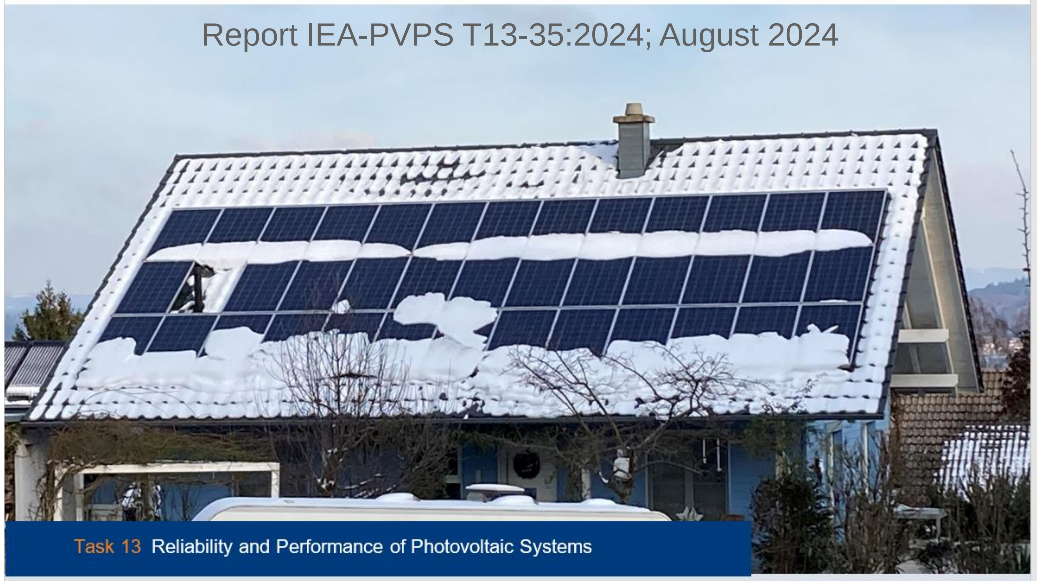


IEA PVPS

Design recommendations of PV system affected by shading – Webtool PVshade

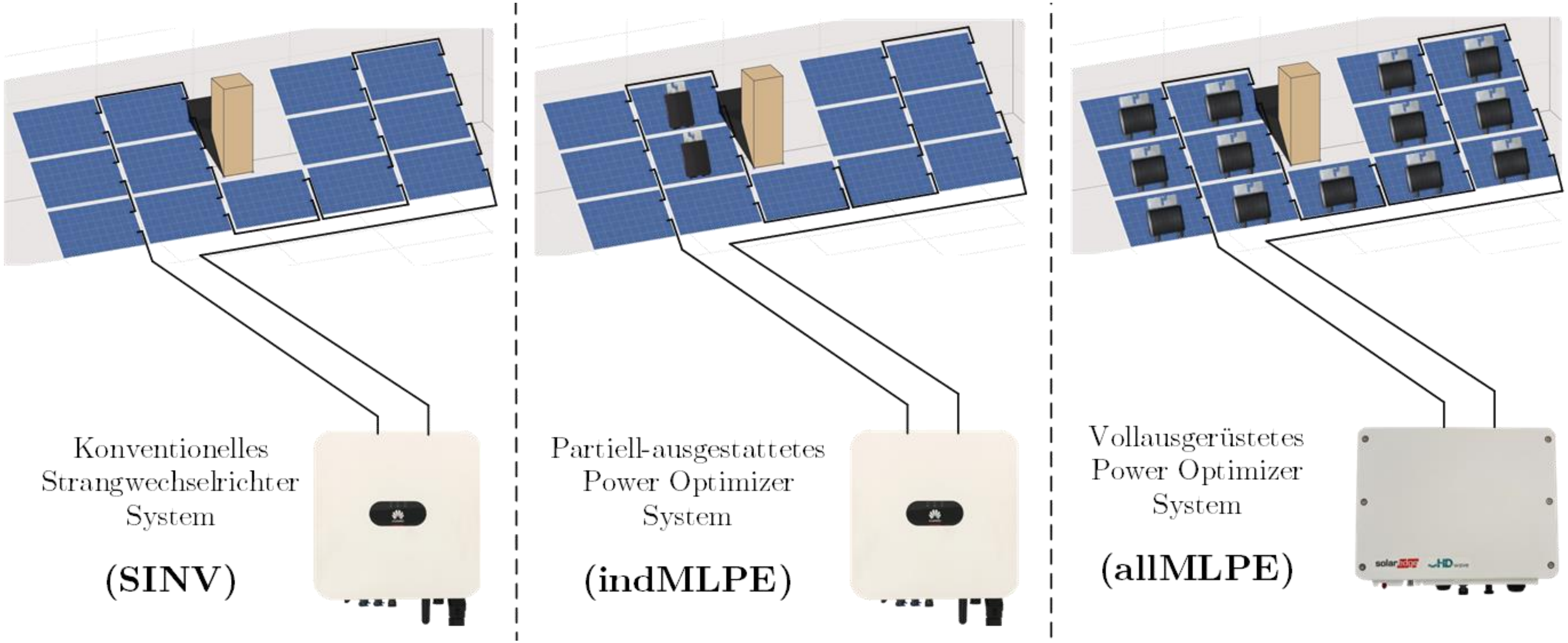
Franz Baumgartner, Cyril Allenspach - ZHAW, Winterthur, www.zhaw.ch/=bauf

