UNEXPECTED LINKS: POWER QUALITY AND ENERGY

ALEX MCEACHERN, POWER STANDARDS LAB (USA)
ICREPQ 2013 – BILBAO, SPAIN

LINKS BETWEEN PQ AND ENERGY

- **Expected and understood:**
  - Harmonic currents and voltages
  - unbalance, zero-sequence and negative sequence on 3-phase systems

- **Unexpected links between PQ and energy**
  1. Impedance measurements using dips
  2. Voltage reduction measurements
  3. Response of PV inverters to voltage dips
  4. FIDVR – Fault Induced Delayed Voltage Recovery
  5. 2kHz-150kHz emissions and energy metering
  6. Microsynchrophasors and energy stability

- **All are new, and good research opportunities!**

1. IMPEDANCE MEASUREMENTS USING DIPS

- Free up-to-the-minute waveform recordings available at **http://map.PQube.com**

1. IMPEDANCE MEASUREMENTS USING DIPS

- During-dip and post-dip waveform data
  - Simple impedance magnitude: ratio of change in voltage magnitude to change in current magnitude
  - Complex impedance at 50 Hz: vector ratio of 50 Hz voltage change to 50 Hz current change
  - Complex impedance available across frequency spectrum, too – limited by changes in current

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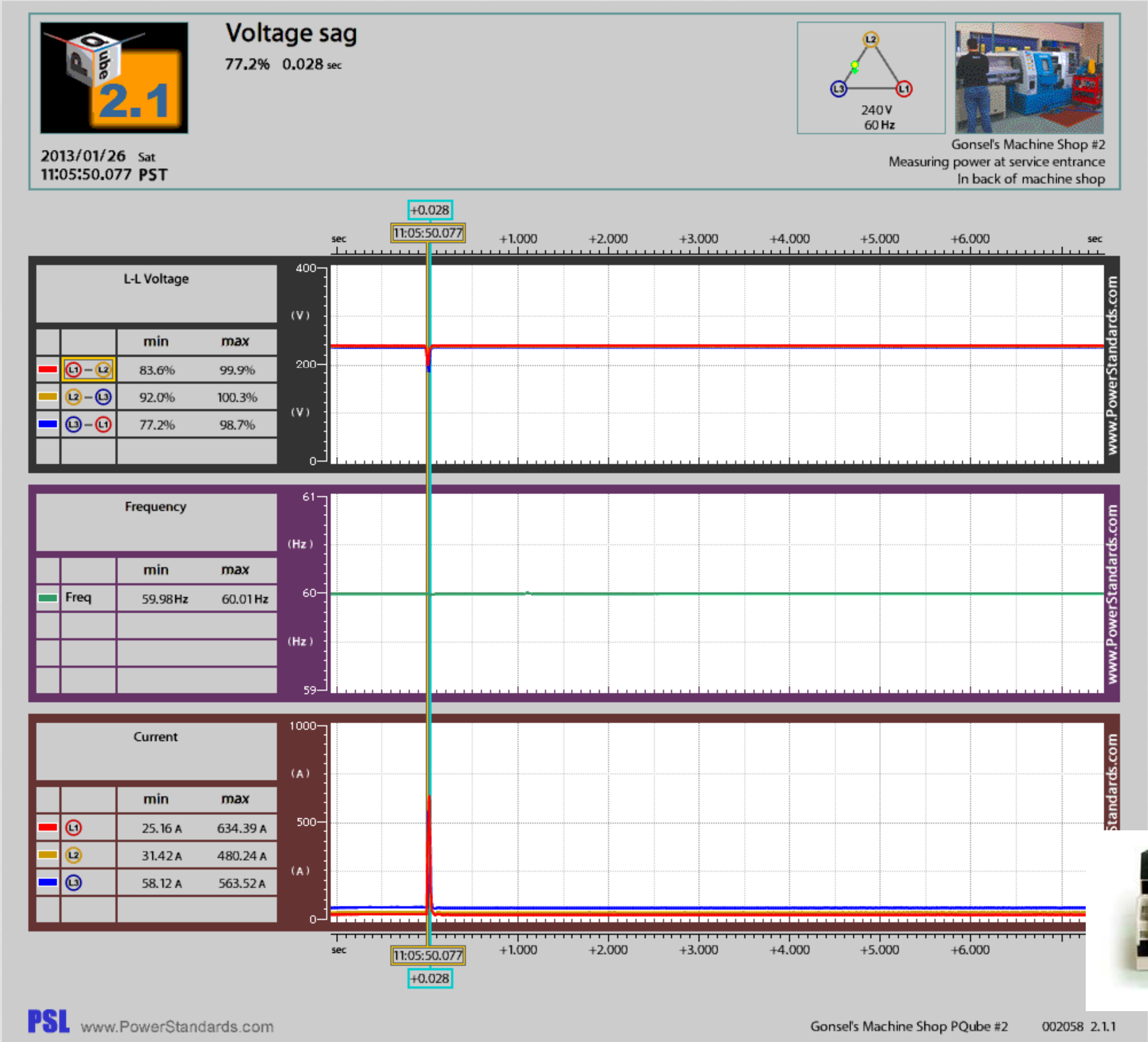

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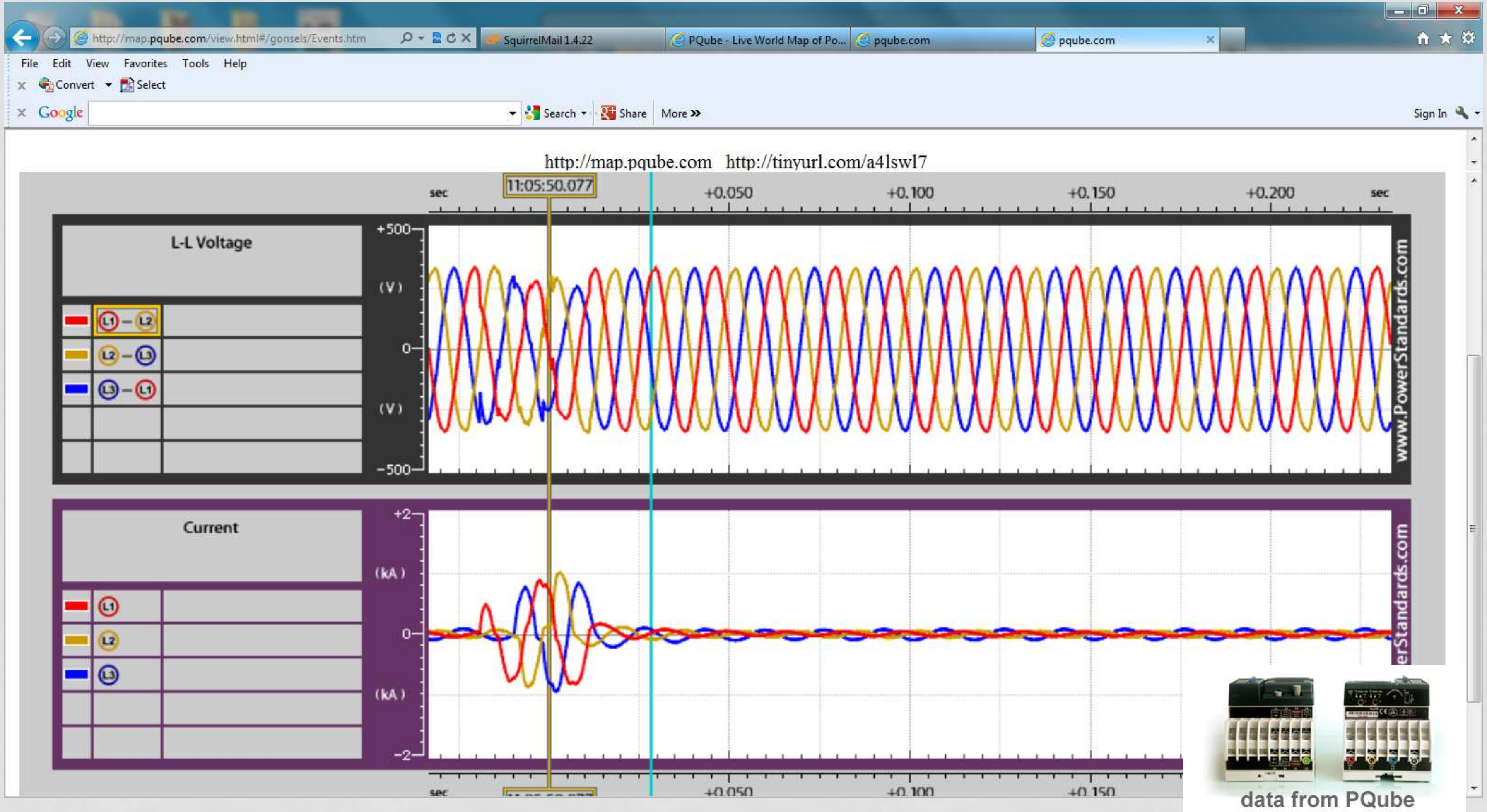

