New VSL high-end reference setup for transformer LMS system calibration

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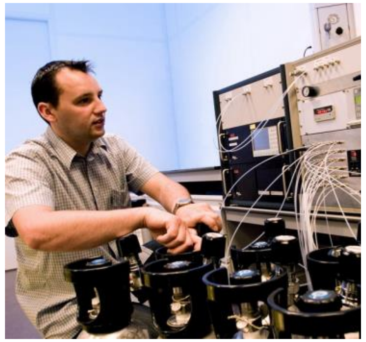
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

VSL: the Dutch National Measurement Institute (NMI)

- Maintain and develop the national measurement standards
- Make measurements directly traceable to international standards
- Support reliability, quality and innovation both in business and society at large

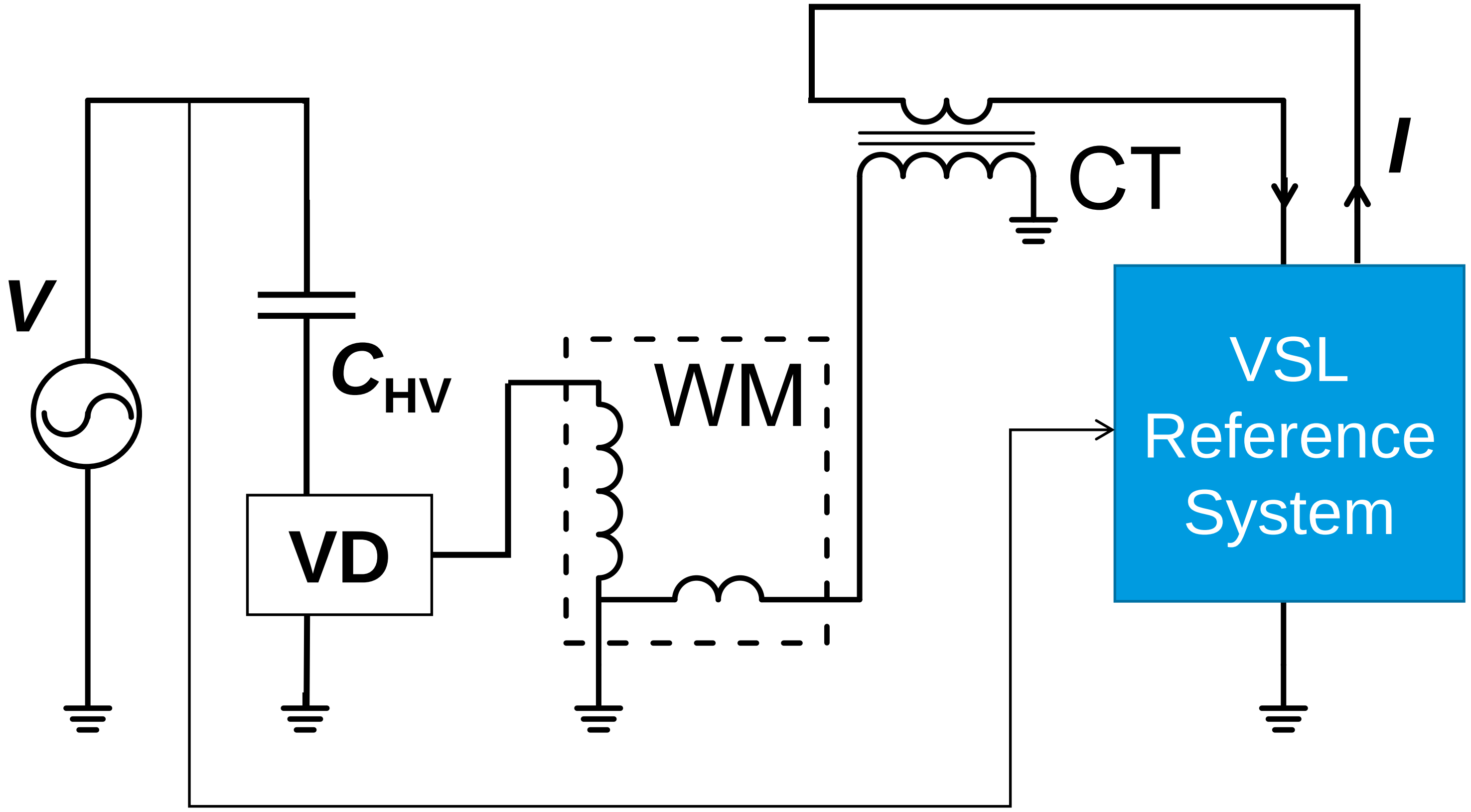


VSL:

- Company with public task
  (100 fte, 50 % MSc-PhD)
- Calibrations, reference materials, R&D, consultancy, training
- Independent, reliable, top in measurement, international
- Focus: **energy**, industry, health, climate

Beyond all doubt

TLMS system calibration – VSL approach



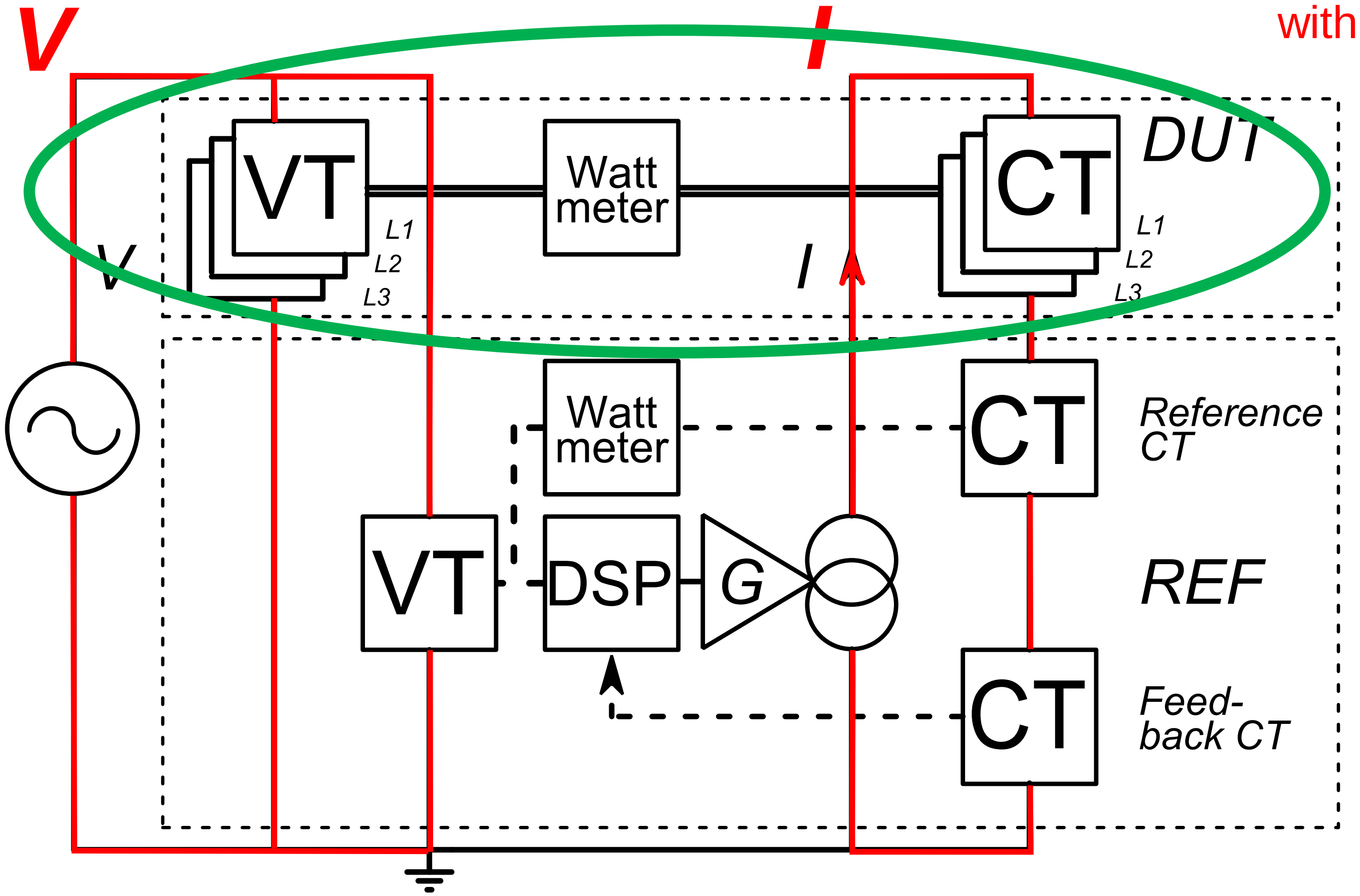
VSL reference system simulates adjustable losses to TLM system