EUPVSEC IEA side event 2023-09-21

State of the art and challenges – PV Shading

- Typical 99% efficiency for the DC/DC Optimizer is totally unrealistic for todays products
- The vast majority of the optimizers in use cannot demonstrate an additional yield of more than 5% relative to the proven string inverter system
- However, most customers believe they have a significant additional profit
- Commercial PV planning and annual yield calculation tools fail by up to 10% for optimizer
- Therefore, even the experienced PV planners do not offer customers any real system alternatives
- They are usually not informed to bear more than 90% of the costs for the replace of defective optimiser on their roof, which can amount to several thousand euros
- Independent Optimizer, shading tolerant PV modules and small string inverters will come
- More independent researcher's should support the PV planer by reliable results

PV power electronic conditioner on the markets



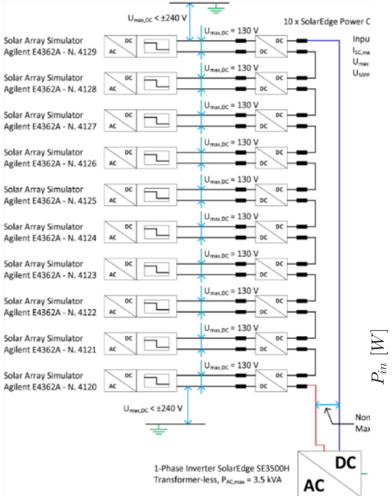
ZHAW Pvshade methode to calculate yield

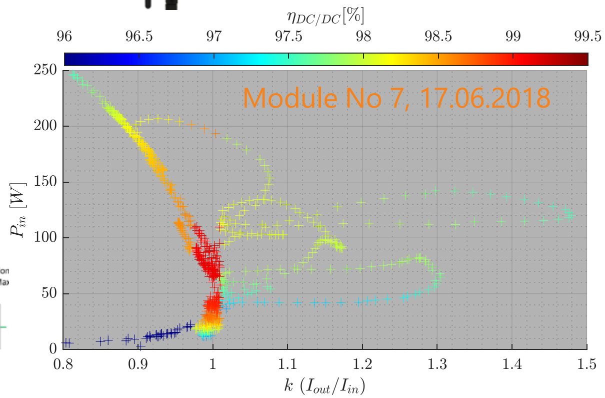
Indoor Measurements

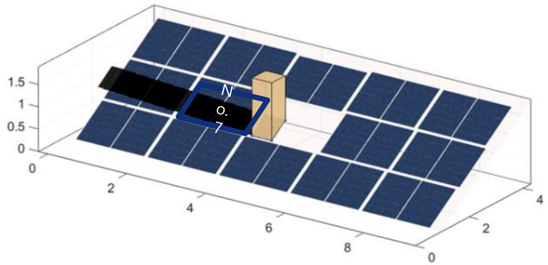
of power electronic components in the relevant operation area

