PSL

A New Measurement Technology (not just for Solar Integration)

SIEEE Israel - October 2013

ARPA-E Micro-Synchrophasors Project
Award Number DE-AR0000340

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The problem

- Over very short time intervals (fractions of a 50 Hz cycle), grid stability relies on inertia of large rotating machinery.

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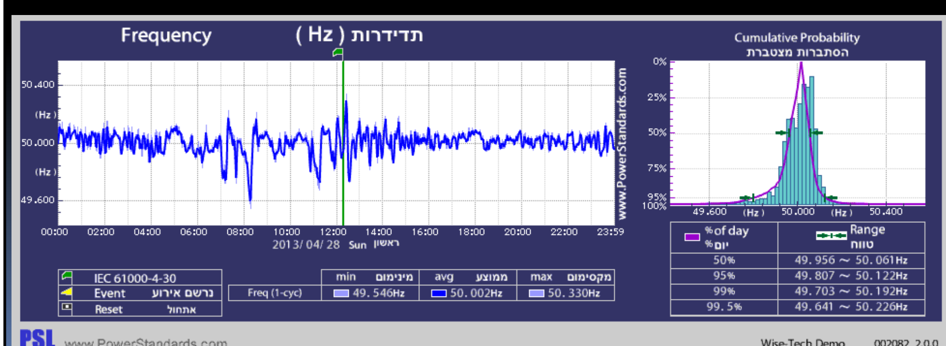

And most "green" energy sources lack short-term inertia.

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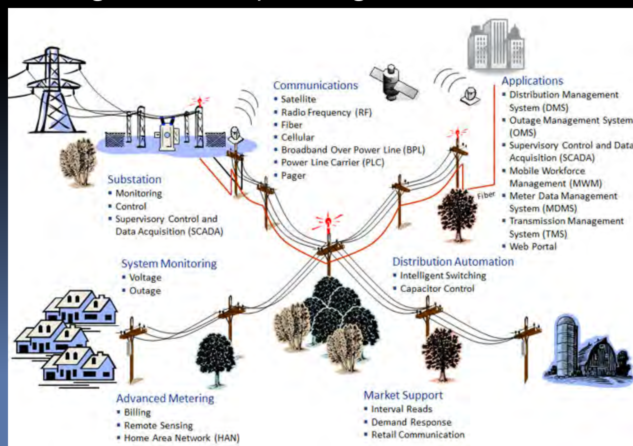
The problem, continued

- Simultaneously, Smart Grids will make the grid less stable.
  - Reconfiguration, dispersed generation, new loads



Courtesy Oncor Inc.

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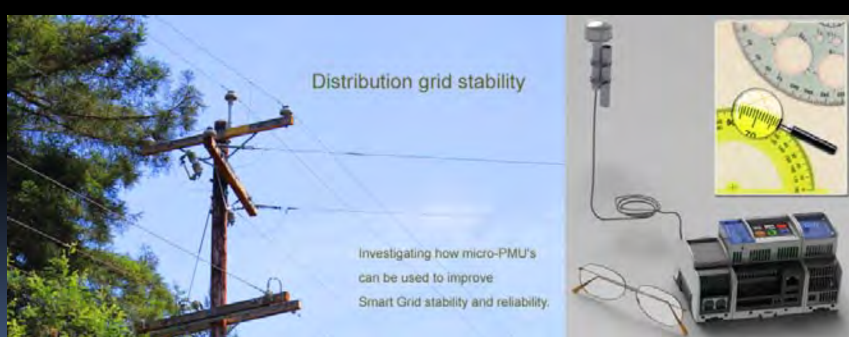

Opportunity for Israeli "mirror" project…

- California Institute for Energy and Environment
- **Power Standards Lab**
- University of California at Berkeley
- Lawrence Berkeley National Lab
- Individual consultants
  W. Mack Grady and Ron Hofmann.

Courtesy Oncor Inc.

