VSL

National Metrology Institute

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Verstoringen bij statische elektriciteitsmeters

CE-markering en productaansprakelijkheid bij elektronicaproducten

11 mei 2022, FHI, Leusden

Helko van den Brom, VSL, Delft

About VSL

- National Metrology Institute of the Netherlands
- Company with a public task
- 100 fte, 40 % MSc or PhD
- Calibrations, reference materials, R&D, consultancy, training
- Focus on energy and industry
- Located in Delft, the Netherlands

Static Energy Meter Errors Caused by Conducted Electromagnetic Interference

Frank Leferink[1,2], Cees Keyer[1,3], Anton Melentjev[3]

[1]University of Twente Enschede, The Netherlands

IEEE EMC magazine, vol. 5, no. 4, pp. 49 – 55, Dec 2016

BOINGBOING / CORY DOCTOROW / 1:46 PM SAT MAR 11, 2017

Smart meters can overbill by 582%

The Telegraph HOME | NEWS | SI

News

UK | World | Politics | Science | Education | Health | Brexit | Royals | Investigation

News

Smart energy meters giving readings up to six times too high, study finds

Finances personnelles > Informations > Actualités

Certains compteurs intelligents surestimeraient la consommation en électricité

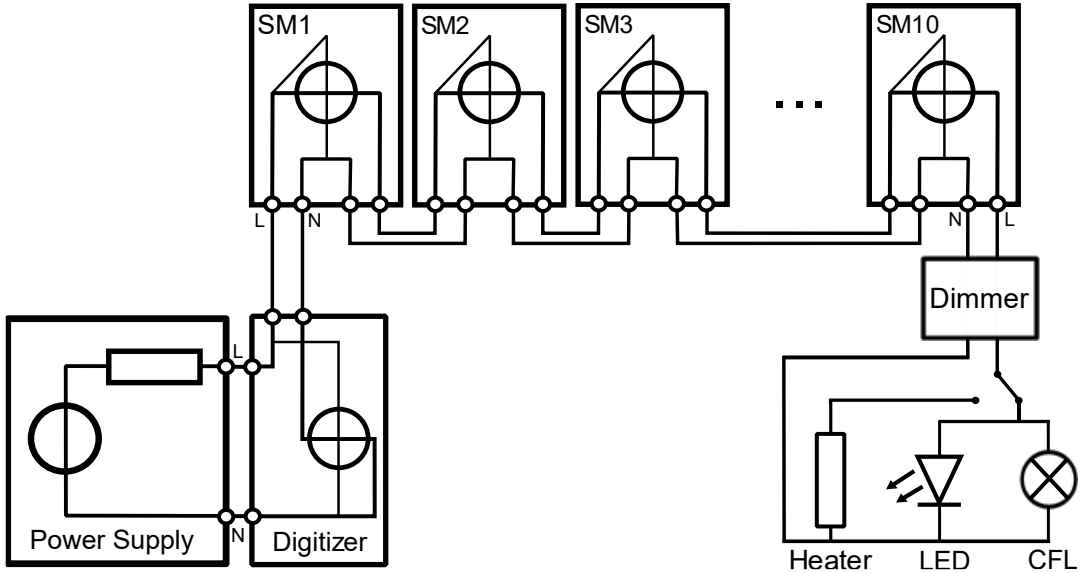
Le Figaro le 12/03/2017 à 14:49 2

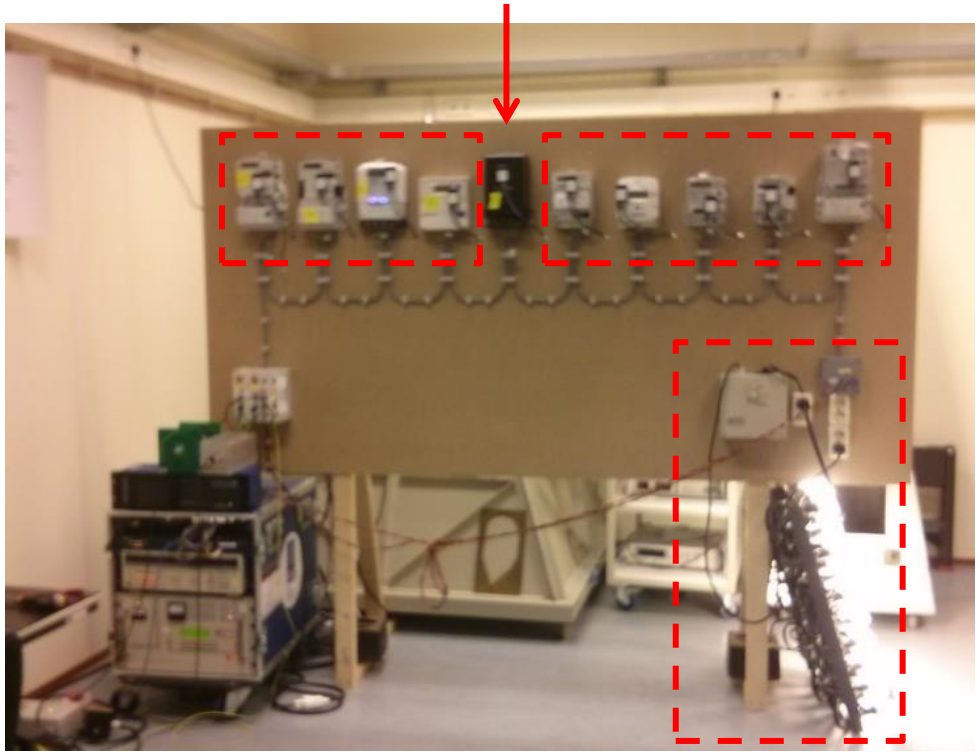
UMSTRITTENE STUDIE

Warum manche Stromzähler extrem falsch messen

Dutch Metrology Institute

Follow-up verification by VSL





G. Rietveld, D. Hoogenboom, and M. Acanski, "Conducted EMI causing error readings of static electricity meters," in *Proc. CPEM*, Paris, France, 2018

Measurements:

- Signal shape, FFT
- Energy of all meters (pulse output)

Traceable to international standards

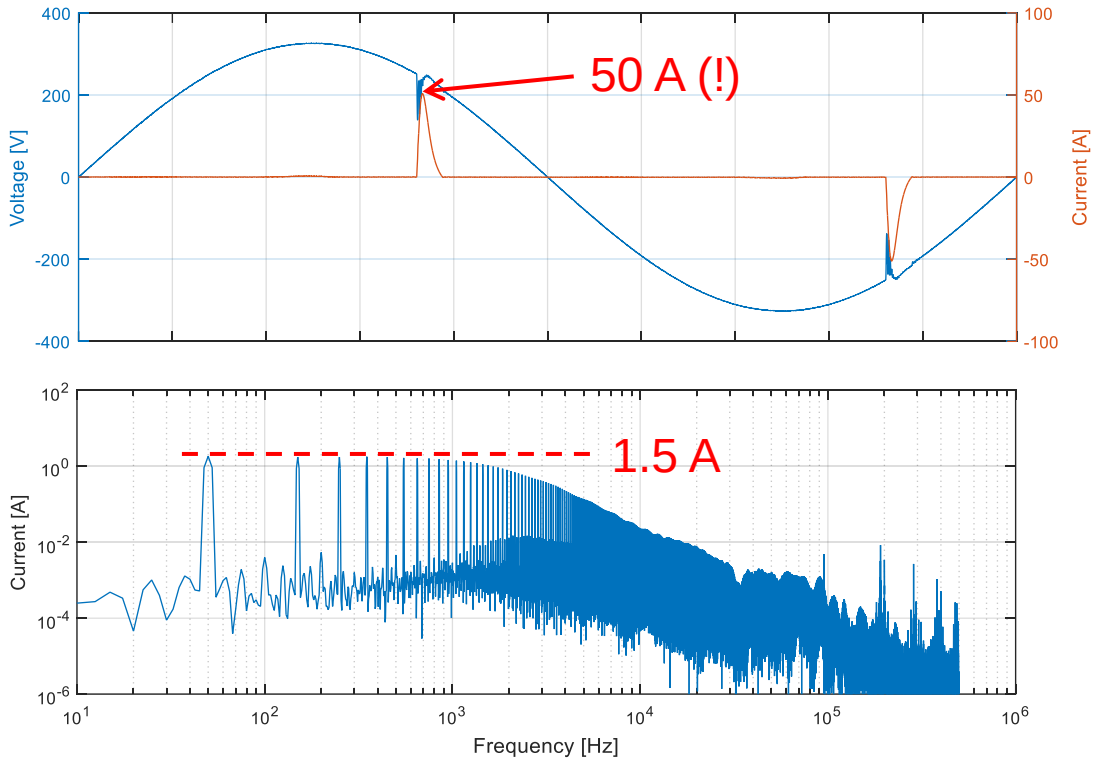
$\Rightarrow$ Confirmation of UT findings

Dutch Metrology Institute

Observations 2016-2018 UT & VSL

Test signals are conducted disturbances;
current is the cause of the problem

- This is not a pure 2 – 150 kHz problem
- Test signals: broad spectrum - step response
  $\Rightarrow$ many components vs 'single tone'
- High & fast current peaks
  $\rightarrow$ maximum *I*, maximum d*I*/d*t*



