Synchrophasors for Distribution Systems

Using phase angle measurements to better understand problems on grids with distributed generation

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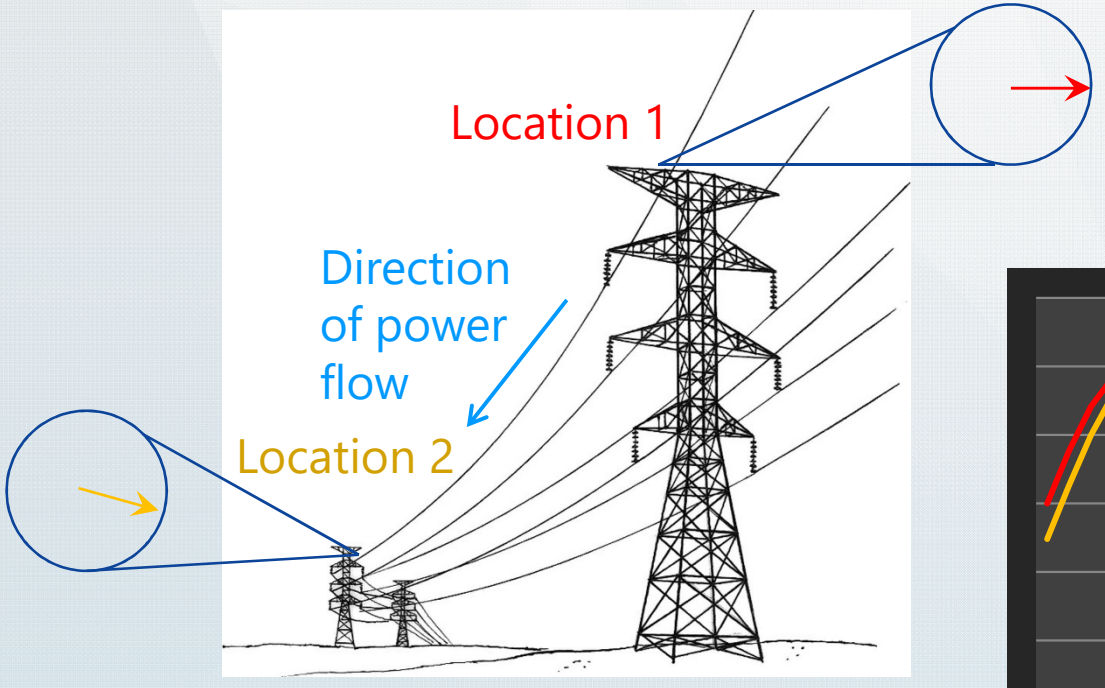
What are synchrophasors?

Synchrophasors compare the phase angle of the voltage between two locations – it is a relative measurement

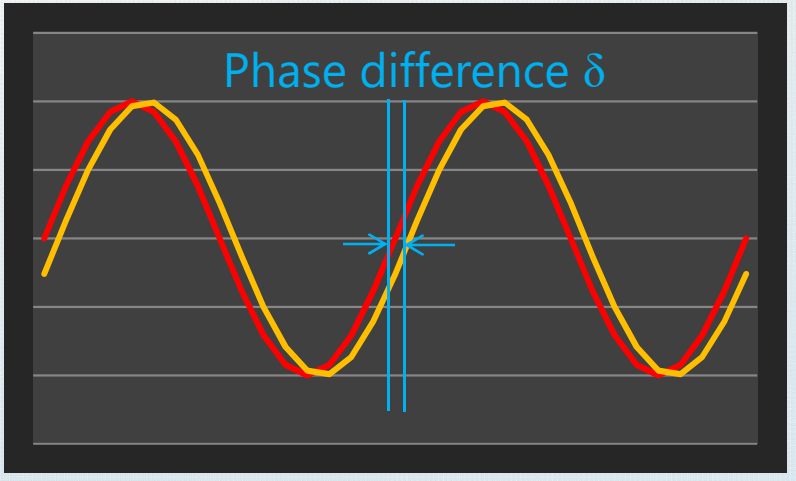
At any given instant in time, the difference in phase angle indicates the direction of power flow on the line

Phase angles and power flow

The voltage at Location 1 leads the voltage at Location 2 due to inductance in the line



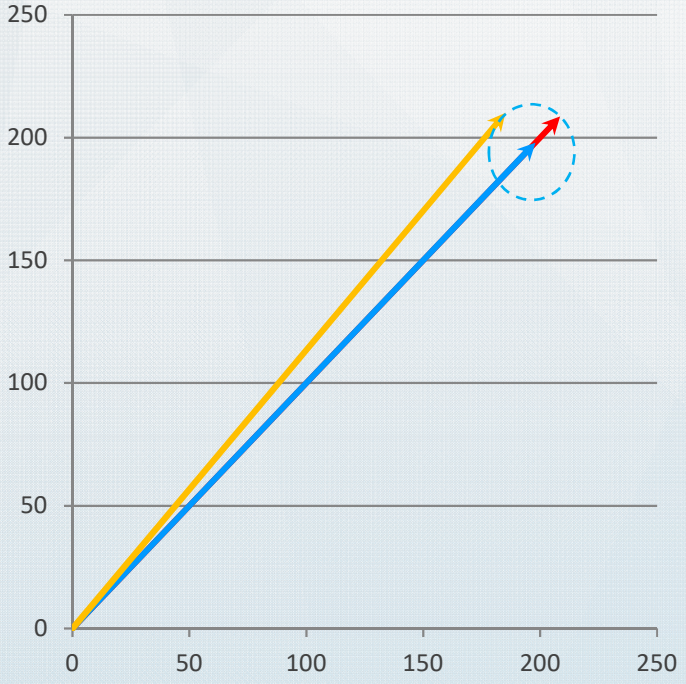
$$P \approx \frac{V_1 V_2}{X} \sin \delta_{12}$$



