European Metrology Research on Electrical Grids supporting the Energy Transition

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EMRP European Metrology Research Programme ▶ Programme of EURAMET
EMPIR EURAMET The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

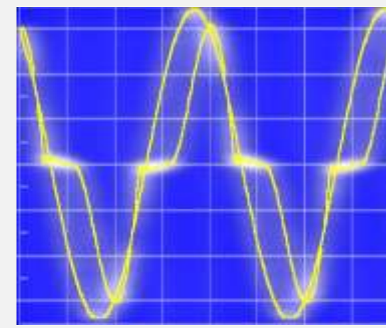
Outline

The Electricity Grid

Metrology challenges

- Grid monitoring
- Power Quality
- New sensors
- Grid losses

Summary



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Greatest Engineering Achievements of the 20th Century

1. The Grid / Electrification

2. Automobile
3. Airplane
4. Water supply
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air conditioning / Refrigeration

Source: US National Academy of Engineering; Courtesy: Terry Boston, President & CEO PJM Interconnection

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VSL

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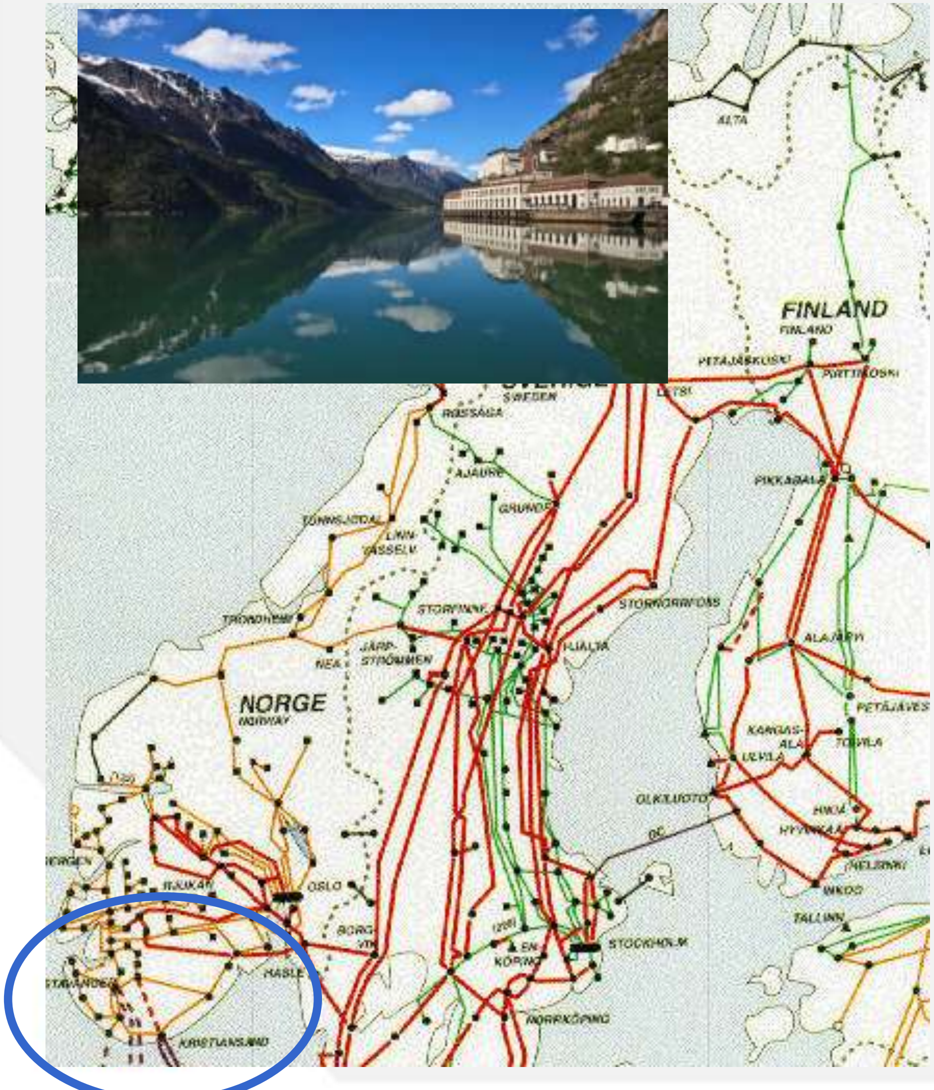
The Norwegian Electricity Grid



NorNed: 700 MW, 450 kV_{dc}, 580 km

Revenue: 450 M€/5 yr (POT 8 yr)

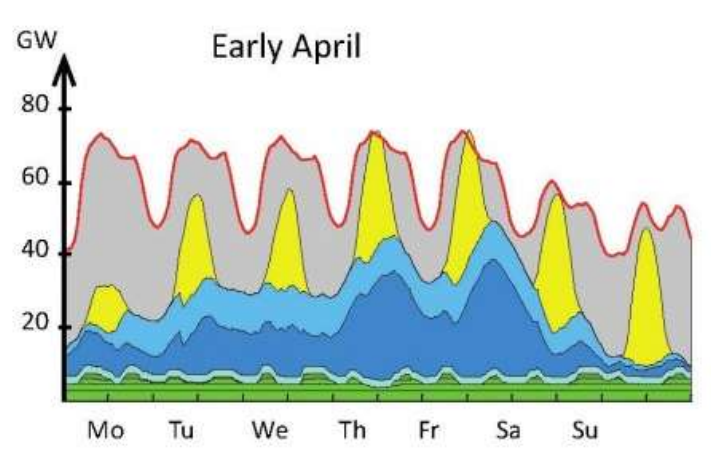
How the grid works

[How the grid works || BURN Radio]

The Energy Transition

20/20/20 aims EU for 2020:

- 20 % reduction CO_2 emission
- 20 % renewable energy
- 20 % less energy (efficiency)