Combination of specific 'test signals' with specific static meters

- Details can have large influence on size (& sign) of the meter error

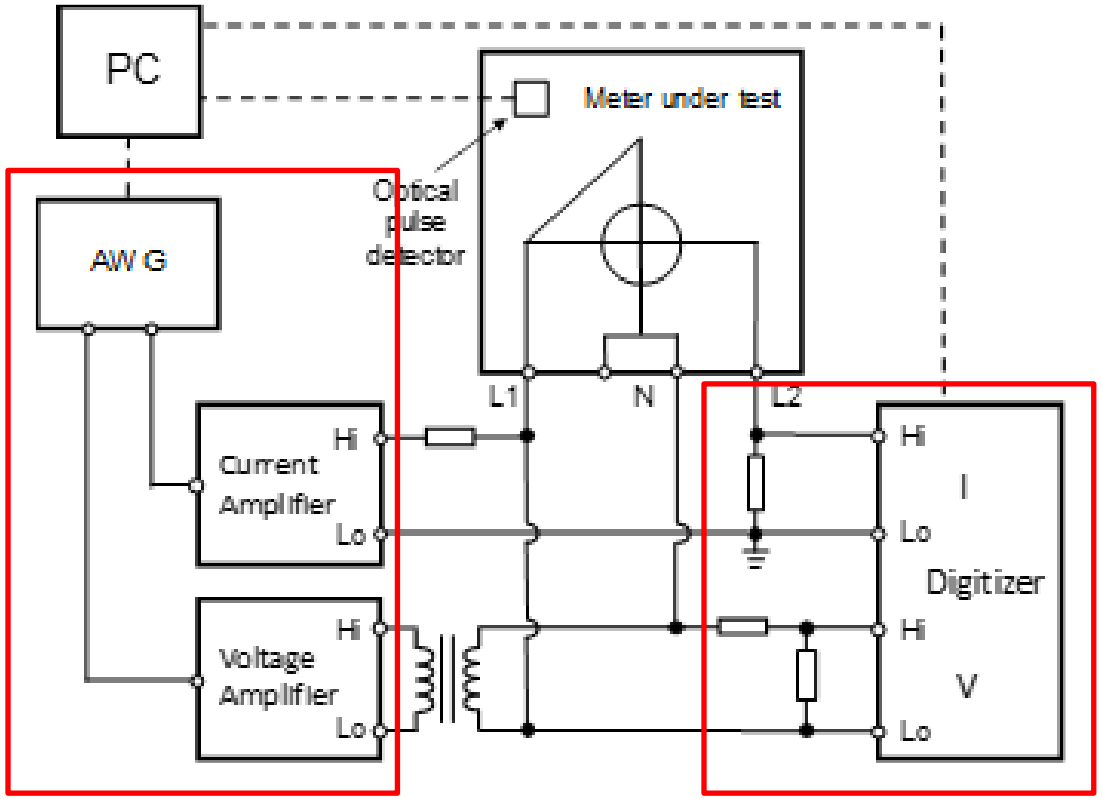
Dutch Metrology Institute

Schematic overview of new VSL testbed

- VSL meter testbed
  - 2-channel AWG provides signal to amplifiers
  - Voltage amplifier isolated from DUT
  - Transconductance amplifier with Lo to ground
  - Calibrated 0.2 Ω high-precision broadband shunt
  - Calibrated 150:1 voltage divider
  - Calibrated isolated 16-bit, 1 MSa/s digitizers
  - Optical sensor E_p read out by PC

- Energy *E(T)* and reading error ε:

$$E(T) = \int_0^T V(t) \cdot I(t)\, dt \quad \Rightarrow \quad \epsilon = \frac{E(T) - E_p}{E(T)}$$