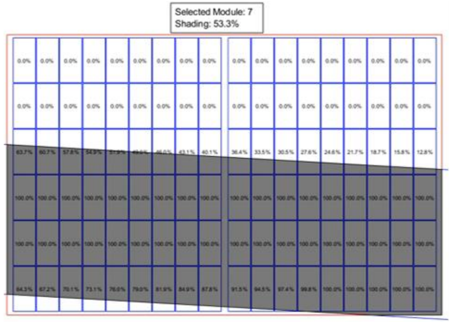
Annual Simulations

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









PVPS

C. Allenspach, F. Baumgartner, et al. Sol. RRL 2022, 2200596
IEA-PVPS T13-15:2021, April 2021, ISBN 978-3-907281-04

Results for different typical shading scenarios

Table 2 – Overview table of the «Shading Adaption Efficiency» (SAE) for the allMLPE and SINV systems with corresponding annual energy yield gains of the MLPE systems for various shading scenarios.

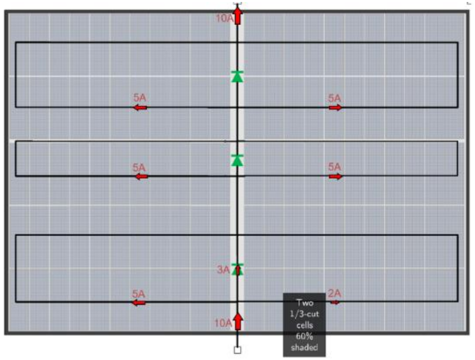
Cases	No:	Shading Severity	Shading index $SI_{DC,Max}$ [%]	Simulated annual yield [kWh] no shading & no loss [kWh]	no losses [kWh]	allMLPE [kWh]	SINV [kWh]	MLPE Gain [%]
Dormer (s)	1	Low	0.9	4410	4368	4207	4247	-1.0
Vent. Pipe	2	Low	2.9	4410	4282	4122	4129	-0.2
Chimney	3	Low	3.6	6337	6109	5904	5858	0.8
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

~ 3%
gain

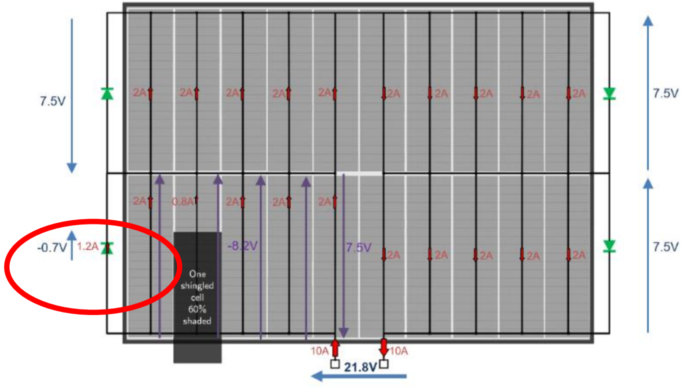
C. Allenspach, F. Baumgartner, et al. Sol. RRL 2022, 2200596
C. Allenspach, 4DO.1.1, EUPVSEC 2023

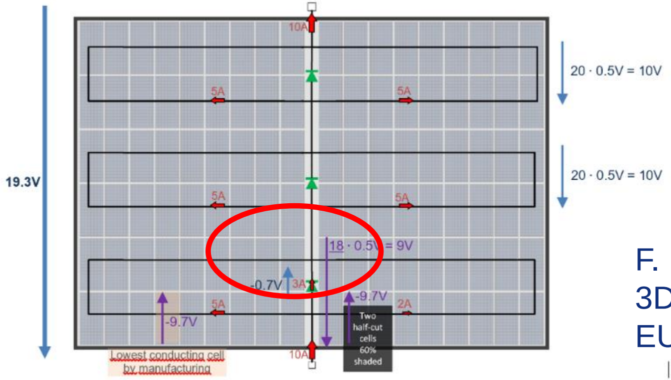
More bypass diodes – shading tolerant modules

