21 April 2021 MeterEMI Final Workshop

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Electromagnetic Interference on Static Electricity Meters

Results from testing a sample of European static meter types

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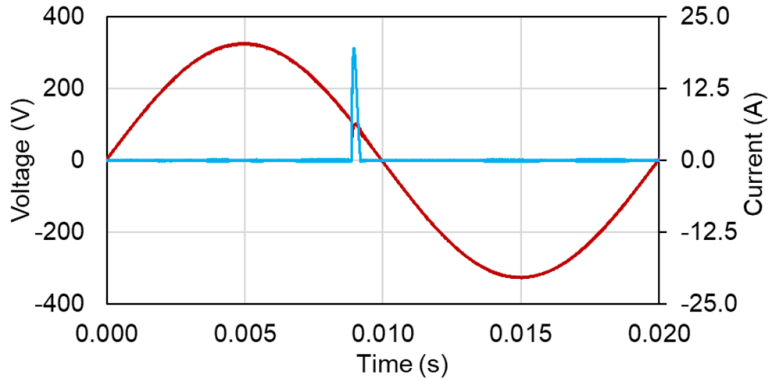
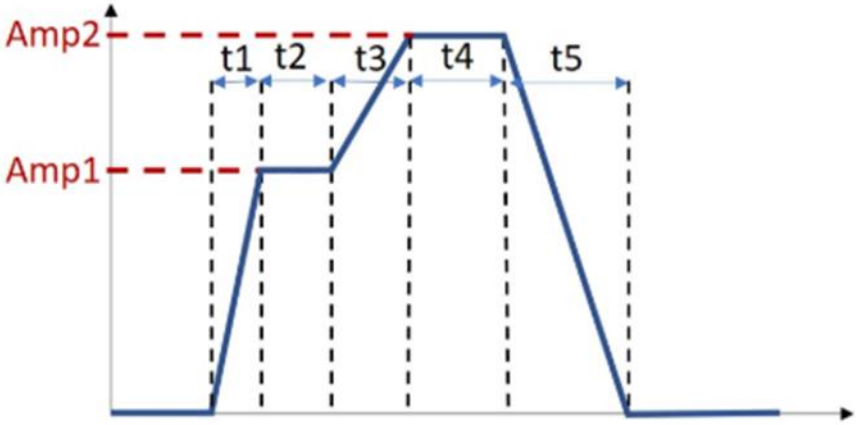
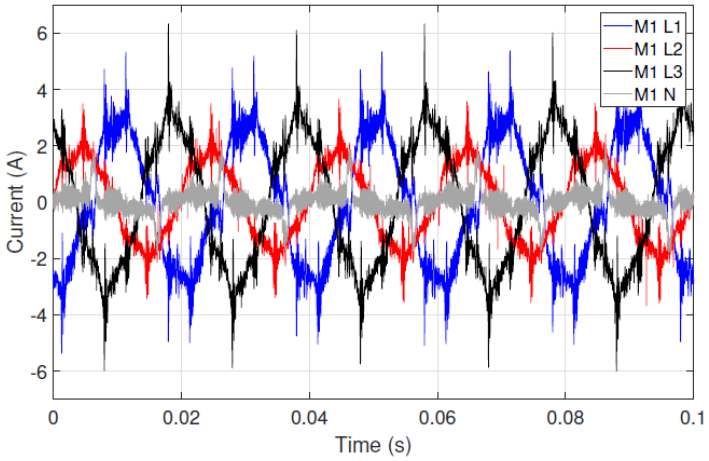
Results with real-world and artificial waveforms

- Survey on 16 representative EU electricity meters from UK, NO, ES, CZ, CH, NL
  1. Household appliances (laboratory)
  2. Domestic areas (on-site)
  3. Artificial waveforms based on real signals







