Smart Grid Metrology: how measurements keep our society up and running

Gert Rietveld
gert.rietveld@vsl.nl

The gateway to Europe's integrated metrology community.

EURAMET

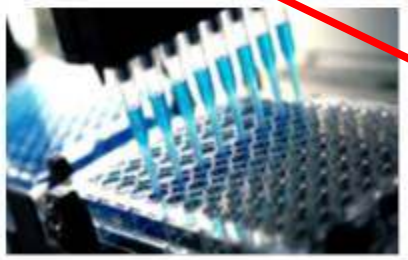
SI Unit

Environment

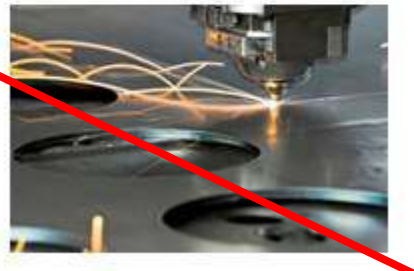
Energy

Fundamental

Health



Industry



30+ projects, each 3.5 M€

- Smart Grids (4x)
- Smart meters
- HV testing
- HVDC
- Transformer efficiency
- Power plants (3x)
- Biofuels, biogas
- Multiphase flow, viscosity fluids
- LNG (3x)
- Solid State Lighting (2x)
- PV (3x)
- Materials: thin films, composites

SMART GRID METROLOGY

Energy Strategic Research Agenda

EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

EMPIR EURAMET

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

Greatest 20th Century Engineering Achievements

1. The Grid / Electrification
2. Automobile
3. Airplane
4. Water supply
5. Electronics
6. Radio & 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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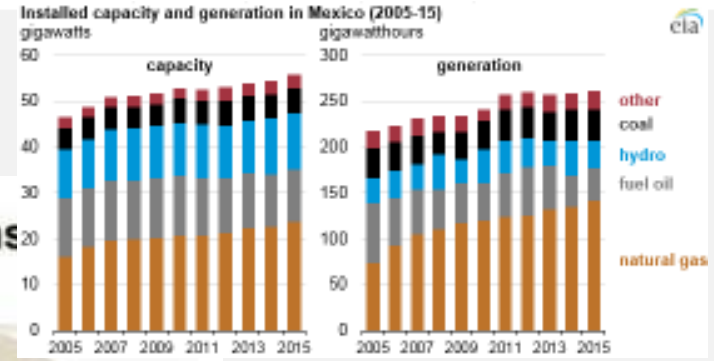
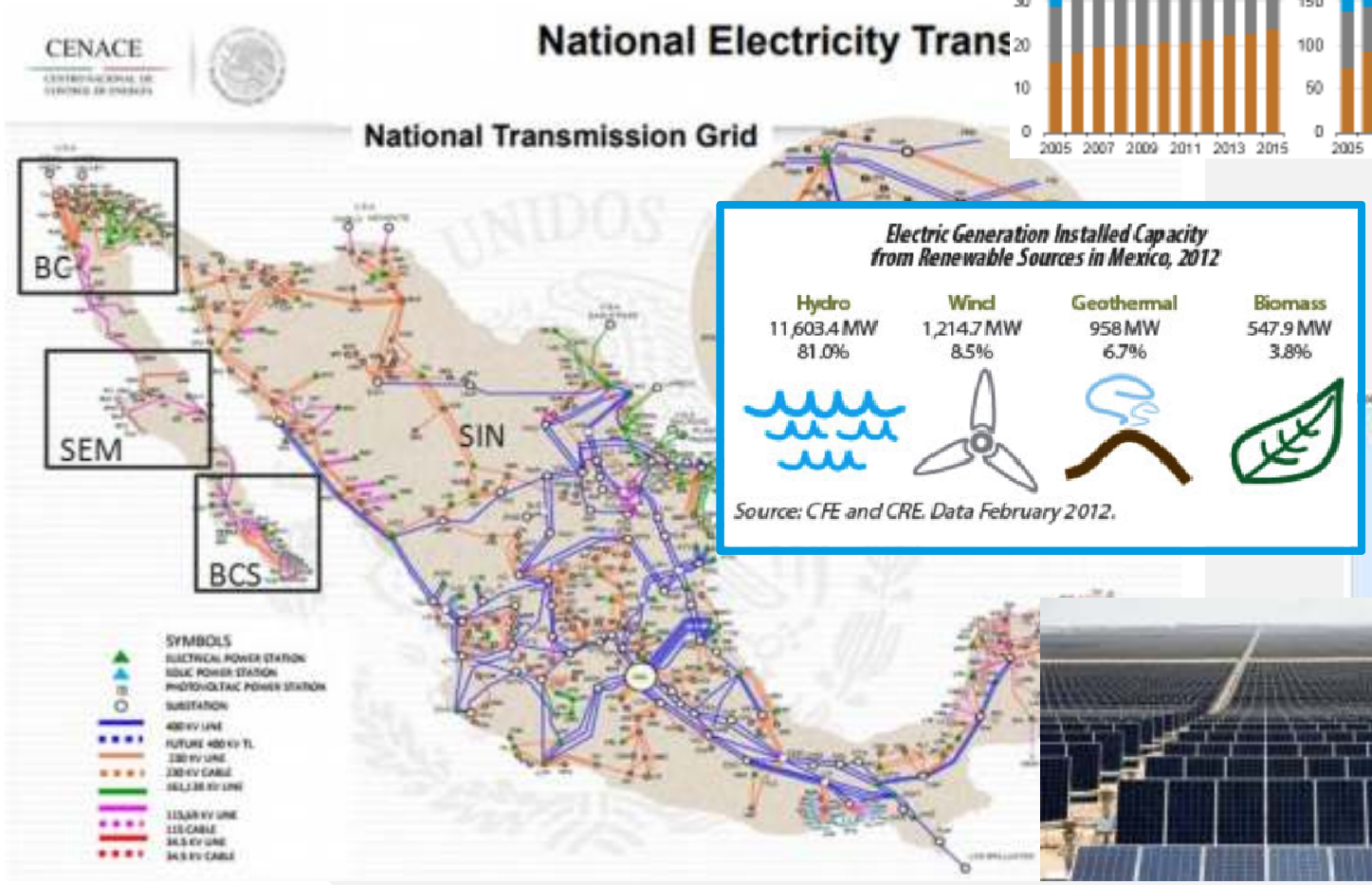
The Mexican Electricity Grid

Transición Energética



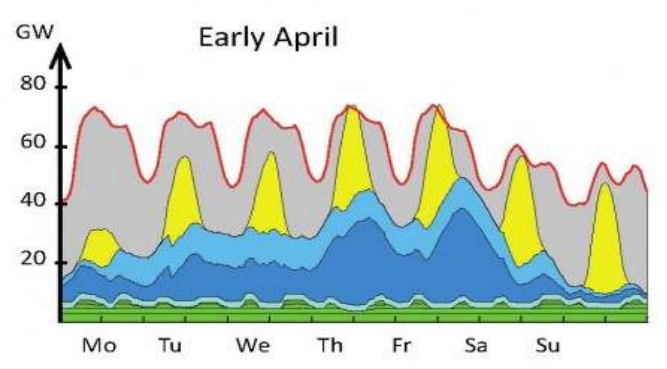


60 MW (2013)
2000 MW (2018)

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

Demand what is produced

⇒ **Metrology**: security & quality of supply via better measurements

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Patient: heart beat frequency