3 BD in the reference standard module

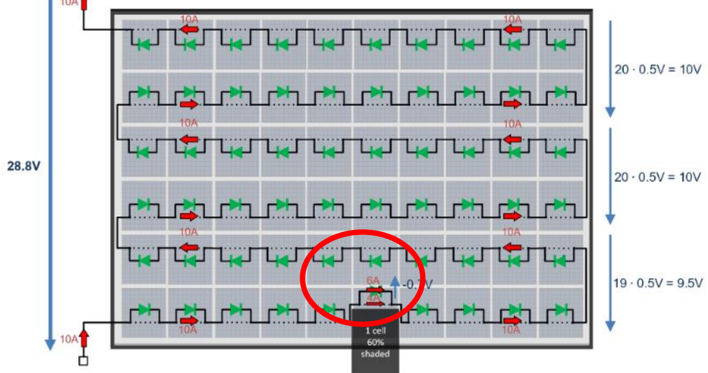


4BD in a shading tolerant module





each cell has a BD



F. Baumgartner,
3DO.16.1
EUPVSEC 2023

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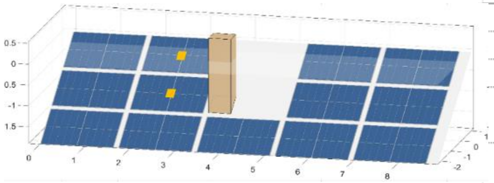
Shading tolerant PV modules are effective 1

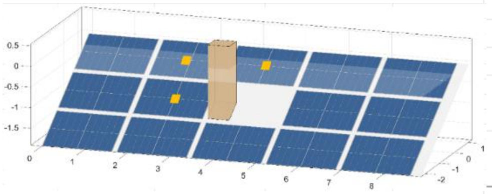


#13 PV modules
SI about 2%

+1.8%

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%

+3.1%

		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%

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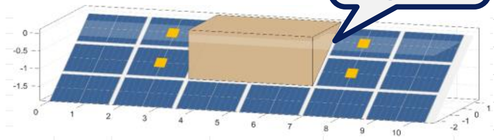
Shading tolerant PV modules are effective 2

smaller gap



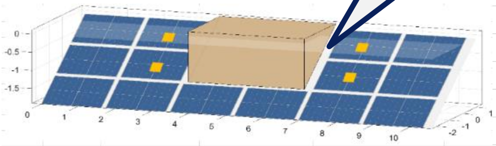
#14 PV modules
SI about 3 - 6%

+4.3%

		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	94.3	93.3	93.5	96.5	96.6	%
SINV	Relative Energy	88.4	87.4	87.1	90.8	92.3	%
indMLPE	Relative Energy	90.6	88.7	88.7	91.6	92.7	%
	MLPE Gain	1.4	1.4	1.7	0.8	0.3	%
allMLPE	Relative Energy	89.6	89.4	89.7	92.5	92.7	%
	MLPE Gain	2.4	2.2	2.9	1.8	0.4	%
	Average Rel. Energy	89.5	88.5	88.5	91.7	92.5	%

Max. SINV diff.: 5.1%
Max. indMLPE diff.: 3.9%
Max. allMLPE diff.: 3.0%
Max. Difference Tot: 5.5%

larger gap +15cm



#14 PV modules
SI about 3 -5%

+3.0%

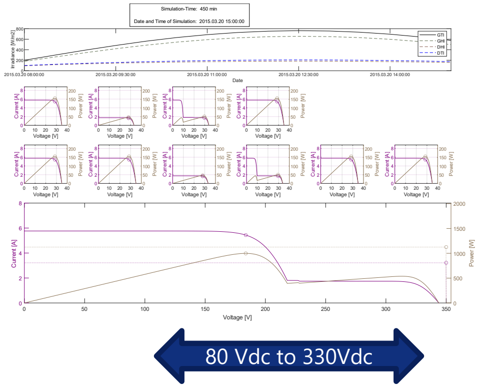
	Relative Annual Energy	Full Cell PV Module	Half-cut cell PV Module	Third-cut cell PV Module	Shading-resistant 4 quadrant	Shading-resistant All Cells + Diode	
	Unshaded + no losses			100			%
	shaded + no losses	95.2	94.4	94.6	97.3	97.1	%
SINV	Relative Energy	90.1	89.1	88.9	92.1	92.9	%
indMLPE	Relative Energy	91.0	90.0	90.1	92.6	93.1	%
	MLPE Gain	1.0	1.1	1.4	0.6	0.3	%
allMLPE	Relative Energy	91.4	90.4	90.8	93.2	93.1	%
	MLPE Gain	1.5	1.5	2.1	1.2	0.3	%
	Average Rel. Energy	90.8	89.8	90.0	92.6	93.0	%