Total Vector Error (TVE)

Combination of magnitude and angle errors

Allowable error (1% typical) forms a radius around tip of reference signal



Synchrophasor Instrumentation

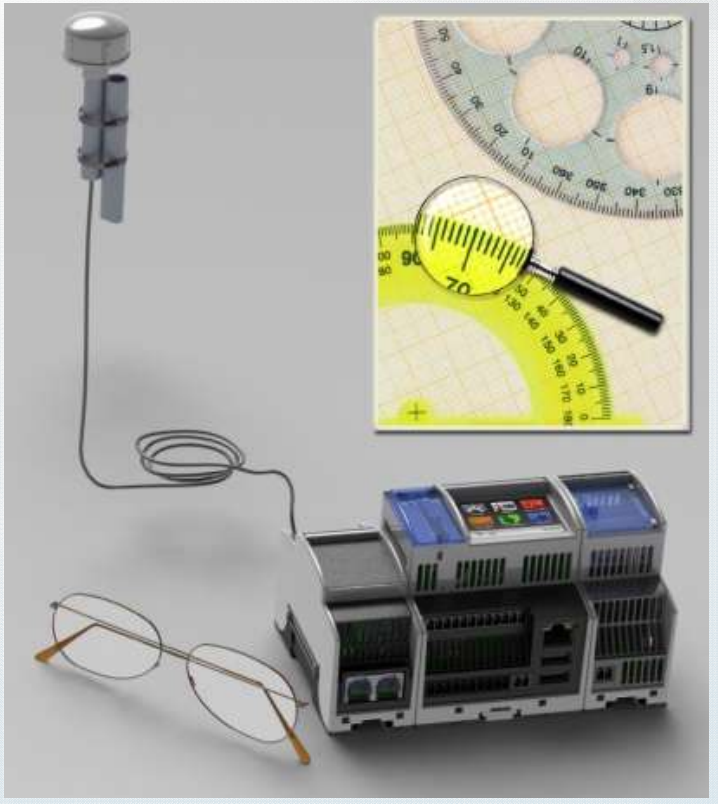
Phasor Measurement Unit (PMU)

- Voltage inputs
- Current inputs (useful)
- GPS for timing
- Networking capabilities

Data streamed to central database server called a Phasor Data Concentrator (PDC)

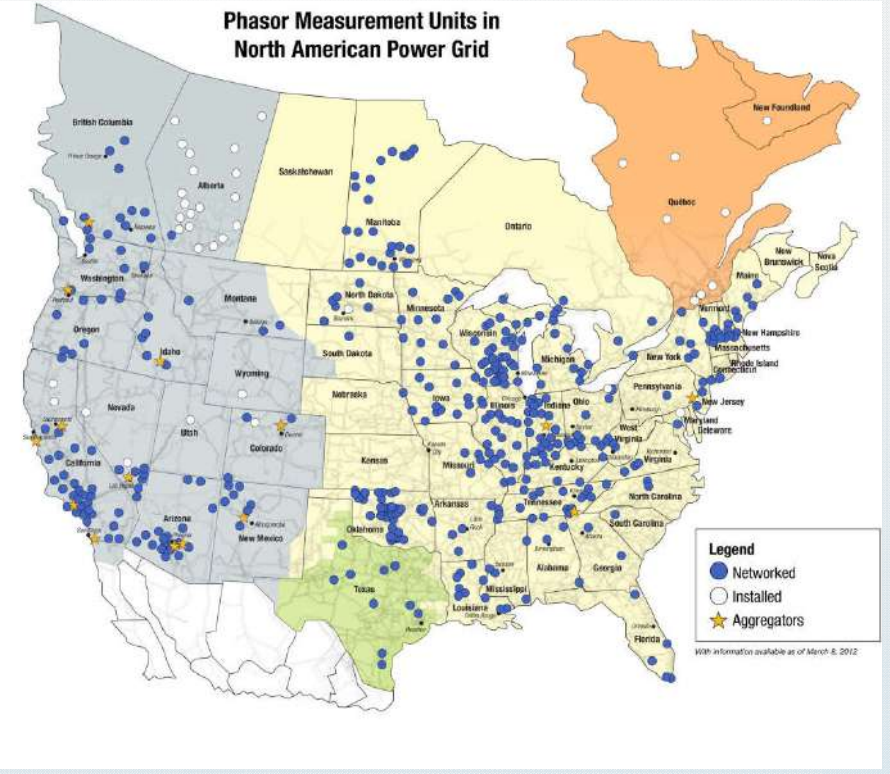
IEEE C37.118

- Part 1 (measurement)
- Part 2 (communications)