1

60 beats/min

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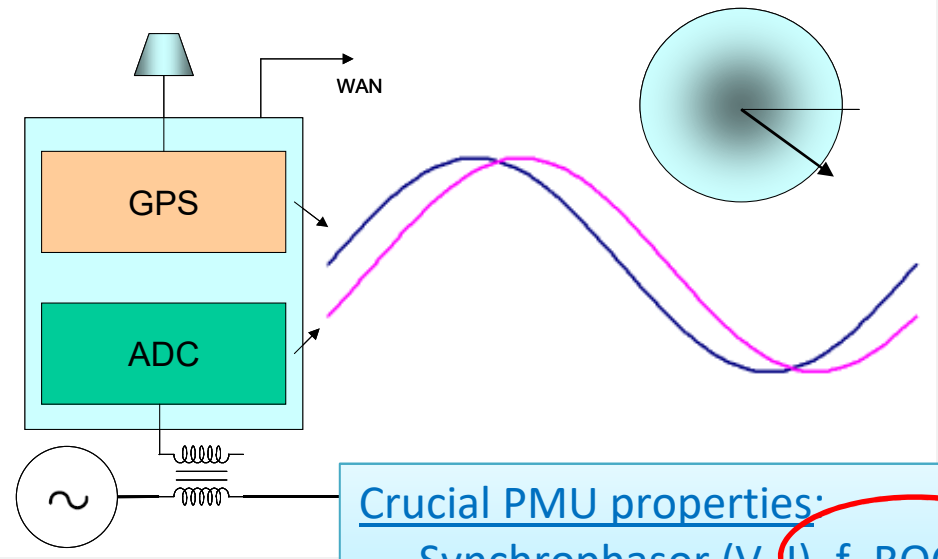
PMU: grid heart beat monitor

1



Inventors: Arun Phadke & James Thorp
1988, Virginia Tech, US

Crucial PMU properties:
- Synchrophasor (V, I), f, ROCOF
- Fast (up to 60 readings/s)
- Accurate (< 1 %)

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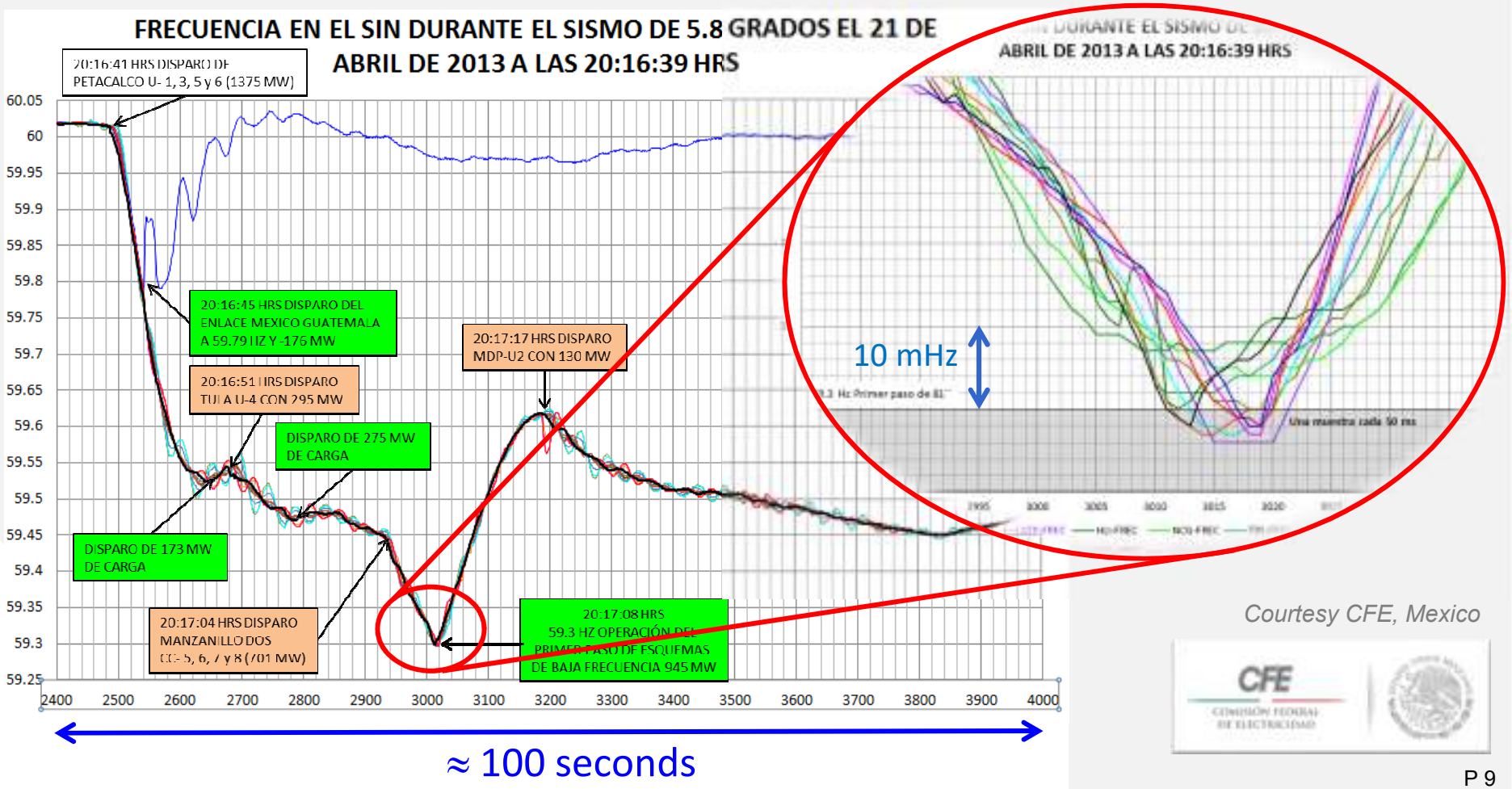
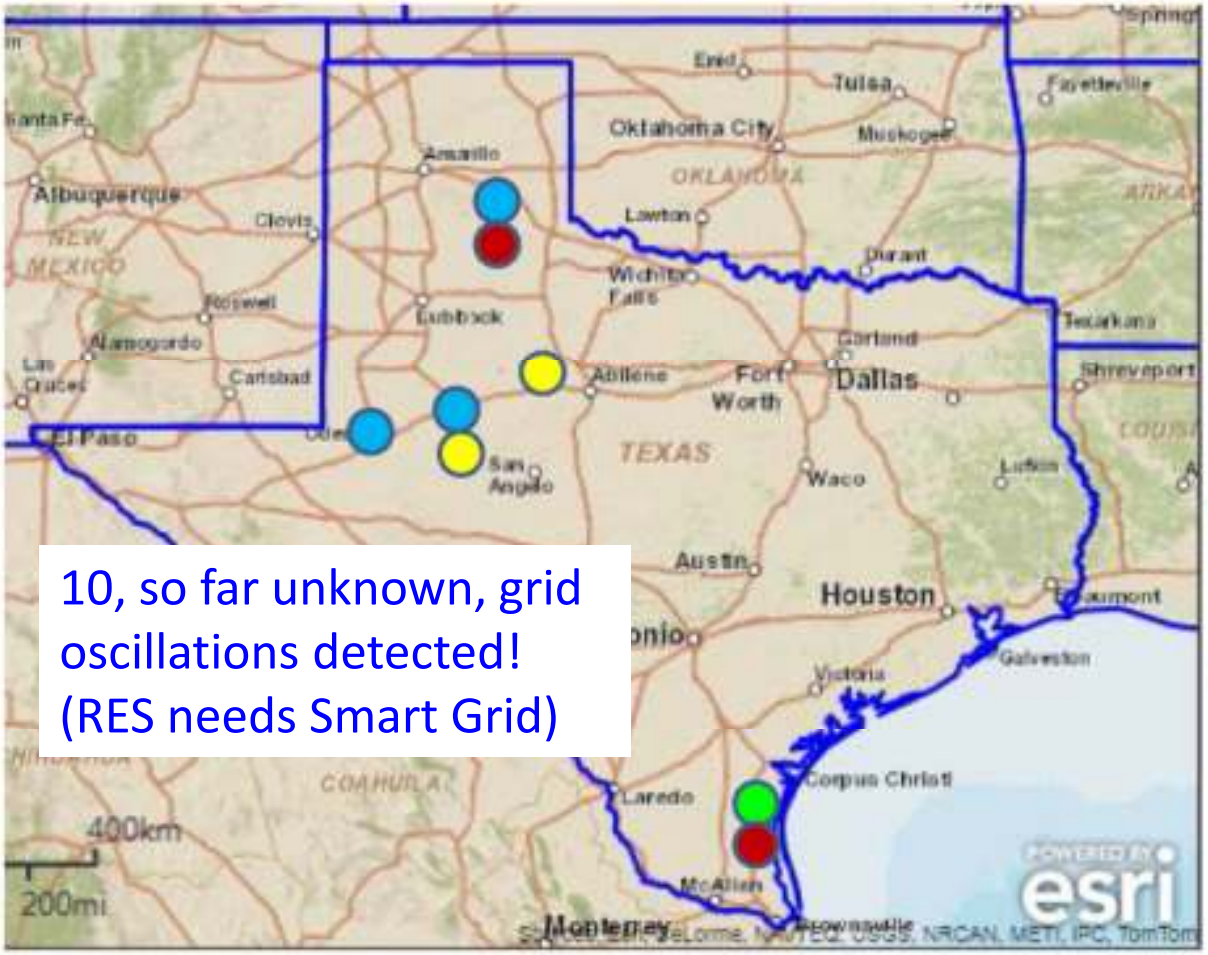
Example: impact earthquake