Max. SINV diff.: 3.9%
Max. indMLPE diff.: 3.0%
Max. allMLPE diff.: 2.4%
Max. Difference Tot: 4.3%

Recommendations – Manufacturer

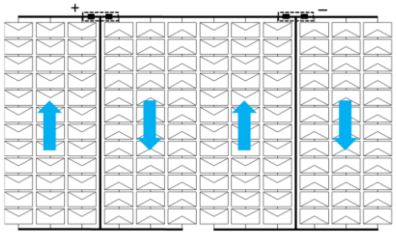
New power electronic components:

- ***Small strings for DC/AC*** need high eff. DC/DC components at lower DC voltage levels, (lower current) + arc detection
- Offer **higher inverter reliability, guarantee** due to operating condition in the building and not on the roof, reducing replacement costs which could significantly exceeds the purchase costs of initial optimizers + inverter
- Show typical system shading losses in your **data sheet** not only the EU or CA efficiency



New shading tolerant PV modules:

- with more than 3 bypass diodes e.g. half cell butterfly modules **6 bypass** or 4 bypass diodes (see L. Rendler 2023) **less hot spot temperatures**!
- all half-cells in serial to get **higher** inverter MPP input **voltages** -



L. Rendler, IEEE PVSC 2023

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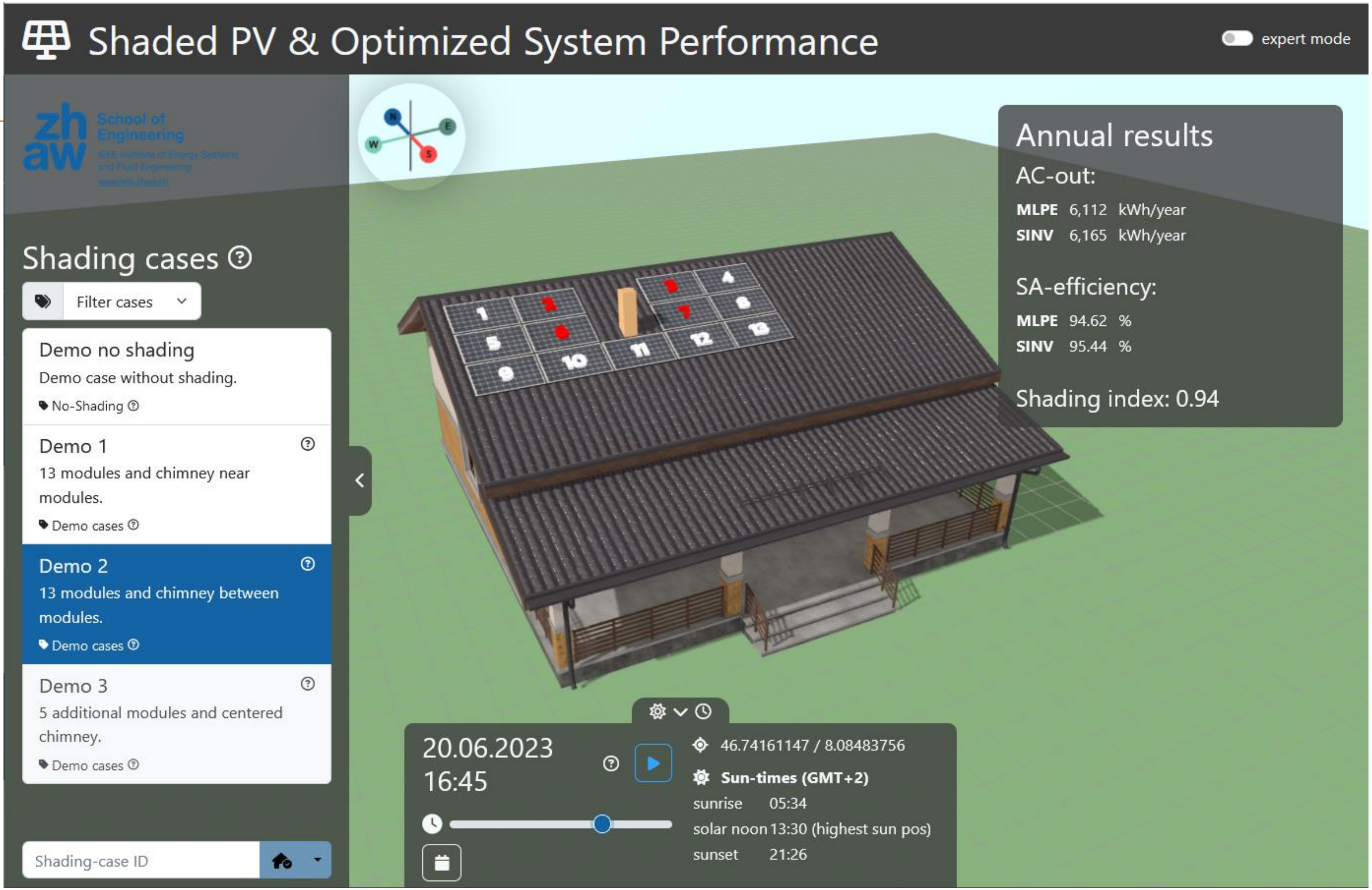