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- During-dip and post-dip waveform data
  - Simple impedance magnitude: ratio of change in voltage magnitude to change in current magnitude
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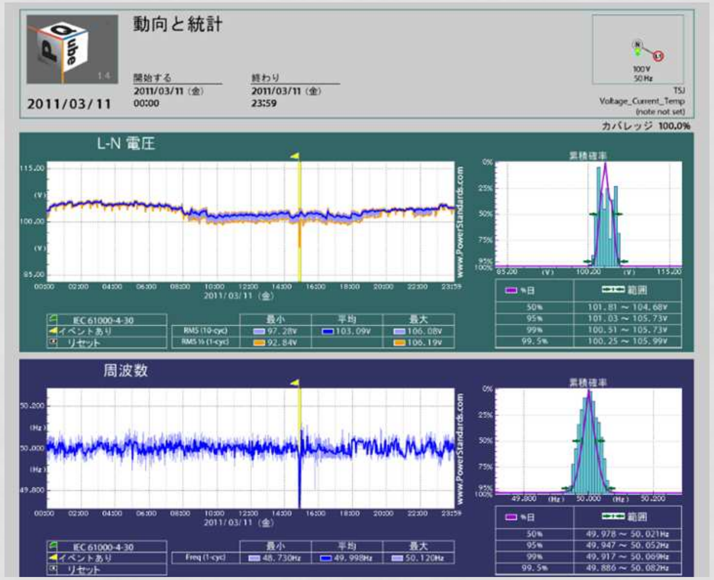
  - Complex impedance available across frequency spectrum, too – limited by changes in current
- <u>Research topic</u>: how much information can be extracted about actual source impedance during dips? Can long-term changes in the source impedance be explained?

map.PQube.com

data from PQube

2. VOLTAGE REDUCTION FOR ENERGY CONSERVATION

- Invisible with hourly or daily data – lost in the noise
- Visible in monthly voltage magnitude recordings
- Fukushima disaster, for example



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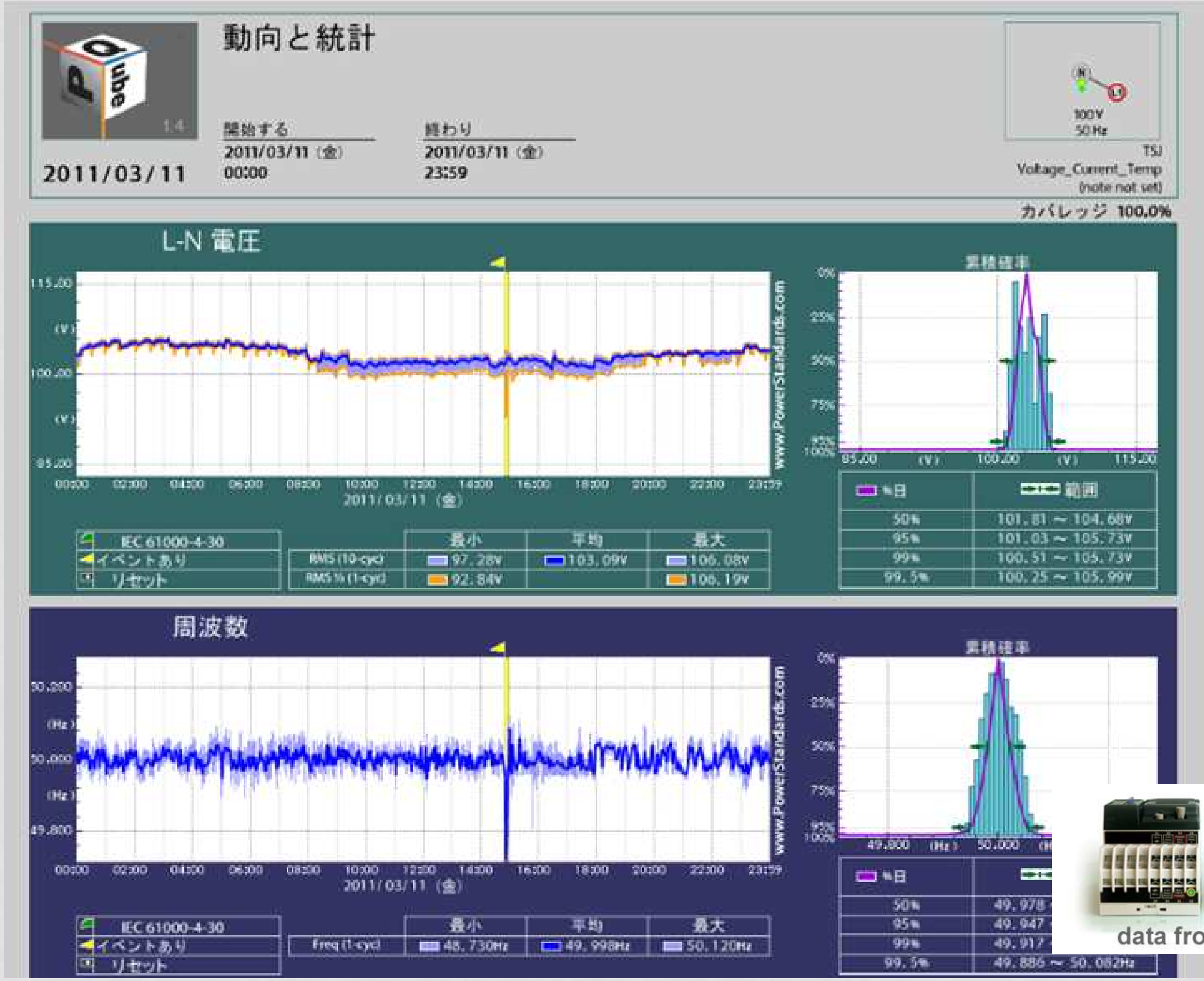