Mexico, 21 April 2013: loss of 1.4 GW production due to earthquake



Courtesy CFE, Mexico

Example 2: Grid oscillations



10, so far unknown, grid oscillations detected!
(RES needs Smart Grid)

- 0.9Hz, 2.7Hz – Wind production Related
- 5.0Hz – Control Systems
- 5.4Hz, 6.0Hz – Control Systems
- 3.2Hz, 1.5Hz, 2Hz – Control Settings

Courtesy: Bill Blevin (ERCOT) et.al: NASPI 2015 March meeting

Electric Power Group

CCET

ERCOT

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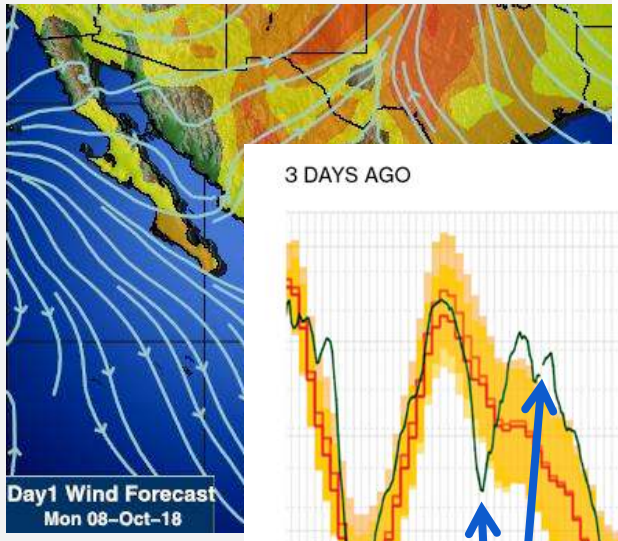
Grid frequency stability

1

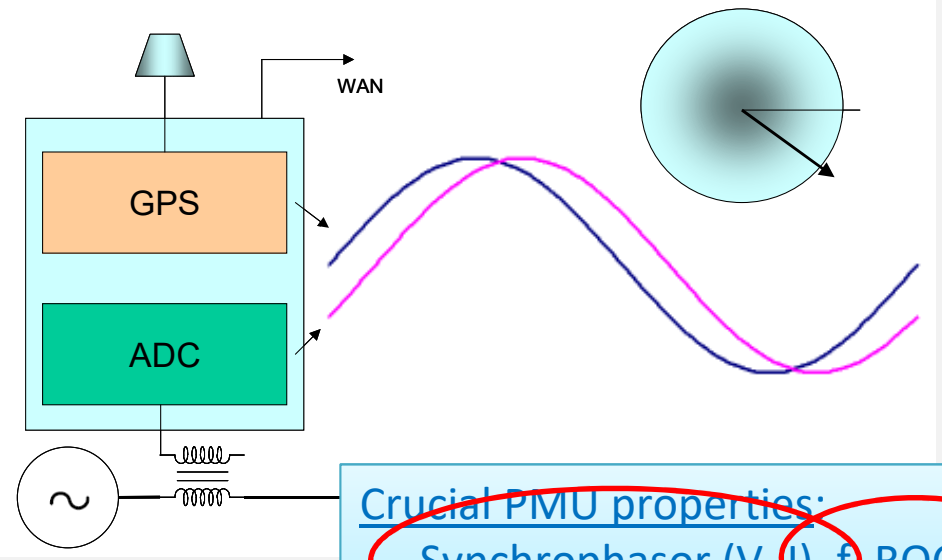
Smart Grid Challenge: maintain grid stability with large, not fully predictable variations in production by Renewable Energy Sources *and at the same time* smaller grid inertia



Mexico WindPower

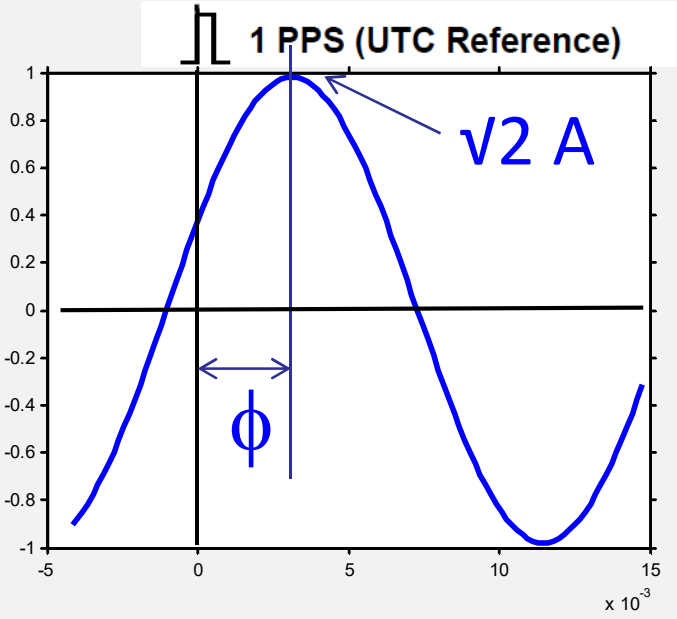
Adjust demand to available production

PMU: grid heart beat monitor



Crucial PMU properties:
- Synchrophasor (V, I), f, ROCOF
- Fast (up to 50 readings/s)
- Accurate (< 1 %)

$$\sqrt{2}\, A \cos(2 \pi \omega_0 t + \phi)$$



A synchrophasor represents the AC grid signal (magnitude **A** and phase angle ϕ) referenced to the 1 pps UTC

Courtesy Ken Martin

"Do all power plants beat in sync?"

