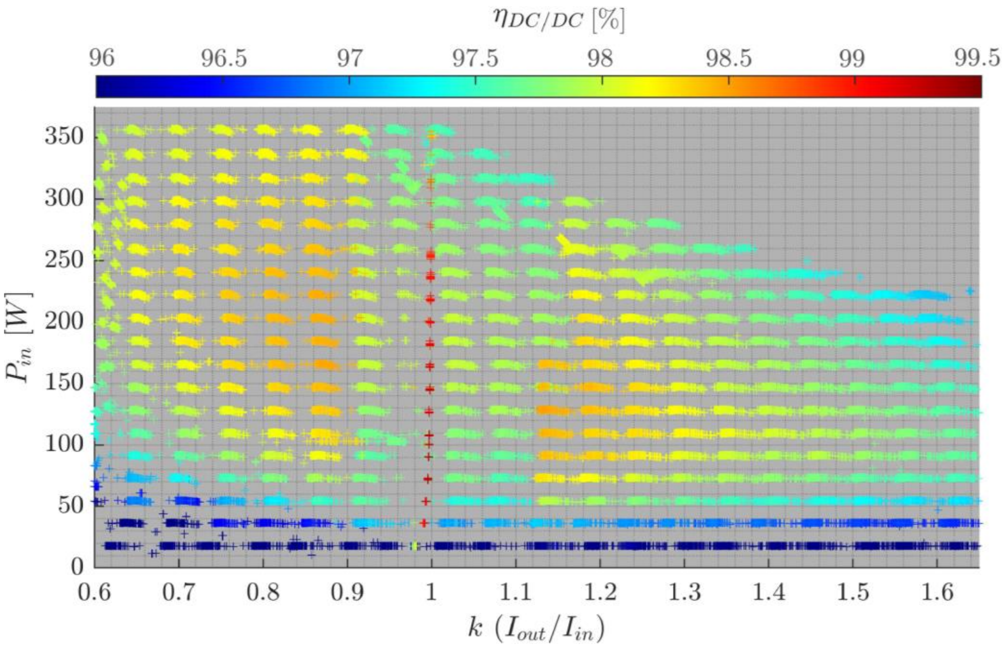

PV system performance of different power conditioner and shading index

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EUPVSEC-40, Lisbon, Portugal, 21st September 2023

State of the art – PV shading

- Partial shading leads to operational challenges, as it produces non-uniform operating conditions in the PV system.
- Power Optimizer are proposed as solution, due to the fact that they can individually operate the equipped modules.
- However, previous studies have shown that common Power Optimizer models have significant conversion losses, which will reduce the potential energy yield gain by the distributed MPPT.[1]
- Therefore, a PV system that is equipped with independent Power Optimizer, only at the PV modules that are affected by partial shading, might offer the best solution for rooftops that encounter only little or localized shading.

[1] C. Allenspach, F. Carigiet, A. Bänziger, A. Schneider and F. Baumgartner; "Power Conditioner Efficiencies And Annual Performance Analyses With Partially Shaded Photovoltaic Generators Using Indoor And Shading Simulations," Solar RRL, Wiley, 2022.