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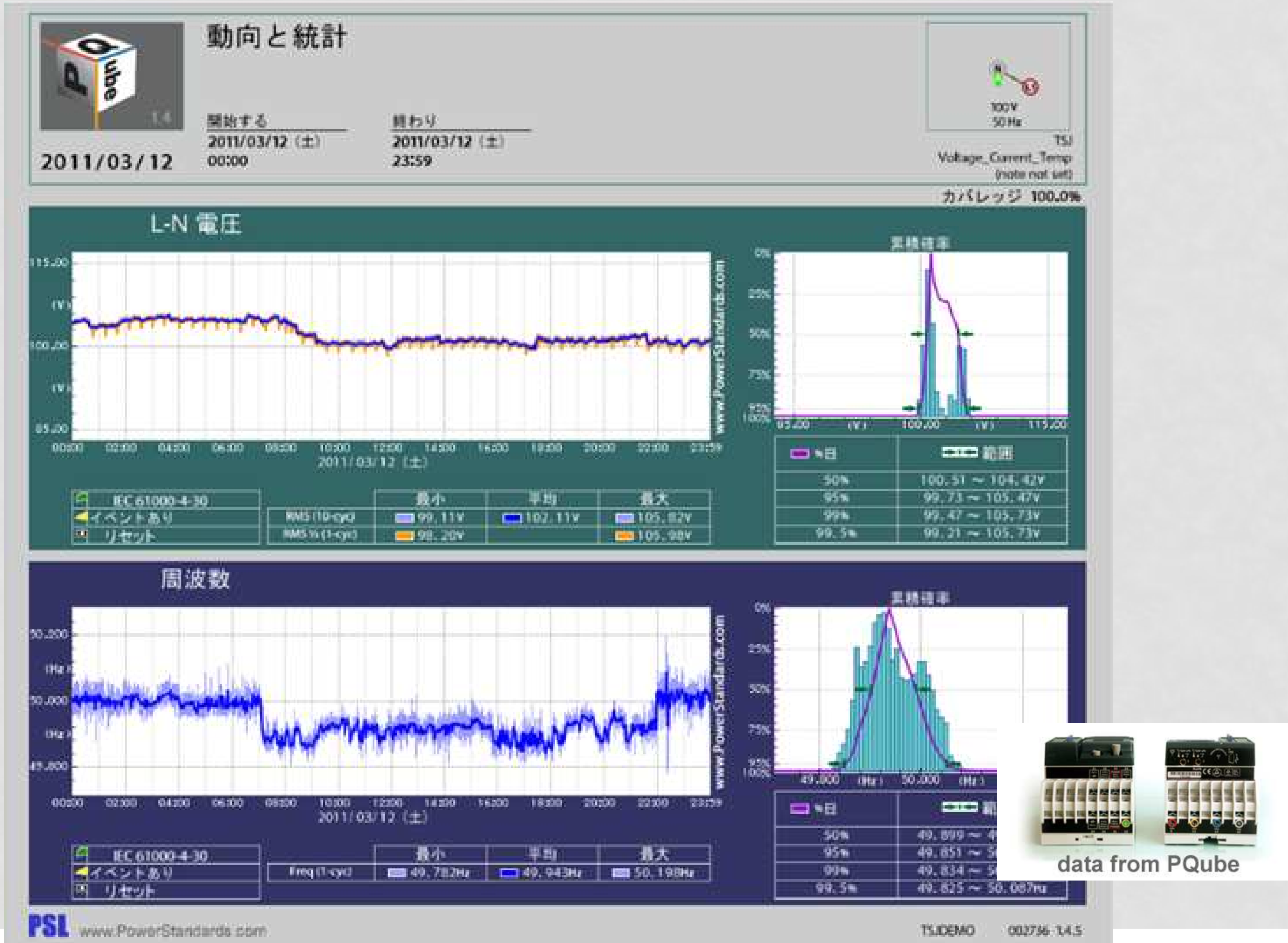

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- Research topic: effect of voltage reduction on actual energy consumption? Second-order effects?

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3. RESPONSE OF PV INVERTERS TO VOLTAGE DIPS

- LVRT standards for wind turbines – but PV inverters?

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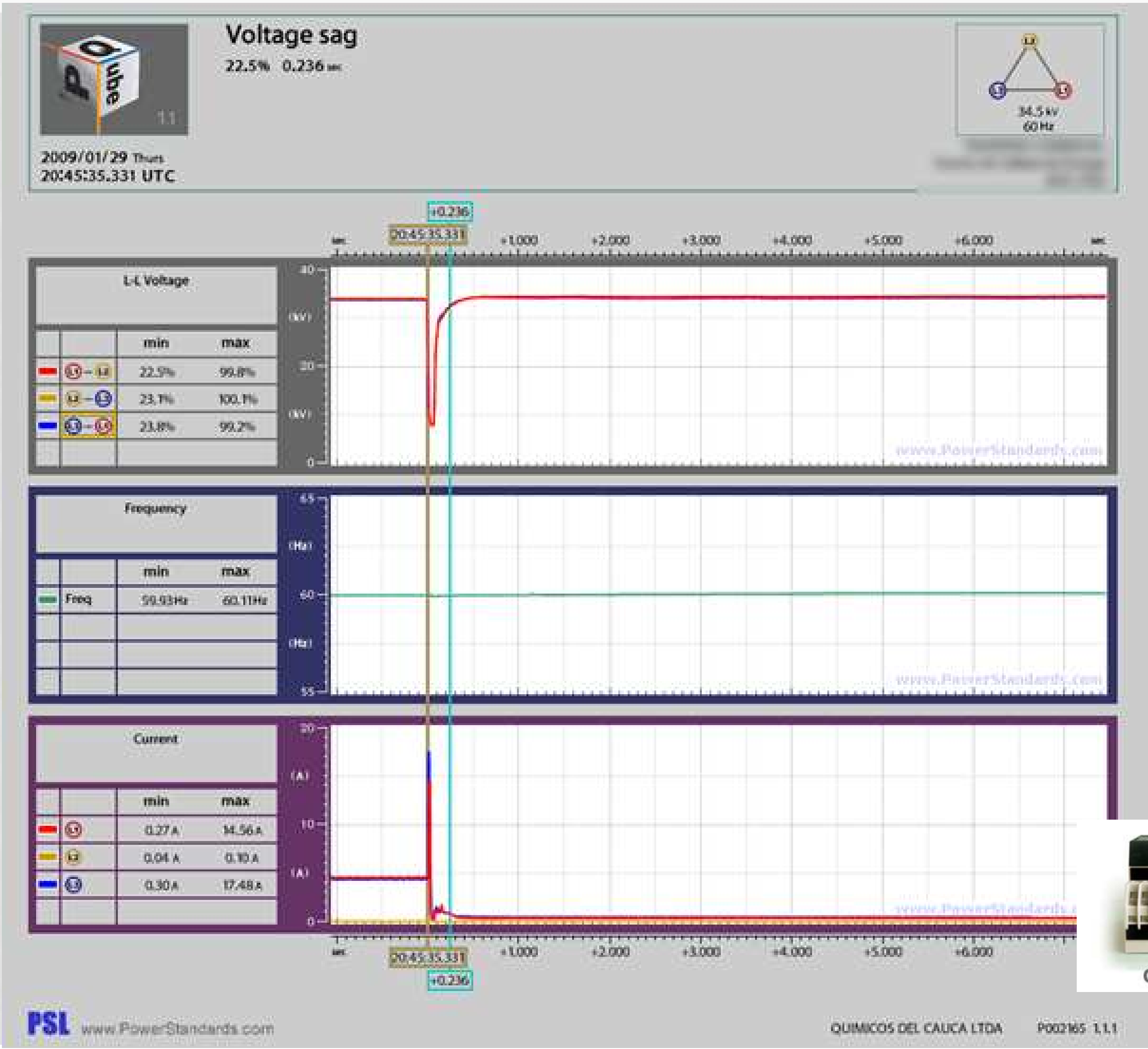

