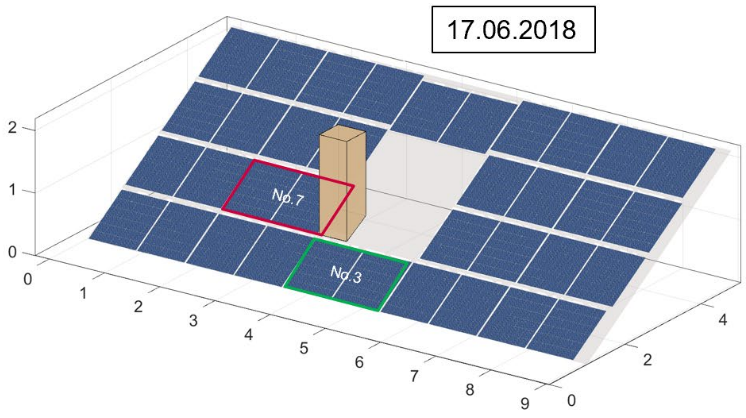
9 PV Modules

PVPS

13 Optimizer im String



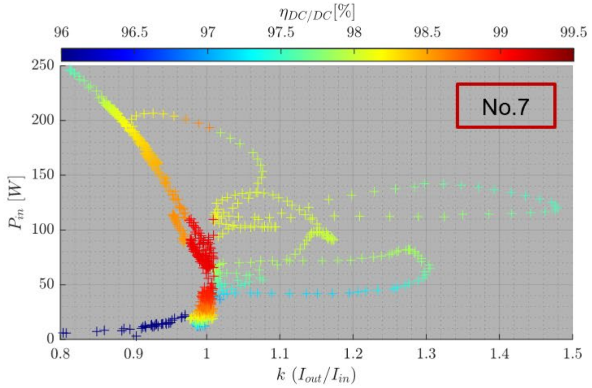


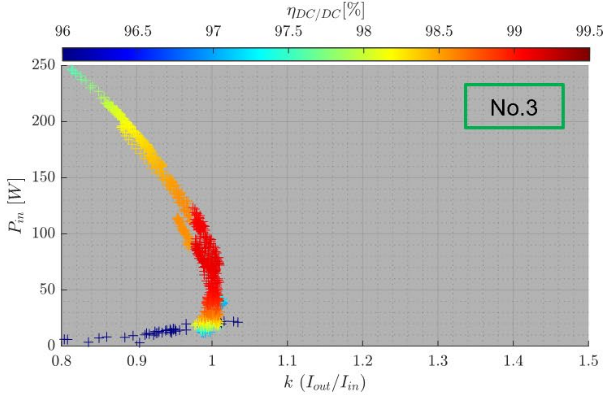


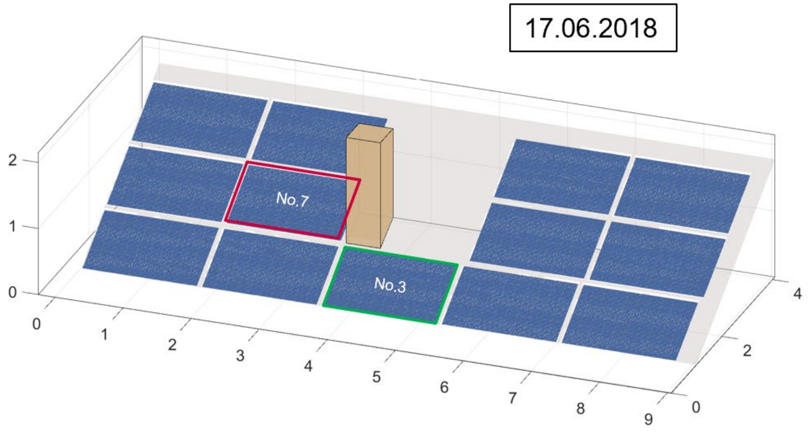
18 PV Modules

PVPS

13 Optimizer im String







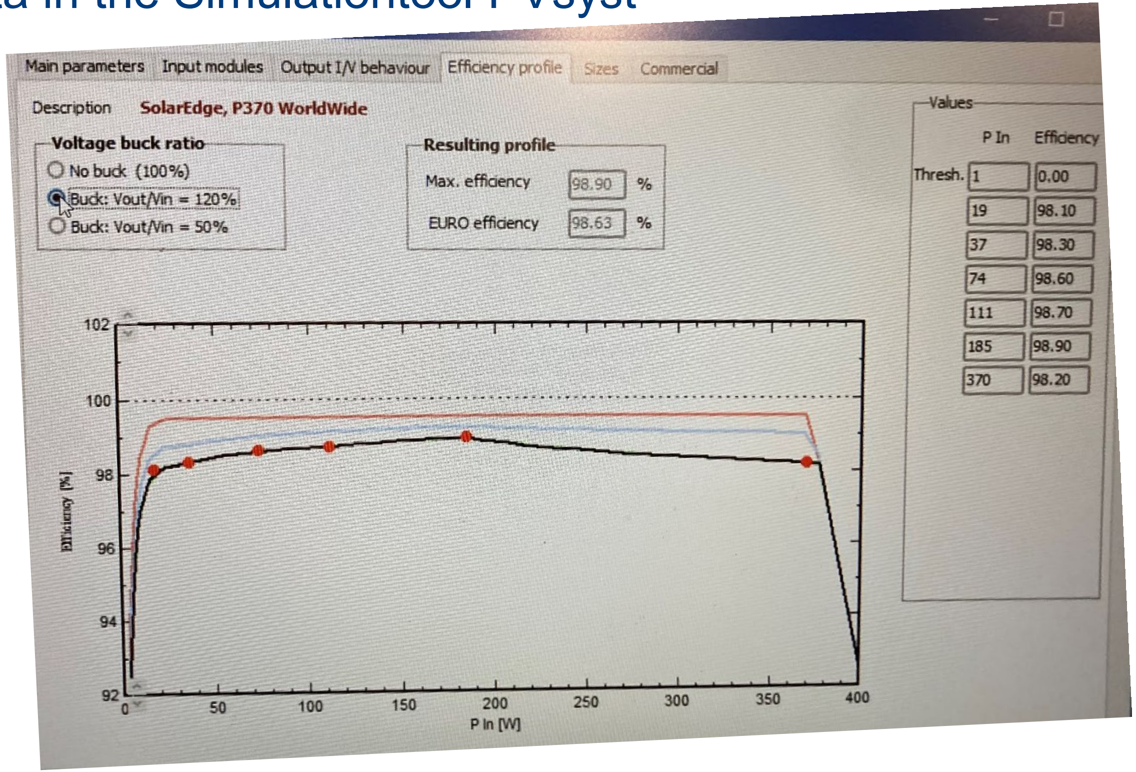
13 PV Modules

PVPS

Cyril Allenspach, Master Thesis, ZHAW 2023

Appendix: Info from PVsyst EUPVSEC 24 Booth

Solaredge data in the Simulationtool PVsyst