US / CA blackout 2003

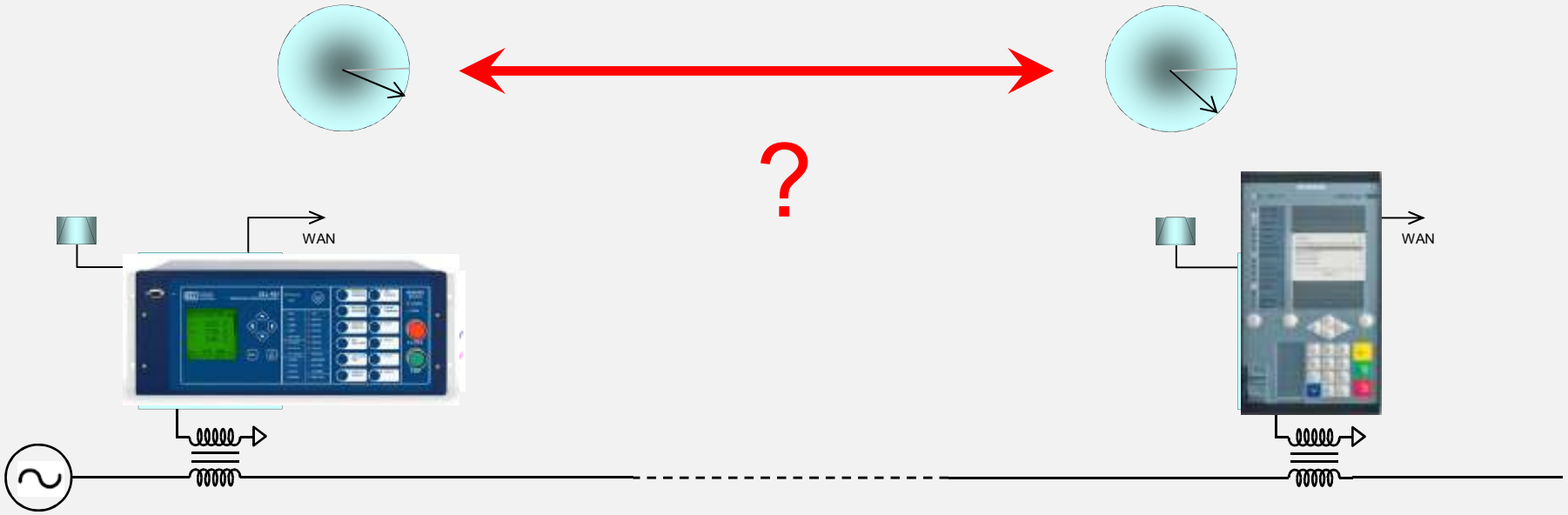
Courtesy NIST

1

Impact:
The blackout affected an estimated 10 million people in Ontario and 45 million people in eight U.S. states (cost: $ 6 billion, > 11 deaths)

Power System Outage Task Force Report:
"A valuable lesson is the importance of having time-synchronized system data recorders. The Task Force's investigators labored over thousands of data items to determine the sequence of events, much like putting together small pieces of a very large puzzle. That process would have been significantly faster and easier if there had been wider use of synchronized data recording devices…"

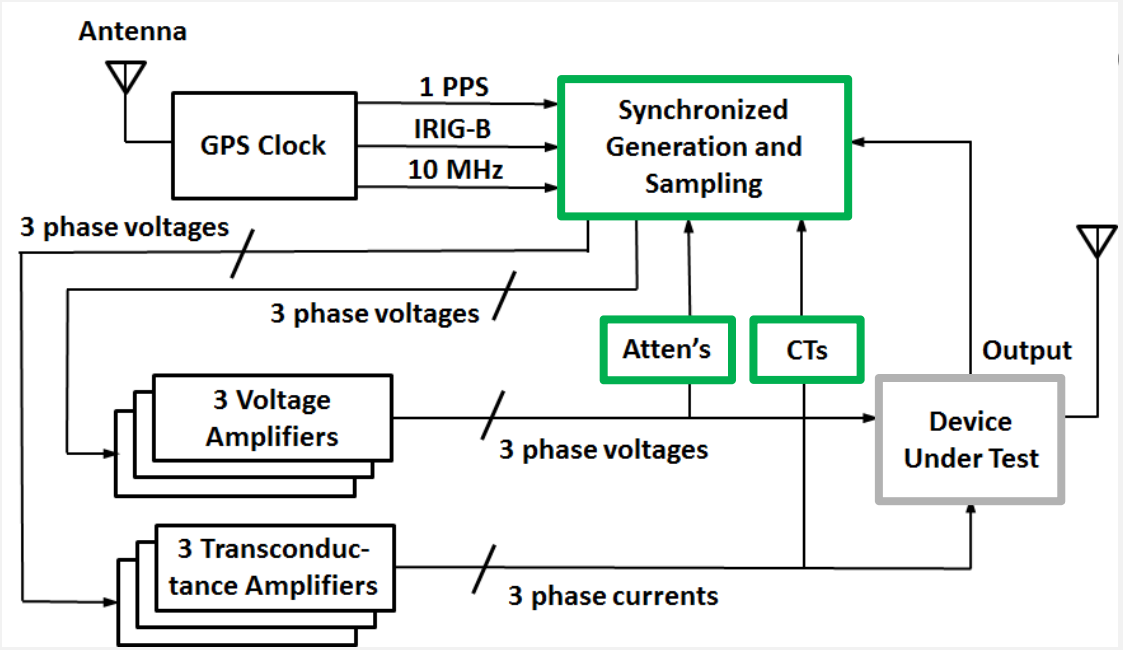
PMU grid monitoring



Reliability required ⇒ *comparability* of data and *interchangeability* of equipment (interoperability)

PMU test / calibration setup

Courtesy NIST



Traceability: << 1 % (26.5 μs)

- Amplitude (V, I)
- Time (t)

Challenge: < 0.01 % (100 ns)