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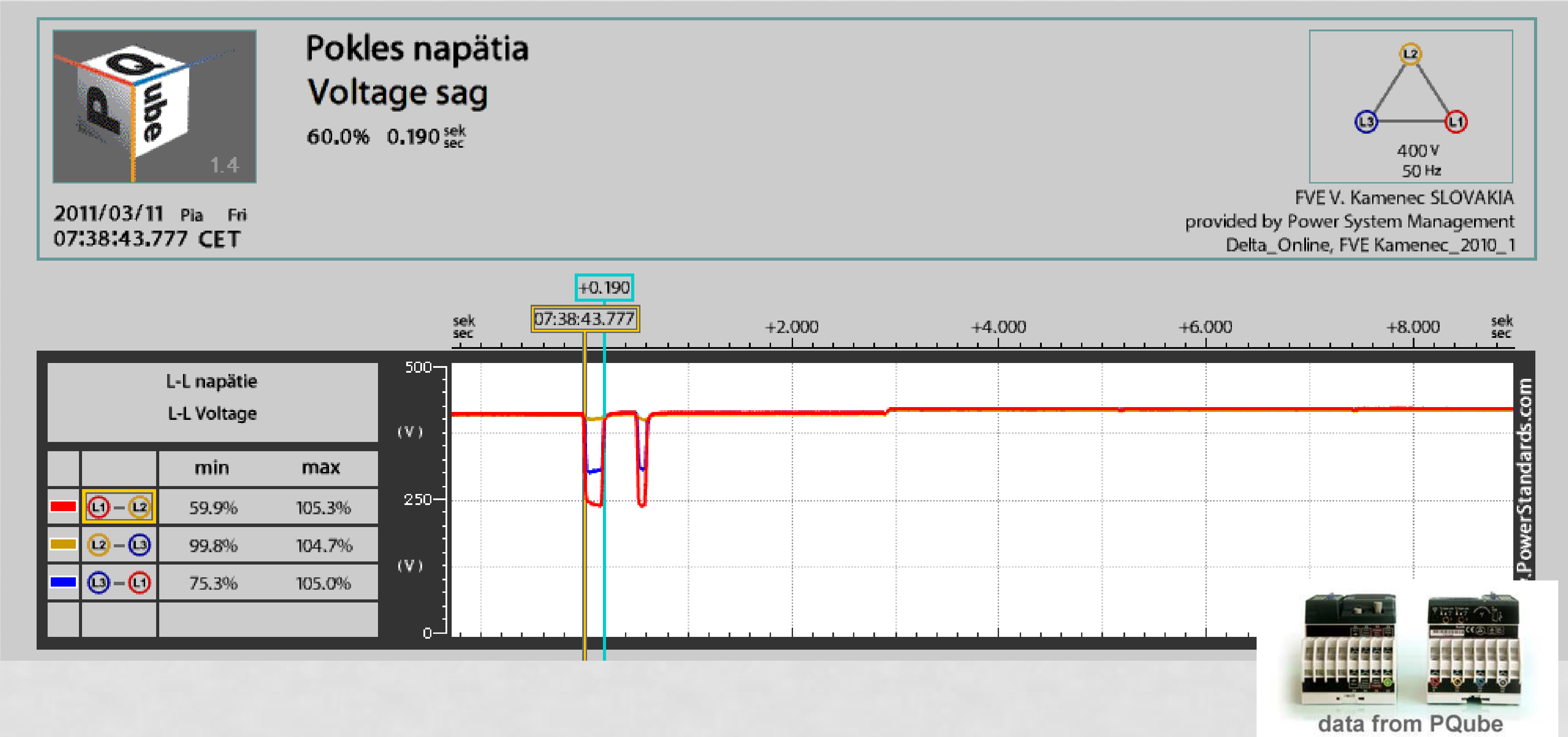

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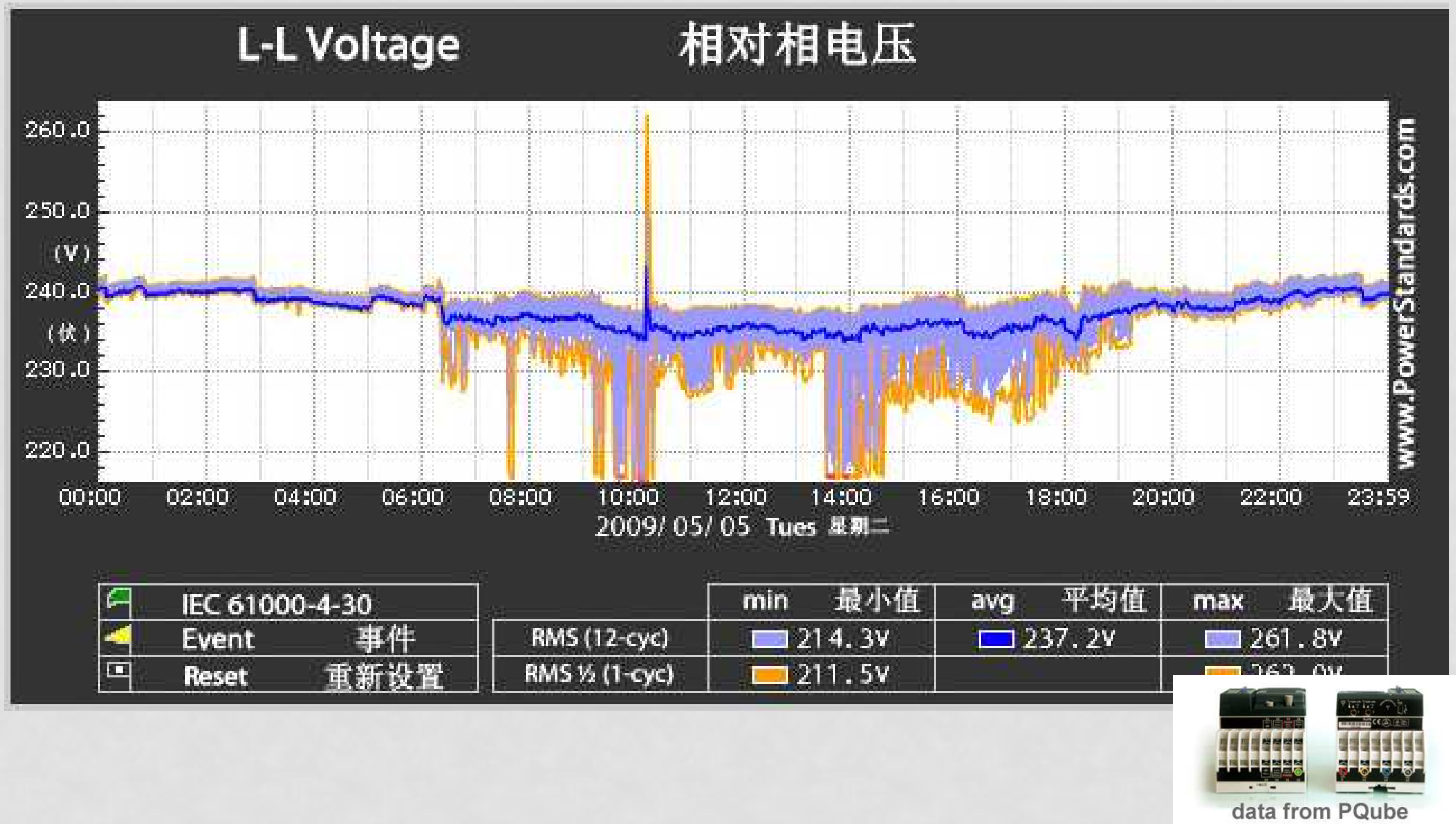
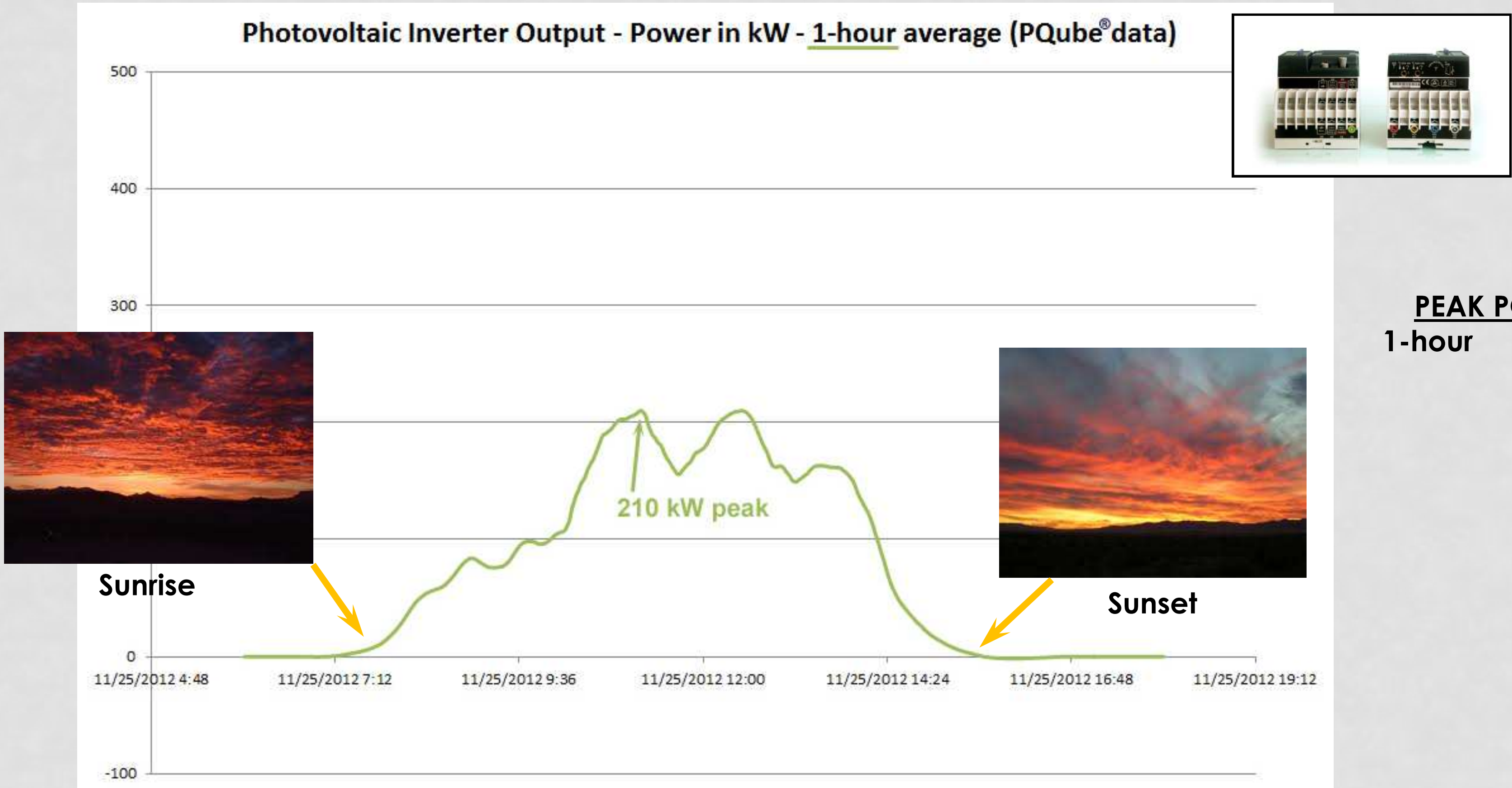