See ZHAW measurement result of P370 in the report IEA-PVPS T13-27:2024, September 2024

Heating with bypass diode activated

2. Kirchhoff Law

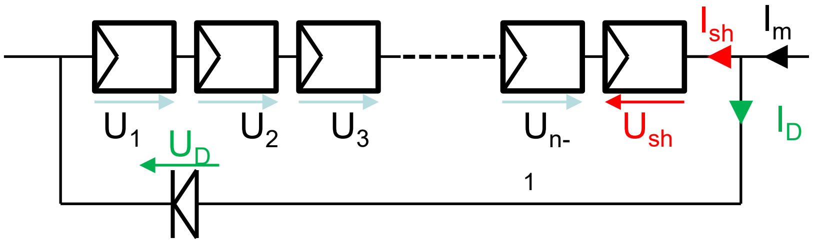
$U_{sh}=U_1+U_2+U_3+\ldots U_{n-1}+U_D$

1. Kirchhoff Law

$I_{sh}=I_m-I_D$

Heating Power

$P_{sh}= U_{sh} \cdot I_{sh}$



Example: n=20, $U_1 = U_2 = U_3 \ldots. U_{n-1} = 0.55V$, $U_D = 0.6V$; $I_m=10A$, $I_D=2A$

$U_{sh}=U_1+U_2+U_3+\ldots U_{n-1}+U_D$ = 11.05 V

$I_{sh}=I_m-I_D$ = 8A

$P_{sh}= U_{sh} \cdot I_{sh}$ = 88.4 W