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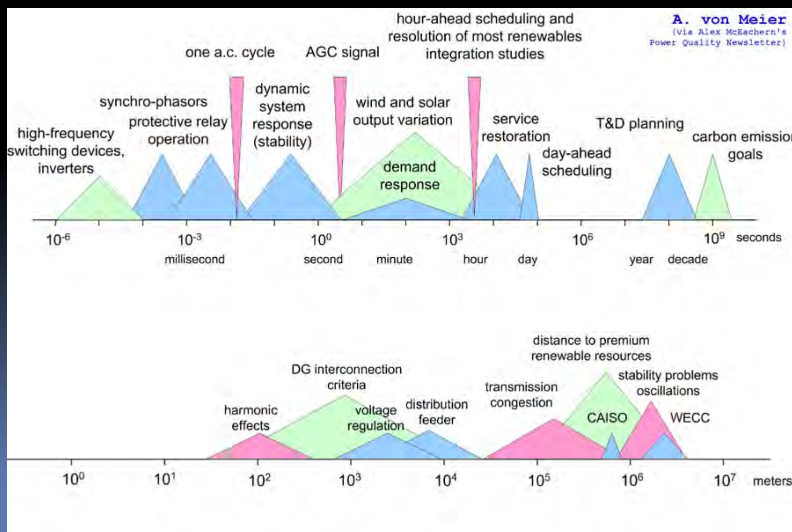
Von Meier's suggestion



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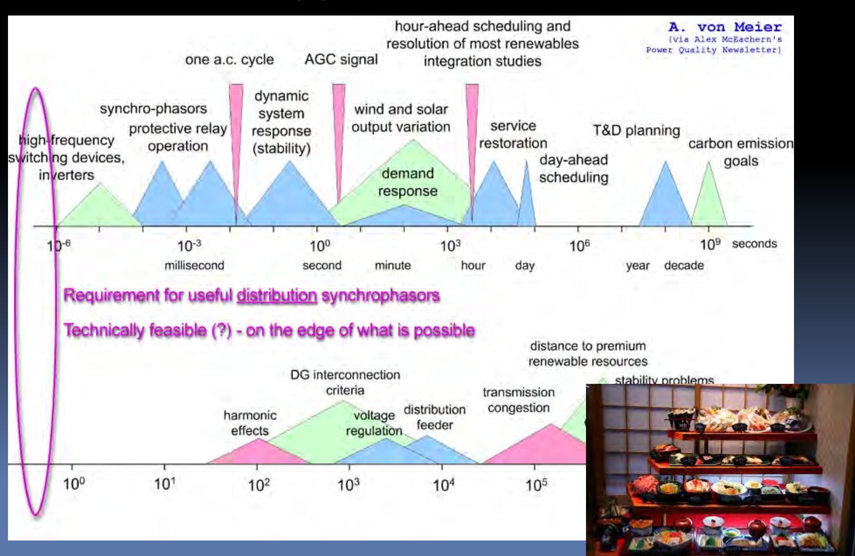
McEachern's suggestion…



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"Synchrophasor" concept

- Measure 50 Hz voltage <u>angles</u> between different physical locations on the grid – best measure of grid stability

Traditional application – Transmission systems

Our question: Can synchrophasors be used on distribution systems to understand solar integration stability?

Proposed Synchrophasor applications on distribution networks

- Diagnostic applications on distribution lines
  - Unintentional island detection
  - Fault detection and location, including high impedance faults
  - Oscillation diagnosis
  - Fault-induced Delayed Voltage Recovery (FIDVR) risk detection
  - Reverse power flow detection
  - Transmission-grid support
  - Renewable generation monitoring (including behind-the-meter)
  - State estimation, and real-world data for verifying models
  - And about 30 other applications…
- Project will investigate control applications, too
- But there are <u>BIG</u> technical challenges… and that's why it's a research project!