3. RESPONSE OF PV INVERTERS TO VOLTAGE DIPS

Photovoltaic integration into a microgrid

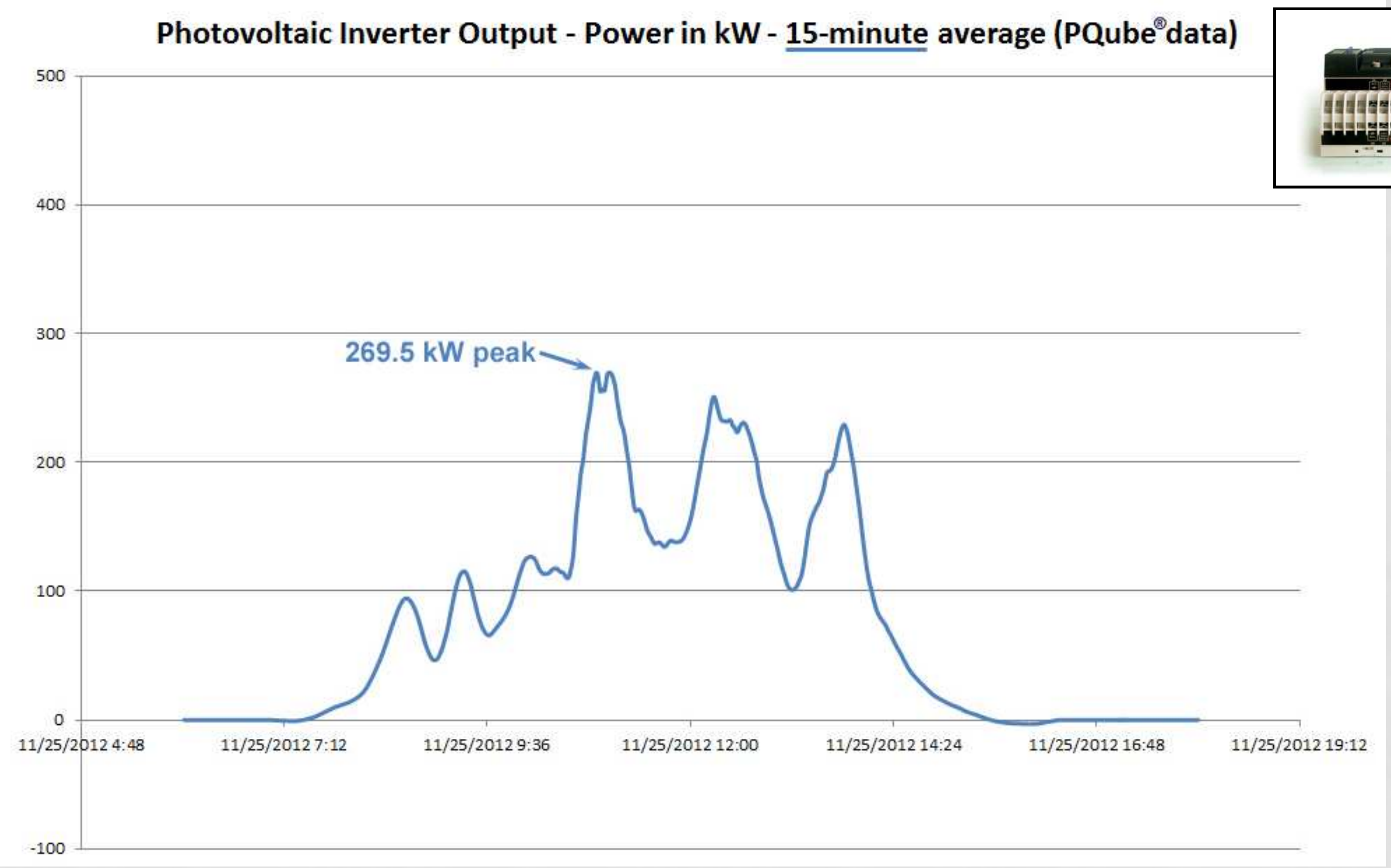


PEAK POWER

1-hour 210 kW

3. RESPONSE OF PV INVERTERS TO VOLTAGE DIPS

Photovoltaic integration into a microgrid – <u>same day</u>



PEAK POWER

1-hour	210 kW
15-min	269 kW