pvshade.engineegring.zhaw.ch website will be available in Jan 2024

PVPS

Shaded PV & Optimized System Performance

expert mode

Shading cases

Filter cases

Demo no shading
Demo case without shading.
No-Shading

Demo 1
13 modules and chimney near modules.
Demo cases

Demo 2
13 modules and chimney between modules.
Demo cases

Demo 3
5 additional modules and centered chimney.
Demo cases

Shading-case ID

System definition

description

	SINV	independent MLPE	all MLPE
Inverter type	Fronius, Symo 5kW	Fronius, Symo 5kW	Solaredge, SE3500
Optimizer system	-	Solaredge, P370	Solaredge, P370
Module type	**13** x JA Solar - JAM60S20 375/MR		

Inclination: 25° **Plant size:** 23.7 m² **Peak power:** 4.9 kW
Rotation: 180° **Theoretical DC-max:** 6,459.5 kWh

Environment

Pos.: 8.08484 / 46.74161 (lon/lat)
Albedo: 0.17
Shading index: 0.941

Simulation

Time-period: 2018-01-01 / 2018-12-31
Sim-steps: 30 min

Annual results

analyse single PV-modules

Performance ratio: 0.95

	SINV	independent MLPE	all MLPE
AC-out	6,164.8 kWh (-0.06%)	6,168.7 kWh	6,111.9 kWh (-0.92%)
DC-out	6,422.6 kWh	6,426.6 kWh	6,320.6 kWh
AC-out (specific)	1,264.6 kWh/kWp	1,265.4 kWh/kWp	1,253.7 kWh/kWp
SA-efficiency (AC)	95.44 %	95.5 %	94.62 %
SA-efficiency (DC)	99.43 %	99.49 %	97.85 %
Total energy loss (to DC max.)	-4.56 %	-4.5 %	-5.38 %

pvshade.engineegring.zhaw.ch website will be available in Jan 2024

Final Recommendation to PV planer/installers

- **Inform the customer** about the expected **performance difference** with your plant layout **with or without optimizer** or **shading tolerant modules** in % of annual yield
- **Inform** the customer about the **replacement costs** of power electronic equipment, inverter and optimizer **including labour cost on the roof**!
- Use **standard string inverter** for **light shading** e.g. one chimney to reduce risk of replacement costs
- **Medium and strong shading** or more shading objects– use
  shading tolerant modules for robust solution (risk of replacement costs also reduced)
  or
  independent optimizer for a few PV modules which are shaded during the highest irradiation a day for a few hours e.g. > 4 hours, or check the availability of shading tolerant PV modules
- Use **all optimizer solution** for **small strings** <8 PV modules and **different orientation** of modules in the PV generator and out of range of the string inverters numbers or MPP inverter tracker
- Ask for **commercial deep technical and reliable PV planning tools** using real **losses of each optimizer** and not the limited available efficiency number at selected unrealistic operating points at simulation runs **periods** smaller then **half an hour**

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pvshade.engineegring.zhaw.ch, Jan 2024 website will be active
IEA T13 Report, PV Shading & MLPE, will be published in 2024
talks videos about optimizer https://youtu.be/NlLg1MOyvWg

IEA PVPS