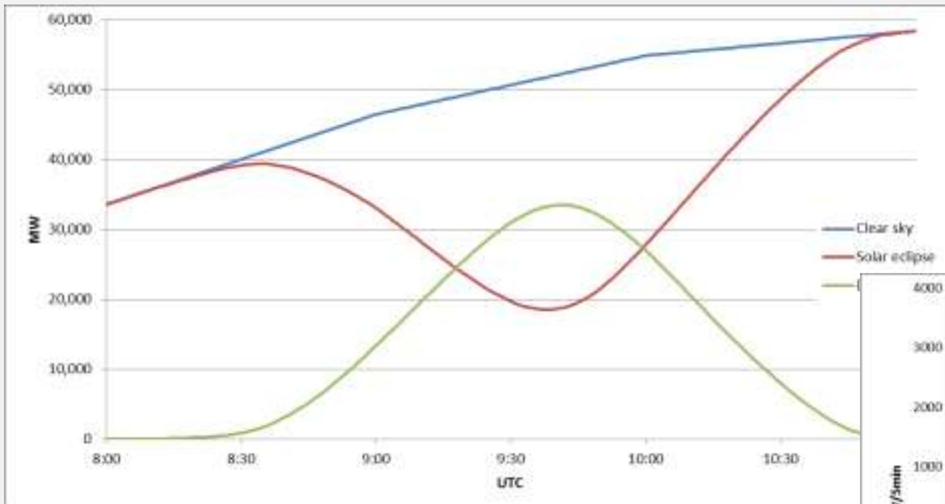


⇒ Major impact on the grids

- Two-way power flows – prosumers
- Complex, highly variable loads
- Renewable energy: highly variable, not fully predictable

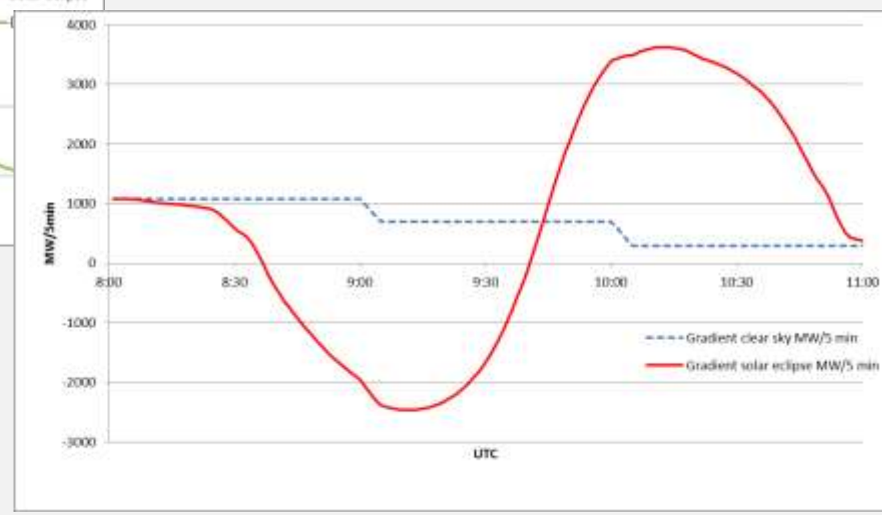
⇒ Metrology: security & quality of supply via better monitoring

Impact of solar eclipse on grids



Solar Eclipse 2015

- Impact Analysis -



Actions from ENTSO-E

- coal, natural gas, biogas, nuclear, hydroelectric power
- Relieve of industrial demand, (e.g. four aluminium plants)
- Switching off PV (Italy: 30 % of PV production, 4.4 GW)

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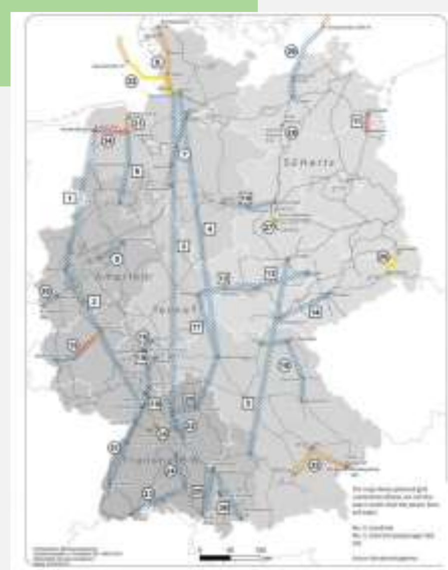
Challenge of wind for grids

Challenge for TenneT (TSO):
connect 7.5 GW to the grid in 4 years (2015 – 2019)

⇒ We need a power plug

⇒ … and we need grid extensions



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Grid sensor networks

Overall aim: Sensor network metrology for determination of electrical grid characteristics

$\Rightarrow$ Observation of distribution grids (RES)

1. Sensor network metrology algorithms to process data from grid monitoring systems
2. To determine uncertain distribution network topologies and line impedances
3. Investigate the use of Phasor Measurement Units (PMUs) or Smart Meters for power flow calculation and state estimation
4. Data security infrastructure

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Sensoring Distribution Grids

How to handle too much data?

Which sensors can be removed ?

How many sensors are needed ?

What happens when a given sensor fails ?

Solar PV,
Fuel Cells,
Biogas,
Natural Gas,
μ-gasturbine

Estimate unknown Cable impedances

How accurate should a given sensor be ?