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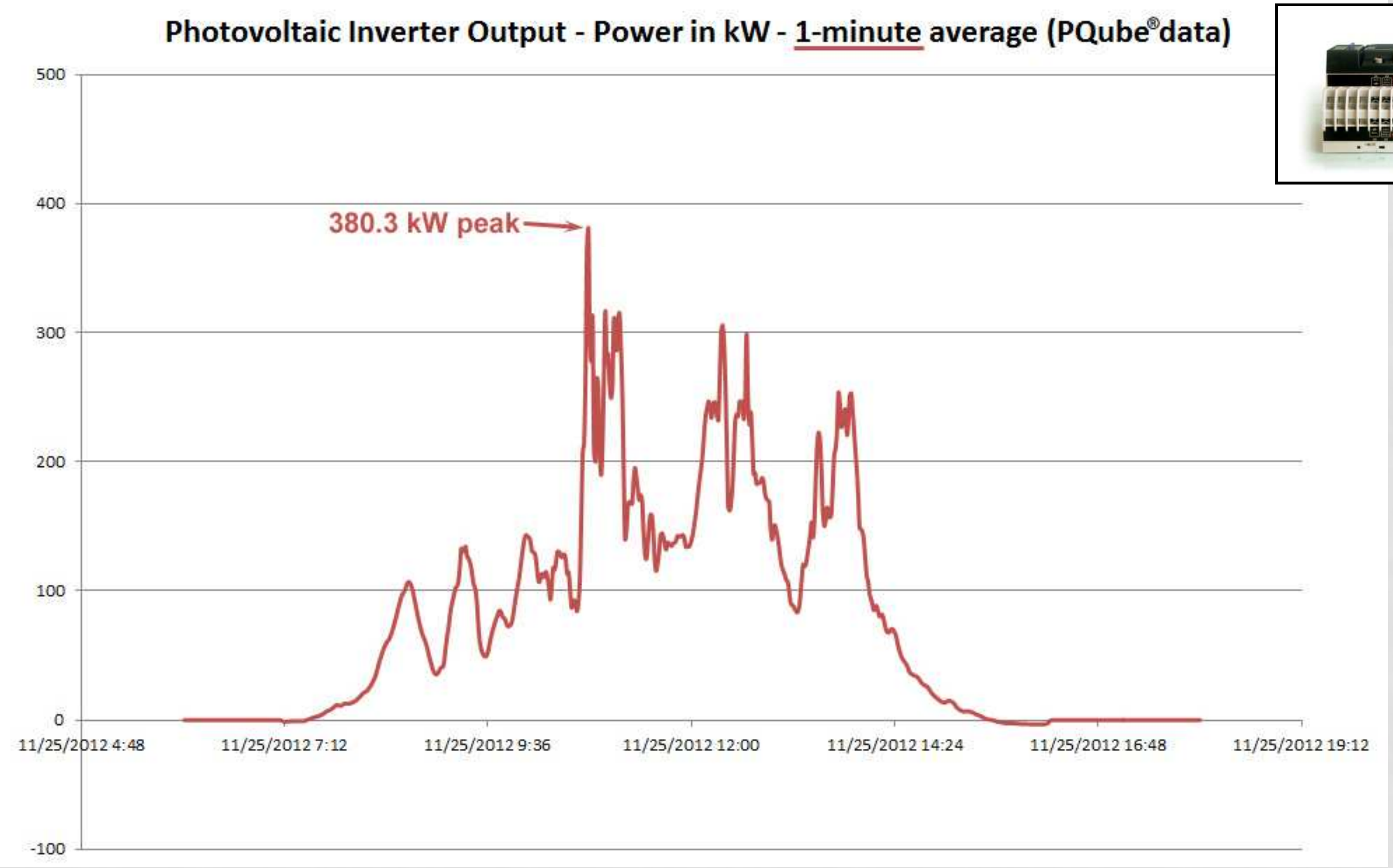
Photovoltaic integration into a microgrid – <u>same day</u>

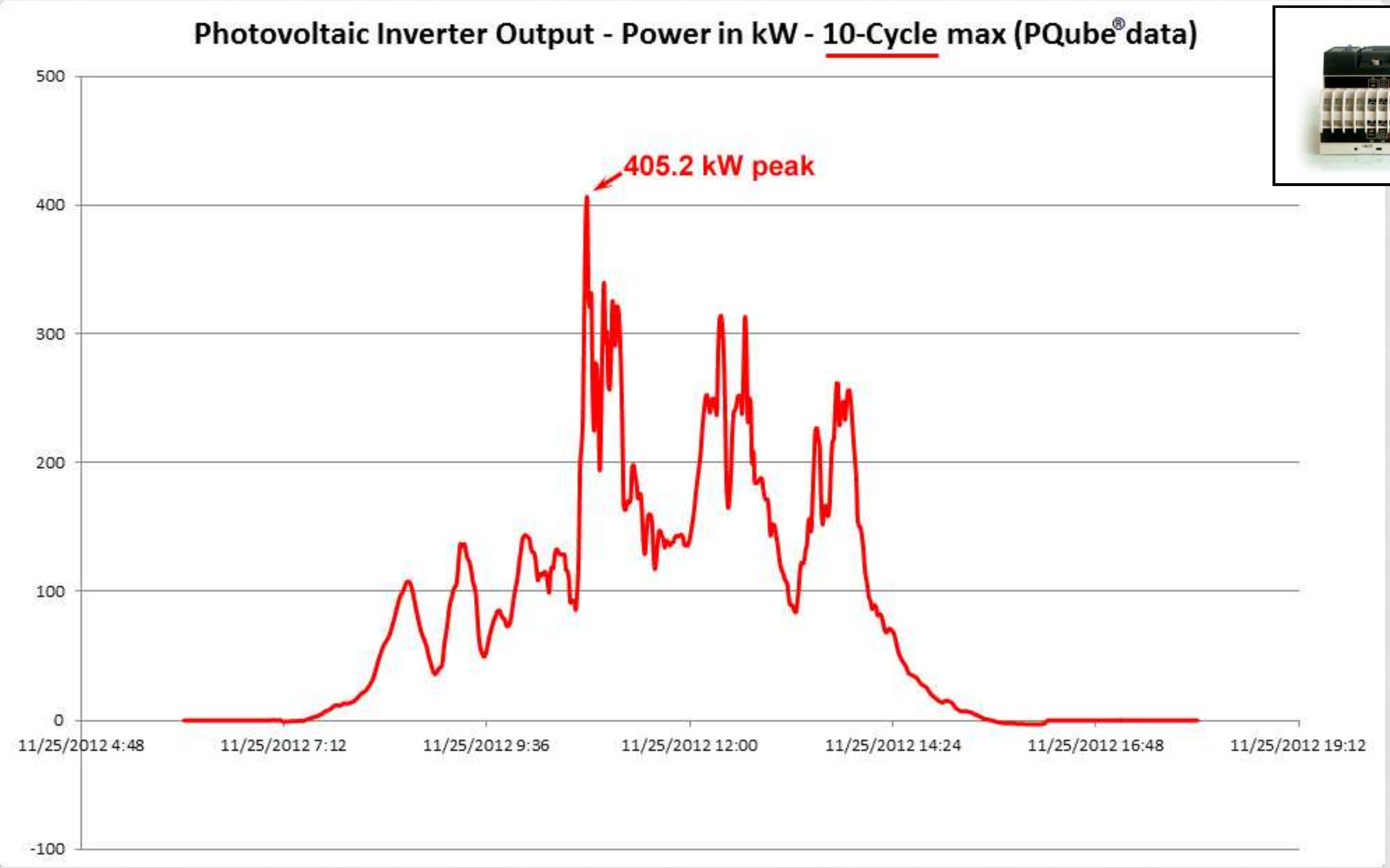


PEAK POWER

1-hour	210 kW
15-min	269 kW
1-min	380 kW

3. RESPONSE OF PV INVERTERS TO VOLTAGE DIPS

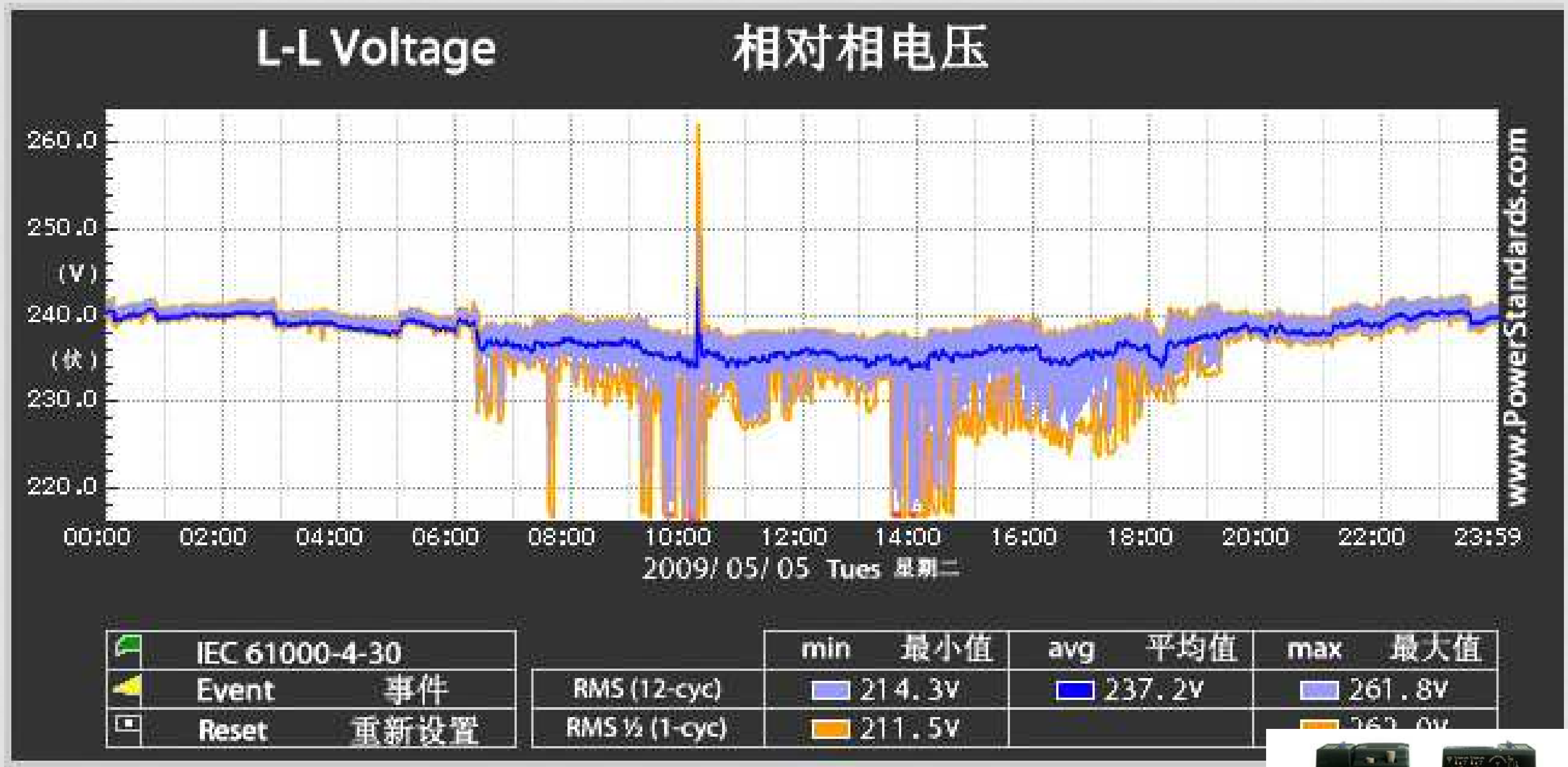
Photovoltaic integration into a microgrid – <u>same day</u>



