Lawrence Berkeley National Laboratory

Micro-Synchrophasors for Distribution Systems

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Team

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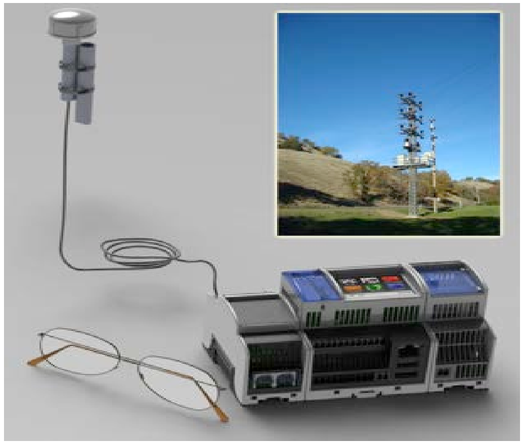
Distribution Phasor Measurement Units

Funded Projects

ARPA-E Project: Micro-Synchrophasors for Distribution

Cybersecurity for Energy Delivery Systems: Intrusion detection and visualization with distribution synchrophasors



Utility and field site partners
Southern California Edison, Sacramento Municipal Utility District, Southern Company, UC San Diego, Riverside Public Utility, NEETRAC

Research Question: Can synchronized distribution level phasor measurements enhance planning for power flow and system control, security and resiliency in the modernized grid?

Approach

- Develop a network of high-precision phasor measurement units (µPMUs) to measure voltage phasors with unprecedented accuracy (~ 0.01°) – Power Standards Laboratory
- Study diagnostic and control applications for µPMU data on distribution systems and develop suitable algorithms including load identification and impedance calculation
- 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

Background

Vision for a future electricity grid in California and the U.S. involves increasing the use of renewable generation on the distribution grid.

With large numbers of distributed generation units, including solar PV, the future grid will have more complex analysis needs and development of new control architectures.

The distribution system has more components than the transmission system and therefore more unknowns and potential for error in models.

- Growing number of measured and grid model data sources becoming available
- They must be accurate, and interpreted correctly.
- Errors in data are more prevalent in the distribution system

To facilitate high penetration of DG, measured and modeled representations of generation must be accurate and validated, giving distribution planners and operators confidence in their performance

Accomplishments

1st & 2nd Year
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

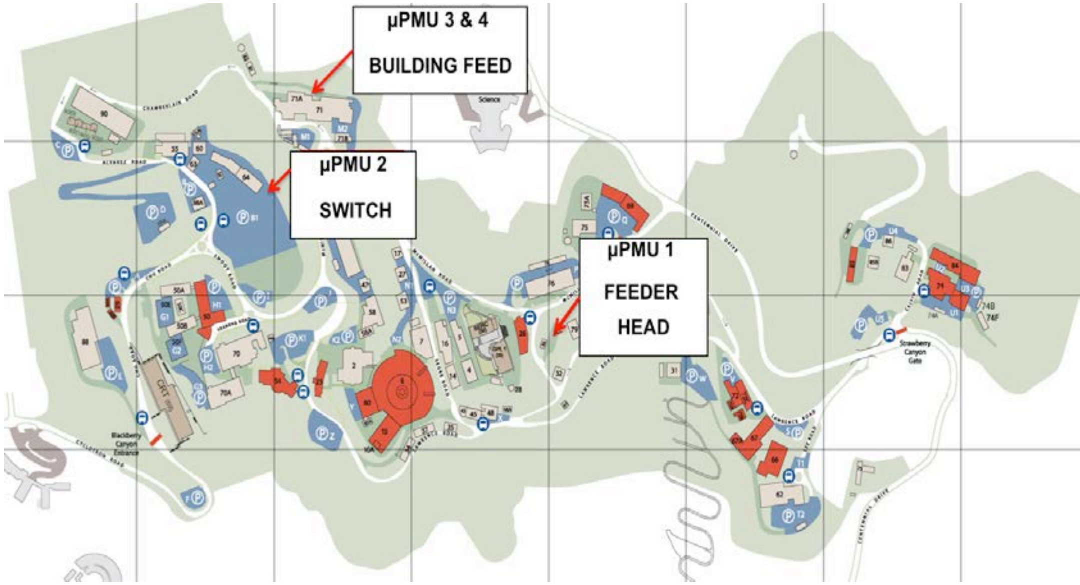
Prepared detailed installation plans with host / partner utilities at four field sites, targeting different applications

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

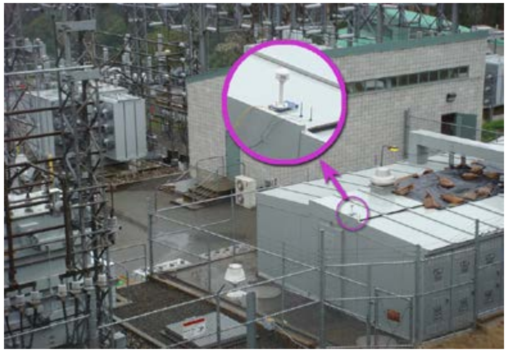
Pilot Site Installation - LBNL

- Installed μPMU devices in 4 locations at LBNL – from substation (feeder head) to Building 71
- Coupled with existing measurement system on site
- Measuring high fidelity voltage and current magnitude and phase angle (512 samples/cycle)
- Developed LBNL system model and advancing research in model validation and calibration
- Preliminary challenges include communications, calibration, and commissioning of sensors