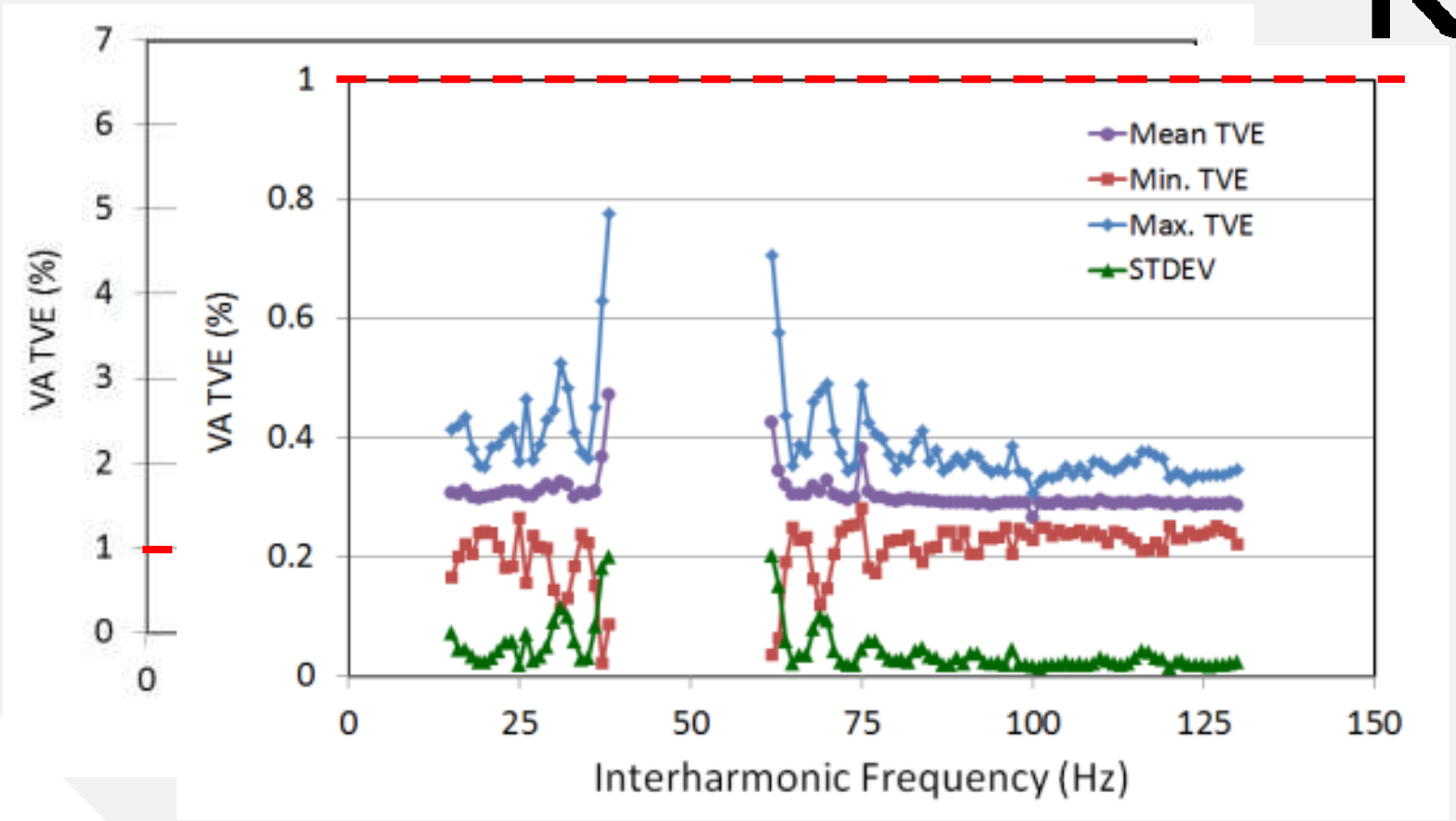
IEEE STANDARDS ASSOCIATION IEEE

IEEE C37.118.1

IEEE Standard for Synchrophasor Measurements for Power Systems

NASPI North American SynchroPhasor Initiative

PMU interharmonic test



PMU testing supports PMU development

Patient: heart beat

Where to put the sensor?

Grid sensor location

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

How to handle flood of data?

Which sensors can be removed?

How many sensors are needed?

What happens if a given sensor fails?

Estimate unknown Cable impedances

How accurate should a given sensor be?

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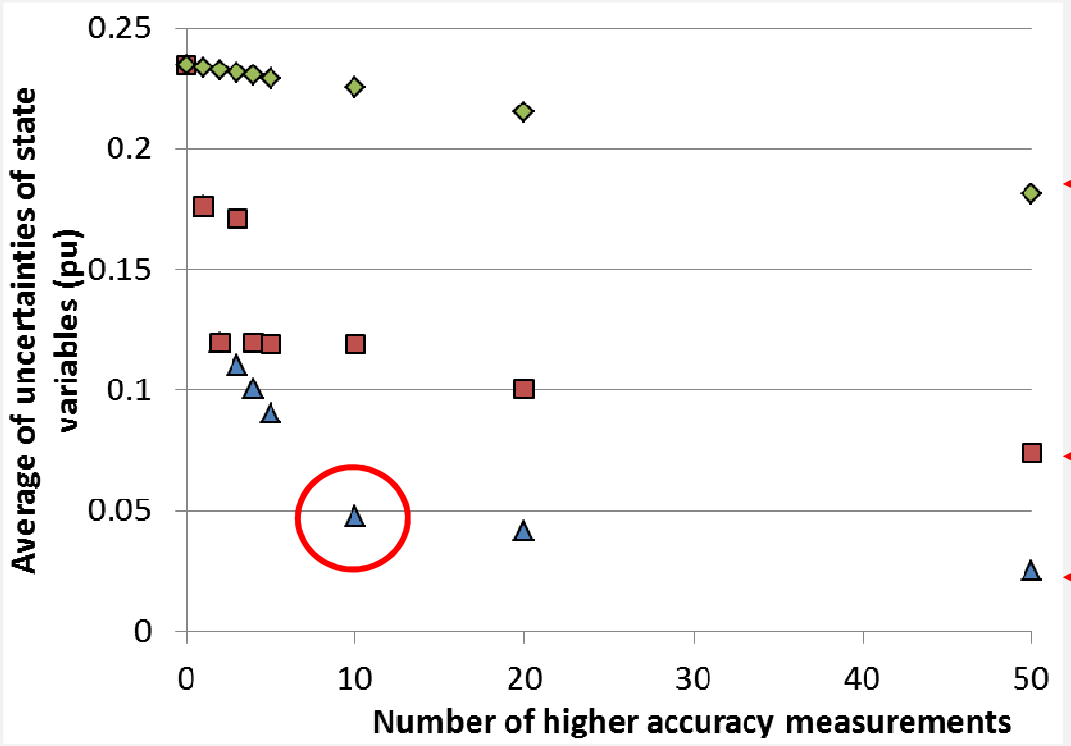
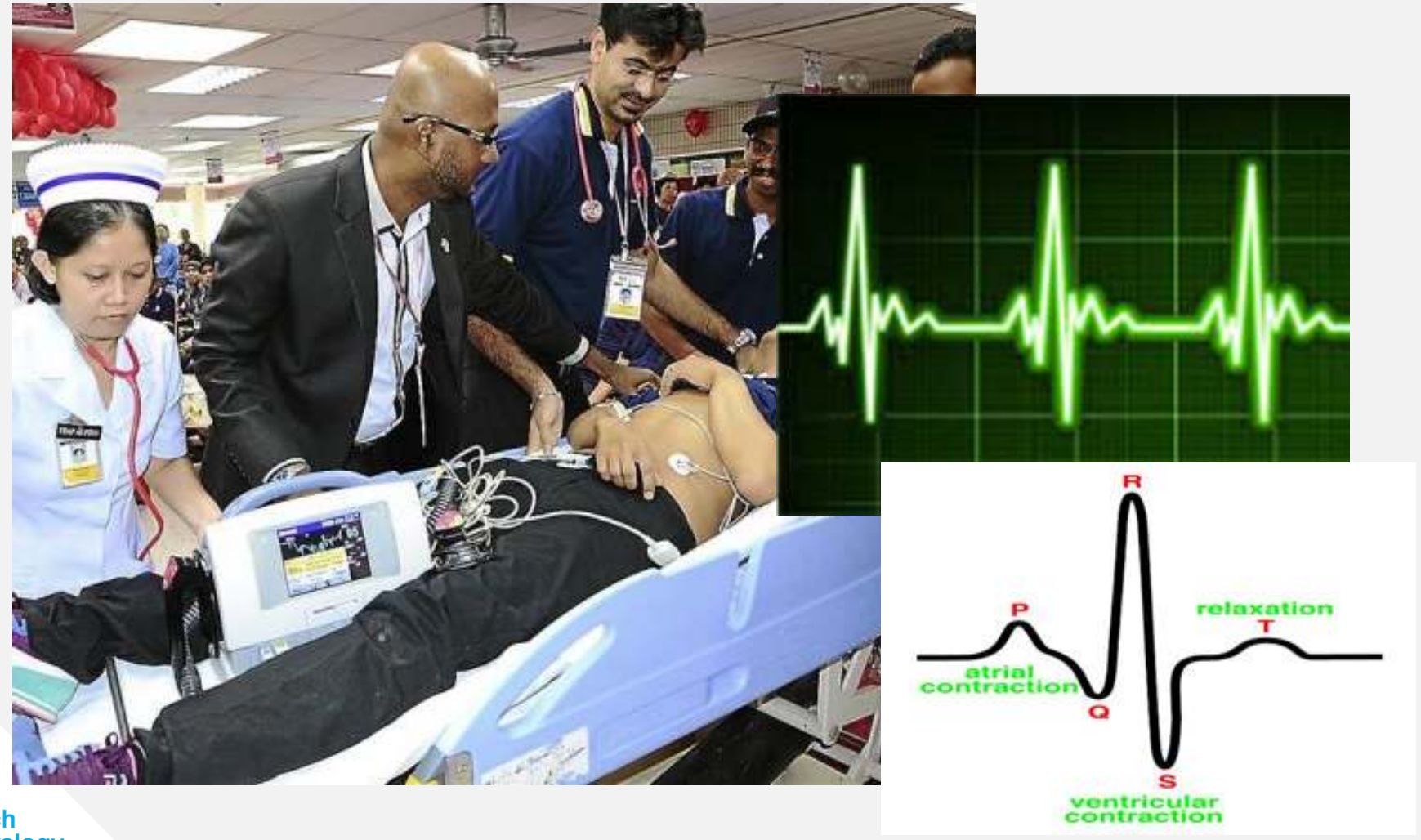
Optimal sensor locations