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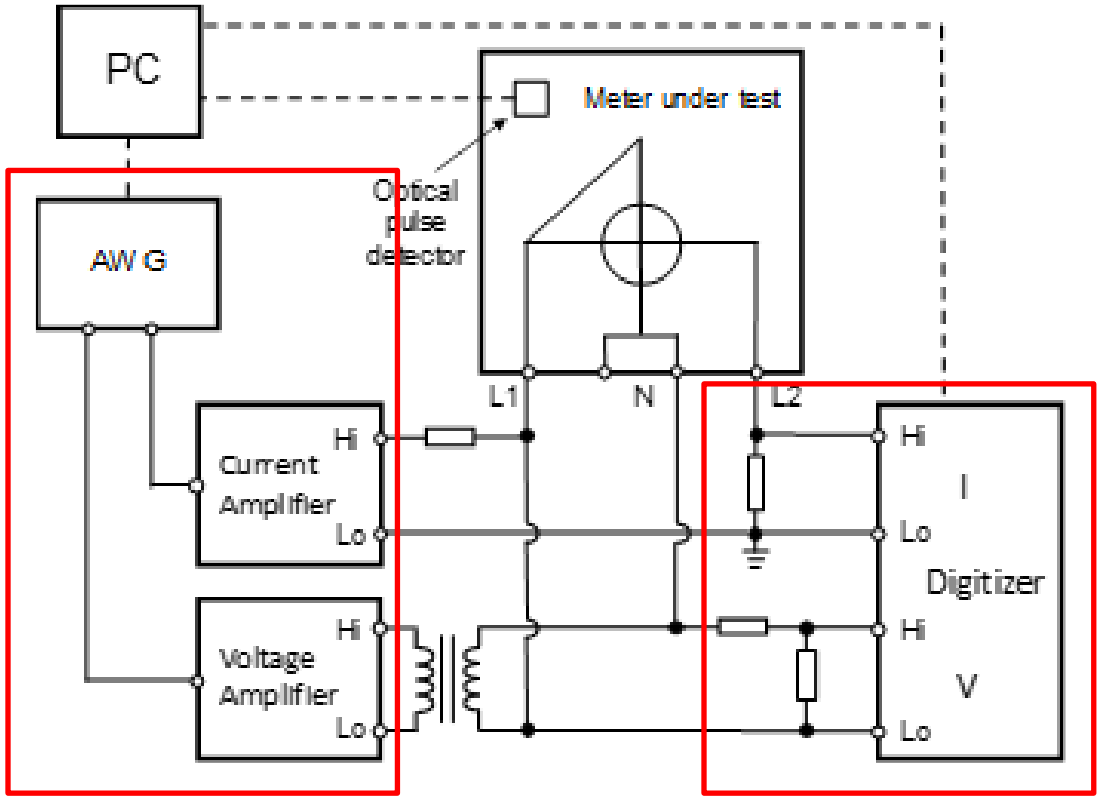
Schematic overview of VSL testbed

- VSL meter testbed
  - 2-channel AWG provides signal to amplifiers
  - Voltage amplifier isolated from DUT
  - Transconductance amplifier with Lo to ground
  - Calibrated 0.05 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



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

- Energy *E(T)* and reading error ε:

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

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

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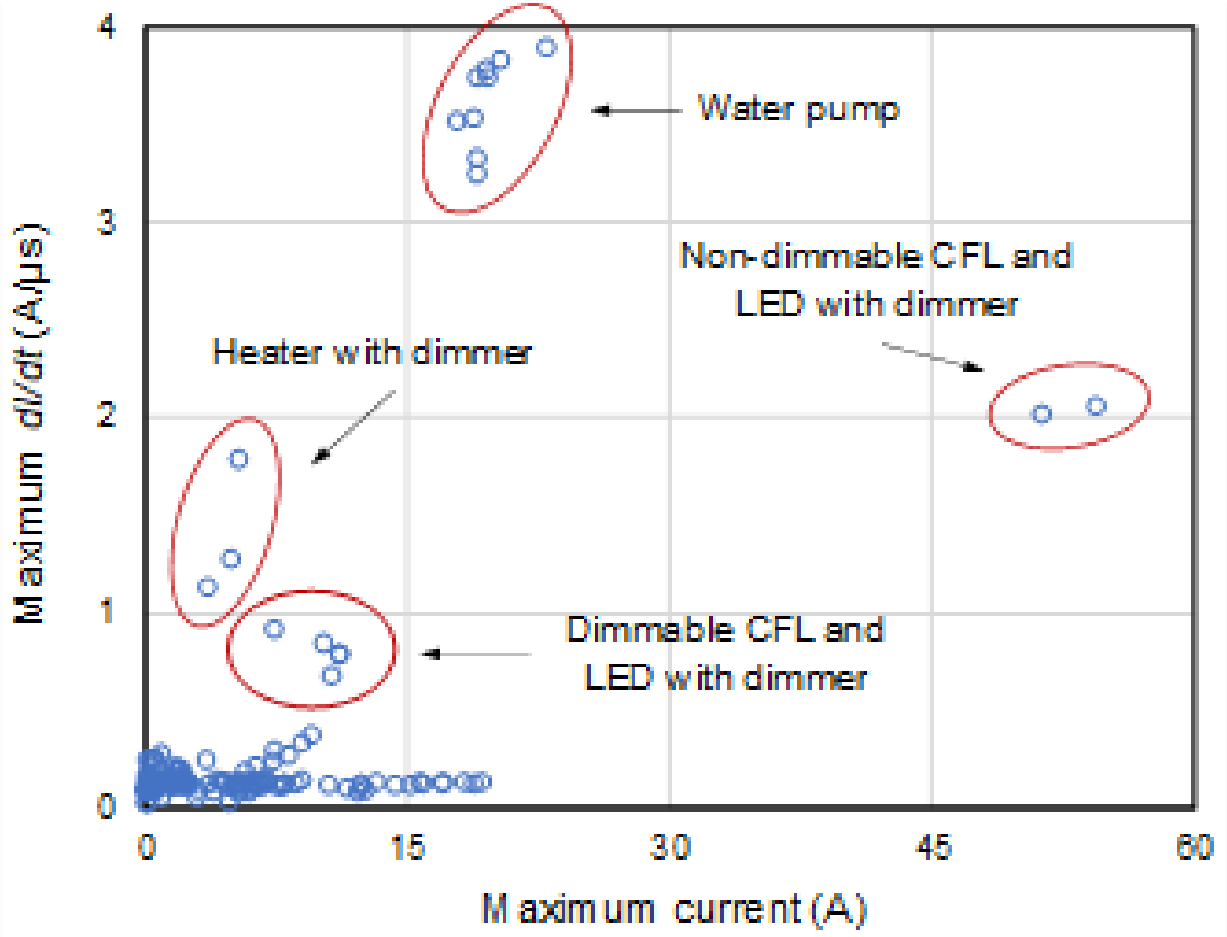
Categorizing Household Appliance Waveforms

- 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*



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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	0.00	0.0	-0.12	-0.1	-0.082	0.1	-0.34	0.0
R50	430	0.1	0.1	0.9	-2.9	-0.3	0.0	-4.6	0.1	0.02	-0.1	-0.09	-1.3	0.256	-0.9	-1.30	0.0
R75	242	0.2	0.3	-0.6	-3.1	-0.6	0.0	191.4	0.2	1.42	-0.1	-0.09	26.8	-1.186	106.6	-2.66	0.3
CL50	329	1.3	1.0	-27.0	-1.4	-0.2	0.3	-70.9	1.3	1.88	6.0	0.48	-6.4	-16.788	-76.7	3.13	-37.5
CL75	293	0.2	-0.3	-0.3	-2.8	-1.7	-0.4	-1.7	-0.4	-0.05	-0.2	-0.19	-0.6	0.388	-0.7	-0.46	0.1
RCL0	1367	0.2	-0.3	-0.3	-2.8	-1.7	-0.4	-1.7	-0.4	-0.05	-0.2	-0.19	-0.6	0.388	-0.7	-0.46	0.1
WP1	19	1.9	3.9	-38.1	-2.0	-7.2	2.2	2711.8	4.5	1.64	5.8	0.11	1119.0	4.245	2648.6	-3.13	-1.9
WP4	34	1.0	2.2	-52.1	-2.3	-3.5	1.3	1368.7	2.6	0.93	3.3	0.02	543.4	3.062	1258.2	-1.60	1.1
WP9	68	0.4	0.6	-56.2	-2.5	-1.7	0.2	200.2	0.6	0.37	1.1	-0.08	31.2	1.851	136.3	-0.53	2.3
WP10	67	0.2	-0.3	-0.3	-2.8	-1.7	-0.4	-1.7	-0.4	-0.05	-0.2	-0.19	-0.6	0.388	-0.7	-0.46	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

