Berner Fachhochschule
Haute école spécialisée bernoise
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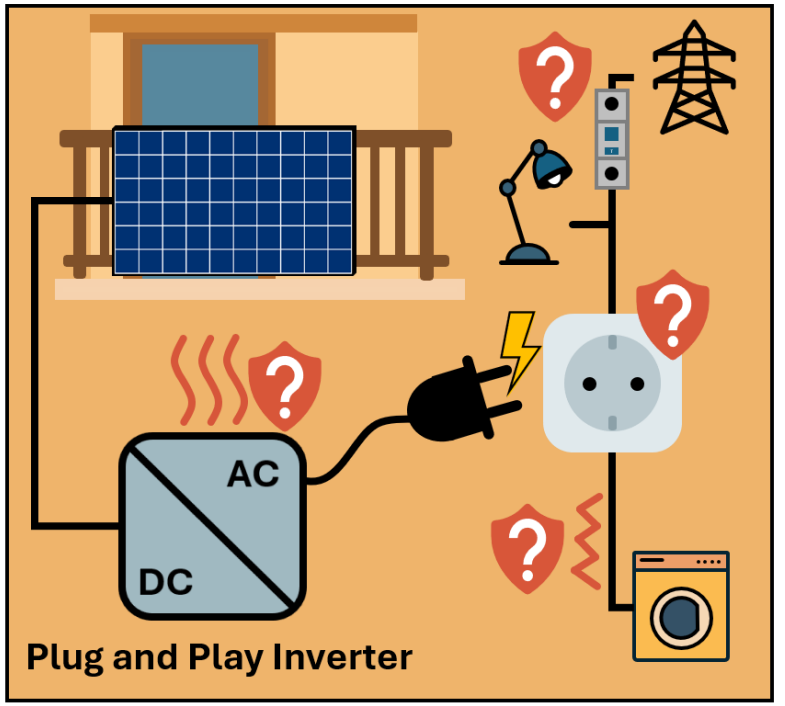
ASSESSMENT OF PERSONAL SAFETY CONCERNS OF PLUG AND PLAY PHOTOVOLTAIC INVERTERS USING A BLACK BOX APPROACH AND LABORATORY MEASUREMENTS

EU PVSEC, Bilbao, 25th of September 2025, Alexander Erber

- Bern University of Applied Sciences | Laboratory for Photovoltaic Systems

Situation of plug and play PV systems

- Rapid growth, notably in Germany
  - June 2025: 1 million registered systems (>1 GWp)
  - Total system numbers considerably higher
  - Most systems sold with Type F plug [1]
- Safety concerns of these systems [2]
  - Installation and personally safety
- Inverter standards (e.g. IEC 62109) only partly cover the inverter concerns
- **Limited data/studies available**
- **Plug and play PV inverters $\stackrel{?}{=}$ microinverter**



[1] J. Bergner et al, 2022,"Der Markt für Steckersolargeräte", https://solar.htw-berlin.de/studien/marktstudie-steckersolar-2022/
[2] H. Laukamp et al.,2022, "Entwicklung einer Produktnorm für Steckersolargeräte," in 37. PV-Symposium/BIPV-Forum 2022

Safety Test in the Laboratory

Literature and standard research

- exchange with experts and standard groups
- Condensed test plan to three main tests

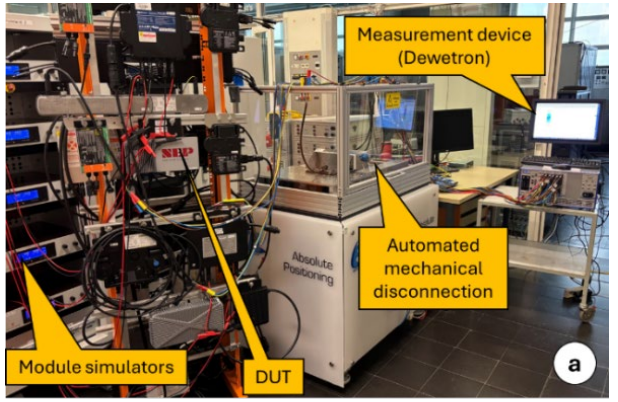
Test approach

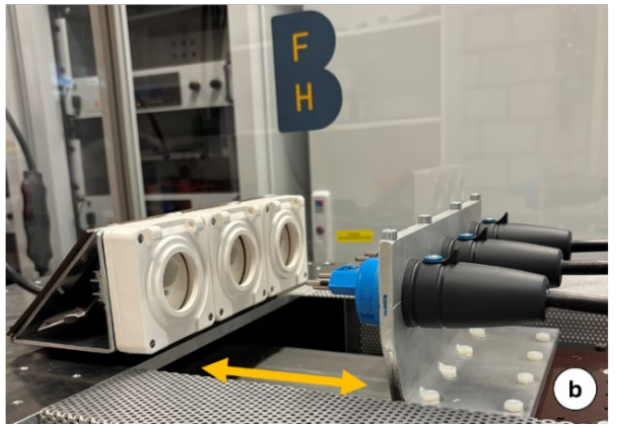
- Black box approach
- 25 inverters to test