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GRID SENS
PTB
University of Strathclyde Engineering
NPL National Physical Laboratory
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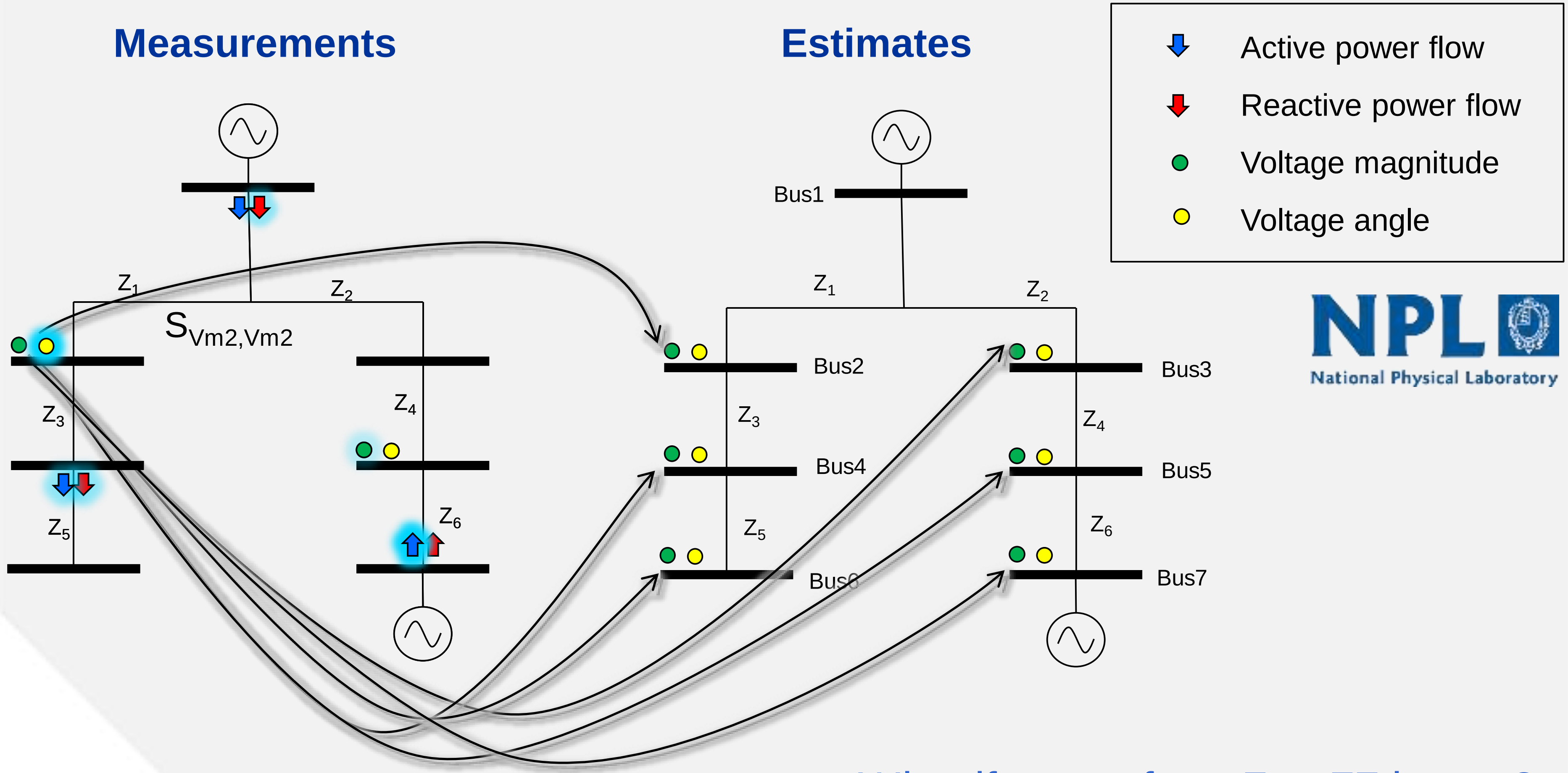
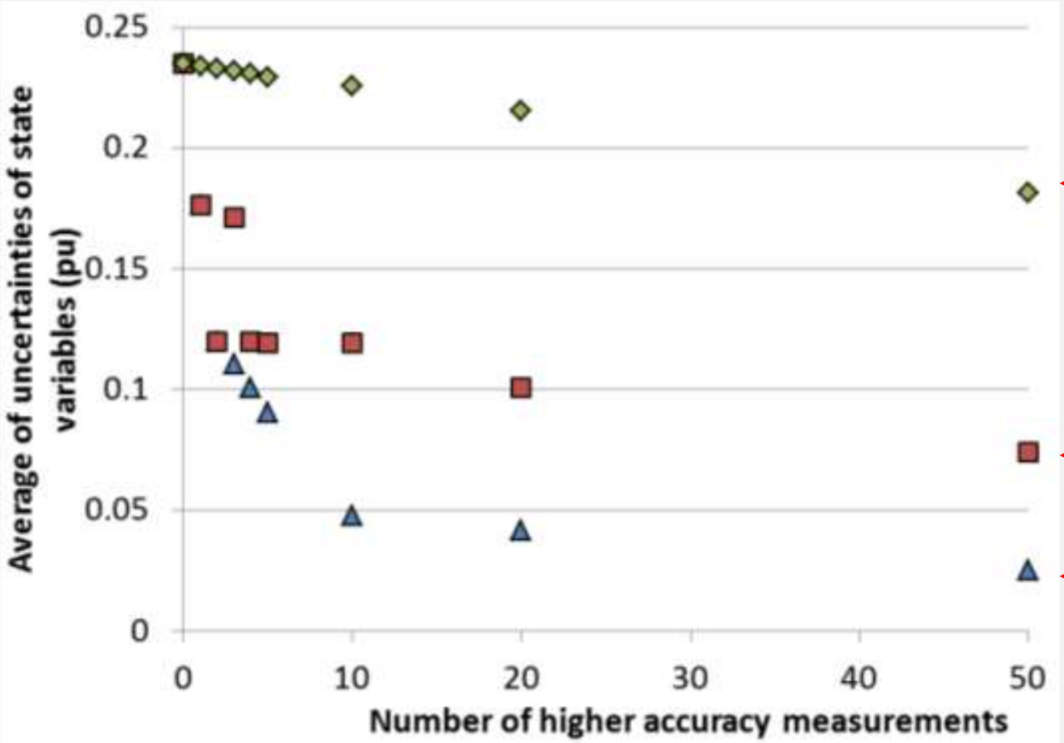
Optimal sensor location



What if we go from 7 to 77 buses?