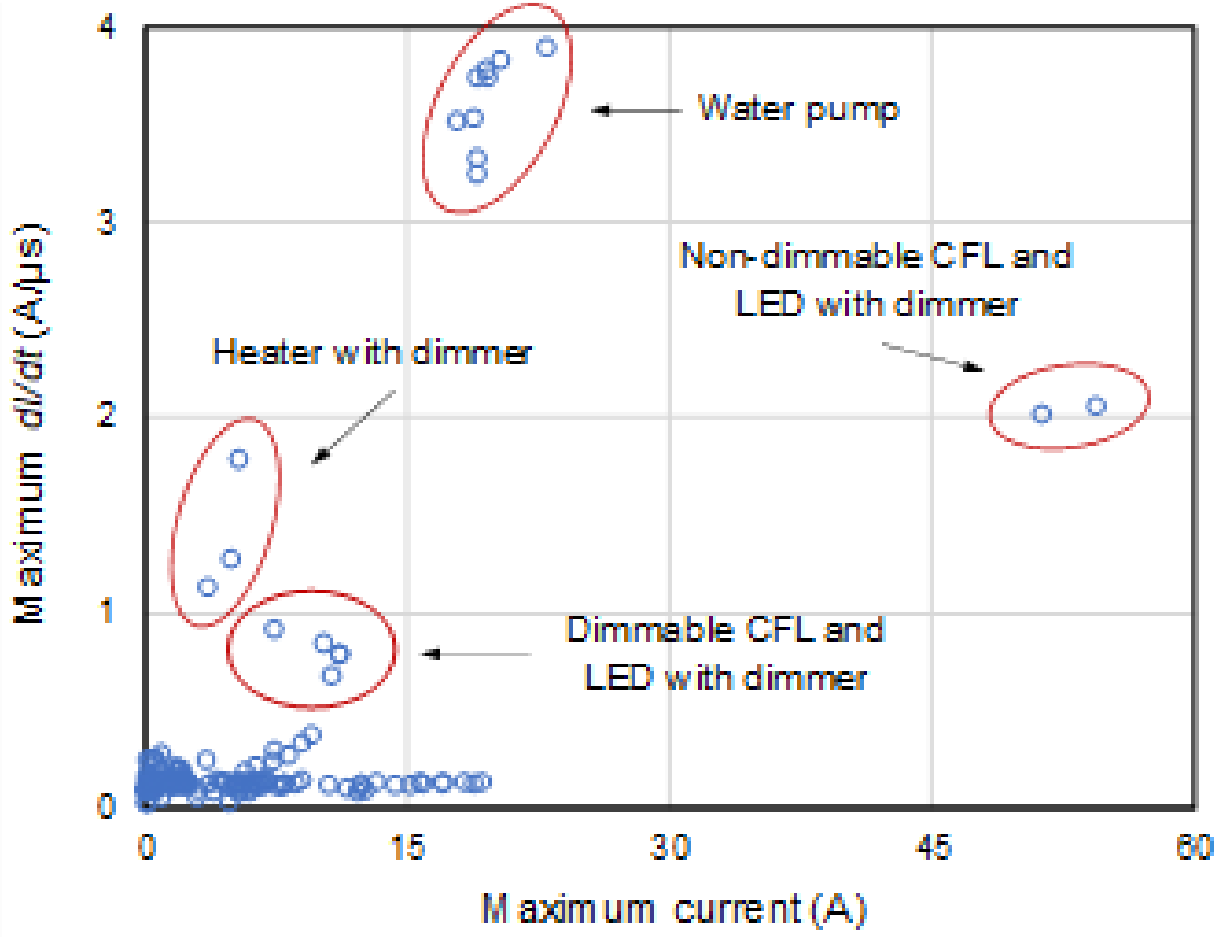


H.E. van den Brom, Z. Marais, D. Hoogenboom, R. van Leeuwen, and G. Rietveld, "A Testbed for Static Electricity Meter Testing with Conducted EMI", *EMC Europe*, Barcelona, Spain, 2019

- Total uncertainty (k=2) of 0.02 % for sinewaves, 0.5 % for all signals

Categorizing Current Waveforms

- 2015-2018: LED and CFL lamps and heater with dimmers
- 2018-2019: laptop, PC + monitor, smart-TV, refrigerator + freezer, microwave, USB chargers, DVD players, induction cookers, blenders, vacuum cleaners, drilling machines, patio heaters, coffee machines, water pump (PV inverters, washing machines, ...)
- Most important parameters: I_{max} and dI/dt



R. van Leeuwen, H.E. van den Brom, D. Hoogenboom, G.J.P. Kok and G. Rietveld, "Current waveforms of household appliances for advanced meter testing," *AMPS workshop*, Aachen, Germany, 2019

Test Results Household Appliance Waveforms

		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16
	Sensor	S	CT	U	U	H	CT	R	CT	S	U	CT	U	H	R	R	S
	Year	2019	2017	2009	2018	2008	2017	2008	2017	2017	2017	2017	2010	2015	2013	2019	2017
Signal	P [W]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]
R0	793	0	0,1	0,0	-2,8	-0,2	0,0	0,1	0,0	0,0	0,0	-0,1	-0,1	-0,1	0,1	-0,3	0,0
R50	430	0,1	0,1	0,9	-2,9	-0,3	0,0	-4,6	0,1	0,0	-0,1	-0,1	-1,3	0,3	-0,9	-1,3	0,0
R75	242	0,2	0,3	-0,6	-3,1	-0,6	0,0	191,4	0,2	1,4	-0,1	-0,1	26,8	-1,2	106,6	-2,7	0,3
CL50	329	1,3	1,0	-27,0	-1,4	-0,2	0,3	-70,9	1,3	1,9	6,0	0,5	-6,4	-16,8	-76,7	3,1	-37,5
CL75	293	1,9	1,7	-39,5	-0,8	-1,4	0,5	117,0	1,7	2,9	7,3	0,7	123,8	173,1	101,8	3,1	-45,3
RCL0	1367	0,1	0,1	0,0	-2,8	-0,1	0,0	0,3	0,0	0,0	0,0	-0,1	-0,1	0,2	0,2	-0,1	-0,1
WP1	19	1,9	3,9	-38,1	-2,0	-7,2	2,2	2711,8	4,5	1,6	5,8	0,1	1119,0	4,2	2648,6	-3,1	-1,9
WP4	34	1,0	2,2	-52,1	-2,3	-3,5	1,3	1368,7	2,6	0,9	3,3	0,0	543,4	3,1	1258,2	-1,6	1,1
WP9	68	0,4	0,6	-56,2	-2,5	-1,7	0,2	200,2	0,6	0,4	1,1	-0,1	31,2	1,9	136,3	-0,5	2,3
WP10	67	0,2	-0,3	-0,3	-2,8	-1,7	-0,4	-1,7	-0,4	0,0	-0,2	-0,2	-0,6	0,4	-0,7	-0,5	0,1