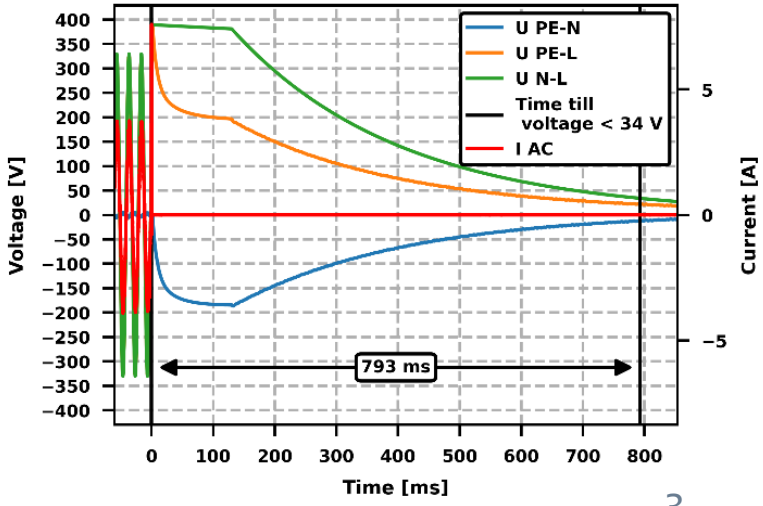
Power category	Power range of category [VA]	Power range of invertrs	Number of inverters
A	<=600	300-600	16
B	>600 & <=800	601-800	5
C	>800	801-2000	4

1.Test: Residual voltage test

- Realistic conditions and repeated measurements (30-50 per inverter)
- Compliancy limit of E DIN VDE V 0126-95:2024-6 (<34 V after 1s)







Safety Test in the Laboratory

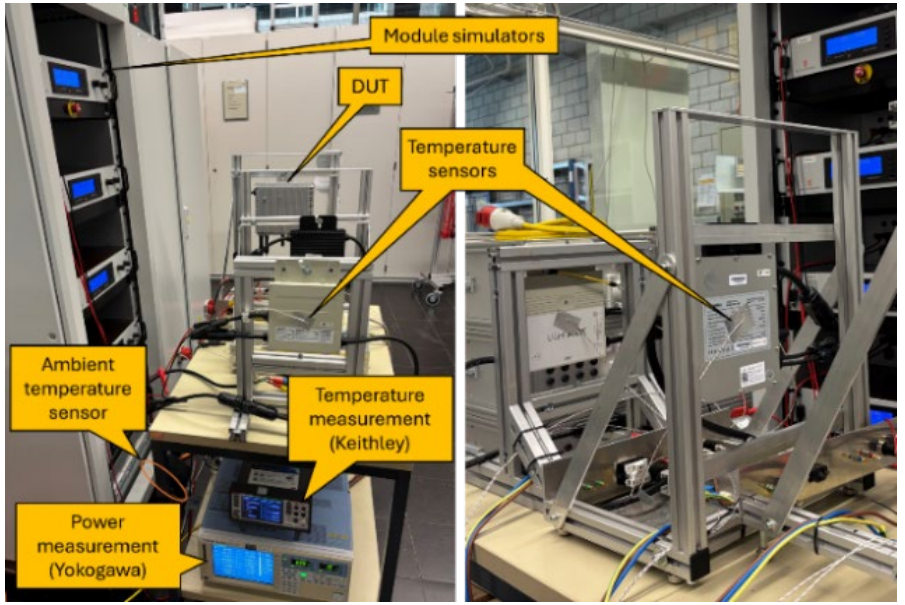
2. Test: Maximum Touch Temperature

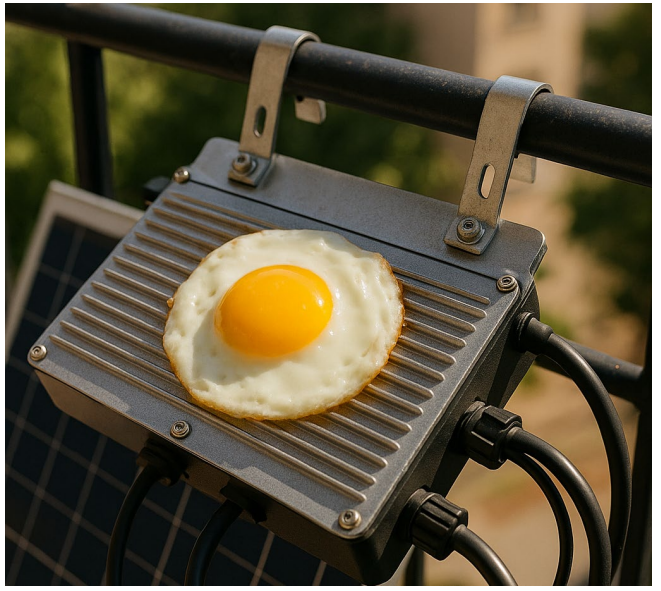
- Determine max. stationary touch temperature @ nominal DC power & overpanelling (150%)
- Limits of IEC 62109-1 (70 °C/95 °C)

3. Test: Limitation of Feed-in Current at Low Grid Voltage

- Determine the max. increase of current
- Voltage profile with reduced testing time (30s steps to 0.7 p.u)
- Limit (E DIN VDE V 0126-95:2024-6): 3.5 A +2%

A detailed measurement steps can be found in the supporting information of our Solar RRL Article (in production)