Synchrophasors for Transmission

- Synchrophasors are used to monitor grid stability on high voltage transmission systems
- Over 1000 PMUs deployed throughout North America transmission grid



Major Challenges for Distribution Grids

- Shorter cable lengths – phase angle differences are immeasurable with existing PMU technologies for transmission
- Less energy (money) passing through distribution networks limits investment for complex/expensive instrumentation systems
- Vastly more measurement points
- Fragmented comms infrastructure, increased latencies
- A microPMU for distribution grids must be **low cost** and have **higher precision** than existing technologies and be **robust** enough to handle communication delays and outages

Difference between Transmission and Distribution (micro) Synchrophasors

Transmission Grid

- $1,000+ per hour
- Angle differences > 1˚
- PMU's widely available
- Homogenous
  - Above ground
  - Few transitions
  - Similar construction
  - Few, large, stable generators
- Well modeled, well understood

Distribution Grid

- $10 per hour
- Angle differences <0.1˚
- µPMU's just starting
- Diverse!
  - Above/under ground
  - Many transitions
  - Re-configuration
  - Many small, unstable generators
- Poorly modeled, and transient behavior=???

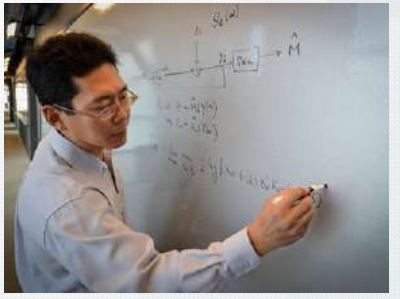
The PQube 3 microPMU

- **PMU** = "phasor measurement unit"
- PQube 3 microPMU developed by PSL, with U.S. government funding: Dept of Energy, ARPA-E Program
- PQube 3 drives all research projects on micro-synchrophasors.

Traditional PMU	**Micro-PMU**
±1% precision (TVE)	±0.05% precision (TVE)
±1˚ angle accuracy	±0.01˚ angle accuracy
±0.1% magnitude resolution	±0.0002% magnitude resolution
±0.1˚ angle resolution	±0.002˚ angle resolution
15 readings per second	100/120 readings per second
For transmission systems…	**For distribution and microgrid**

Who cares about micro-synchrophasors on distribution systems?

1. **Today, it's a <u>research</u> question.**
   a) Researchers on distribution grid stability
   b) Researchers on micro-grids
2. **Areas of research**
   a) Smart-grid stability
   b) Effects of dispersed generation (and how to add more…)
   c) Detecting and measuring behind-the-meter generation
   d) Impedance measurements for precise fault locations
   e) Detecting substation cyber attacks
   f) Phase identification
   g) Separating distribution sags from transmission sags
   h) Verifying and improving models …more!