Optimal sensor location



Average of 1000 random trials

Minimum of 1000 random trials

Optimum choice

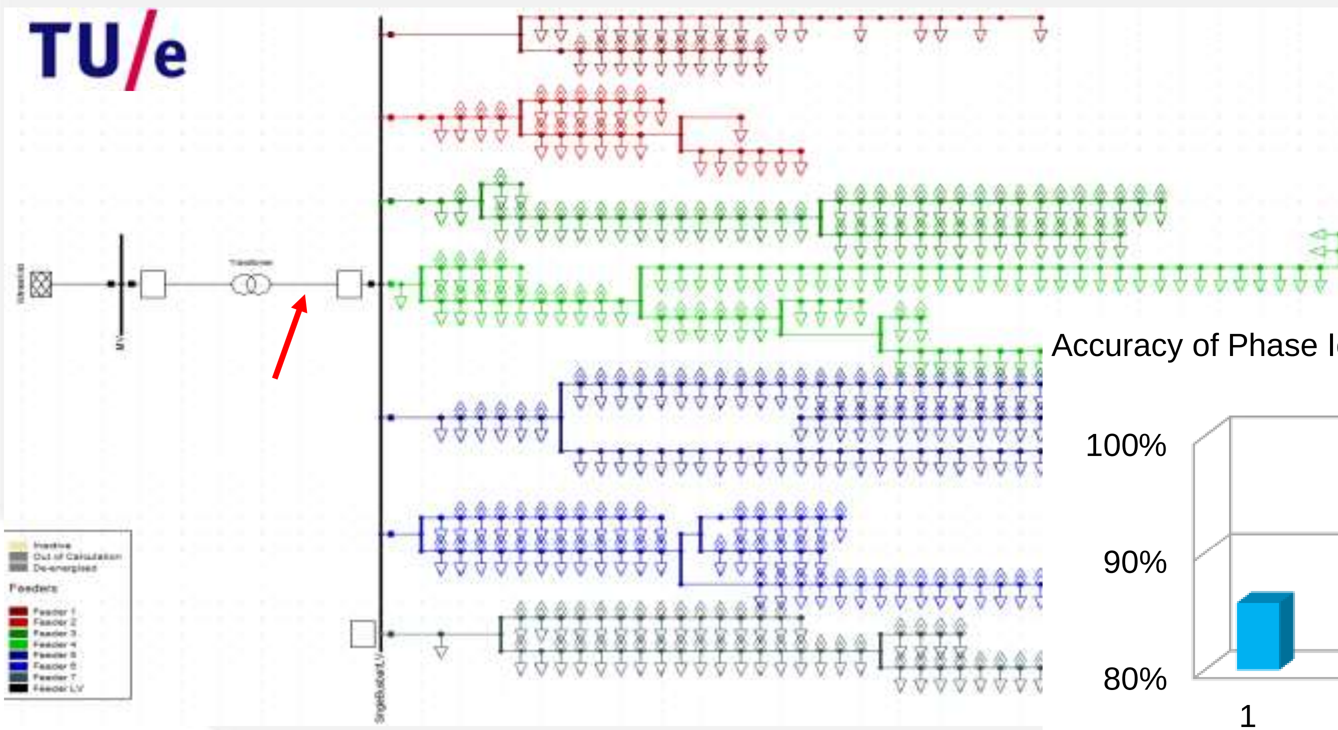
⇒ Already with measurement s on 10 out of 77 grid buses, grid state variables can be determined with < 5 % uncertainty

⇒ cost effective!

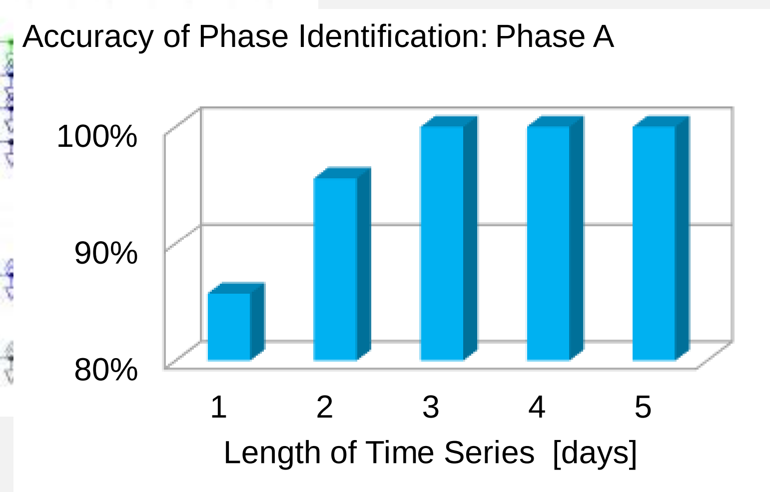
Aggregation Smart Meter data

Key question: can Smart Meter data be used for state estimation?

⇒ First: determine phase (A, B, C) to which meters are connected



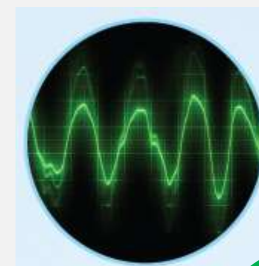
Correlate smart meter data with measurements at LV side of MV/LV power transformer



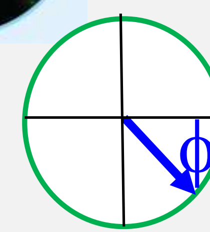
Smart Grid measurements

Overall aim: to develop, demonstrate and validate new measurement tools for network operational stability and power quality

⇒ Support stability and quality of supply (RES)



1. PQ disturbance "radar" – locate major sources of poor PQ for mitigation and enforcement.
2. Phasor Measurement Units (PMU) – traceability; on-site measurements ⇒ "life support monitor" for Smart Grids



3. Grid impedance using synchronised data
4. Transducers – non-invasive; crucial to connect PQA, PMU to grid

Study Leonardo institute: "PQ costs in Europe have an economic impact exceeding € 150 bn/year"

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Power Quality propagation

Challenges: How do PQ disturbances propagate through networks?