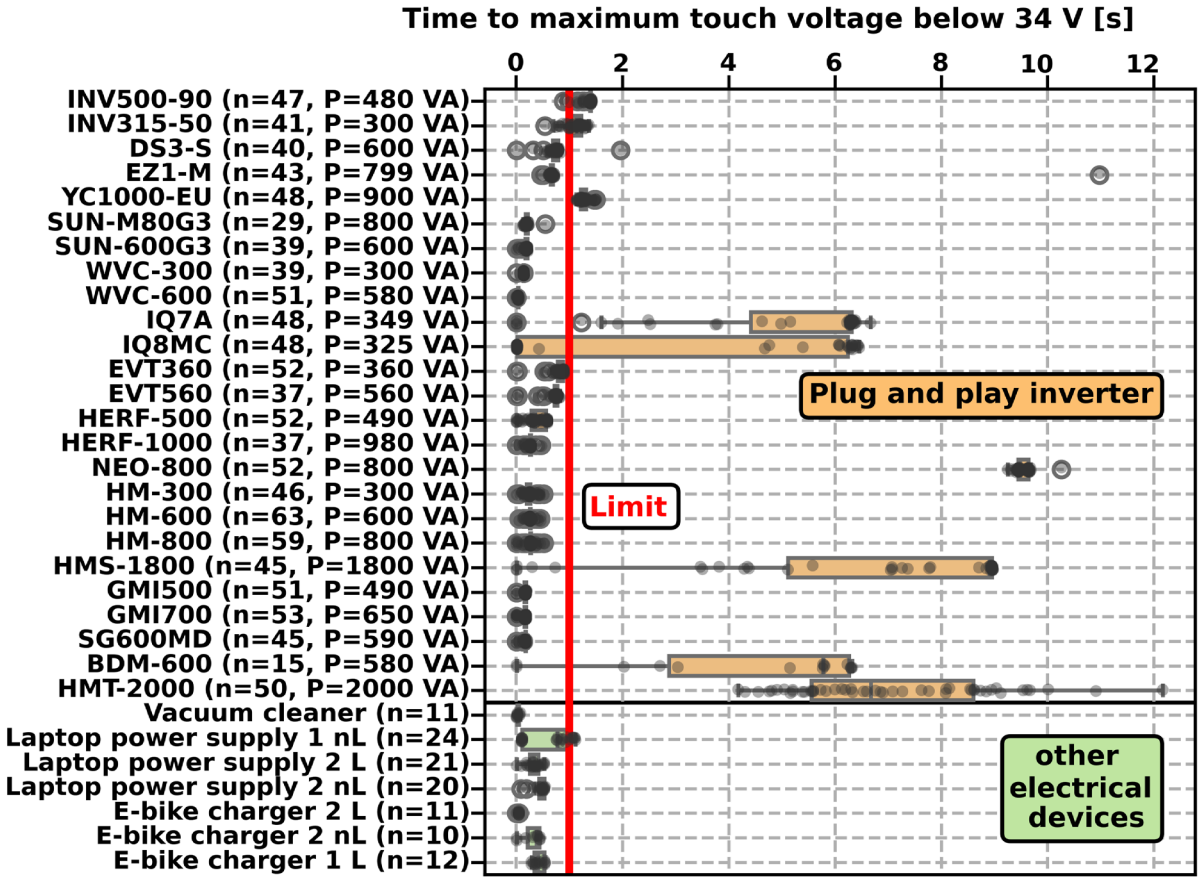


AI generated

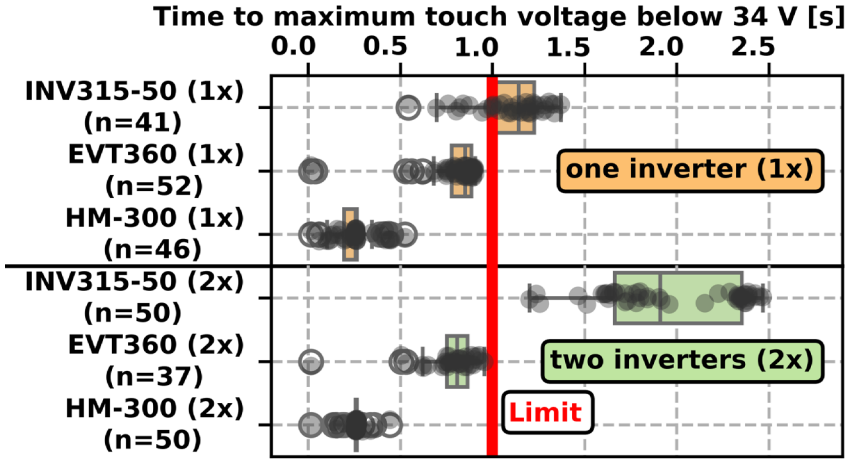
Further “hot” research → 4CV.1.61

Residual Voltage Test

- Times to 34 V: 15 ms to 12 s
- 56% compliancy of tested inverters

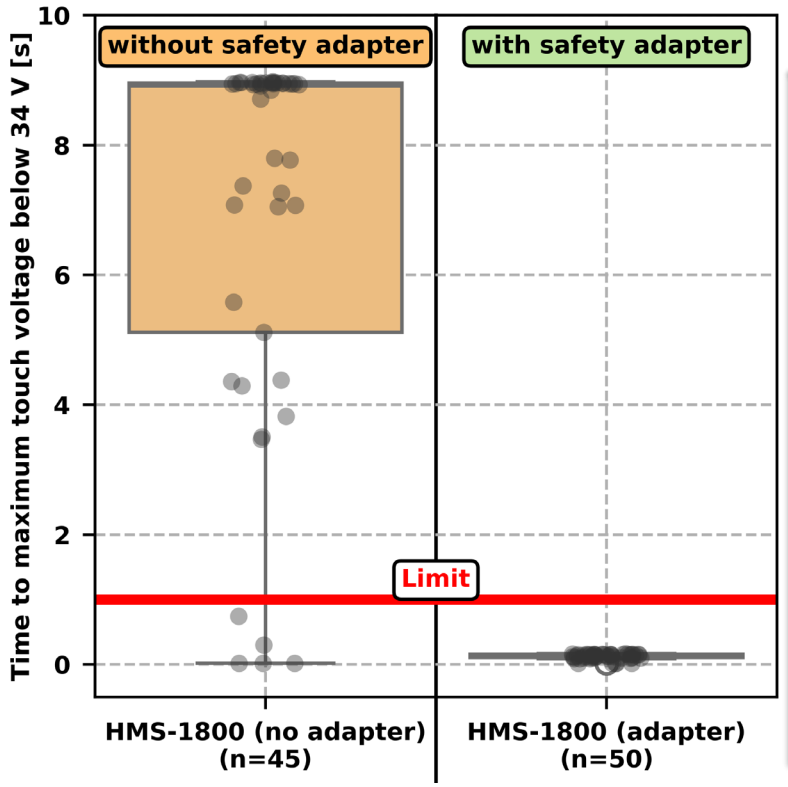


- Phase-angle dependency could be partly confirmed
- System testing for systems with more than one inverter is recommended

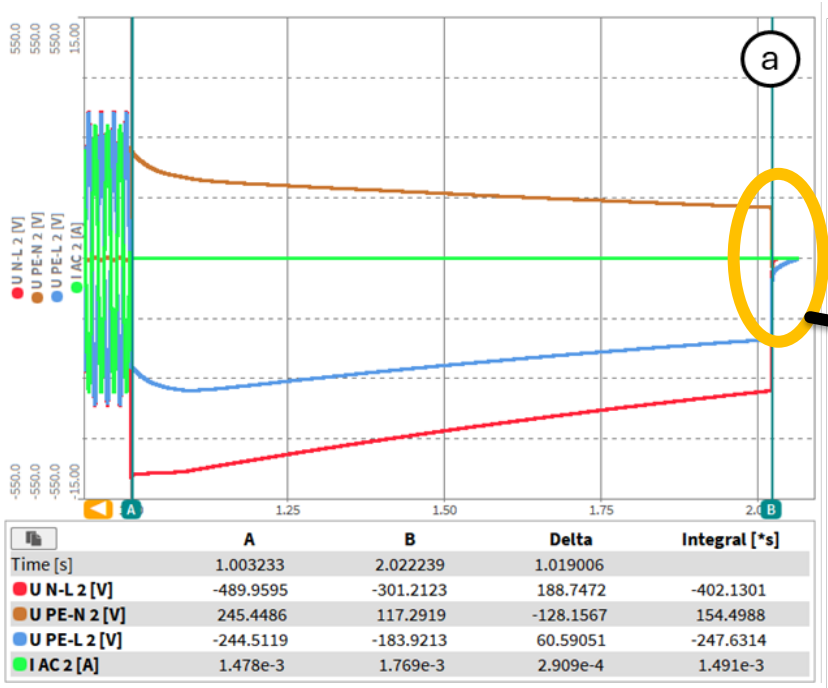


Residual Voltage Test

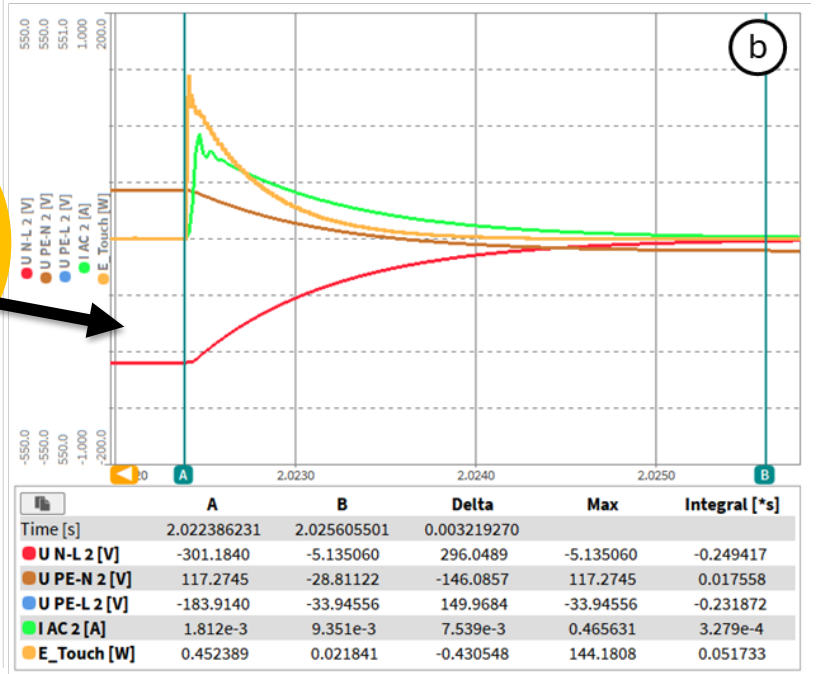
- Safety adapter (touch safety + optional discharge functionality) for a compliant system



- Exemplary measurement:
  Touching L and N (finger to finger) after 1s with a 1 kOhm body resistance
  - 1 non-compliant inverter
  - Energy: 52 mJ
  - Peak current: 465 mA
  - Time: 3.2 ms



	A	B	Delta	Integral [*s]
Time [s]	1.003233	2.022239	1.019006	
U N-L 2 [V]	-489.9595	-301.2123	188.7472	-402.1301
U PE-N 2 [V]	245.4486	117.2919	-128.1567	154.4988
U PE-L 2 [V]	-244.5119	-183.9213	60.59051	-247.6314
I AC 2 [A]	1.478e-3	1.769e-3	2.909e-4	1.491e-3