→ *Meter errors are found for isolated household appliances*

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Test Results On-site Waveforms

	Meter	A2	A7	A13	A14
	Sensor	CT	R	H	R
	Year	2017	2008	2015	2013
Signal	P [W]	ε [%]	ε [%]	ε [%]	ε [%]
JV2.1	286	0	10	0	0
JV2.2	422	0	4	0	0
JV2.3	591	0	0	0	0
JV2.4	291	0	0	0	0
JV2.5	2313	0	0	0	0
UPC1.1	3494	0	-23	0	1
UPC1.1	3500	0	-31	0	-4
UPC2.1	620	0	17	0	17
UPC2.1	2032	0	-1	0	-1
UPC2.3	554	0	-9	0	3
UPC2.4	119	0	-17	0	-1
UT1.1	752	0	10	0	9
UT1.2	190	0	55	0	43

- Test waveforms recorded on-site at metered supply points (JV, UPC, UT)
- Test waveforms selected using UT tool
- 4 selected meters, 3 countries, 4 manufacturers, different years of appearance
- S = shunt, R = Rogowski, CT = CT, H = Hall, U = Undisclosed
- blue = negative error, red = positive error, green = OK

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

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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	0.01	0.0	-0.11	-0.1	0.012	0.2	-0.39	-0.1
UPC2.2	-131	0.0	-0.1	0.2	2.9	TO	0.0	TO	0.0	-0.02	0.0	0.09	-0.4	-0.544	3.1	0.88	0.0
UPC2.3	694	0.1	0.0	0.0	-2.8	-0.2	0.0	0.1	0.0	0.01	0.0	-0.11	-0.6	0.321	0.1	-0.04	0.0
UT1.1	719	0.1	0.1	0.3	-2.8	-0.2	0.0	8.9	0.0	0.00	0.0	-0.11	0.0	-0.055	10.1	-0.32	-0.1
UT1.2	237	0.2	0.8	-0.3	-2.9	-0.6	0.9	-2.1	1.0	-0.02	-0.1	-0.12	0.0	0.448	-0.9	-0.93	-0.2
UT1.2a	180	0	-3.0	-0.4	-2.6	-0.6	-3.6	-58.2	-3.9	0.03	0.0	-0.15	5.2	1.921	-59.0	1.09	-3.9
UT1.2b	179	0	3.0	-0.3	-3.0	-0.8	3.7	25.5	3.6	-0.07	-0.3	-0.13	-0.9	-0.341	28.6	-2.10	-6.7
VSL1	2233	0.1	1.3	0.8	-2.9	-0.1	1.1	0.7	1.3	0.04	0.1	-0.08	2.2	0.132	0.3	-0.76	0.0
VSL2	31	0.3	-0.5	-1.5	-2.4	-3.4	-0.3	640.2	-0.5	-0.18	-0.4	-0.33	5.0	-0.092	333.7	1.66	-4.5
VSL3	69	0.3	0.1	0.3	-2.6	-1.6	0.0	-5.1	0.1	0.02	0.0	-0.14	0.1	1.268	-0.9	0.89	-0.1
VSL4	32	0.1	-0.1	TO	-2.8	-3.4	-0.2	818.0	-0.2	-0.51	-0.5	-0.41	-30.3	2.831	796.5	0.18	-0.7
VSL5	1392	0.1	0.2	0.4	-2.8	-0.1	0.0	31.4	0.1	0.04	0.1	-0.09	1.7	0.067	28.7	-0.43	-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)