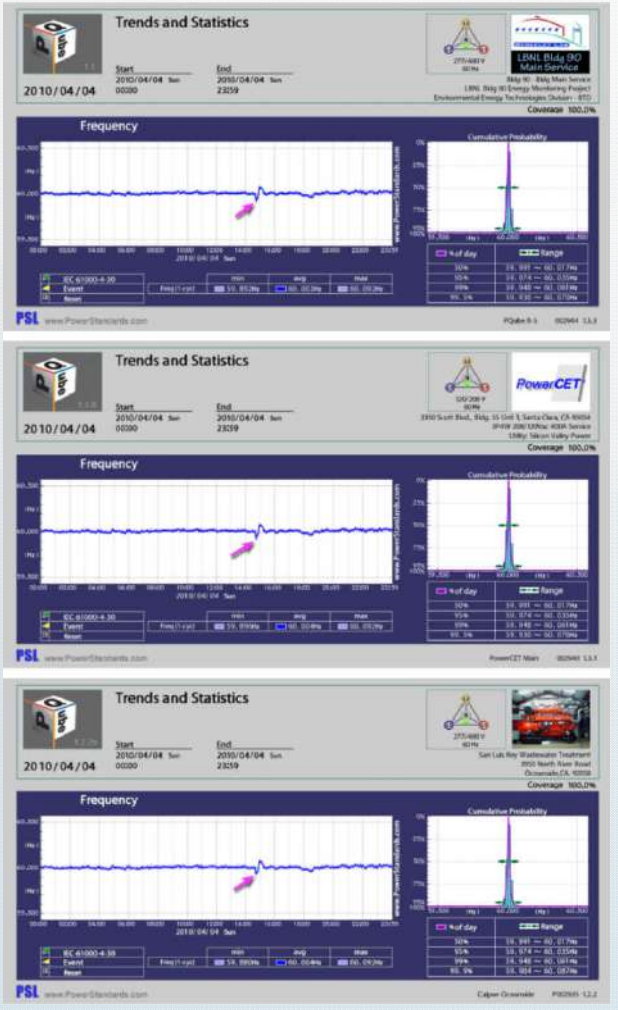


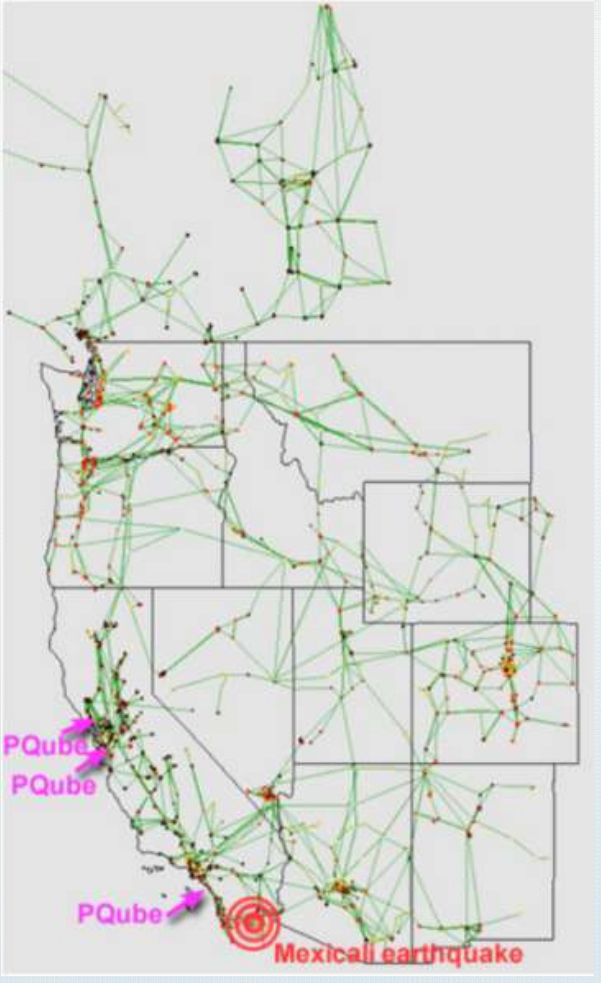
Who cares about micro-synchrophasors on distribution systems?

Darren Kimura, chief executive of Sopogy, shows how his technology uses the Big Island's abundant sunshine to return electricity to the power grid. Solar power is now so popular that Hawaii's utilities worry about damage from excess electricity pumped back into their systems. (Alana Semuels / Los Angeles Times)

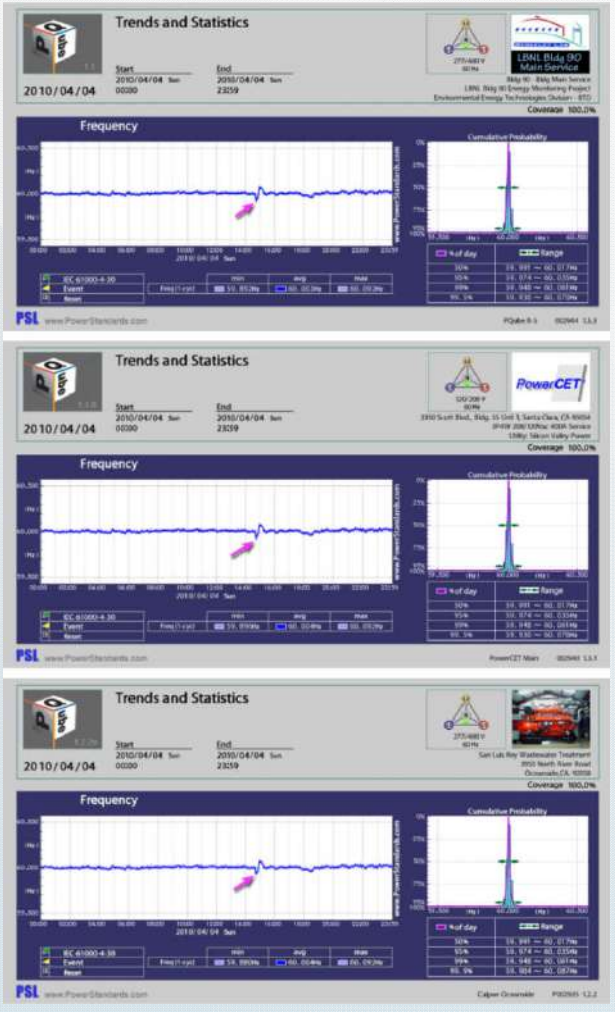
http://articles.latimes.com/2012/nov/17/nation/la-na-hawaii-solar-20121118