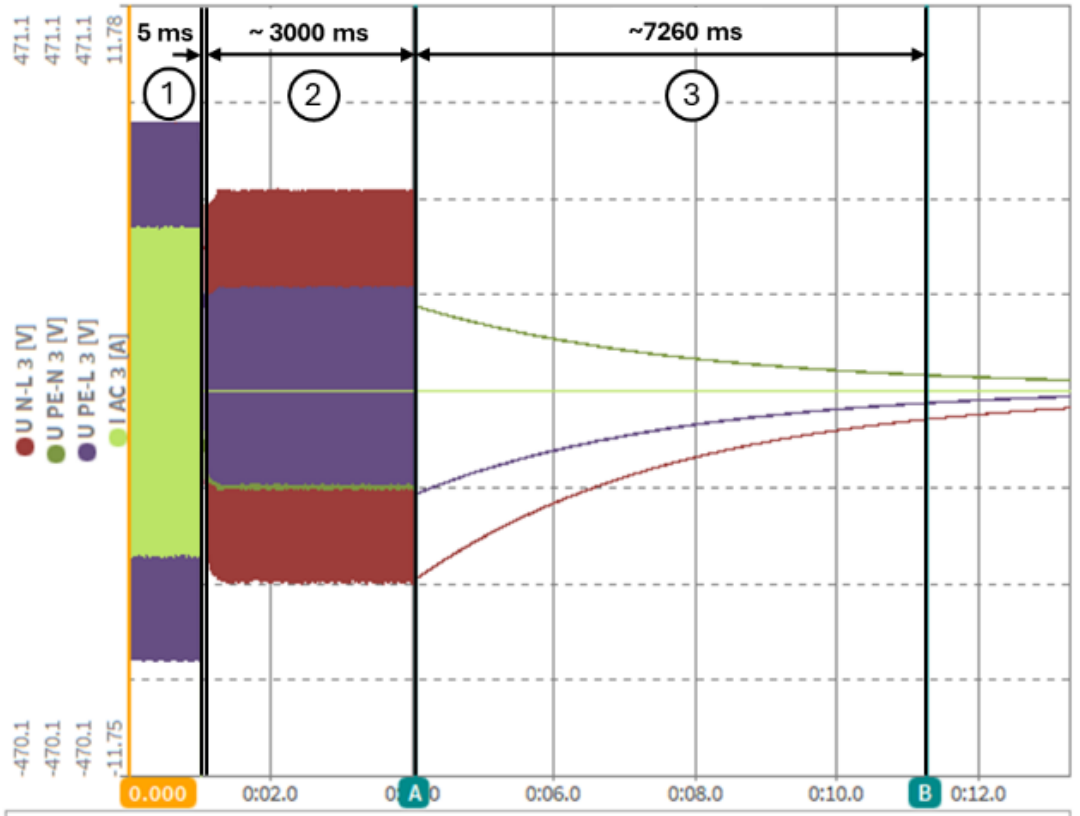


	A	B	Delta	Max	Integral [*s]
Time [s]	2.022386231	2.025605501	0.003219270		
U N-L 2 [V]	-301.1840	-5.135060	296.0489	-5.135060	-0.249417
U PE-N 2 [V]	117.2745	-28.81122	-146.0857	117.2745	0.017558
U PE-L 2 [V]	-183.9140	-33.94556	149.9684	-33.94556	-0.231872
I AC 2 [A]	1.812e-3	9.351e-3	7.539e-3	0.465631	3.279e-4
E_Touch [W]	0.452389	0.021841	-0.430548	144.1808	0.051733

Residual Voltage Test

- Problematic behaviour of complaint device
  - 1 out of 52 measurements
  - Islanding after grid disconnection
  - Fault-ride through for 3 s
  - Disconnection through voltage drop protection time (<0.8 V_N for 3 s)

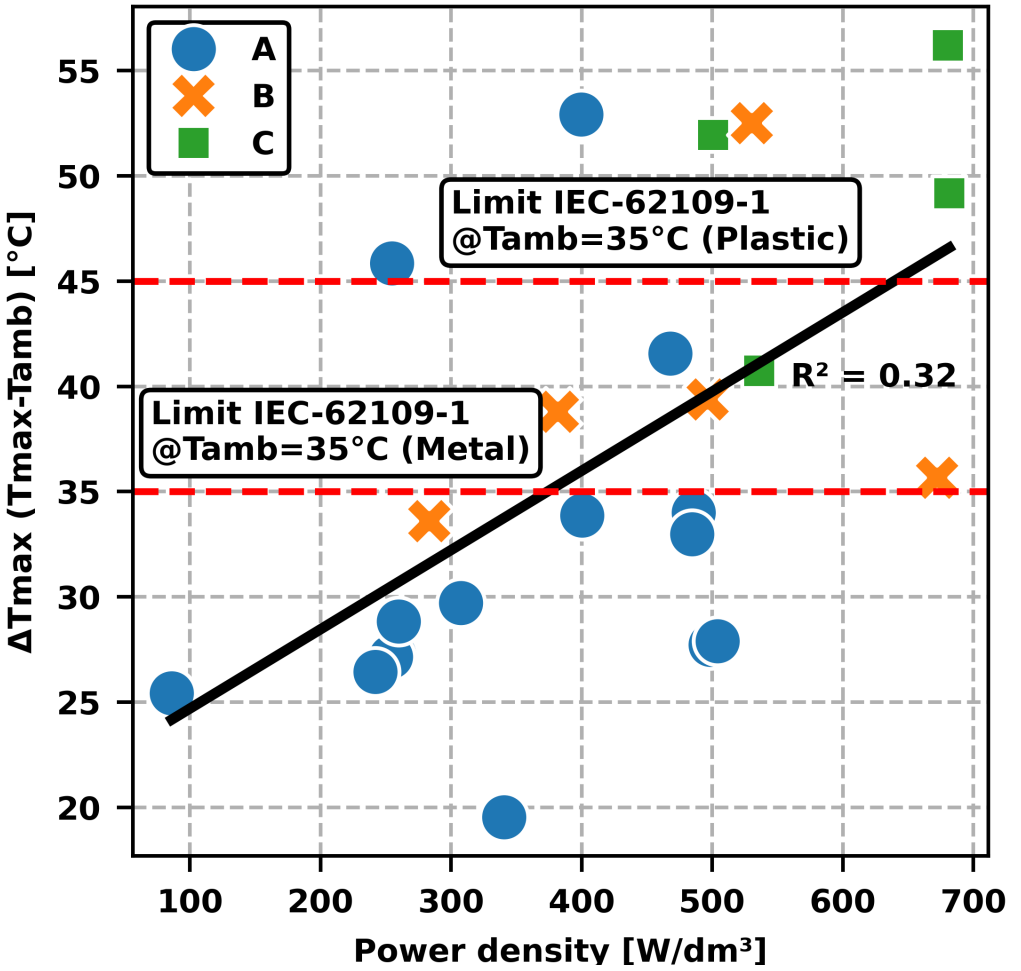
- **Reduced grid profile/code for plug and play inverters**