Publications on MLPE

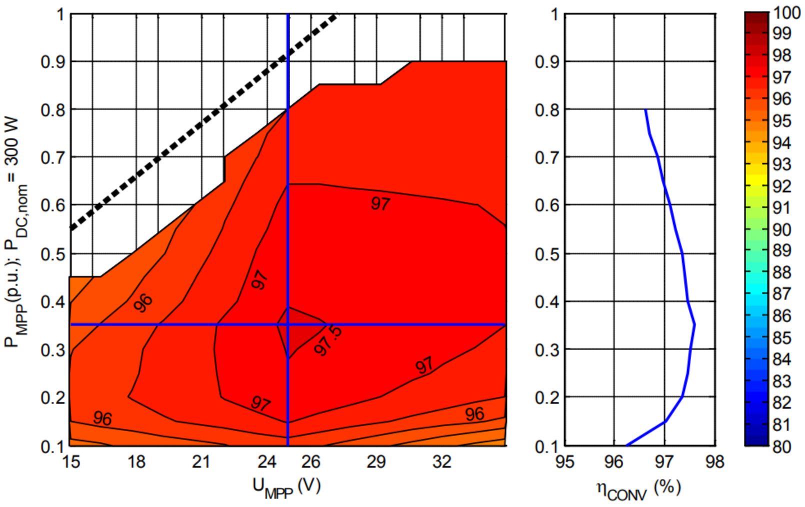


Figure 1 – First independent Indoor laboratory measurement for DC/DC-conversion efficiency of a Power Optimizer by Bründlinger [2]. The mapping shows the measured conversion efficiency at an output voltage of 25V.

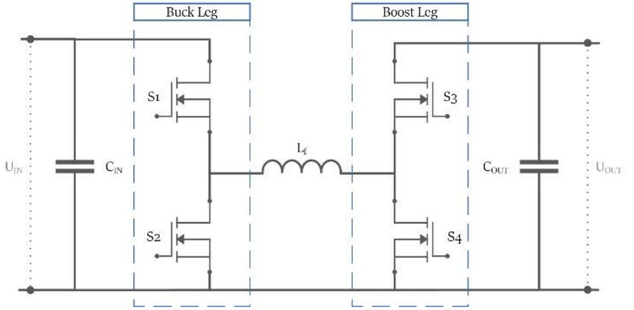


Figure 2 – Topology of a «Four-switch, buck-boost DC/DC converter», which is comparable to the circuitry of a SolarEdge Power Optimizer.

Shading Index (SI) by NREL [3]:

$$SI = 1 - \frac{\sum P_{modX,actual}}{\sum P_{modX,unshaded}} \qquad (1)$$

[2] R. Bründlinger, et al., «Module integrated power converters - a comparison of state-of-the-art concepts and performance test results», In Proceedings of the 26th European Photovoltaic Solar Energy Conference and Exhibition (EUPVSEC), pages 3204 – 3211, Munich, Germany, 2011. WIP Renewable Energies.

[3] A. J. Hanson, et al., «Partial-shading assessment of photovoltaic installations via module-level monitoring», IEEE Journal of Photovoltaics, 4(6):1618–1624, 2014.