Frequency Response of Generators in Transmission





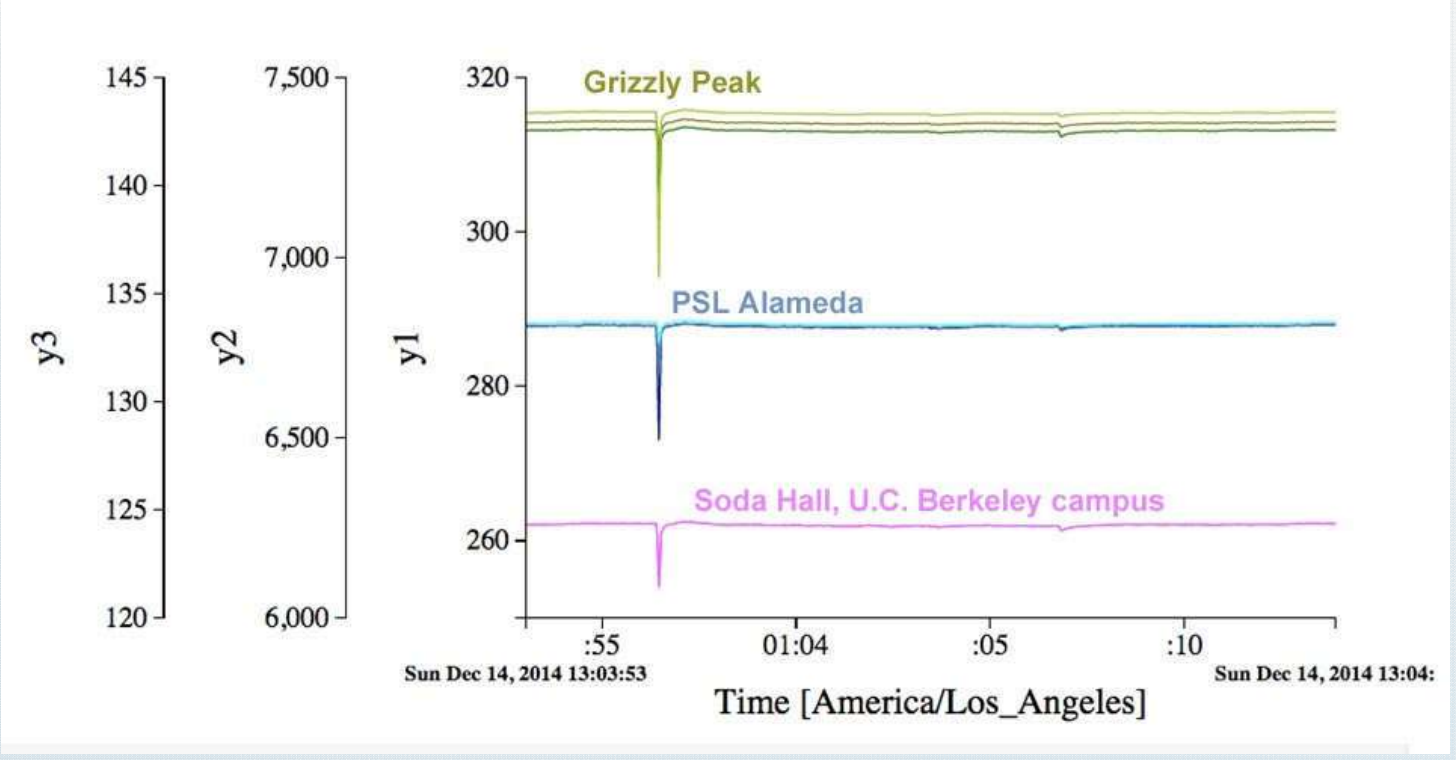
Frequency Response of Generators in Transmission



- Earthquake knocks generator offline
- Increased demand on remaining generators causes a frequency drop
- Generators ramp up frequency in response
- Brief overshoot before stabilizing frequency
- In contrast, PV inverter has instant response time – how does this affect grid stability?

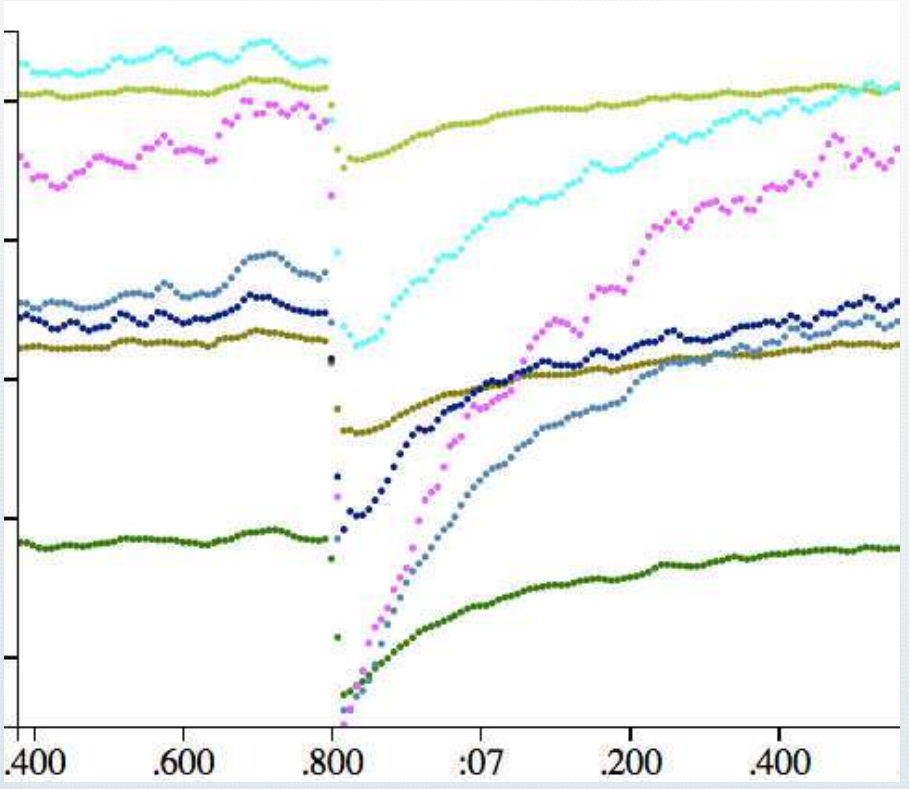
Some interesting microPMU measurements

We're going to look at some interesting measurements from Grizzly Peak, near Berkeley, and PSL, in Alameda. Keep in mind these locations are 40 km apart electrically, and separated by 3 substations.