- Use multiple GPS-synchronised digitisers at locations in a grid
- Reconcile modelling with PMU/PQ measurements
- Develop a PQ disturbance location method: “PQ Radar”

Results so far:

- Organised measurement campaigns in a variety (4) of Smart Grids
- Identified data and modelled grids, selected measurement sites
- Calibrate & install instrumentation, data collection and analysis software

Alliander LiveLab

Bornholm Island

Enduris Ring Grid

VSL

PQ field measurements

SMART GRID METROLOGY

2

NPL National Physical Laboratory

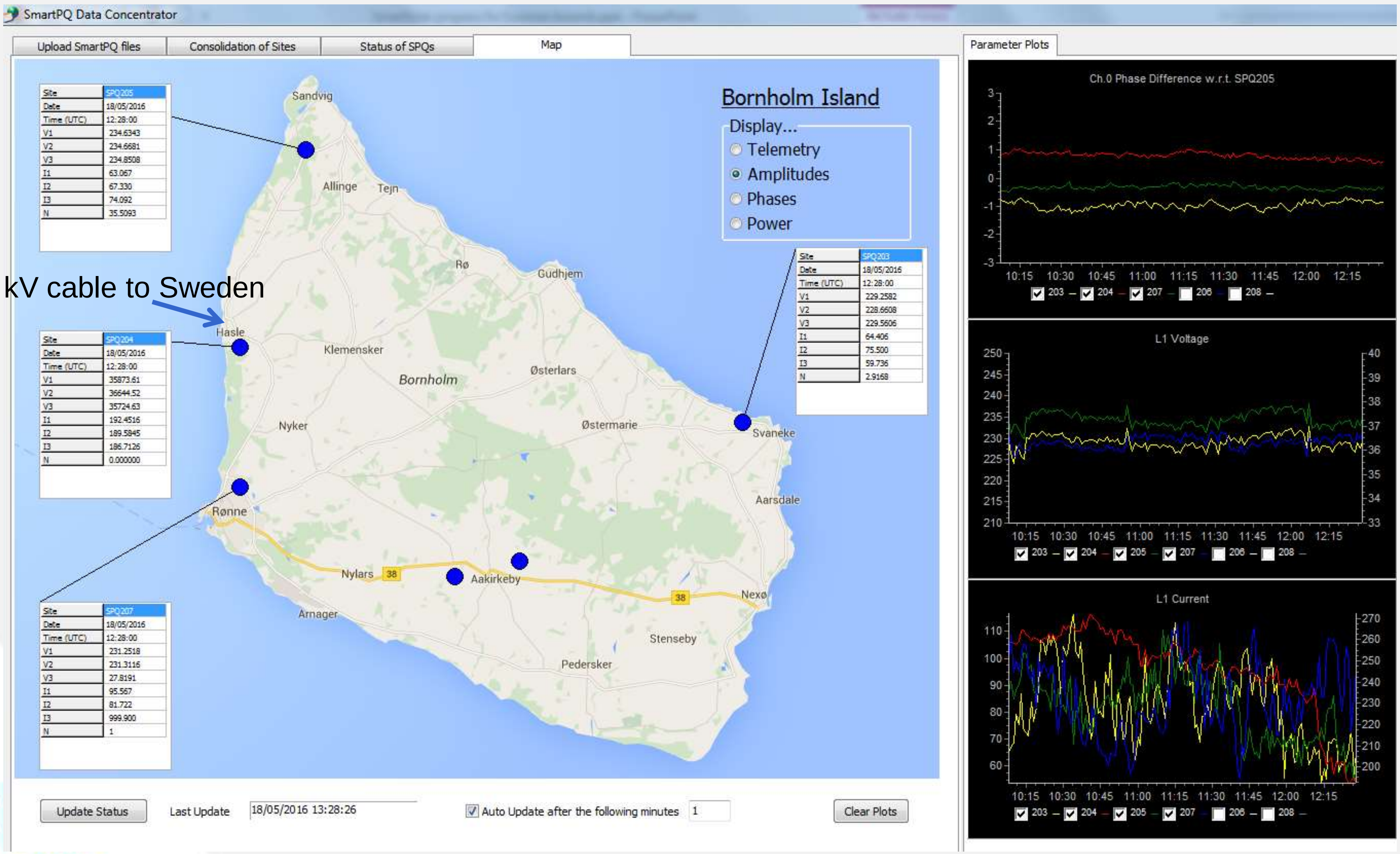
Trescal

SP

Windturbine grid Connection (SE)

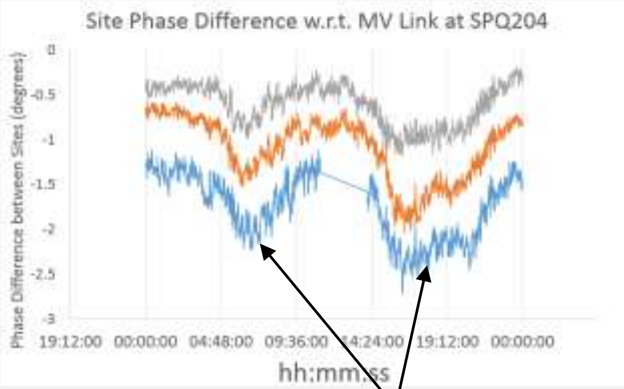
Ideal Lab conditions on Bornholm (DK)...