- Phantom power
- Calibration includes *all systematic effects*
- Calibration under actual PF values

⇒ More complex to perform, but smaller overall system uncertainty (0.07 min)

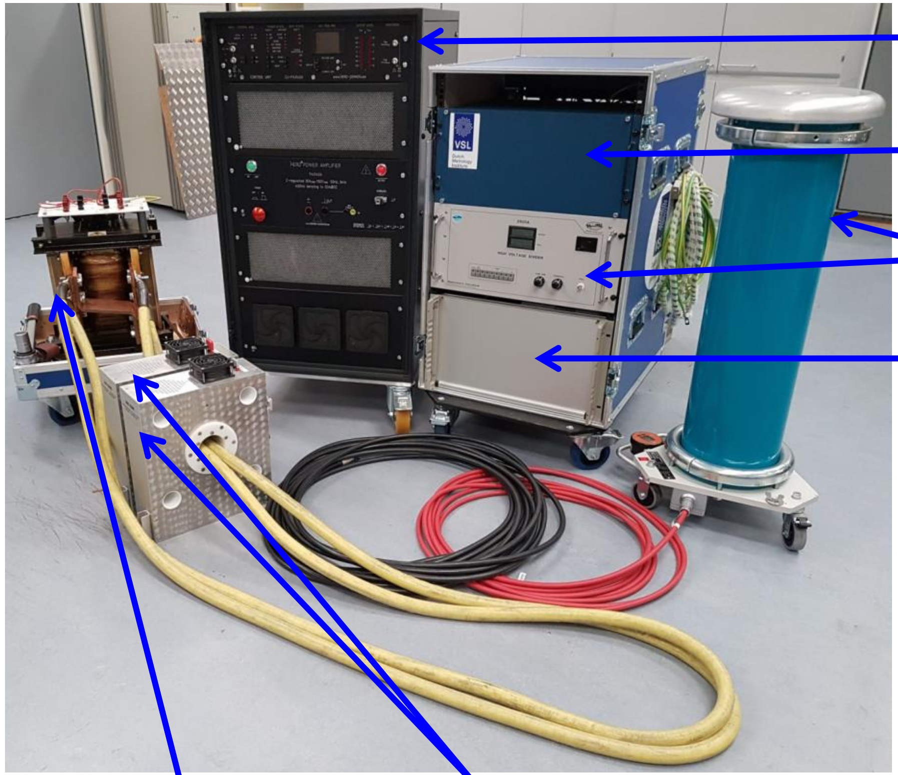
VSL TLM system calibration setup

Challenge: lock *I* to *V* within 0.3 m° (5 µrad)



- 100 / 230 kV, 2000 A
- Test current generated in feedback loop; digital control
- Accuracy: 20 µW/VA (0.2 % at PF = 0.01)
- Fully automated, transportable – suitable for on-site calibrations

VSL TLMS system calibration setup - components



Power amplifier (G)