	A	B	Delta
Time [s]	4.04699	0:11.26454	7.21755
U N-L 3 [V]	-228.3714	-33.97536	194.3960
U PE-N 3 [V]	104.3599	19.81878	-84.54109
U PE-L 3 [V]	-123.9855	-14.13059	109.8549
I AC 3 [A]	4.556e-4	1.600e-4	-2.956e-4

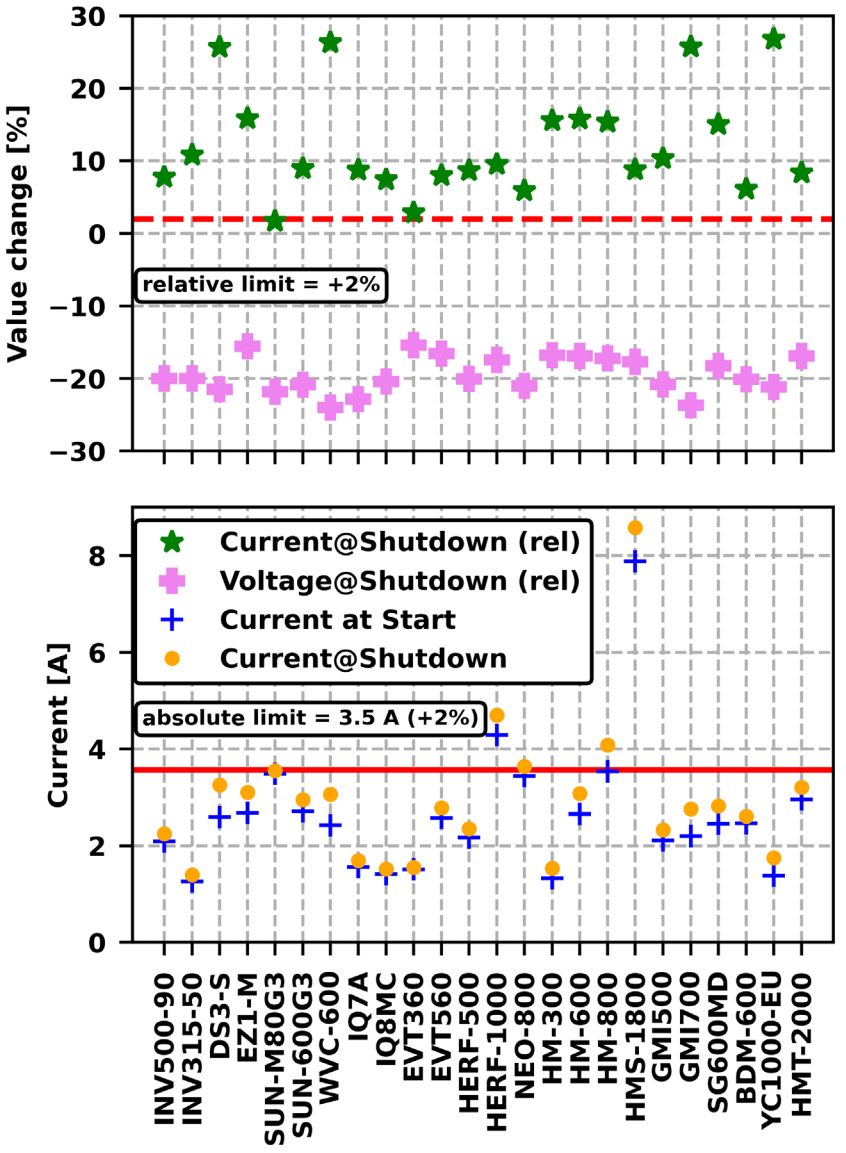
Maximum Touch Temperature

- Maximum touch temperatures:
  43.40 °C to 80.33 °C (~23 °C ambient temp)
- 18 inverter (75%) comply with limits
- Ambient temperature dependency
- Correlation between power density and power dependent temperature increase
- **A microinverters is a non-touchable system part, a plug and play inverter is touchable**