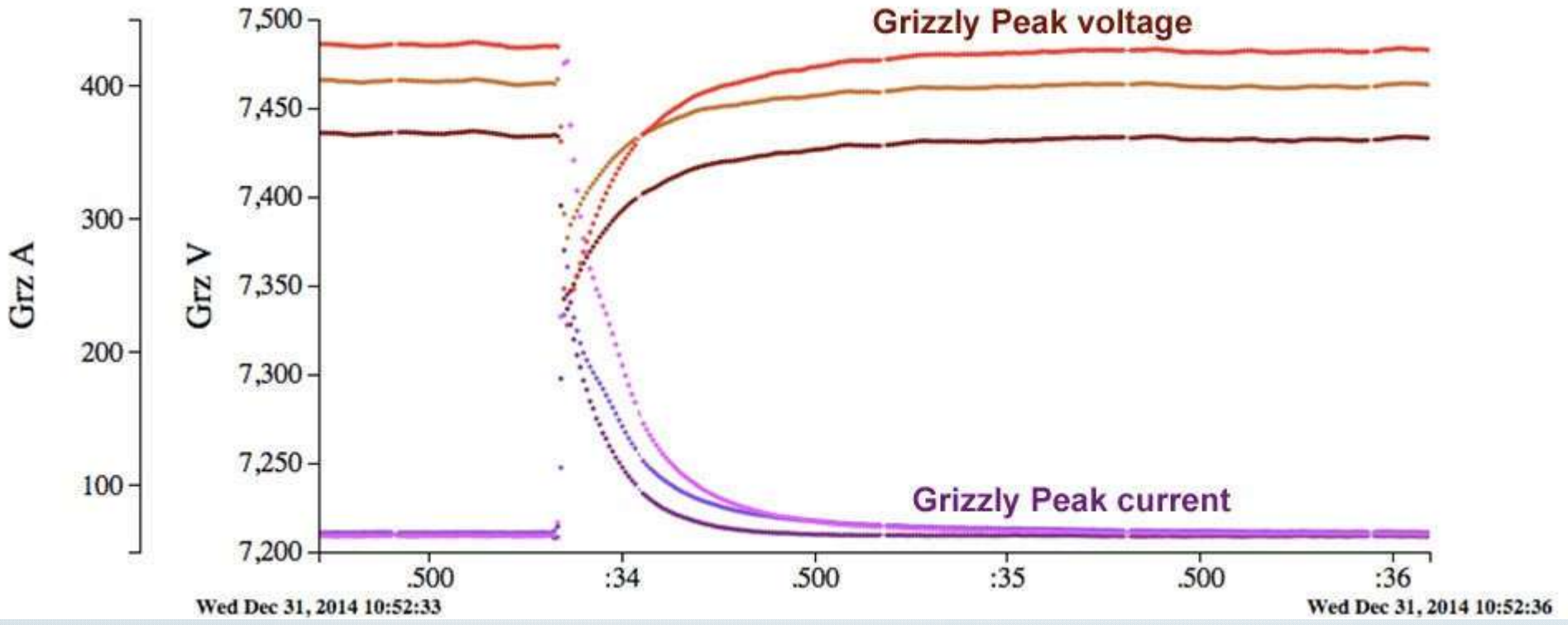
Simultaneous sags, at many locations: must be a transmission-level sag.

Some interesting microPMU measurements



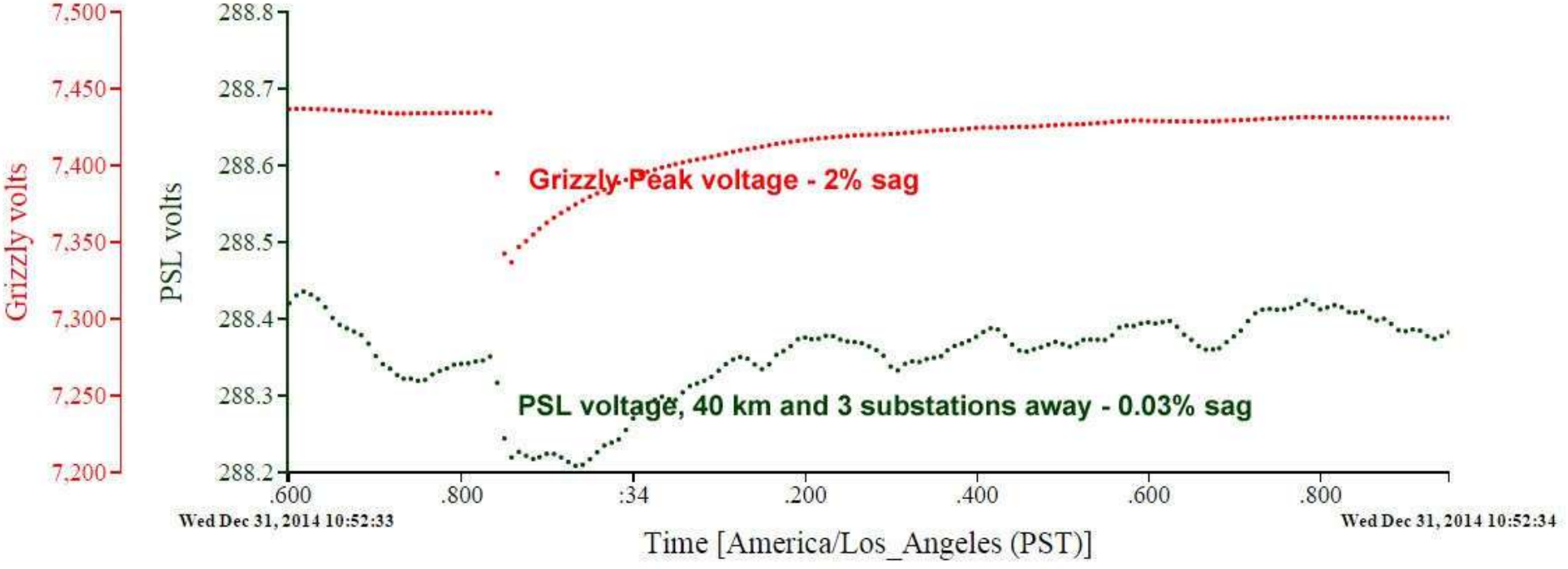
Same sag, zoomed in. Each dot represents ½-cycle. Note how precisely the sags are aligned in time, even 40 km apart.