PEAK POWER

1-hour	210 kW
15-min	269 kW
1-min	380 kW
200-ms	405 kW

3. RESPONSE OF PV INVERTERS TO VOLTAGE DIPS



data from PQube

3. RESPONSE OF PV INVERTERS TO VOLTAGE DIPS

- LVRT standards for wind turbines – but PV inverters?
- Research topic: effect of voltage dips on availability of PV inverters? Second-order effects? Ideas about desired behavior? Standards?
- Research topic: Optimal time interval for planning PV integration into grid?

map.PQube.com

data from PQube

4. THE FIDVR PROBLEM

- "Fault Induced Delayed Voltage Recovery"
- Voltage sag, plus a certain class of air conditioner
  - Not much rotating inertia
  - 5x – 6x current in locked-rotor condition
  - Thermal protection – 3-20 seconds to trip
- Extends the duration and depth of voltage sags

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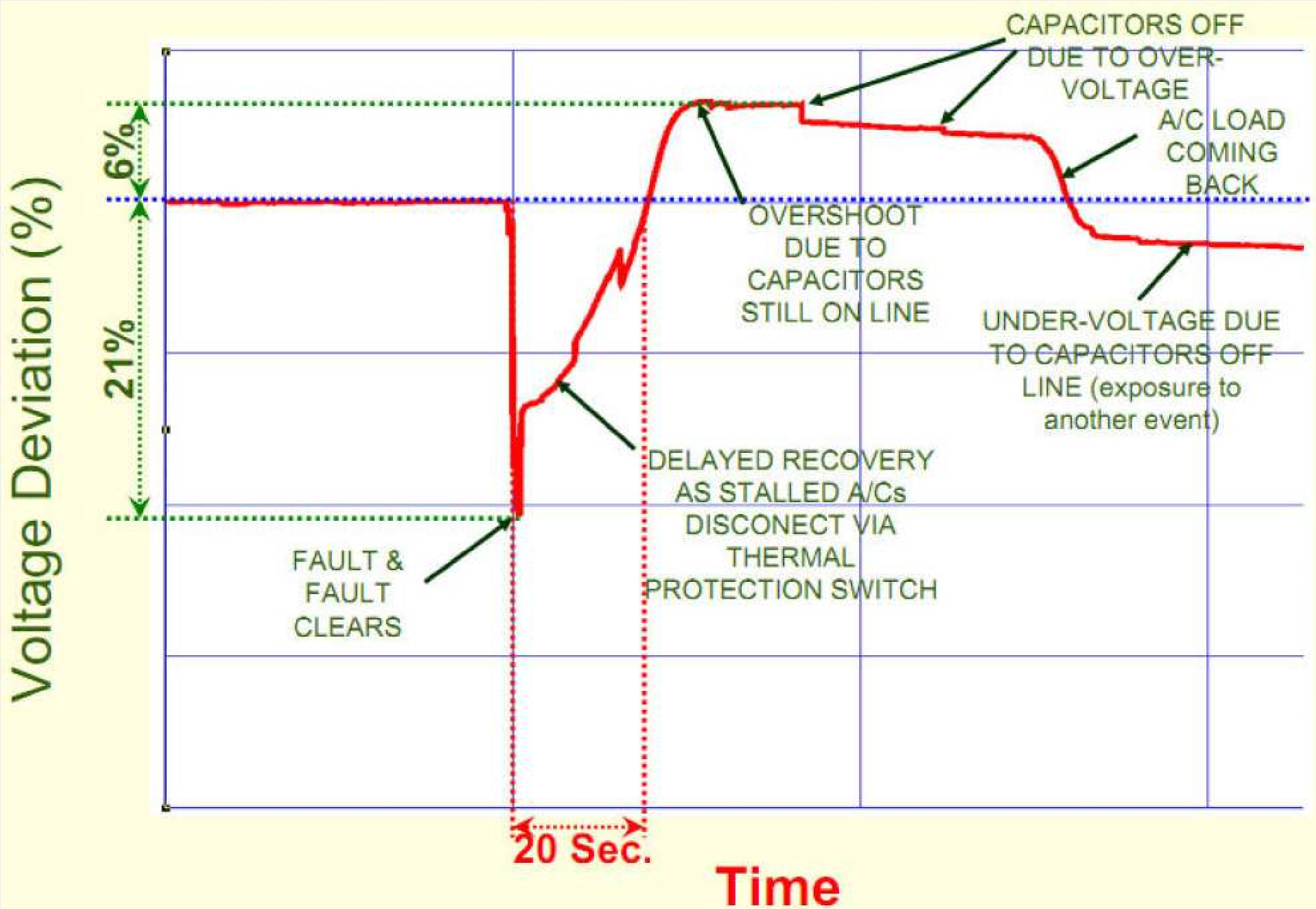