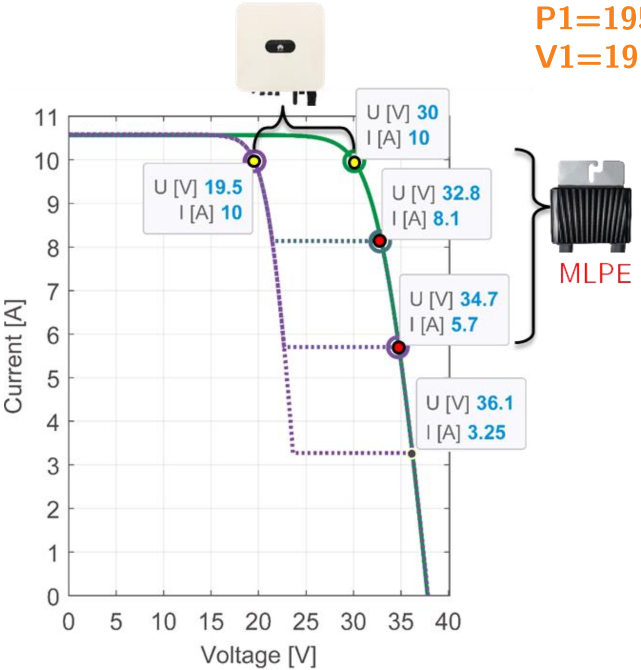
Shading effects and module-level MPPT

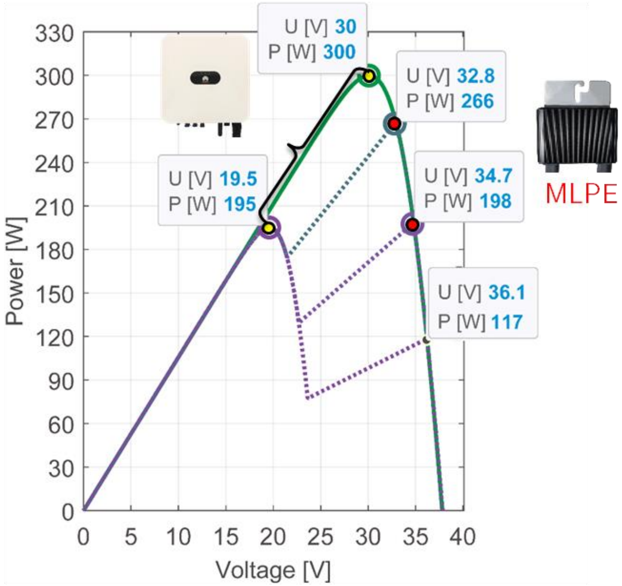
Single Cell shaded by 20% (MLPE benefical), 43% (equal), 66% (MLPE same to SINV)

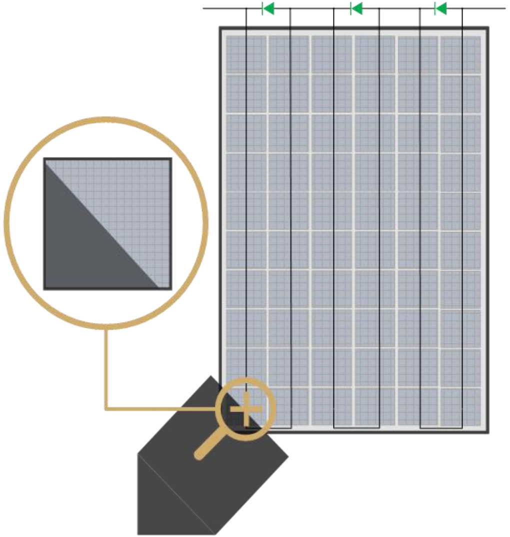
Pn=300W

P1=195W | P2=266W | P3=198W

V1=19.5V V2=32.8V V3=34.7V

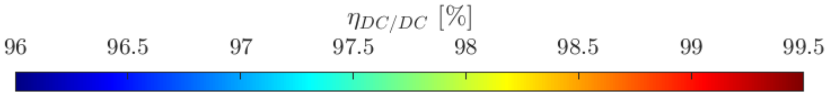






[4] F.Baumgartner, «ZHAW School of Engineering – PV Research Collection», [Online]. Available: www.zhaw.ch/~bauf