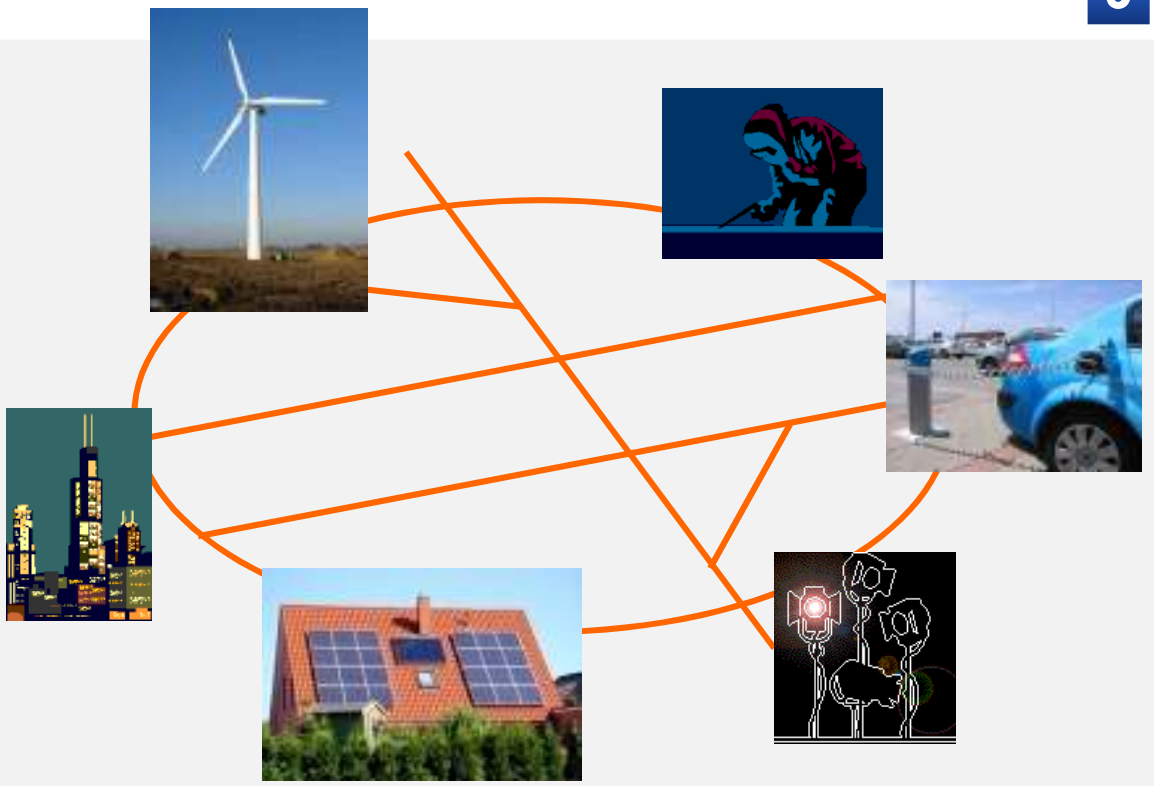
⇒ Already with measurements on 10 out of 77 grid buses, grid state variables can be determined with < 5 % uncertainty

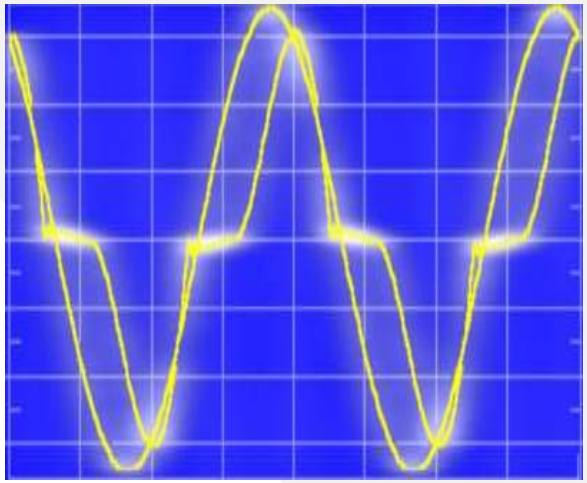
Patient: heart beat quality



Grid Heart Beat Quality (PQ)

Price of poor Power Quality (PQ)





Study (Leonardo institute):
"PQ costs in Europe are responsible for serious reduction in industrial performance with an economic impact exceeding € 150 billion / year"

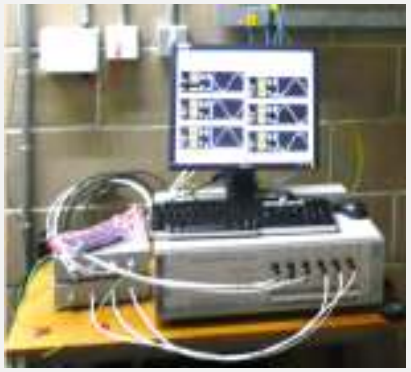
⇒ Fines on causing bad PQ!