NERC Technical Brief on FIDVR

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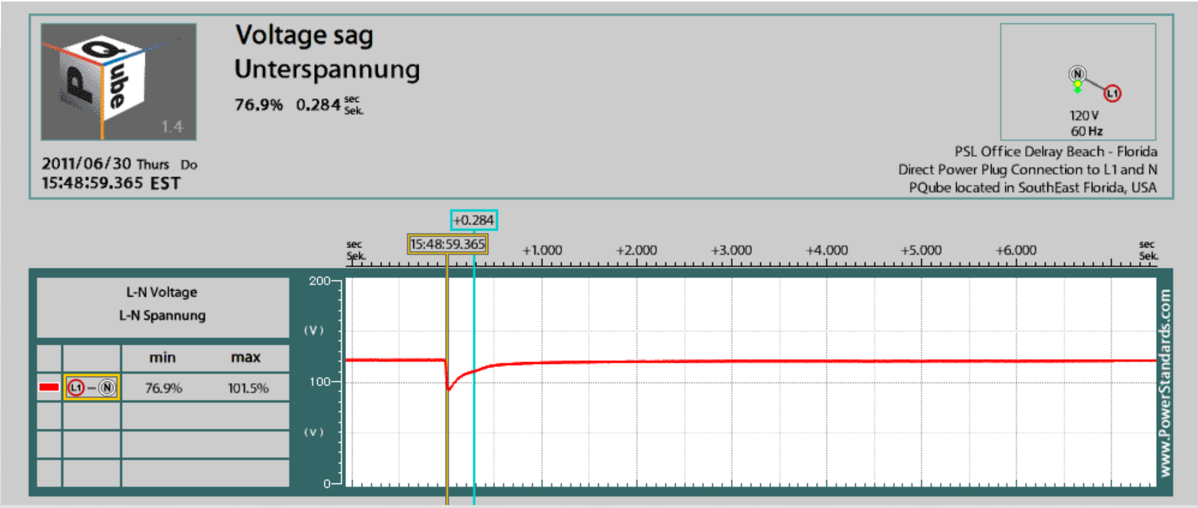
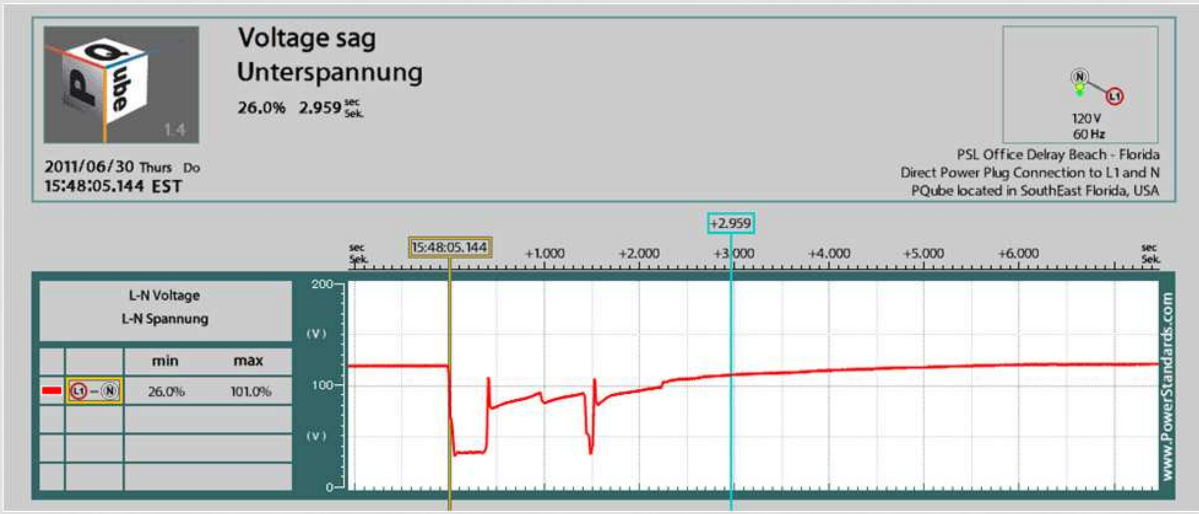


(map.PQube.com)
typical voltage sag



(map.PQube.com)
FIDVR voltage sag

4. THE FIDVR PROBLEM

- Research questions – are there southern European Fault Induced Delayed Voltage Recovery problems? How are they different due to differing fault impedance, compared with North America, Japan, South America, South Africa, etc.? What changes to high-efficiency air conditioners could solve the problem?

map.PQube.com

5. 2KHZ-150KHZ EMISSIONS AND ACCURATE ENERGY METERING

- 2kHz – 150kHz is the "Wild West"

- Recent recognition that some "Smart" energy meters are disturbed by high levels of conducted emissions in this frequency range
- Switching frequency for inverters, for example
- New measurement and immunity test standards being developed

5. 2KHZ-150KHZ EMISSIONS AND ACCURATE ENERGY METERING

- Research topics: Measurement should be conducted between phase-earth, or phase-phase, or phase-neutral? What frequency resolution is required? 200 Hz? 2kHz? What magnitude? 0,01V? 0,1V?100V?

- Immunity has similar questions…

6. MICRO-SYNCHROPHASORS AND ENERGY STABILITY

- Synchrophasors are widely used on transmission system
- New ARPA-E US$4000000 project with Power Standards Lab for measurements on distribution system stability
- Closely related to Smart Grid and Distributed Generation penetration

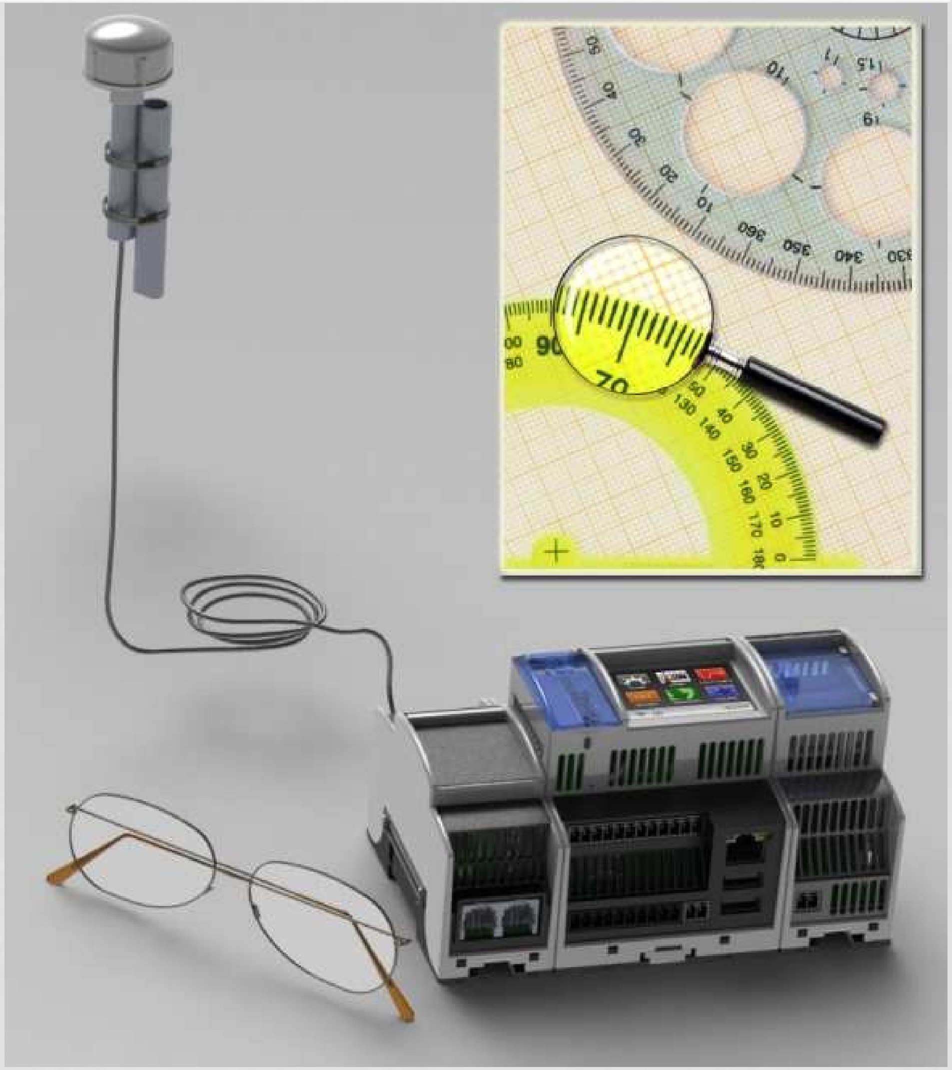
6. MICRO-SYNCHROPHASORS AND ENERGY STABILITY

New low-cost, ultra-high-angular precision instrument (soon)

Developed with funding from U.S.A. ARPA-E ($4 million)

Optimized for much lower cost compared to traditional synchrophasors

Optimized for distribution measurements, especially with PV and wind turbines – ultra precise angle measurements



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- Synchrophasors are widely used on transmission system
- New ARPA-E US$4000000 project with Power Standards Lab for measurements on distribution system stability
- Closely related to Smart Grid and Distributed Generation penetration
- New low-cost, ultra-high-angular precision instrument available via U.S. ARPA-E project
- Research topic: Local grid measurements with U.S.A. ARPA-E instruments, then share data and analysis with ARPA-E project?

RESEARCH OPPORTUNITIES!
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- Free world-wide data at map.PQube.com
- Please contact Power Standards Lab for PQube instrument information, ARPA-E project instruments

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