Power Optimizer DC/DC-efficiency



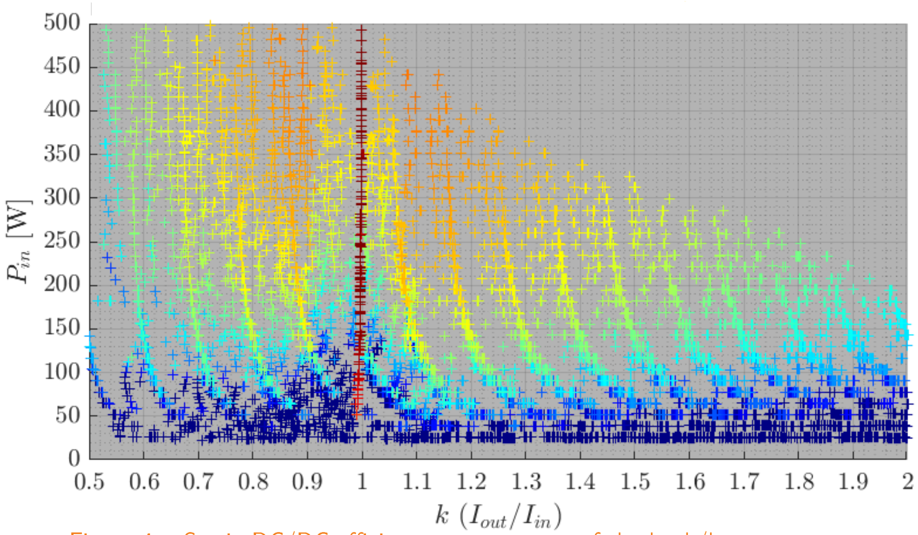


Figure 4 – Static DC/DC-efficiency measurement of the buck/boost-type power optimizer SolarEdge S500B at static input voltage U_{IN} = 35 V relative to input/output current ratio.[5]

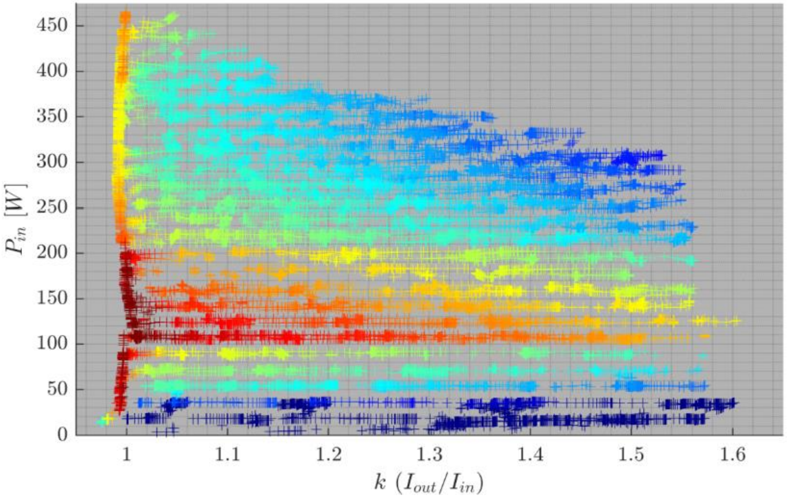


Figure 5 – Static DC/DC-efficiency measurement of the buck-type power optimizer of model Tigo TS4-R-O at an input voltage U_{IN} = 35V relative to input/output current ratio.[6]

[5] SolarEdge Technologies Inc., «SolarEdge Residential Offering for Installers», [Online], Available: www.solaredge.com/sites/default/files/residential_catalogue_eng.pdf.

[6] TigoEnergy Inc., «TigoTS4-A-O -Case Study: Harvesting 36% Energy with Optimization», [Online], Available: www.tigoenergy.com/product/ts4-a-o.