Live data display Bornholm



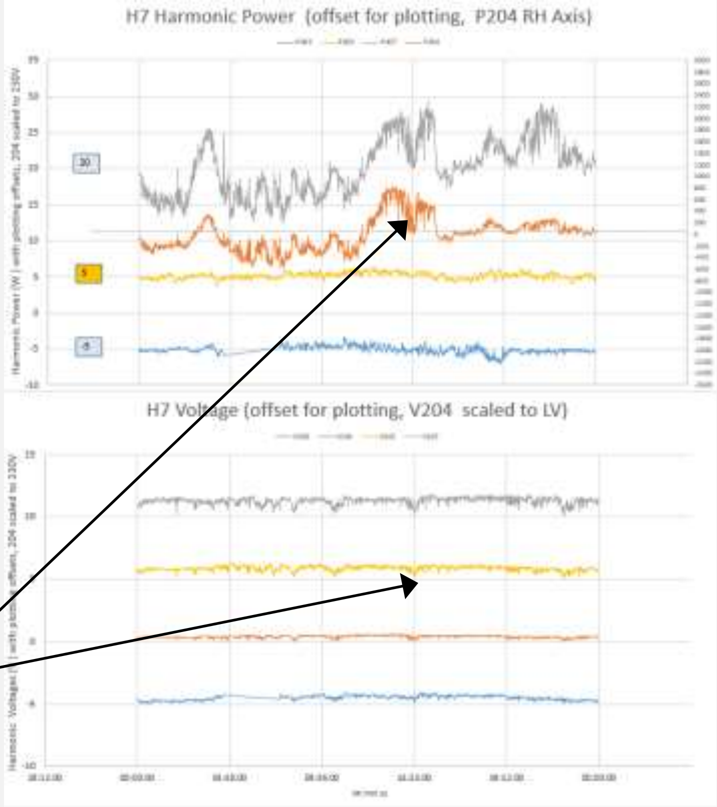
First analysis results

Bornholm Data



Inter-site Phase increases at time of high load in the morning and evening

Harmonic events visible propagating on the voltage around the island

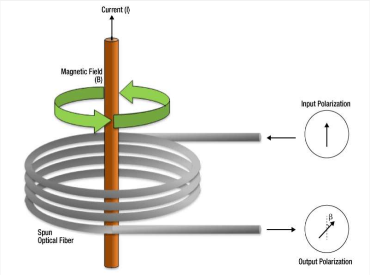


Future Grid - sensors

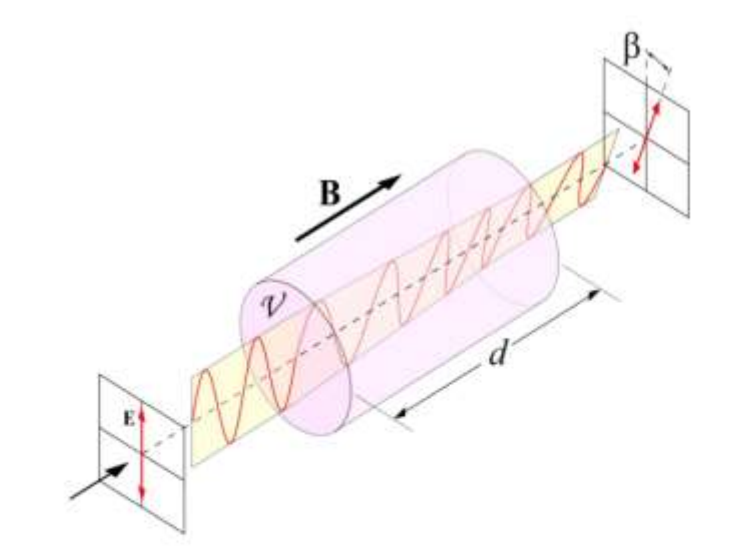
Overall aim: emerging measurement technologies for future power grid

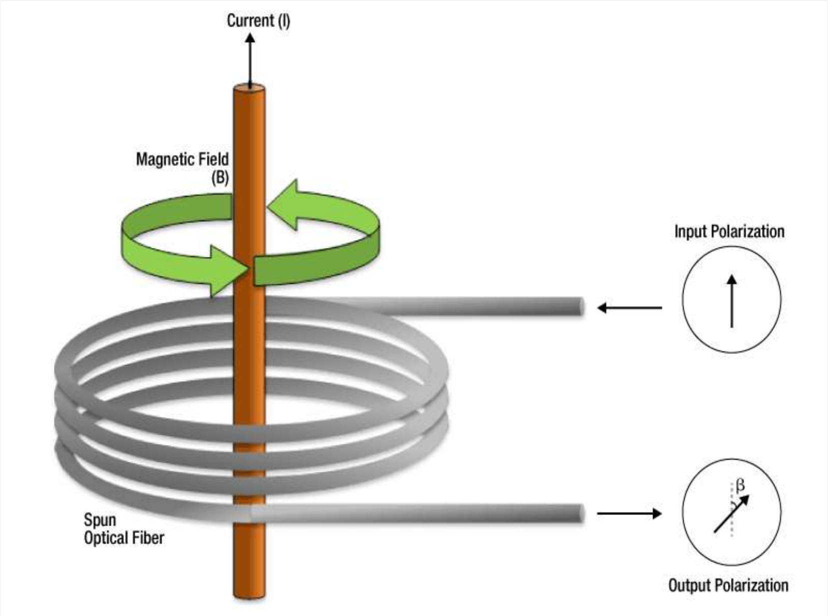
Development, performance evaluation, and calibration of new wideband sensors:

1. Metrology grade optical current sensor
   - Based on optical Faraday effect
2. Novel sensors techniques
   - Improved Rogowski coil, voltage divider for harmonics MV grid
3. Development of calibration methods
   - Current and voltage w. digital or non-conventional analog output
   - Commercial ‘test sets’



Optical Faraday effect





$$\beta \sim VBd$$

$$\beta \sim NVI$$

V: Verdet constant

- Advantage: linearity, wideband, light-weight, ease of insulation
  Digital output → easy integration of digital substations
- Challenge: sensitivity, accuracy (effect T), expensive readout