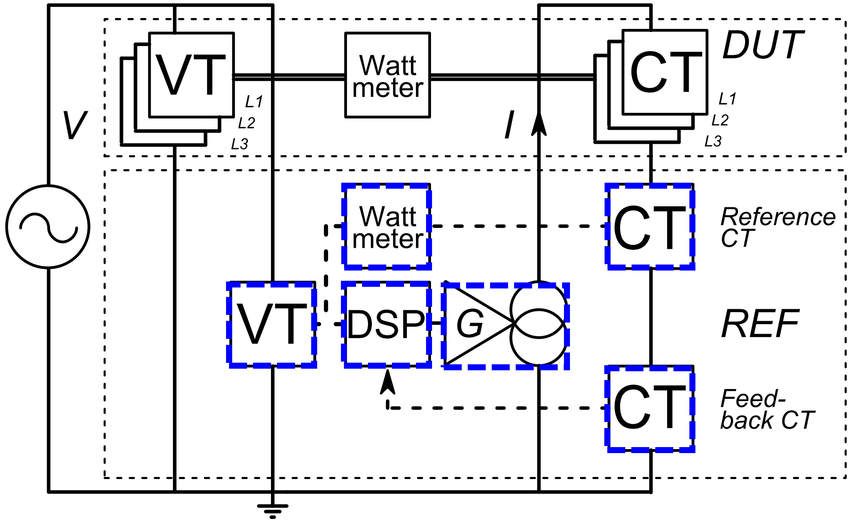
Control (DSP)

VT (CC-based capacitive divider)

Power reference (RD22 watt meter)

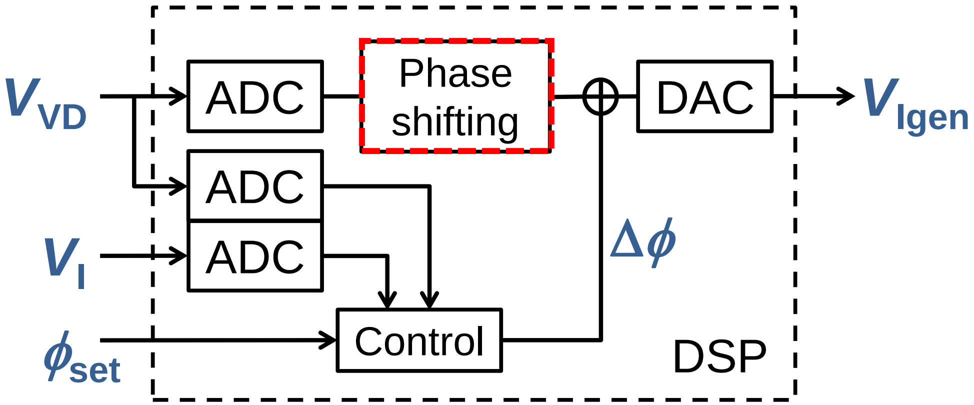
Transformer / current generator

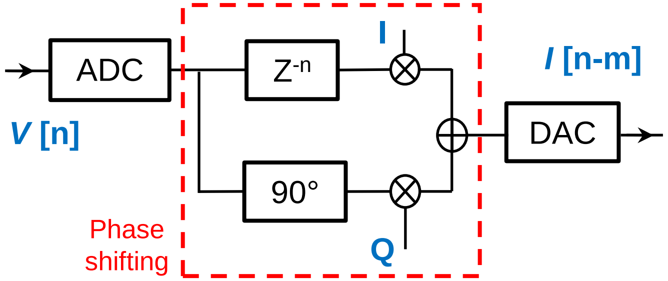
CTs (3-stage active compensation)



Control loop

The DSP is the critical part of the setup, with 2 main parts:

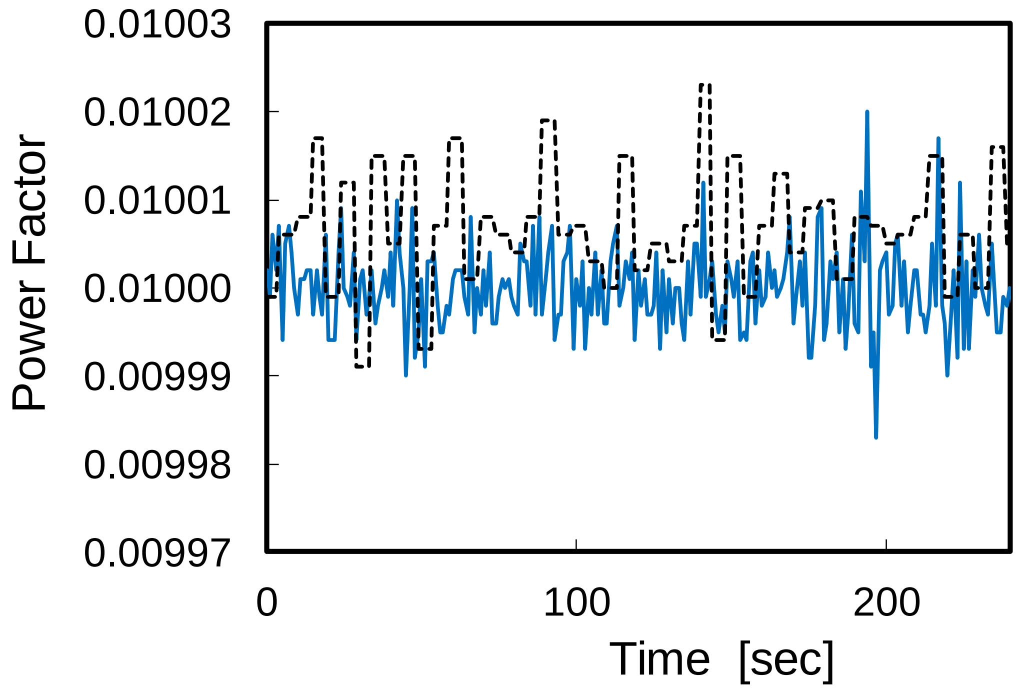




Critical elements:

- DC offset removal (output of HV divider has varying DC offsets
- Accuracy via two 24-bit ADCs; phase shifting does not have to be accurate!
- Power measurement with averaging over 200 ms (5 points / sec)

Typical control loop test result



Noise: < 6 µrad (1 s)

Agreement LL and RD22: < 3 µW/VA
(after corrections for their errors)

Noise in feedback loop affected by:

- THD (preferably THD < 0.5 %; no effect on accuracy!)
- Capacitive compensation, needed to generate currents > 1500 A

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Uncertainty budget

Uncertainty source	[%]
Voltage scaling - HV cap	0.05
Voltage scaling - LV unit	0.07
Current scaling	0.05
Power measurement	0.08
Noise	0.05
System effects	0.07
Total uncertainty ($k = 2$)	0.15

Improvements in the past years:

- Voltage channel from 15 to < 8 ppm (IEEE paper; study of cable effects)
- Power from 12 to 8 ppm
- Lower noise at higher currents (where capacitive compensation is needed)
- Improved capacitive compensation – in primary current circuit

Present CMC claim: 0.20 % at PF = 0.01 (20 μW/VA)