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

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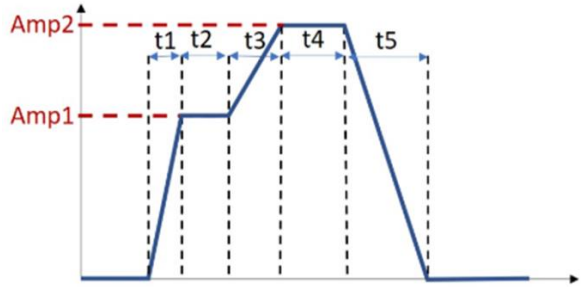
Test Results Simplified Waveforms

	Meter	A2	A7	A13	A14
	Sensor	CT	R	H	R
	Year	2017	2008	2015	2013
Signal	P [W]	ε [%]	ε [%]	ε [%]	ε [%]
WP1	28	8	968	1	334
WP1M	27	8	974	1	342
WP1T	19	6	1377	3	525
WP1TB	39	0	1362	-16	572
WP4	60	5	397	0	141
WP4M	59	5	399	1	153
WP4T	46	5	394	1	98
WP4TB	91	0	393	-6	118
WP9	117	1	29	0	3
WP9M	114	1	30	0	3
WP9T	101	1	50	1	16
WP9TB	202	0	51	0	14
WP1*	29	6	2527	1	1961
WP1*M	28	6	2565	2	1998
WP1*T	23	5	3234	3	2520
WP1*TB	46	0	3214	54	2552

- 4 selected meters, 3 countries, 4 manufacturers, different years of appearance
- S = shunt, R = Rogowski, CT = CT, H = Hall, U = Undisclosed



- WPx = waterpump level x
  WPxM = modelled
  WPxT = trapezoidal
  WPxTB = trapezoidal bipolar
  * = mains signal (instead of sinusoidal)

→ *Simplified waveforms cause similar meter errors as the equivalent real-world waveforms*

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Summary and conclusion

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

- Testbed used for **testing EU meters**

  → *Suitable as a new standardized test method*

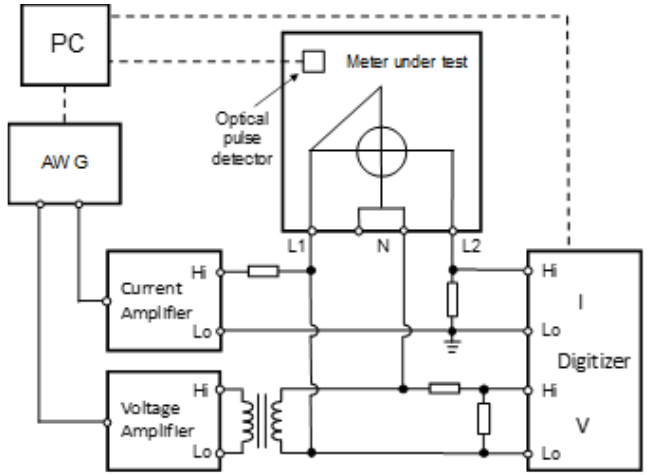
- Potentially **harmful waveforms** recorded:
  - Caused by isolated household equipment
  - Measured on-site at metered supply points

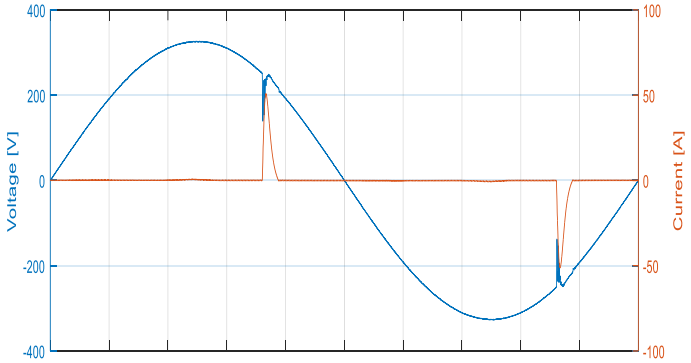
  → *Meter errors are found for both types of waveforms*

- **Simplified waveforms** specified with few coefficients

  → *Cause similar meter errors*

  → *Can be used as input to written standards*





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