Some interesting microPMU measurements



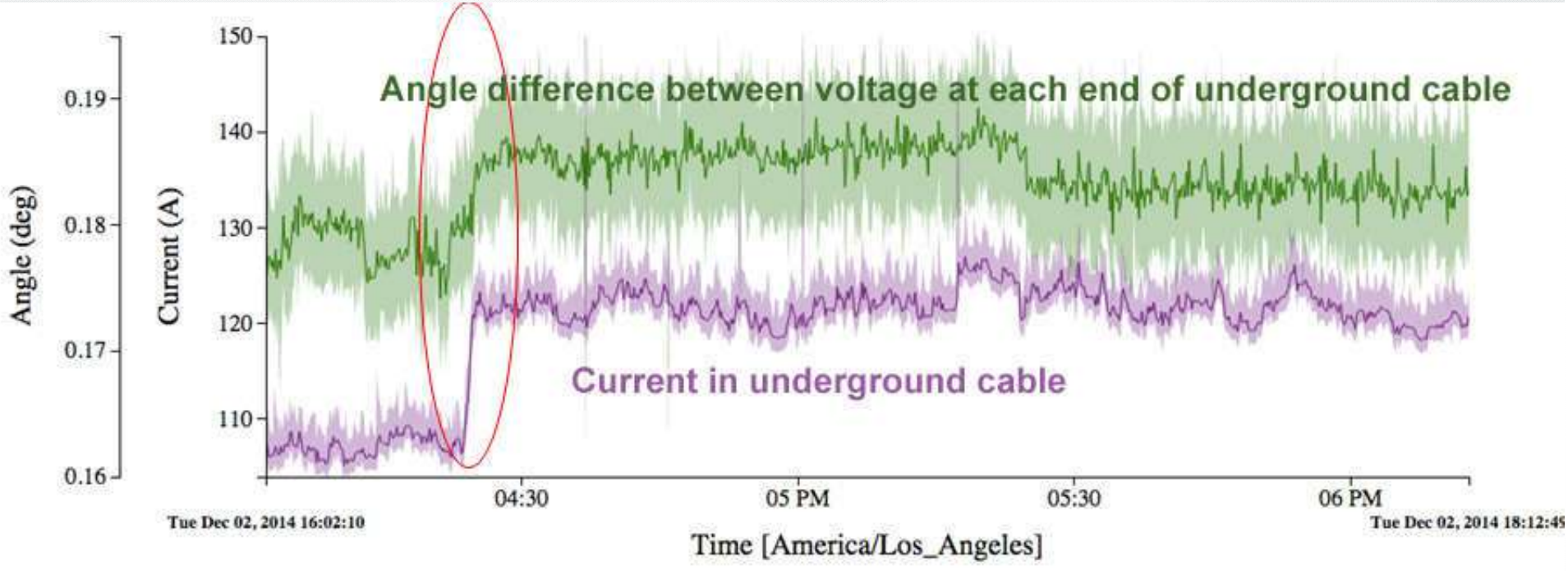
The current goes up at Grizzly Peak, so the voltage goes down 2% there – nothing surprising, until you see the next slide.

Some interesting microPMU measurements



Same 2% voltage sag at Grizzly Peak, zoomed in. But note how the micro-PMU can display the voltage change at PSL, too, 40 km away!
The short-term magnitude resolution of the uPMU is about 2 PPM, or 0.0002%.

Some interesting microPMU measurements



An increase in current causes a voltage phase angle change of 0.008˚ - typical resolution of the microPMU.

ARPA-E Project Status

1. Three-year ARPA-E pilot project nearing conclusion. Many lessons learned regarding installation, regulations, operating environments, and big data management.