- Test waveforms from dimmed household appliances (heater, LED/CFL, water pump)
- 16 meters, 6 countries, 10 manufacturers, different years of appearance
- S = shunt, R = Rogowski, CT = CT, H = Hall, U = Undisclosed
- blue = negative error, red = positive error, green = OK

H.E. van den Brom *et al.*, "EMC Testing of Electricity Meters Using Real-World and Artificial Current Waveforms," in IEEE Trans. on EMC, 2021

→ *Meter errors are found for isolated household appliances*

Yes, but that was an artificial laboratory situation…

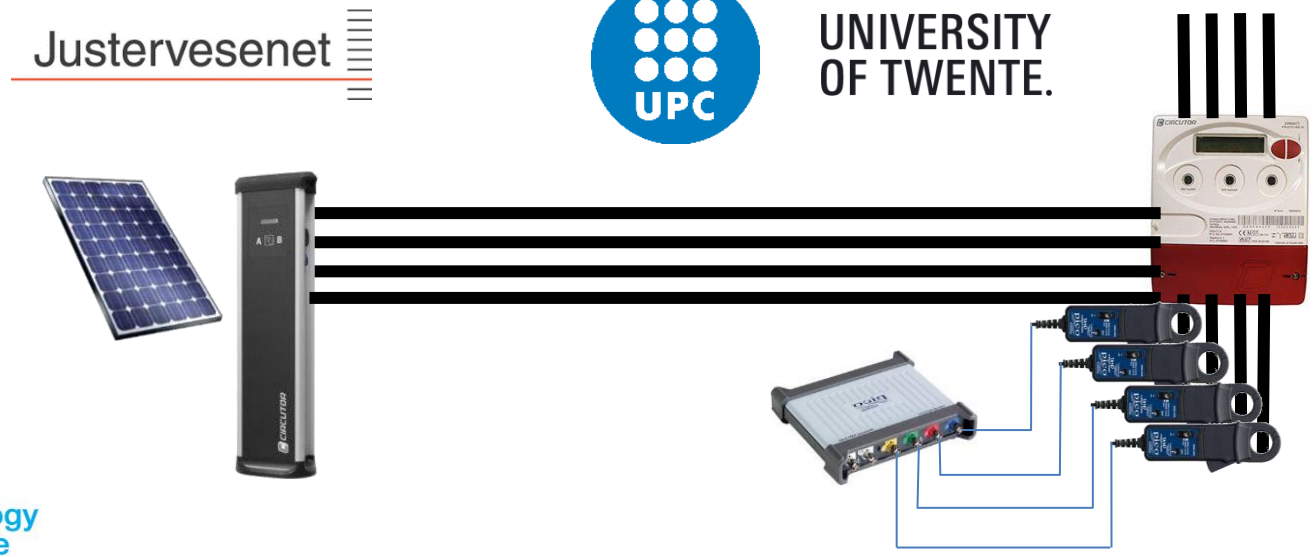
"*Yes*, but in reality …"

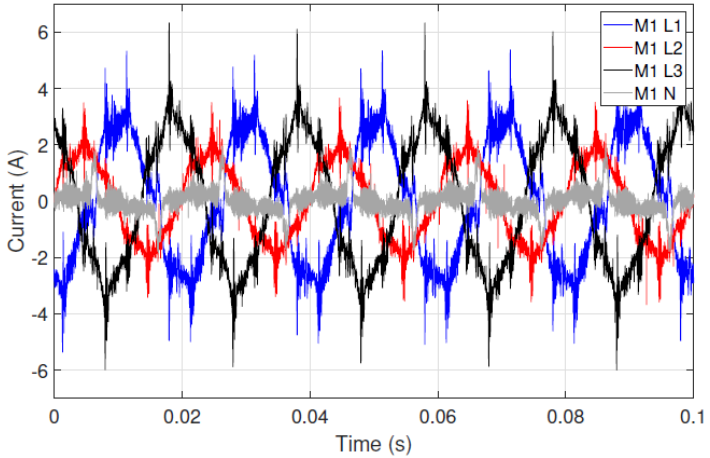
- metering is done at the metered supply point only, not at an appliance
- the cable inductance in the building will damp the fast rise times and high peaks
- one will use the correct dimmer with the correct LED lamp
- equipment has a CE mark and will not cause such disturbances
- different signals will be combined, and the result is not that extreme
- so, it won't be too bad after all