Synchrophasor challenges - distribution

1. Angles are tiny – two orders of magnitude smaller
2. Solar variations are faster – clouds, inverter control loops
3. Distribution grids are far more complex than transmission
4. Underlying assumption (wrong) that power only flows from substations to loads
5. Cost / benefit – transmission conductors carry millions of dollars, distribution conductors carry hundreds of dollars…

Huge potential benefit, though:
Accept larger amounts of solar without stability concerns.

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Synchrophasors: Transmission vs. Distribution

Transmission / control	Distribution / research
± 600 millidegrees	± 10 millidegrees
Real time measurements for control	Latency not an issue for research data
Cost of system "no object"	Low cost, high quantity data points
Homogenous system	Diverse system
Few disturbances	Many power quality disturbances – link the data
Confined locations, no certifications required	Safety certifications (UL, CE, etc.) are essential
Expectations well established	Unknown – it's research!

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ARPA-E $4.4M (£2.7 million) project

- ARPA-E is U.S. Government / Department of Energy
- Project executed by Power Standards Lab, U.C. Berkeley, Lawrence Berkeley National Lab
- Project based on commercial PQube® instrument
  - Thousands deployed – 50% North America
  - Semiconductor, telecom, military, data centers, solar arrays, utilities, transport, space launch, shipboard, off-shore platforms, aircraft, research
  - **Excellent video – Northern Power in England**
    http://www.PowerStandards.com/SmartGrid.mp4

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PQube® 3 instrument

Five simultaneous measurement modes:

- Triggered power disturbances
- Quasi-steady-state power quality issues
- Precision power flow & energy
- Environment & DC voltages/currents
- Micro-synchrophasor

All data is <u>open format</u>. All communication is <u>standards-based</u>.
- 16 gigabytes of data storage on every instrument
- Microsoft® Excel® files - raw data, waveforms, min/avg/max
- Email, web server, FTP file transfer, thumb drive transfer
- PQDIF, IEEE, XML, GIF file formats too

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PQube® 3 instrument

WiFi network: PQube 3 Demo

Server inside PQube 3:
http://PQubeDemo.com

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PQube® 3 instrument – Silicon Valley technology

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PQube® 3 inst m nt
PQube 3 AC Analyzer
System
Meters
Events
Actions
Save File
Diagnosis
10/100
USB 2
USB 3
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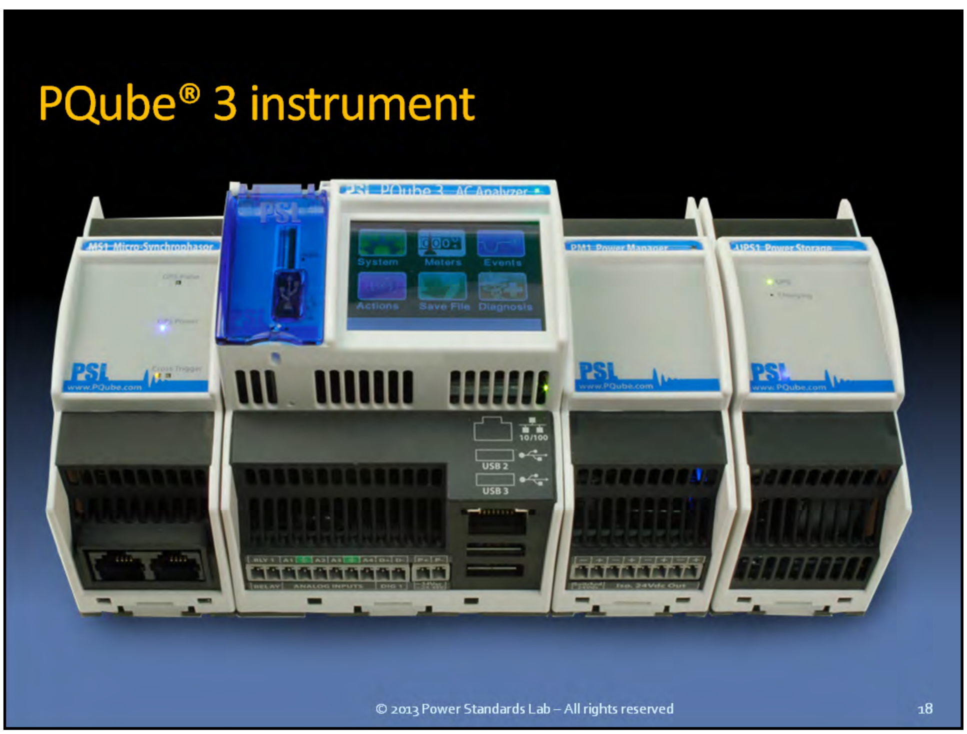