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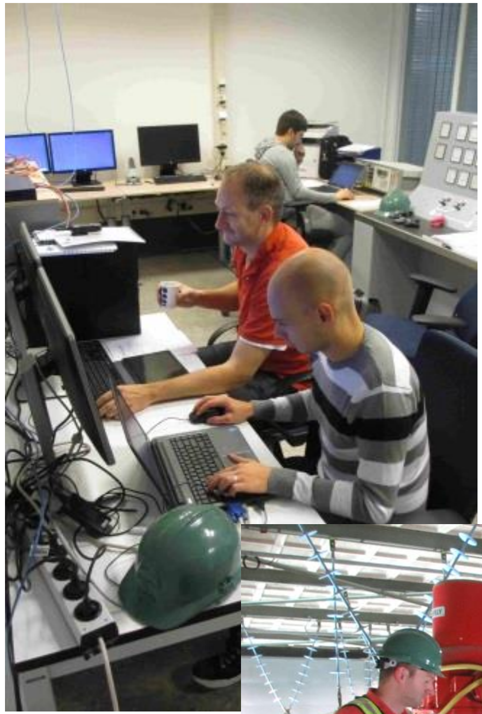
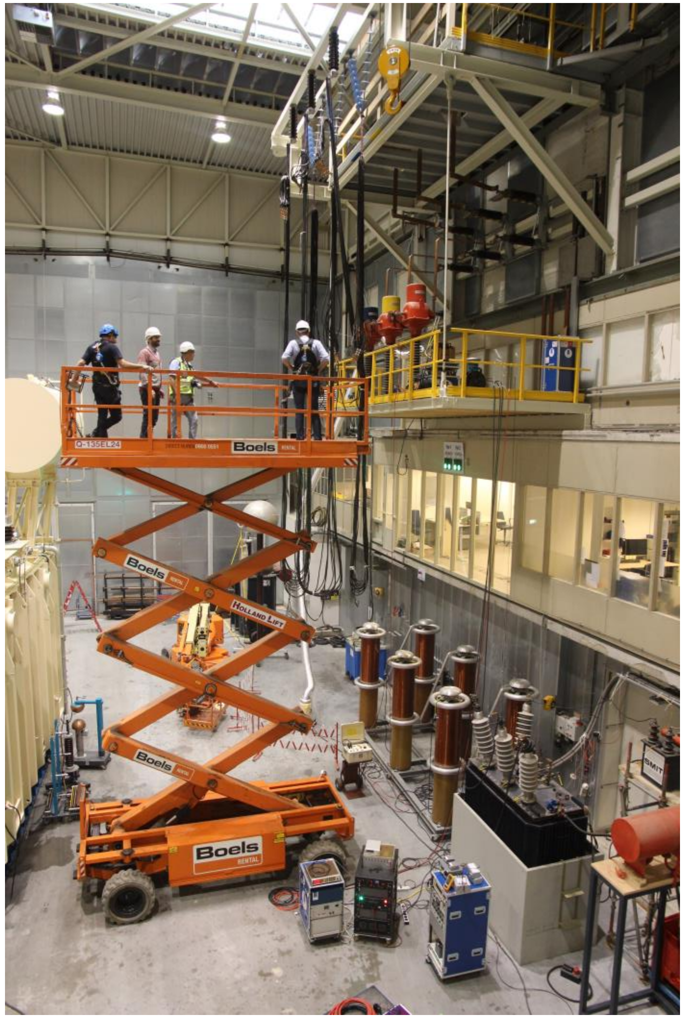
On-site experiences



- Extensive attention paid to safety, shielding (triax cables), grounding.
- Completely automated: 2 f × (3 V × 7 I) × 5 PF × 2 = 420 pts in 1 weekend.
- Fiber readout.



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System calibration certificates

VSL
Dutch Metrology Institute

Certificate of Calibration

Table 6 System errors of the reactor loss measurement system at 250 A

TMS581 Range kV	Applied Voltage kV	Voltage SF -	Applied Current A	System error PF 0.001 %	System error PF 0.002 %	System error PF 0.005 %
100	40	1000	250	-0.3	0.2	0.0
100	100	1000	250	0.8	0.4	0.1
200	80	2000	250	1.8	0.8	0.4
200	200	2000	250	1.4	0.5	0.2
Uncertainty				3.0	1.5	0.6

Errors in percent

60 Hz, 20 kV, MIL 2500A range: 20 kV

Test current: 0.6 A

Power Factor	Phase U	Phase V	Phase W	3 Phase
0.100	1.4	1.3	1.2	1.3
0.250	0.8	0.9	0.8	0.8
0.500	0.7	0.7	0.7	0.7
0.900	0.6	0.6	0.6	0.6

Test current: 2 A

Power Factor	Phase U	Phase V	Phase W	3 Phase
0.050	2.4	2.2	2.3	2.3
0.100	1.2	1.1	1.2	1.2
0.500	0.3	0.2	0.3	0.3
0.900	0.1	0.1	0.1	0.1