Grid PQ – effect PV generation

Solar PV retro-fitted housing estate

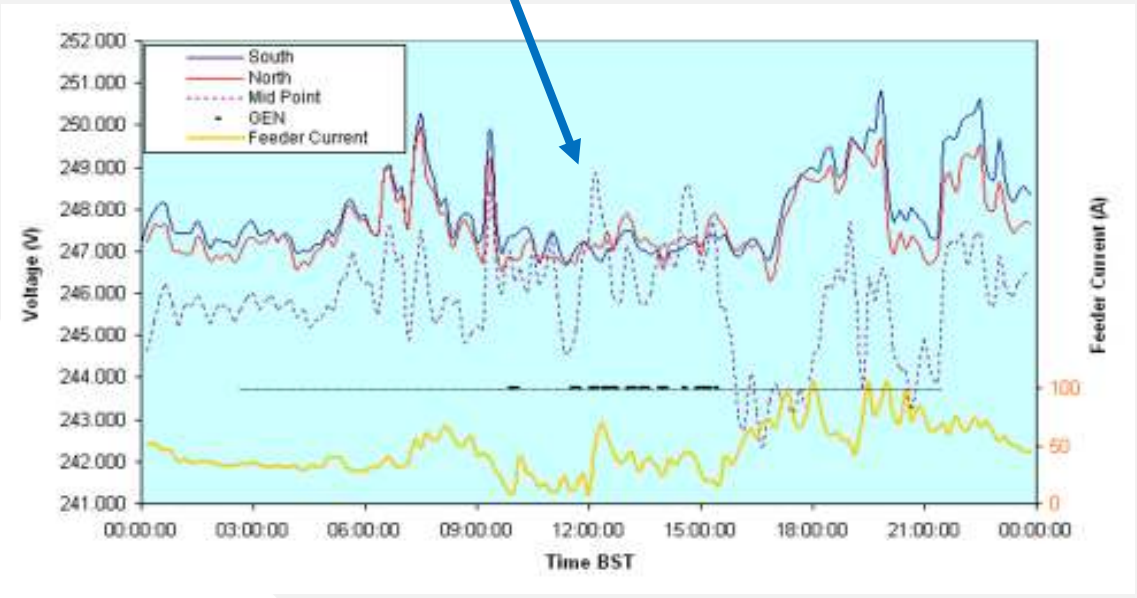
DNO interested in transients,
surges, flicker, harmonics

⇒ on-site ≠ lab!

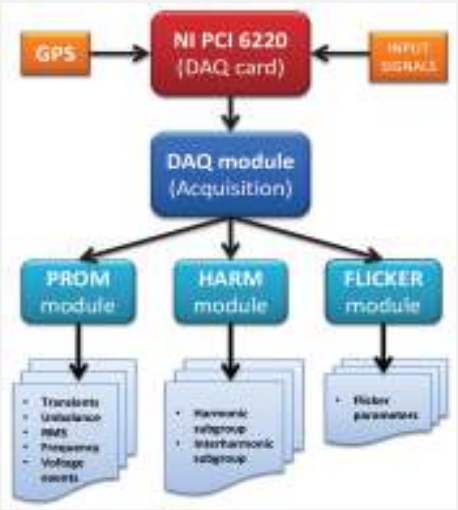


NPL

V rise during PV generation



Grid PQ – industry park

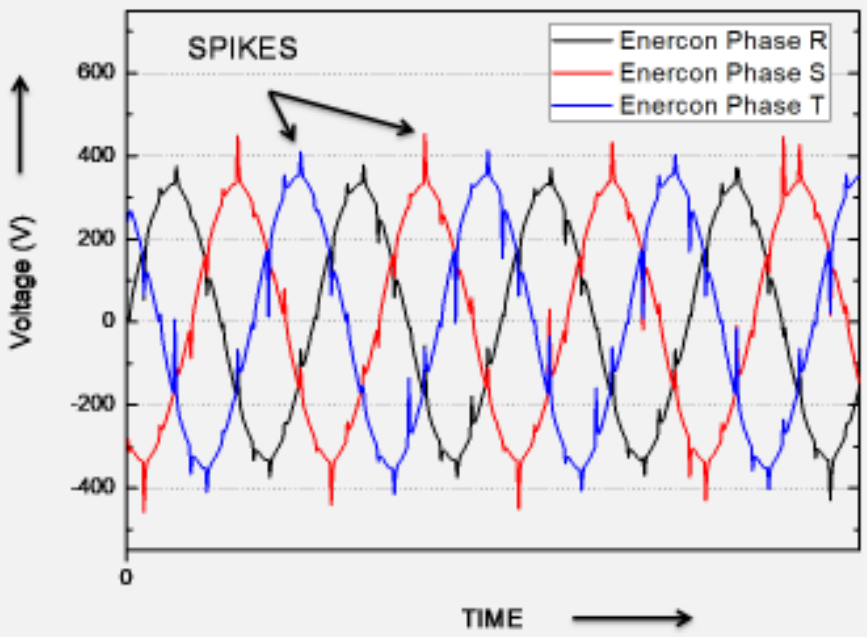


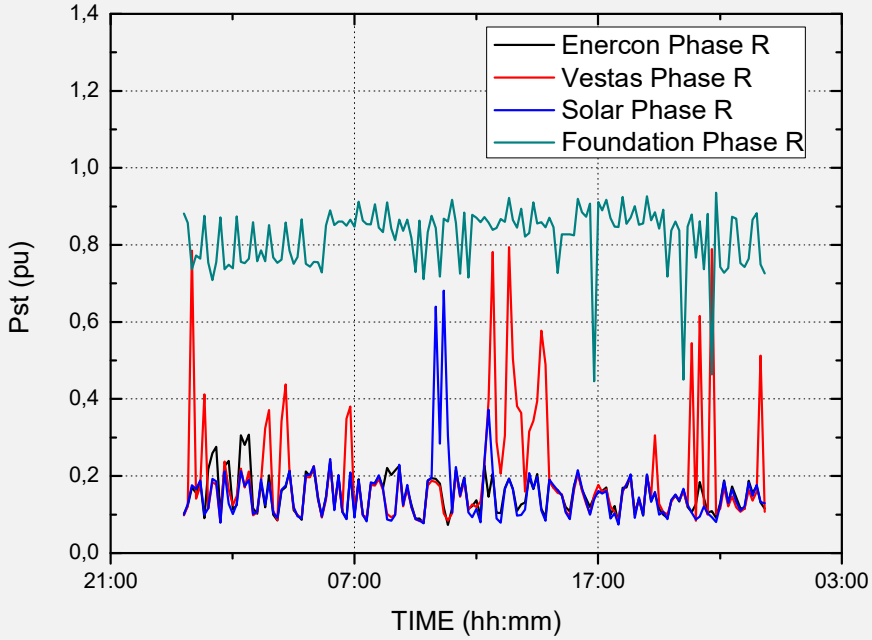
250 variables
every 200 ms
⇒ 2 TB of data

Big Data & Data Analytics!

Industry park PQ results

Old windmill major cause of bad PQ





Future research: PQ propagation / source location in extended grids (fines!)