PQube® 3 instrument
PQube 3 AC Analyzer
MS1 Micro-Synchrophasor
PM1 Power Manager
UPS1 Power Storage
System
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USB 2
USB 3
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PQube® 3 instrument

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PQube® 3 instrument - µPMU

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PQube 3 – Triggered Power Disturbances

- Auto-configures to any 1-phase, 3-phase system
  - ✓ 100VAC – 690VAC, 50/60/400 Hz
- IEC 61000-4-30 Class A disturbances
  - ✓ Sags, swells, interruptions
  - ✓ Pre-, post-trigger voltage/current waveforms
  - ✓ RVC – rapid voltage change
  - ✓ Frequency disturbances
- Beyond Class A triggered disturbances
  - ✓ Low-frequency transients (PF correction capacitors)
  - ✓ High-frequency transients
    - 1 MHz (4 MHz) waveform circular buffer
    - ±6kV peak

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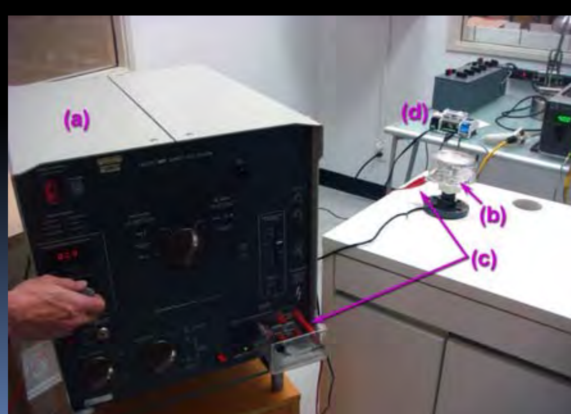
6,000-volt, 500-amp damped oscillatory pulse



PASS

Lightning surge test, 6 kilovolts, 500 amps. (a) Surge generator. (b) Foil-wrapped GPS receiver. (c) High-voltage surge connection cable. (d) micro-PMU.

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PQube 3 – Quasi-steady-state PQ issues

IEC 61000-4-30 Class A, 61000-4-7, 61000-4-15

- Harmonics through 150^{th}
  - Voltage and current
  - Magnitude and angle
- Interharmonics through 150^{th}
- Unbalance – IEC, IEEE, ANSI, voltage & current
- Flicker – P_{inst}, P_{ST}, P_{LT}
- Mains signalling
- 2kHz-150kHz voltage emissions, 2kHz bins
- Voltage magnitude
- Frequency, as a disturbed value
- Current inrush triggers, overcurrent triggers

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PQube 3 – Power flow

- IEC 62053-22, ANSI C12.20
- **Class 0.2** (most accurate revenue standard)
- Full **NIST-trace Certificate** with every PQube

- kW, kVA, kVAR (fundamental and Budeanu), PF, etc.
- Bi-directional kWh, kVARh – delivered and received

- Technology – calibrated current transformers
- Technology – calibrated phase shifts between channels

- Full UL recognition, CE, TUV, ABS, CCC, S-mark…

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PQube 3 – Environment & DC

- Ambient temperature & humidity
- Surface temperature
- Barometric pressure (kPa, mmHG, barometric altitude)
- X-Y-Z acceleration / vibration
- K-type thermocouple (-60˚C - +275˚C)
- **Global horizontal solar irradiance (W/m²)**
- Two complete sets of above – indoor/outdoor, etc.