Test current: 10 A

Power Factor	Phase U	Phase V	Phase W	3 Phase
0.010	1.8	1.9	1.8	1.8
0.025	0.7	0.7	0.7	0.7
0.050	0.4	0.4	0.4	0.4
0.100	0.2	0.2	0.2	0.2
0.500	0.0	0.0	0.1	0.0

Test current: 50 A

Power Factor	Phase U	Phase V	Phase W	3 Phase
0.005	2.1	2.5	2.3	2.3
0.010	1.0	1.3	1.1	1.1
0.025	0.4	0.5	0.5	0.5
0.050	0.2	0.3	0.2	0.2
0.100	0.1	0.1	0.1	0.1

Test current: 100 A

Power Factor	Phase U	Phase V	Phase W	3 Phase
0.005	2.0	2.4	2.2	2.2
0.010	1.0	1.2	1.1	1.1
0.025	0.4	0.5	0.5	0.5
0.050	0.2	0.3	0.2	0.2
0.100	0.1	0.1	0.1	0.1

Test current: 500 A

Power Factor	Phase U	Phase V	Phase W	3 Phase
0.002	1.1	0.7	0.9	0.9
0.005	0.3	0.2	0.3	0.3
0.010	0.2	0.1	0.1	0.1
0.025	0.1	0.0	0.1	0.0
0.050	0.1	0.0	0.1	0.0

Test current: 1000 A

Power Factor	Phase U	Phase V	Phase W	3 Phase
0.002	0.4	0.3	0.3	0.3
0.005	0.2	0.2	0.2	0.2
0.010	0.2	0.1	0.1	0.2
0.025	0.1	0.1	0.1	0.1
0.050	0.0	0.0	0.1	0.0

- Test points completely flexible to meet the needs
- Typically: mostly-used *V* – *I* combinations
- Final uncertainty of the system calibration strongly depends on the on-site conditions!

CIPM MRA

CALIBRATION
RvA K 999

VSL

Conclusion

VSL has developed a unique reference setup for on-site system calibration of industrial LMS up to 230 kV and 2000 A with 20 μW/VA uncertainty

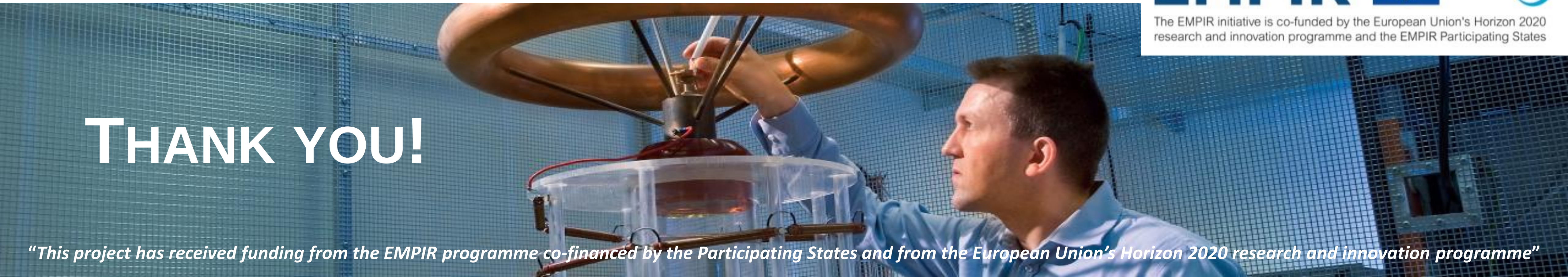
- 50 Hz, 60 Hz
- Fully automated: 21 *V-I* combinations, at 2 frequencies (420 test points) in 1 weekend
- Suitable for reactor systems (230 kV, 2 % uncertainty at PF = 0.001)
- Traceable to national standards, accredited (ISO 17025, CIPM MRA)

Reference setup already used in more than 10 on-site LMS calibrations!

TRAFOLOSS

EMPIR EURAMET

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



THANK YOU!

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