↘ Synchronised PQ at multiple sites in the grid

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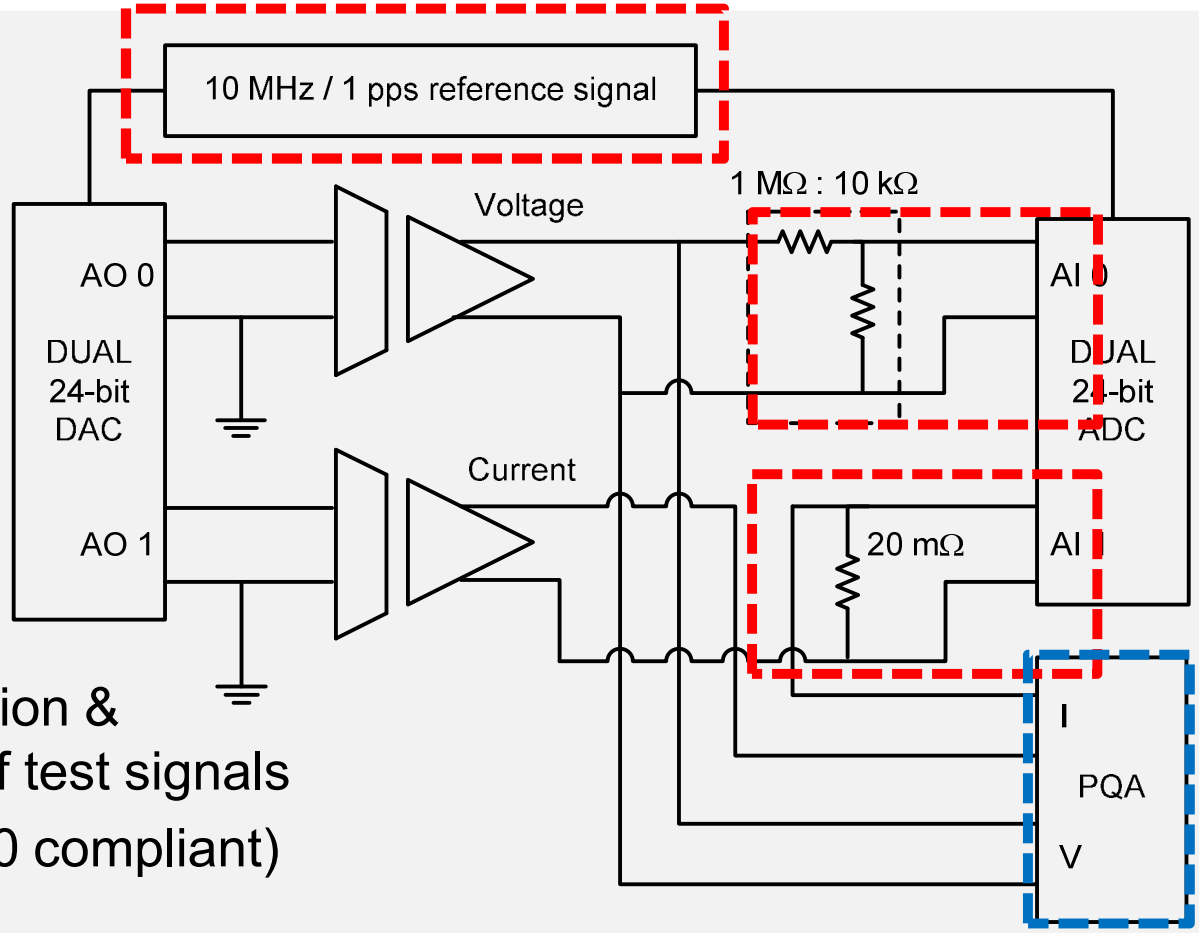
PQ calibration setup



Parallel generation & measurement of test signals (IEC 61000-4-30 compliant)

Reference ideally 5 – 10 times more accurate than PQ analyser

⇒ VSL PQ reference setup: amplitude 0.01 %, timing < 1 μs

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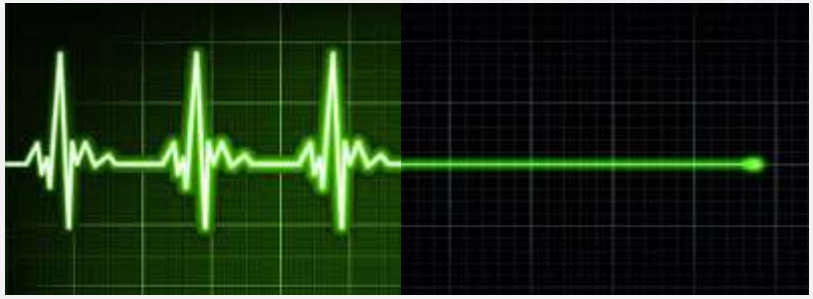
Measurements in perspective



f = 60 beats/min

f = 0 beats/min

patient died

We need
actionable information!

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P 26

The bigger picture

data flow

applications

sensors

action

visualization

Summary

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

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

- Grid stability: frequency, oscillations, PMU calibration, PMU applications
- Sensoring: best measurement locations, determine & predict grid state
- Power quality: on-site PQ campaigns, PQA calibration

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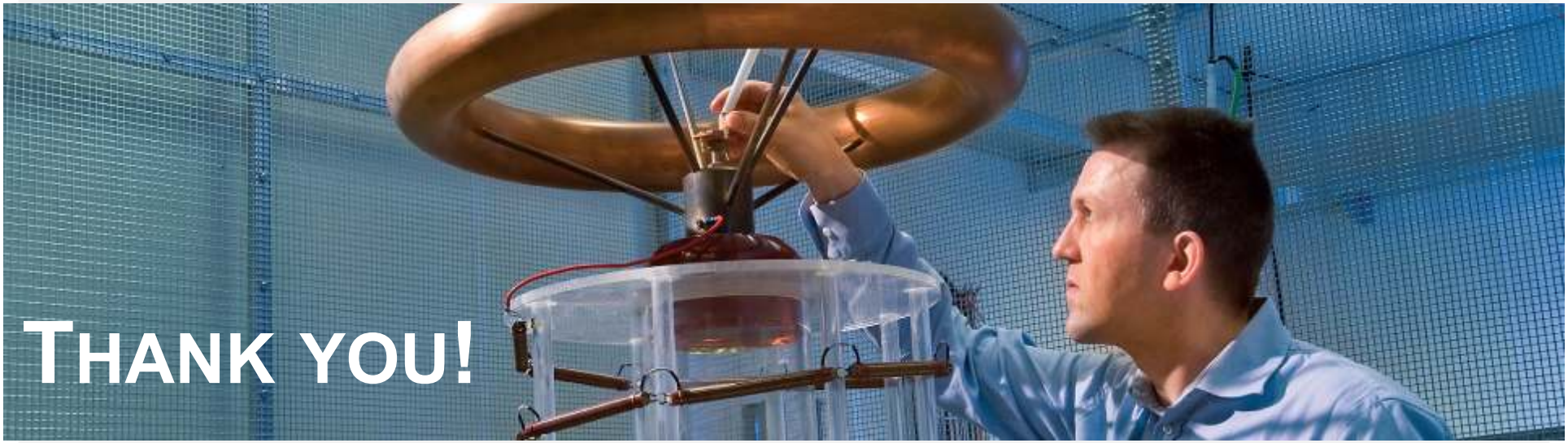

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