DC – volts, amps, watts

- ±100Vdc, ±1,000Vdc, ±2,000Vdc
- Current sensors from 5 amps DC to 3,000 amps DC
- DC bus voltages, solar arrays, electric vehicles, chargers…

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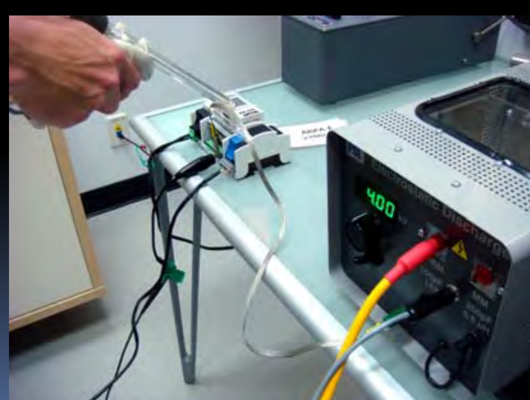
4kV Electrostatic discharge tests



PASS

Electrostatic discharge test, 4 kilovolts, Human Body Model and Machine Model. Static discharge applied to all accessible conductors on the micro-PMU while it was functioning, including Ethernet ports, low-voltage inputs, high-voltage inputs, SD-card connectors. No problems were detected.

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RF emission immunity, radiation

In progress

Open field (literally) testing of emissions for an earlier generation of the micro-PMU at ITC.

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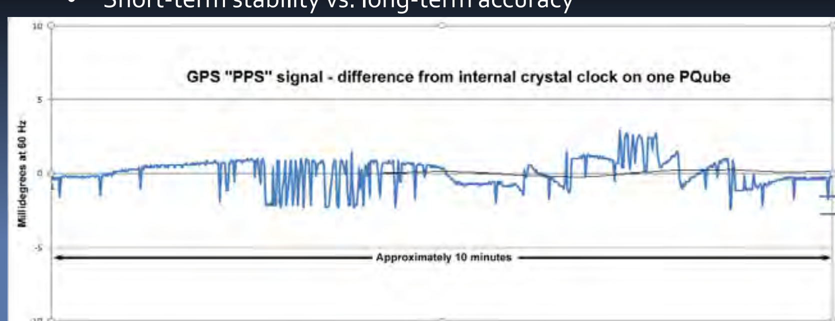
PQube 3 µPMU – technology (1)

- Total error budget – roughly 300 nanoseconds
- (Brief discussion of TVE, and why it doesn't really work for measurements at this precision)

Technology #1: GPS-disciplined 150 MHz clock
- Resolution of GPS PPS signal – 1 µsecond (?)
- Short-term stability vs. long-term accuracy



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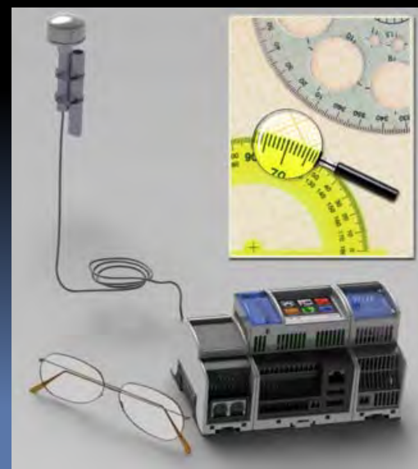
PQube 3 µPMU – technology (2)

- Total error budget – roughly 300 nanoseconds

Technology #2:
Calibrated & floating GPS receiver

(Still to come – compensation for GPS dithering…)



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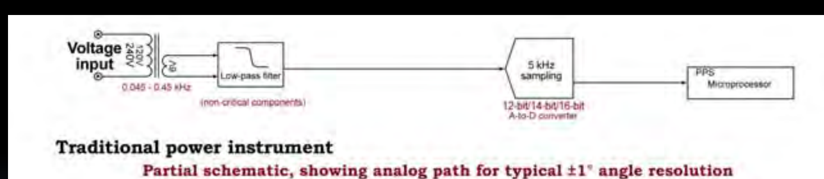
PQube 3 µPMU – technology (3)