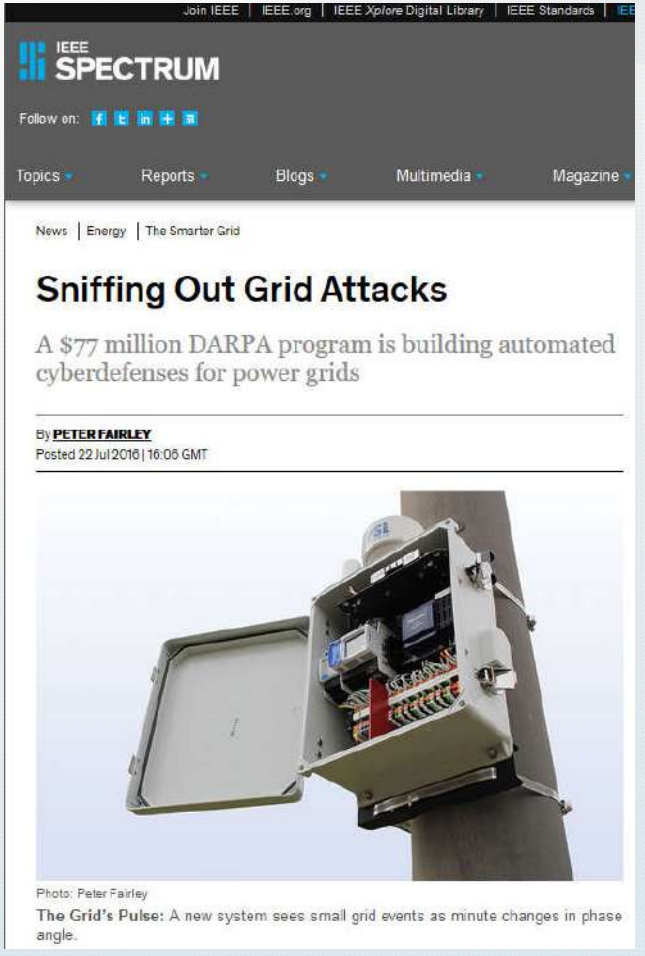
2. Increasing cooperation with universities and utility R&D groups. Japan, China, other countries starting.

3. The open-source software developed for this project to analyze micro-synchrophasor data is still being refined. It will eventually be available. Meanwhile, free software like OpenPDC can be used with microPMU's.

ARPA-E Project Status

4. New applications include impedance measurements, model verifications, stability measurements, and increasing allowable dispersed generation. More applications keep being discovered.

   For example, a new project has been funded by the U.S. government to use μPMU's to detect substation cyber attacks.
   http://spectrum.ieee.org/energy/the-smarter-grid/sniffing-out-grid-attacks



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Sniffing Out Grid Attacks

A $77 million DARPA program is building automated cyberdefenses for power grids

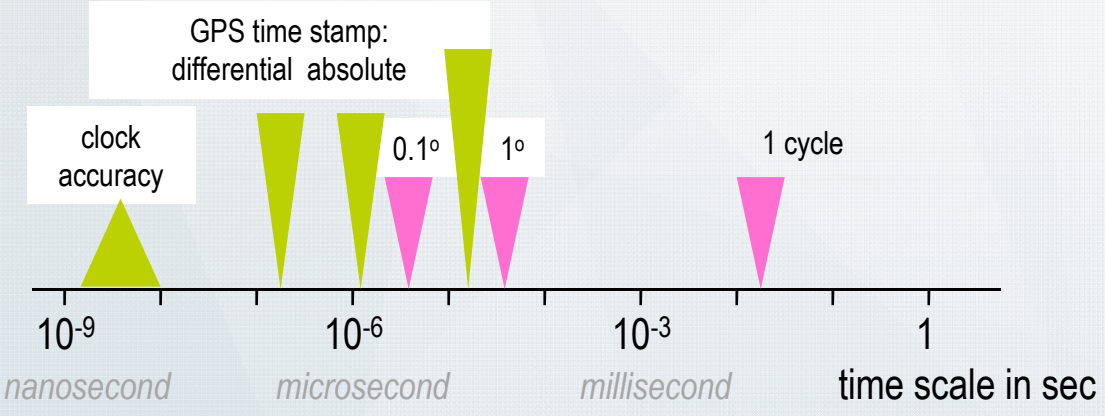
By PETER FAIRLEY
Posted 22 Jul 2016 | 16:06 GMT

Photo: Peter Fairley

The Grid's Pulse: A new system sees small grid events as minute changes in phase angle.

ARPA-E Project Status

5. Low-cost Micro-PMU instruments are available commercially from PSL.



ARPA-E Project Status

6. We have been "surprised" by commercially available modeling software for distribution grids.
7. **We don't know what "frequency" is.**
   - Time between zero-crossings? How many?
   - Rate-of-change of angle? PF capacitor switching?
   - FFT? Resolution… and history.
   - **This is important.** Different definitions in:
     - Protection Relays
     - Solar, wind inverter loop controls
     - Generator loop controls
     - Frequency-responsive loads
   - Similar to "True-RMS voltage" 20 years ago…

Questions/Comments?

Conclusions

- Distributed generation is increasing every year, but the effects on grid stability are still not well understood
- Synchrophasors increase system visibility of your distribution network
- Still scratching the surface – we keep coming up with more questions than answers
- New applications for this technology?