→ OK, so let us measure at metered supply points

On-site measurements at meter supply points

- PV installation
- Electric Vehicle charging station
- Manufacturing site
- Electric tool shop
- Phase controlled water pump
- Urban and rural houses





T. Hartman et al., "On-site Waveform Characterization at Static Meters Loaded with Electrical Vehicle Chargers", *EMC Europe* , Barcelona, Spain, 2019

Dutch Metrology Institute

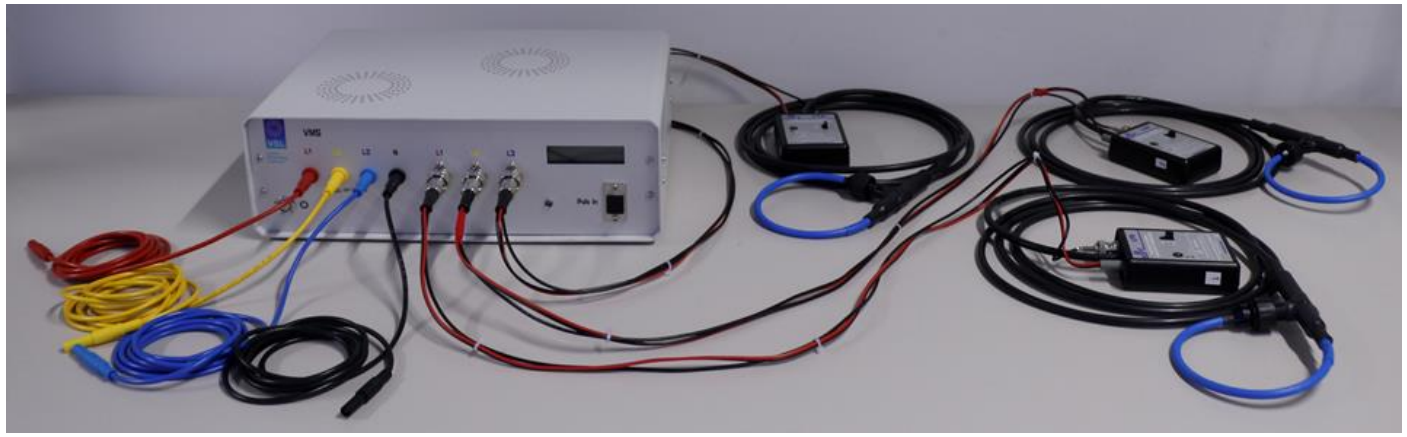
VSL benchmark meter & waveform recorder

- Used to record on-site waveforms and energy at metered supply points

- 3-phase *V* & *I* waveform recorder:
  - Rogowski coils, 120 A or 1200 A peak, 0.3 Hz – 1 MHz
  - Resistive/capacitive dividers, DC – 100 kHz
  - 8-channel, 12-bit, 1 MSa/s digitizer
  - Optical sensor, 1000 pulses per kWh
  - Minicomputer with dedicated home-built software
  - 4G-connection

Z. Marais, H.E. van den Brom, G. Kok and M.G.A. van Veghel, "Reduction of Static Electricity Meter Errors by Broadband Compensation of Voltage and Current Channel Differences," *IEEE Trans. Instrum. Meas.* 70, 2021

- Measure for 1-2 weeks:
  - 200 ms periods
  - Every minute
  - Triggered by dI/dt or CF



Dutch Metrology Institute

Test Results On-site Waveforms (2)