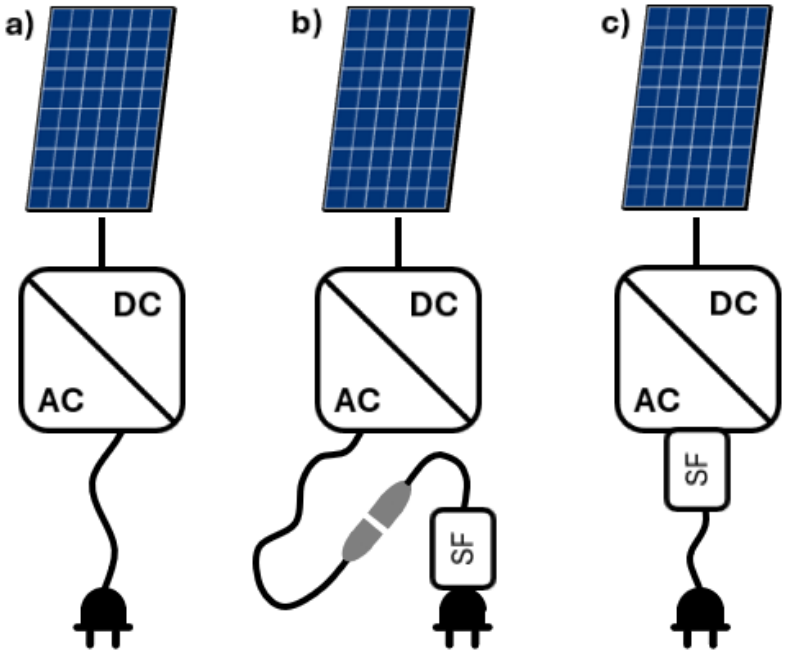
Limitation of Feed-in Current at Low Grid Voltage

- Current increase between 1.7% to 26.3%
- Absolute limit (3.5 A +2%)
  - 4 non-compliant inverters
- Relative limit (+2%)
  - Only 1 compliant inverter
- Absolute vs relative limit?
  - Relative limit for uniform requirements



Conclusions and Recommendations

- Residual voltage
  - 56% compliancy rate of tested set
  - System testing is recommended
  - Different solutions for this concern (without and with additional hardware)
  - Separate and reduced grid profile
- Touch temperature
  - Inclusion in plug and play system standard(s) and note in IEC 62109-1
  - More smaller inverters are better than one single inverter
  - Larger power limited inverter(?)
- Limitation of Feed-in Current
  - Fix through software update(?)
- **Plug and play PV inverters ≠ microinverter**



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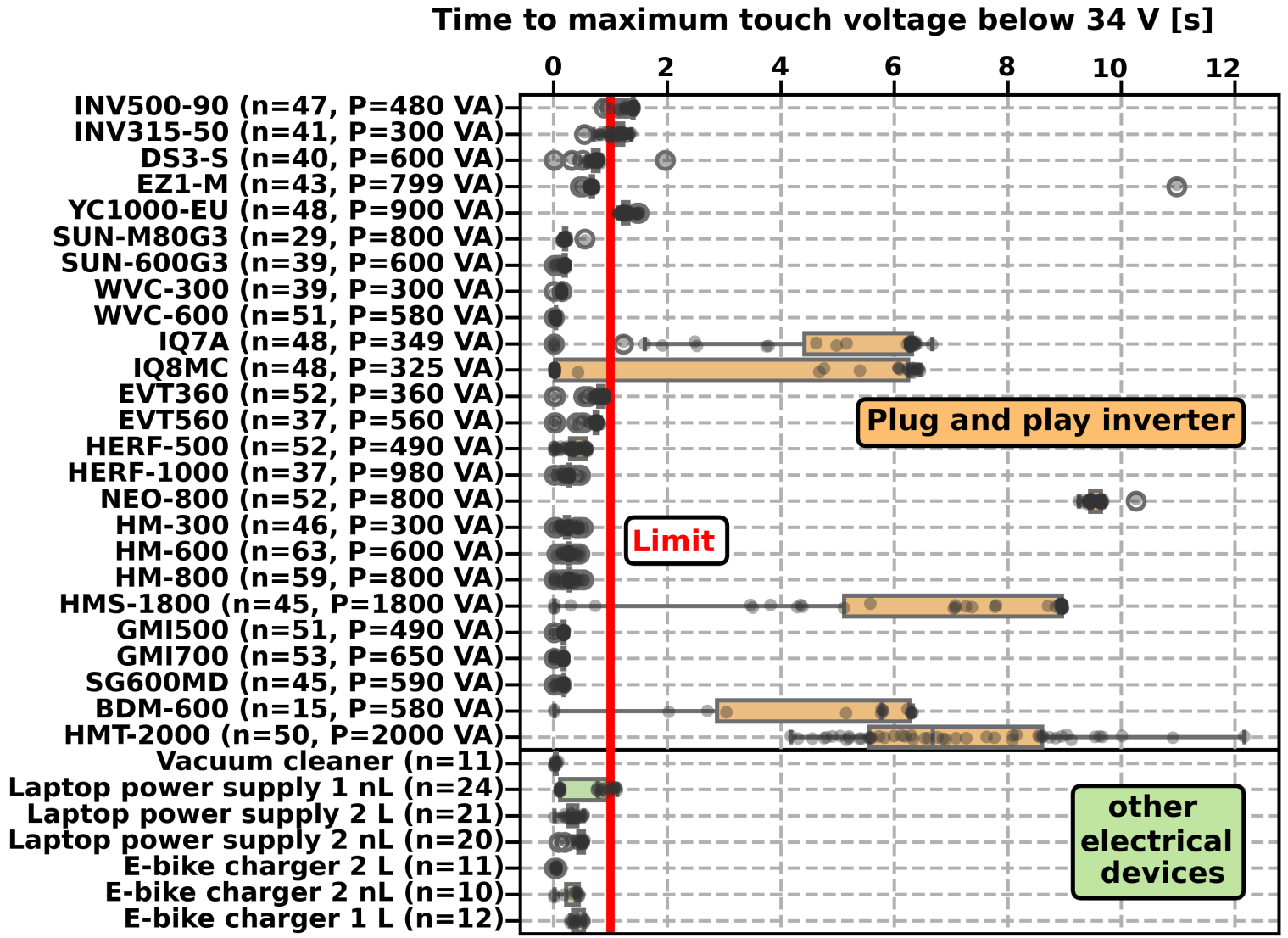
Merci PV-Lab and thank you for your attention!

