Micro-Synchrophasors for Distribution Systems

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Project Objectives

- Develop a network of high-precision phasor measurement units (µPMUs) to measure voltage phasors with unprecedented accuracy (~ 0.01°)
- Study diagnostic and control applications for µPMU data on distribution systems and develop suitable algorithms
- Challenges include multiple sources of measurement error and noise: learning what matters
- Performance metrics include angular resolution, overall accuracy, latency; key objective is to match data quality with applications
- Develop useful, practical tools for a new type of visibility and management of distribution circuits
Accomplishments

- Demonstrated μPMU device performance on lab bench
- Installed and networked prototype μPMUs at Berkeley Lab pilot site with 4G wireless communication
- Debugged hardware, firmware, installation design
- Built scalable database and plotting tool “Quasar 2.0” for fast and flexible access to high-resolution time-series data
- Prepared detailed installation plans with host / partner utilities at four field sites, targeting different applications
- Analyzed requirements and use cases for a broad spectrum of diagnostic and control applications
- Developed theoretical algorithms for topology detection, state estimation, fault location based on μPMU data
Synchronized magnitude measurements reveal phenomena common to different measurement locations.

Legend:
- uPMU/upmu/grizzly_new/L1MAG
- uPMU/upmu/grizzly_new/L2MAG
- uPMU/upmu/grizzly_new/L3MAG
- uPMU/upmu/psl_alameda/L1MAG
- uPMU/upmu/psl_alameda/L2MAG
- uPMU/upmu/psl_alameda/L3MAG
- uPMU/upmu/soda_a/L1MAG

Soda Hall Voltage (V)

Grizzly Voltage (V)

Alameda Voltage (V)
Synchronized magnitude measurements reveal phenomena common to different measurement locations.

This graph shows full resolution of 120 samples / sec.

(Voltage scales adjusted)
Voltage phase angle difference (green) and current (violet) between two locations on a 12kV cable over a two-hour time period.

Plotter shows min-max-mean of 120 samples/sec data.
Voltage phase angle difference (green) and current (violet) between two locations on a 12kV cable, seen at greater resolution.
In Progress

- Empirical data analysis: identify phases, power flows, interpret events…
  
  *What’s hard: small signal-to-noise ratio, identifying error sources (e.g. PTs & CTs)*

- Validate circuit models: calculate impedances
  
  *Pilot site has short, lightly loaded, asymmetrical underground cables*

- Modify installation plans to allow more simple, direct validation at some locations
  
  *It’s hard to ground-truth field data absent other good instrumentation*
In Progress

- Proceed with field installations
  
  *Must address diverse utility criteria for hardware specs, tailor peripherals and placement strategy to specific environments, manage expectations*

- Integrate new µPMU data streams and implement distillates on Quasar

- Perform state estimation and topology detection algorithm computations offline in Matlab environment

- As an alternate method, integrate C37.118 µPMU data stream with OSIsoft PI server, compatible with existing tools

- Continue theoretical work on control applications
Technology-to-Market

- Targeting electric utilities, system integrators, microgrid projects and vendors of distribution controls for hardware sales
- Discussions with potential partners for software commercialization, which may include
  - new products based on open-source code developed by UC Berkeley
  - expansion of existing software products to integrate μPMU data
- Generally positive interest, especially international
- Challenge is to have persuasive empirical evidence in hand early in project
Objectives

- Complete field installations at manageable scale
- Demonstrate empirical µPMU data provide useful, actionable intelligence about the distribution system
- Exercise topology detection and state estimation algorithms with field data, evaluate performance
- Test algorithms for decentralized control of distributed resources based on µPMU measurements in simulation environment
- Identify most promising and fruitful directions for follow-on research, development and demonstration
Post ARPA-E Goals

- Significant work remains on developing µPMU applications, including
  - expansion and refinement of algorithms and software developed within this project, and
  - study of applications outside the scope of this project

- Control applications are likely a key area of interest, as the needs and opportunities for distributed control are growing

- Model-based vs. non-model based approaches to be compared

- Control applications will require extensive simulations as well as field testing to allow proper confidence

- Synchrophasors will be useless where transmission & distribution networks convert to d.c.
Conclusions

- Distribution synchrophasors are an idea that is resonating well throughout research community and industry, esp. in California
- Scary data volume (terabytes) can be handled effectively
- Practical implementation of field measurements faces mundane, time-consuming hurdles
- Key remaining challenges for measurement accuracy reside outside, not inside μPMU
- Many advanced application opportunities appear worth exploring