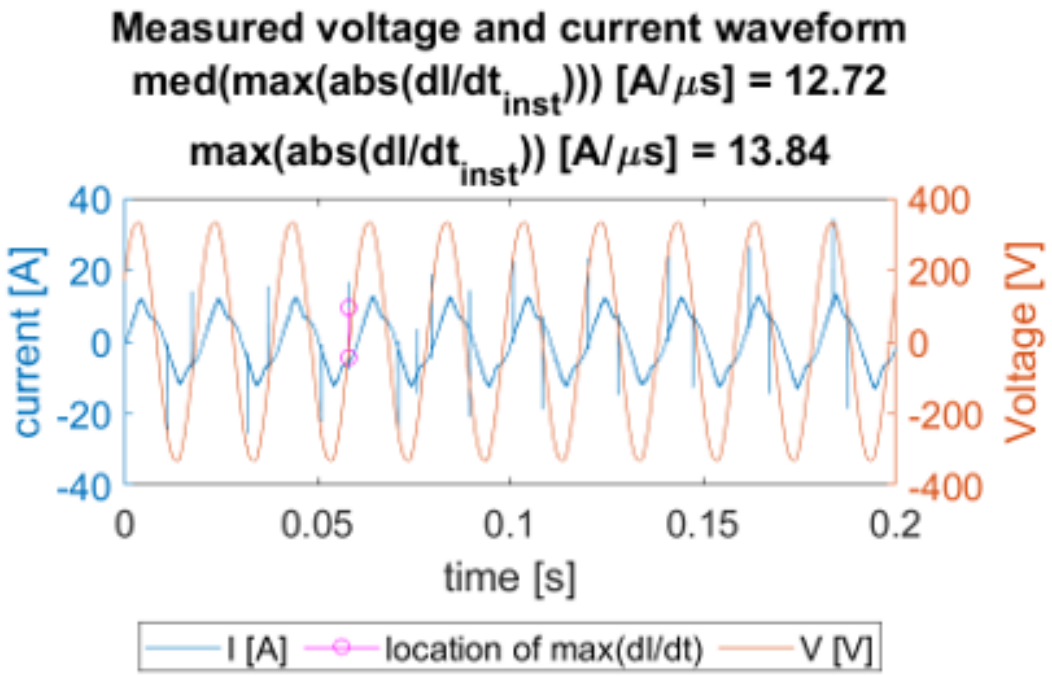
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16
	Sensor	S	CT	U	U	H	CT	R	CT	S	U	CT	U	H	R	R	S
	Year	2019	2017	2009	2018	2008	2017	2008	2017	2017	2017	2017	2010	2015	2013	2019	2017
Signal	P [W]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]
UPC2.1	1848	0,1	0,1	0,0	-2,8	-0,1	0,0	0,2	0,1	0,0	0,0	-0,1	-0,1	0,0	0,2	-0,4	-0,1
UPC2.2	-131	0,0	-0,1	0,2	2,9	TO	0,0	TO	0,0	0,0	0,0	0,1	-0,4	-0,5	3,1	0,9	0,0
UPC2.3	694	0,1	0,0	0,0	-2,8	-0,2	0,0	0,1	0,0	0,0	0,0	-0,1	-0,6	0,3	0,1	0,0	0,0
UT1.1	719	0,1	0,1	0,3	-2,8	-0,2	0,0	8,9	0,0	0,0	0,0	-0,1	0,0	-0,1	10,1	-0,3	-0,1
UT1.2	237	0,2	0,8	-0,3	-2,9	-0,6	0,9	-2,1	1,0	0,0	-0,1	-0,1	0,0	0,4	-0,9	-0,9	-0,2
UT1.2a	180	0	-3,0	-0,4	-2,6	-0,6	-3,6	-58,2	-3,9	0,0	0,0	-0,1	5,2	1,9	-59,0	1,1	-3,9
UT1.2b	179	0	3,0	-0,3	-3,0	-0,8	3,7	25,5	3,6	-0,1	-0,3	-0,1	-0,9	-0,3	28,6	-2,1	-6,7
VSL1	2233	0,1	1,3	0,8	-2,9	-0,1	1,1	0,7	1,3	0,0	0,1	-0,1	2,2	0,1	0,3	-0,8	0,0
VSL2	31	0,3	-0,5	-1,5	-2,4	-3,4	-0,3	640,2	-0,5	-0,2	-0,4	-0,3	5,0	-0,1	333,7	1,7	-4,5
VSL3	69	0,3	0,1	0,3	-2,6	-1,6	0,0	-5,1	0,1	0,0	0,0	-0,1	0,1	1,3	-0,9	0,9	-0,1
VSL4	32	0,1	-0,1	TO	-2,8	-3,4	-0,2	818,0	-0,2	-0,5	-0,5	-0,4	-30,3	2,8	796,5	0,2	-0,7
VSL5	1392	0,1	0,2	0,4	-2,8	-0,1	0,0	31,4	0,1	0,0	0,1	-0,1	1,7	0,1	28,7	-0,4	-0,1