Project information and contact

ACKNOWLEDGEMENT
This research was carried out in the project “Plug & Play Photovoltaic Systems” funded by the Swiss Federal Office of Energy (Project number SI/502662). The responsibility for the content and conclusions lies solely with the authors.

Residual Voltage Test

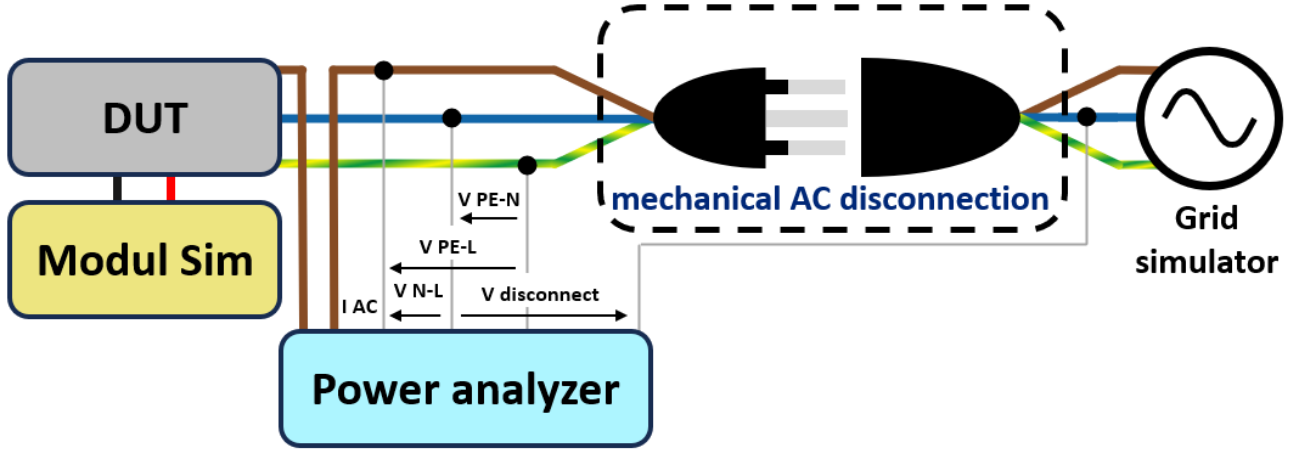


Inverter	R_{L-N} [kOhm]	C_{L-N} [nF]	share of values exceeding the VDE limit
INV500-90	140	380	95.7%
INV315-50	1300	416	73.2%
DS3-S	OL	98	2.5%
EZ1-M	OL	100	2.3%
YC1000-EU	OL	400	100%
SUN-M80G3	900	90	-
SUN600G3	950	89	-
WVC-300	OL	OL	-
WVC-600	OL	OL	-
IQ7A	120	924	89.6%
IQ8MC	55	980	39.6%
EVT360	810	587	-
EVT560	712	487	-
HERF-500	198	433	-
HERF-1000	194	440	-
NEO-800	OL	1455	100%
HM-300	200	435	-
HM-600	196	424	-
HM-800	197	438	-
HMS-1800	OL	1100	88.9%
GMI500	OL	OL	-
GMI700	OL	OL	-
SG600MD	OL	OL	-
BDM-600	OL	1800	86.7%
HMT-2000	OL	1872	100%

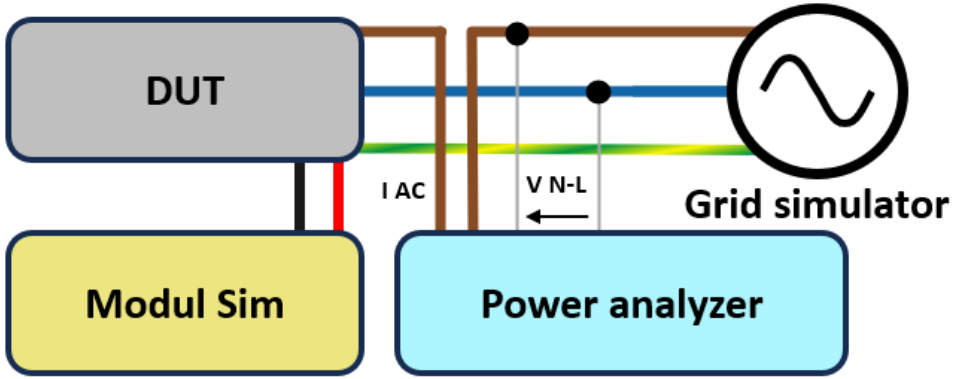
- OL = open load

Measurement Setup

- Residual Voltage Test



- Limitation of Feed-in Current at Low Grid Voltage



- Maximum Touch Temperature