- Total error budget – roughly 300 nanoseconds

Technology #3:
Calibrated, temperature-compensated analog channel delay

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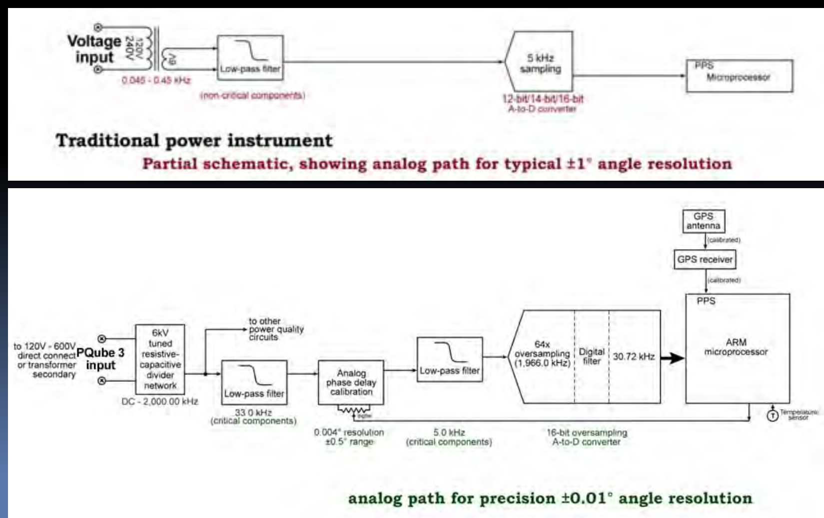
PQube 3 µPMU – technology (4)



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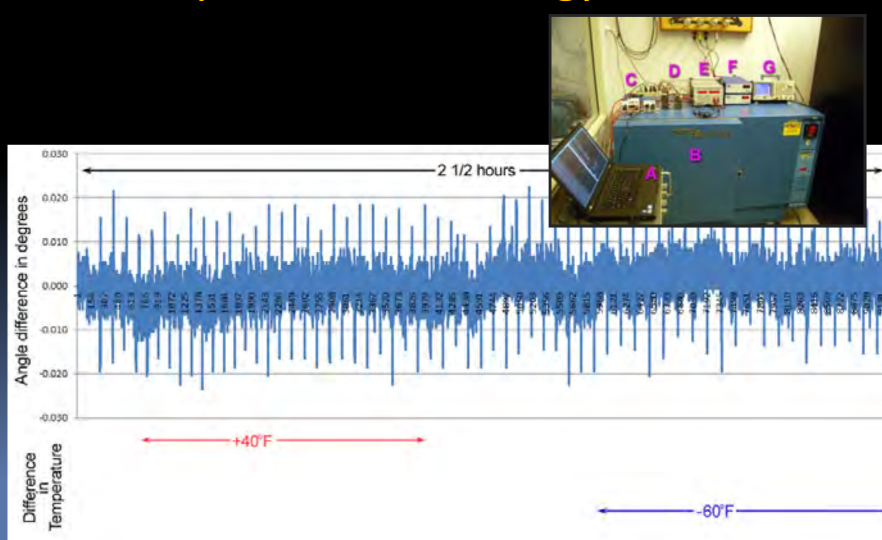
PQube 3 µPMU – technology (5)



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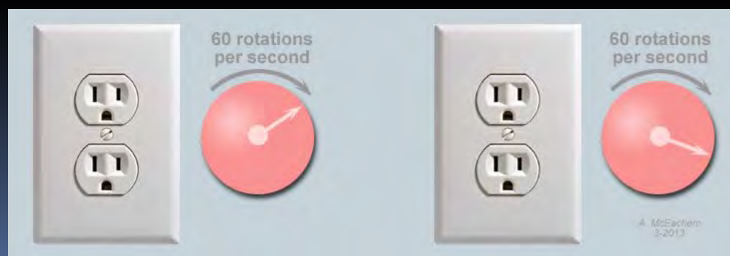
PQube 3 µPMU – technology (6)

- Sub-cycle angle measurements – do they exist? Do they mean anything?