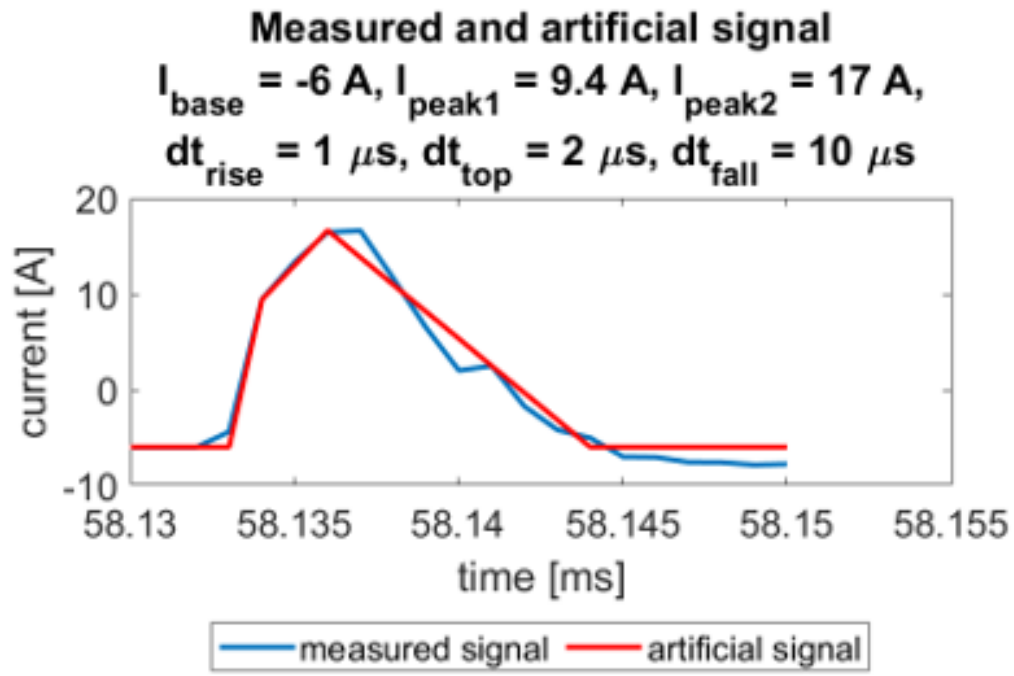
- 16 meters, 6 countries, 10 manufacturers, different years of appearance
- Test waveforms recorded on-site at metered supply points
- S = shunt, R = Rogowski, CT = CT, H = Hall, U = Undisclosed
- blue = negative error, red = positive error, green = OK, TO = timed out (no pulse)

H.E. van den Brom *et al.*, "EMC Testing of Electricity Meters Using Real-World and Artificial Current Waveforms," in IEEE Trans. on EMC, 2021

→ *Meter errors are found for further waveforms recorded on-site*

Proposal to CLC TC13 WG01





Waveform recorded on-site; current peaks are observed in the graph on the left (in blue), which is zoomed in and parametrized as TK6 in the graph on the right.

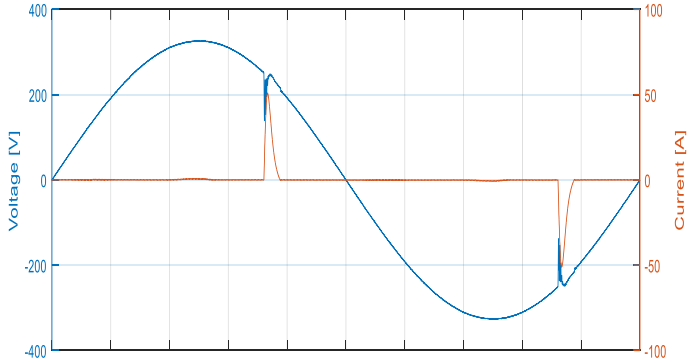
Liability?

- Static meter manufacturers?
  → Standardization (IEC TC13 WG11, CLC TC13 WG01, …)
- Household electronics manufacturers?
  → CE mark
- Customers?
  → Common sense
- Utilities, metering companies?
  → "It is *their* energy bill"
- Government?
  → Regulations (OIML, Welmec)

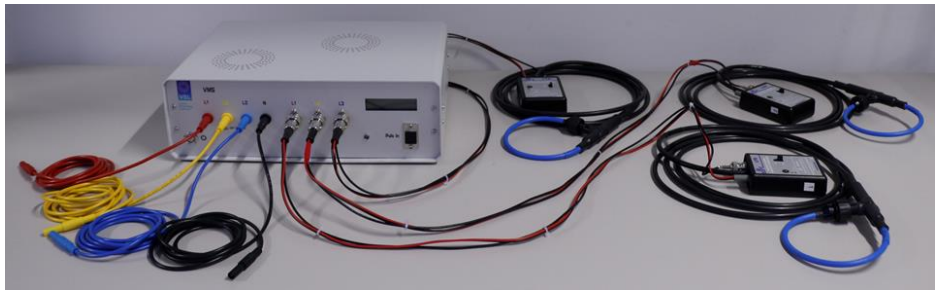
- What about the potential effects on other equipment?
  → Do present emission and immunity tests cover these waveforms?

Summary

Conducted disturbances caused by electronic equipment can have significant impact on reading errors of static meters



- New potentially harmful waveforms identified:
  - Caused by isolated household equipment
  - Recorded on-site at meter supply points



- *Liability*?
  - Utilities increased requirements for new meters
  - Standardization working group implementing changes
  - Government informing legal metrology organizations
  - Who else should take responsibility?