Micro-synchrophasors:

a promising new measurement technology

for the AC grid

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How the grid works (1)

- Electricity **moves** energy from one place to another
- Generators: spinning stuff → electricity
How the grid works

- Current = flow. Voltage = pressure.
- Power = voltage x current
- The voltage/current $$$ tradeoff
- “Transmission”: long distance, high voltage
- “Distribution”: medium distance, medium voltage
- “End-use”: inside the building, “low voltage”
How the grid works

- Many generators and loads in a big network
- No central control of generation
- Each generator has its own PID loop for power output
The transmission system is stable...

Rotating mass in large generators, plus load diversity
...except when it isn’t:

What does a stable system do when you whack it?
...except when it isn’t.

Courtesy Texas Synchrophasor Network, Mack Grady, U.T. Austin
Introduction to synchrophasors

Very early example of synchrophasors?
a.c. sine wave
Phasor in the complex plane

\[ j = \sqrt{-1} \]

\[ V = |V| e^{j\theta} \]

using Euler:

\[ e^{j\theta} = \cos \theta + j \sin \theta \]

\[ \omega = 2\pi \times 60 \text{ s}^{-1} \]
Power flow and voltage angle

the small phase angle $\delta$ between different locations on the grid drives a.c. power flow

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

power flows from Unit 1 toward Unit 2
Transferring power: torque & twist analogy

rotational angle is slightly different
Real and reactive power flow: driven by voltage magnitude and angle
Synchrophasors compare voltage angle at different locations…

phasor measurement units (PMUs)

synchronous data

useful real-time information for system operators
...to give insight about the grid’s operating state
...to the System Operator (CAISO)
Transmission PMU’s in North America

Phasor Measurement Units in North American Power Grid

Legend:
- Networked
- Installed
- Aggregators

NASPI 2010

i4E lecture – 10/19/2012
Voltage phase angles separating, just before a major blackout
Just before our 2006 Blackout:

What actually happened

What the operators’ model saw
Low frequency oscillations on Western Grid require de-rating of major transmission lines

- North-South: 0.25-0.3 Hz
- East-West: 0.6-0.7 Hz
- California-Desert: 0.5 Hz
- Alberta: 0.45 Hz
This application analyzes PMU data to show damping of characteristic sub-synchronous oscillation modes.
Why PMUs only on transmission, and not on the distribution system?

- Cost / Value proposition
- More challenging measurements – fractions of a degree
- Historically, no need:
  - unidirectional power flow, from substation to load (?!)
  - unquestioned stability of distribution system (??)
μPMU concept (1)

- Very low cost: piggy-back on existing distribution instrument, PQube

- Allows sync with disturbance recordings, too
µPMU concept (2)

- Very low installation cost – no comm channel required
- Millidegree resolution – orders of magnitude better than synchrophasors
μPMU concept (3)

- Angular resolution: impulse capture
- Waveform changes: 256 samples per cycle
- RMS sags, swells, interruptions
- Voltage and current harmonics: W, VAR, VA
- Frequency, dF/dt, angle measurement interval
- W, VAR, VA +/−/0 sequence imbalance
- Minimum/average/maximum recording
- Temperature, humidity
- μPMU data buffer and notifications

- Clock accuracy: nanosecond, microsecond, millisecond, second, minute, hour, day, month

- Proposed μPMU measurements
- Proposed μPMU device capabilities
- Reference magnitudes

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μPMU concept (4)

- 24 samples per cycle, traditional synchrophasor
- 512 samples per cycle, microsynchrophasor
- Phase-locked sampling for power quality measurements, and time-based sampling for synchronized measurements
μPMU concept (5)
i4Energy Research Project on μPMUs

- Team has formed:
  CIEE, UCB, LBNL, Power Standards Lab, UT Austin
- Support letters from California utilities:
  SDG&E, SCE, PG&E
- One funding application submitted – awaiting results…
i4Energy Research Project Plan

- Validate μPMU performance
- Develop communications, data analysis based on sMAP
- Install on selected distribution feeders to make first empirical observations of voltage angle at high resolution
  
  note: μPMU can connect to single- or 3-phase, primary (e.g. 12kV) or secondary (e.g. 120V) distribution

- Study the promise of voltage angle as a new state variable
- Examine diagnostic and control applications for μPMU data
Possible diagnostic applications:
- island detection
- oscillation detection
- characterization of inertia
- FIDVR diagnosis
- fault location, protective relaying

Possible control applications:
- Volt-VAR optimization
- microgrid balancing
- seamless intentional islanding and re-synchronization
- creative recruitment of distributed resources for ancillary services
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These will have different requirements for measurement accuracy, communication speed, data transfer rate, continuity...
...but for starters, we don’t even know:

What are we going to see?

Illustration: Michael Sowa
What are we going to see?
Things that matter in a world with lots of distributed resources? (We think, probably yes.)

- Which way the power is flowing
- Rapid changes in voltage or power flow - transients
- Oscillations, stability issues?
- How inverters interact with the legacy grid?
- Nothing interesting?

“If we knew what we’re doing, it wouldn’t be called research.”
We’re excited, but we don’t know the results.
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QUESTIONS? COMMENTS? IDEAS?

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