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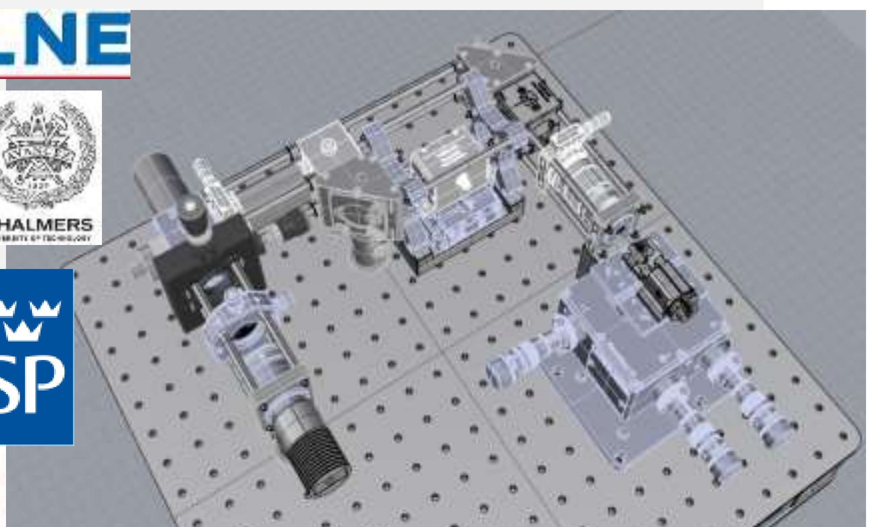
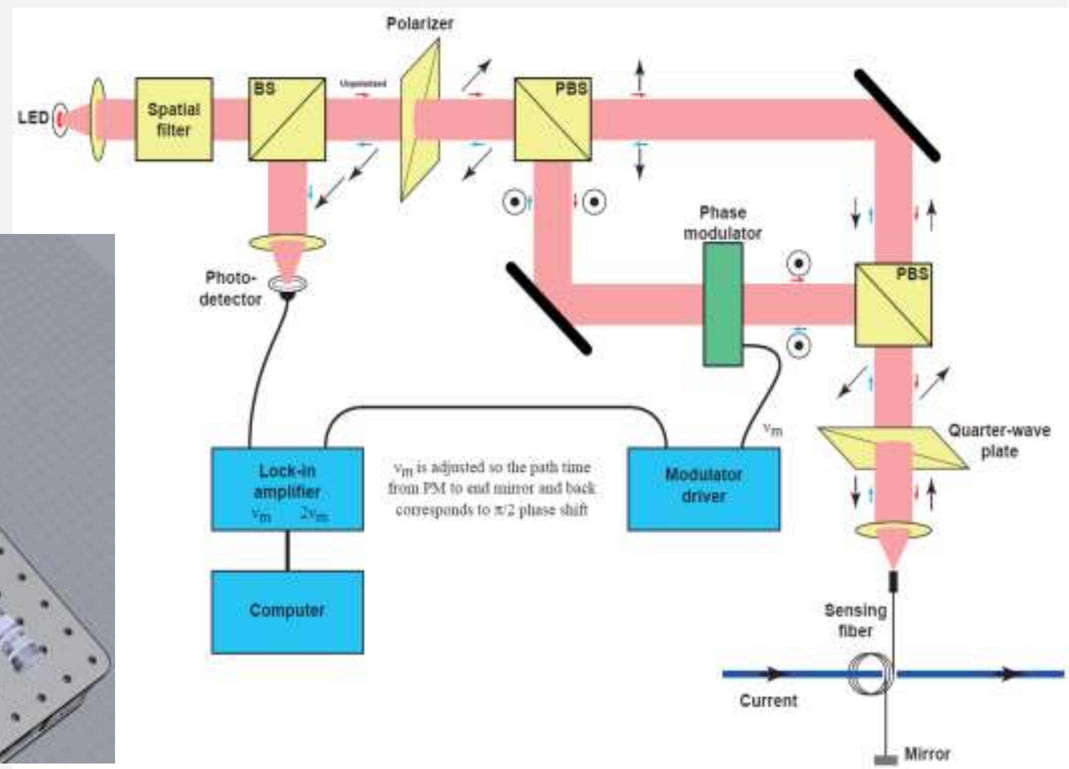
System design optical sensor

Cooperation of several NMIs and Universities:

- Theoretical work by REG (Chalmers, Sweden) has led to new solutions to improve the sensitivity of the method.
- Cooperation NIM (China) on detection.
- Cooperation Southampton University (UK) on custom fiber development.
- Fibers are tested at LNE

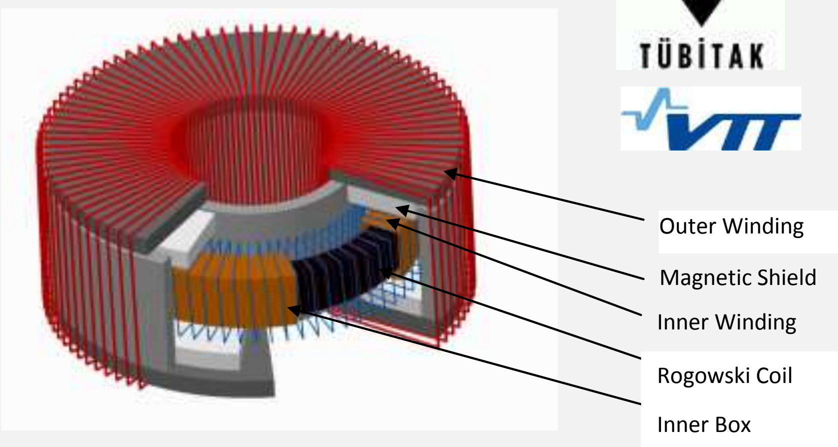
⇒ First tests at SP underway



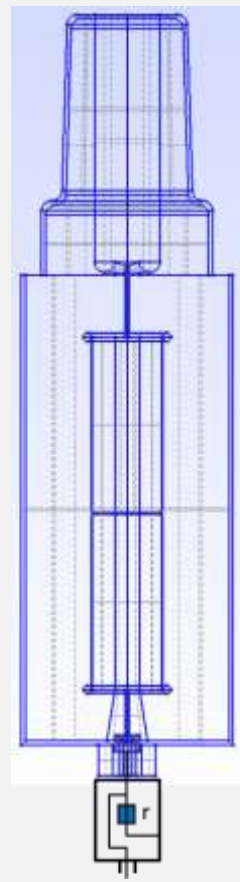


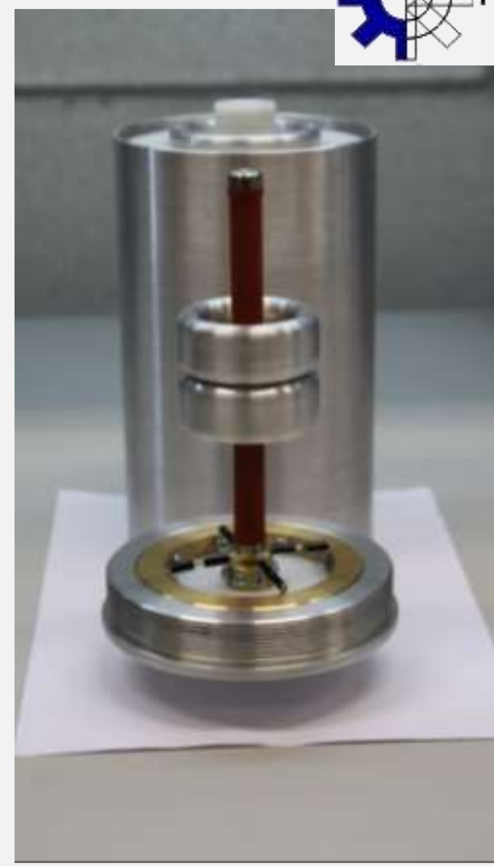
New current & voltage sensor

Shielded Rogowski coil



MV wideband voltage sensor





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Metrology for electric power industry