Power Optimizer DC/DC-efficiency

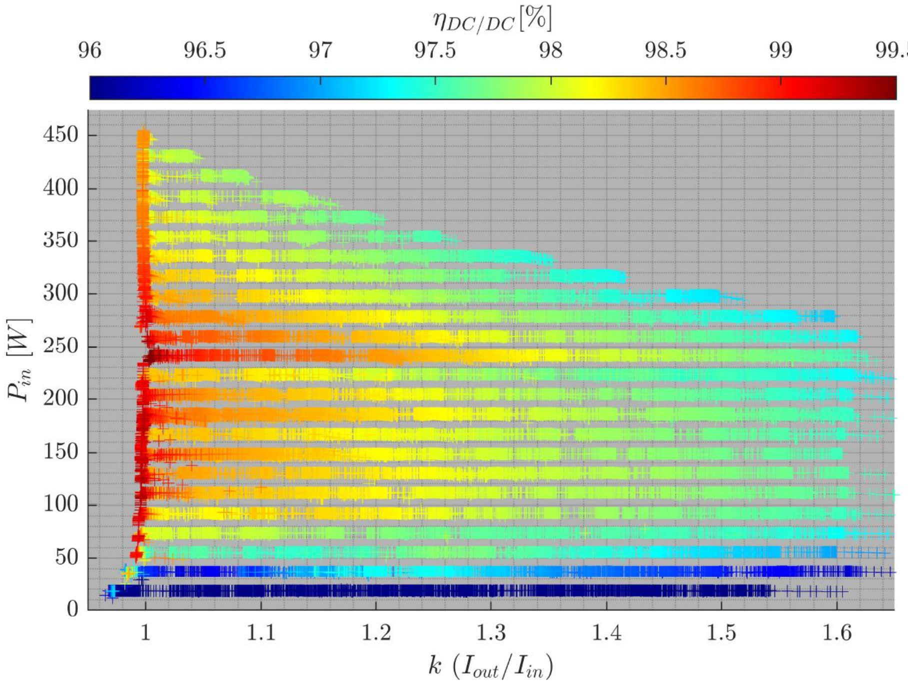


Figure 6 – Static efficiency measurement of the buck-type power optimizer Huawei SUN2000-450W-P at a constant input voltage of 35V as a function of $k_I = I_{OUT}/I_{IN}$ and P_{IN} [W].[7]

- Data sheet values: 99.5% max. & 99% wgt. efficiency can only be found at k=1.[6]
- In normal operation: 97.5 - 98.3% weighted DC/DC efficiency according to measurement.

Table 1 – Mean weighted DC/DC efficiencies of the measured Power Optimizer models, based on the Euro efficiency method for inverters.[8]

Name	k=0.7	k=0.9	k=1	k=1.1(*)	k=1.25(*)	k=1.5(*)	Unit
P370	97.8	98.1	99.0	97.5	98.0	97.3	%
450W-P	-	-	99.1	98.3	98.0	97.5	%
TS4-R-O	-	-	98.9	98.0	97.6	97.2	%

[7] Huawei Technologies Co. Ltd., «Datasheet -SUN2000-450W-P»,[Online], Available: solar.huawei.com/en-GB/datasheet-SUN2000-450W-P.pdf.

[8] Franz Baumgartner (author), Nicola Pearsall (editor). «The Performance of Photovoltaic (PV) Systems, Chapter 5: Overall efficiency of grid connected photovoltaic inverters (references to EN 50530:2010+A1:2013)». Elsevier, London, GB, 2017.

MLPE Performance in different shading severities

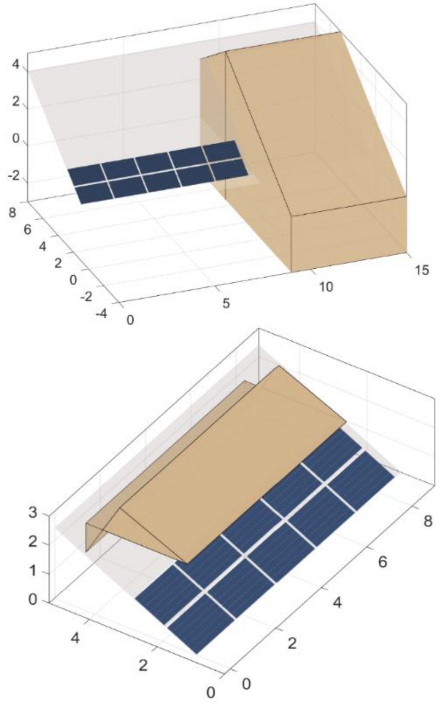


Figure 7 – 3D model of the PV system "Building" (top) and for PV system "Roof Edge" (bottom).

- SINV: SUN2000-3.68KTL-L1 ($\eta_{EURO} = 97.3\%$)
  allMLPE: SE3500H ($\eta_{EURO} = 98.8\%$) und P370 Power Optimizer
- Höchster und tiefster SAE-Wert ergab sich beim SINV-System

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]				MLPE Gain [%]
				no shading & no loss [kWh]	no losses [kWh]	allMLPE [kWh]	SINV [kWh]	
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

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