- (not yet implemented in µPMU)

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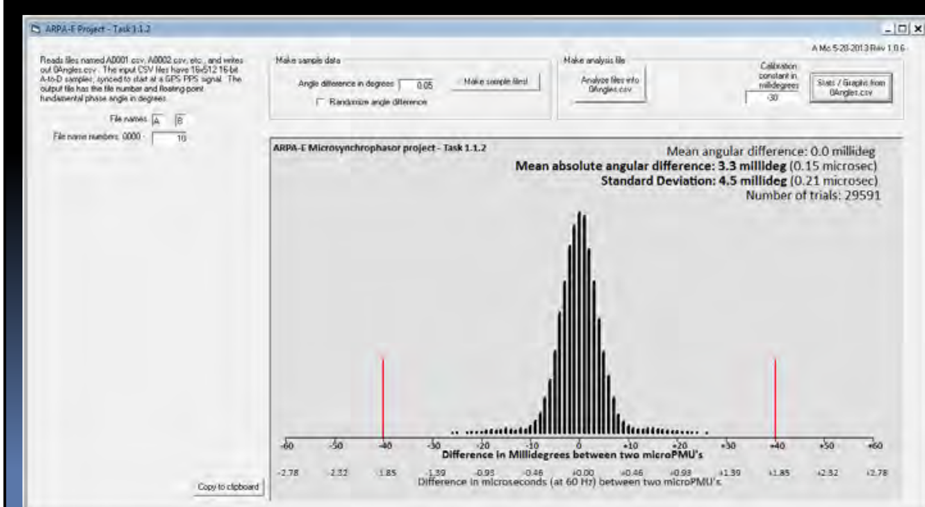
PQube 3 µPMU – technology – results (7)



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PQube® 3 µPMU – status as of 10/2013

- Prototypes up and running – ~50, with ~200 more in progress
- Field installations – South Africa, Japan. Berkeley next…
- Certifications
  - UL recognition – pre-tests complete; in progress at UL
  - FCC/IEC immunity & emissions – in progress
  - Class 0.2, NIST-trace accuracy – completed
  - Class A power quality – completed, Certified
- Still in progress
  - Final firmware for simultaneous µPMU, Class A, Class 0.2
  - µPMU output file formats – extended from IEEE
  - Automated calibration system (manual at present)
- 3-year project – 2.3 years to go.

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Next steps in project

- Install uPMU's on dozens of distribution feeders
- Collect, manage angle data (and manage privacy concerns)
- Develop diagnostic applications
  - Stability with high solar penetration
  - Measure behind-the-meter solar generation
  - 43 other applications
- Investigate/Develop control applications
- Follow this project at http://micro-pmu.info

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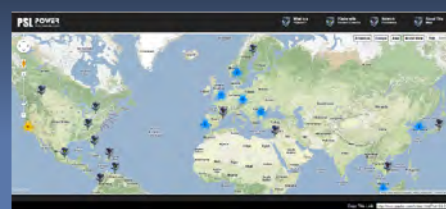
Research Project opportunities in Israel

- Set up "mirror" project to use microsynchrophasors to study <u>grid stability & solar integration</u>
  - University-led project?
  - Israeli Electric Company project?
  - Other?
- Similar "mirror" projects under development in China, Africa, India, Latin America, etc.
- Alex@PowerStandards.com



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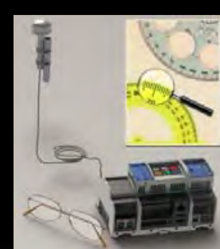

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