Overall ELPOW aim: to prove the quality of products developed for higher efficiency in electricity grids (i.e. with higher grid voltages and lower losses)

$\Rightarrow$ Support leading EU HV industry

1. Ultra-high lightning impulse
   - Ensure quality and reliability of HV equipment
2. Very fast transients
   - Ensure compatibility of testing
3. Loss of AC power equipment
   - Support Eco-Design directive
   - Provide basis for assessment of efficiency of equipment
4. HVDC station loss
   - Develop base for determination of ac/dc converter efficiency

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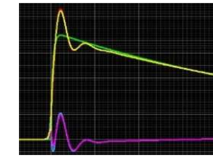
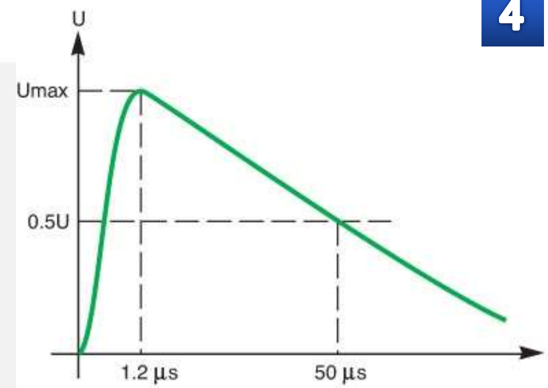
Lightning impulse





State of the art:

- Direct measurement of LI up to 300/500 kV
- Extrapolation using the linearity method (20% - 100 %)

System voltages are currently increasing to levels higher than 1000 kV (*lower losses in the grid*)

⇒ urgent need for

- LI references for voltage levels of > 800 kV
- Calibration techniques for linearity measurement
- Extending traceability of the linearity methods into the ultra-high voltage range

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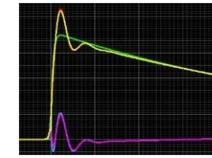
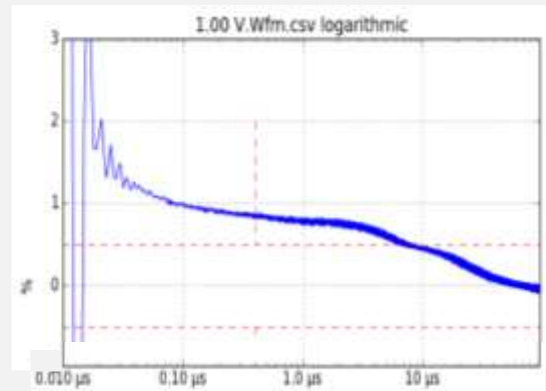


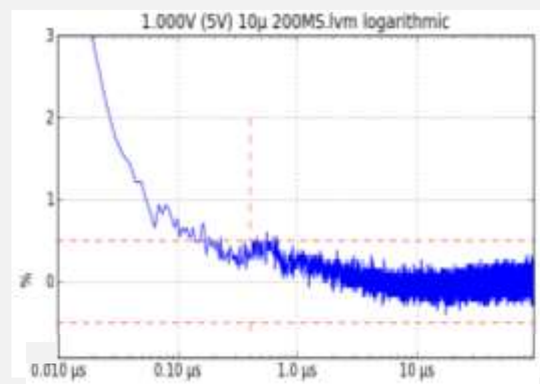
New LI references

1 MV damped capacitive reference divider for LI

Screening of transient recorders for LI capture - settling time



High-end oscilloscope 2 GHz bandwidth



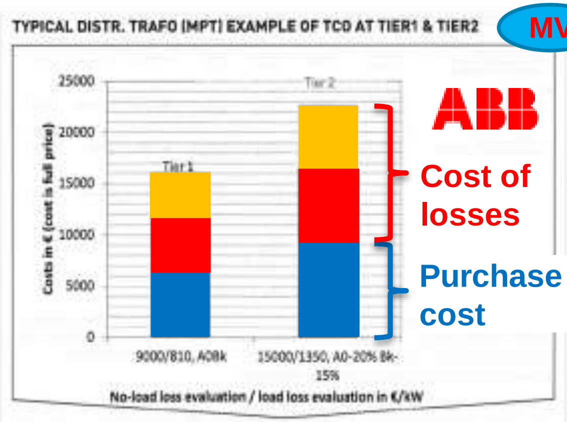
Sampling card 200 MHz bandwidth

⇒ Recorders optimised for speed, not accuracy

Power Transformer Losses

Ecodesign Requirements:
maximum losses or minimum Peak Efficiency

COMMISSION REGULATION (EU) No 548/2014
of 21 May 2014
on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers



⇒ TCO is important!

Proof of conformity: via calibrated Transformer Measurement System

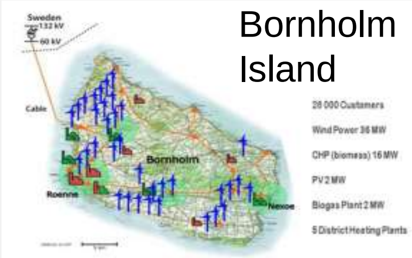
- Calibration challenge: < 30 μrad (0.1 min)
- Lower uncertainty = less risk
  (typical fine: 10 k€/kW)
- On-site conditions!
- Traceable to national measurement standards
  = less debate

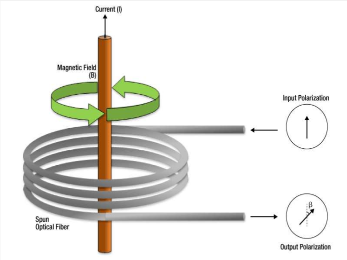
Summary

Electricity grids are key infrastructure of our society, at the same time facing major challenges (Energy Transition)

$\Rightarrow$ ***Metrology can make crucial contribution to support quality and security of supply, and ensure higher efficiency***

- Sensoring: best measurement locations, determine & predict grid state
- Smart Grid measurements: on-site PMU and PQ campaigns
- New sensors: optical & improved existing technologies
- HV power industry: support better efficiency





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