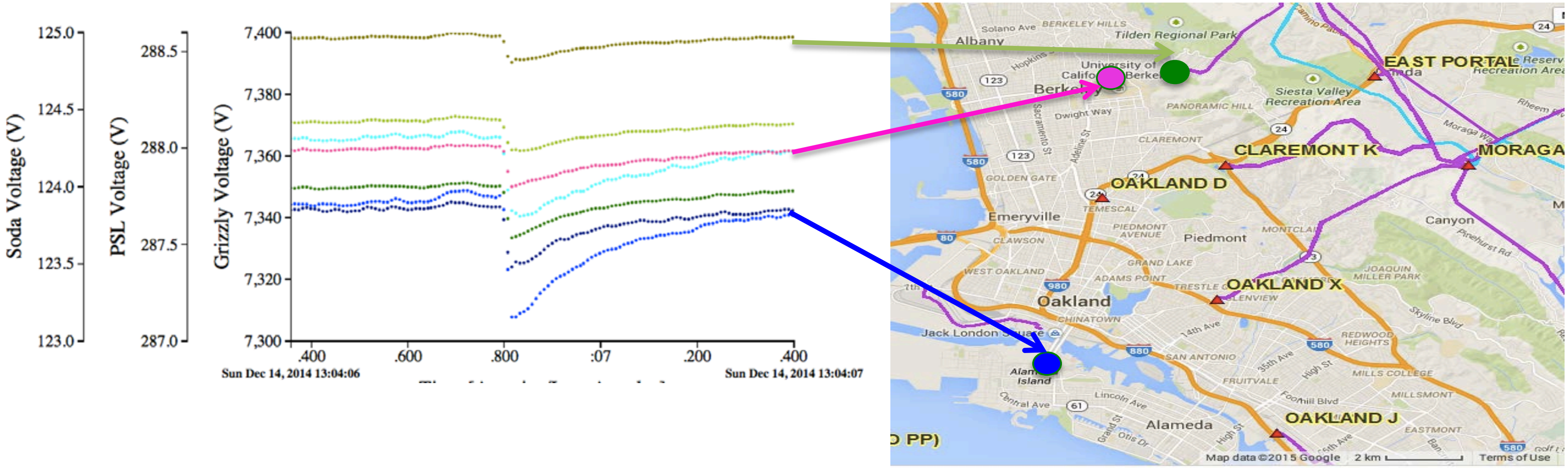
New Work: Early detection system for grid-network cyber attacks working with Computational Research Division

Grizzly Peak μPMU 1



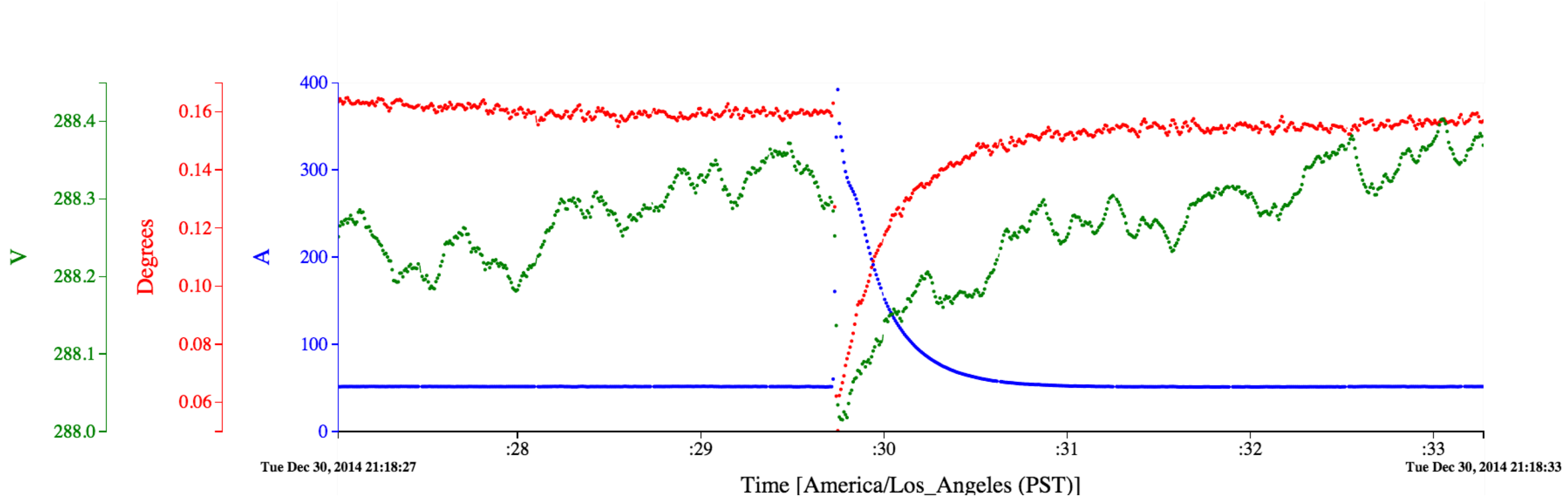
How do we know what it is & what it means?

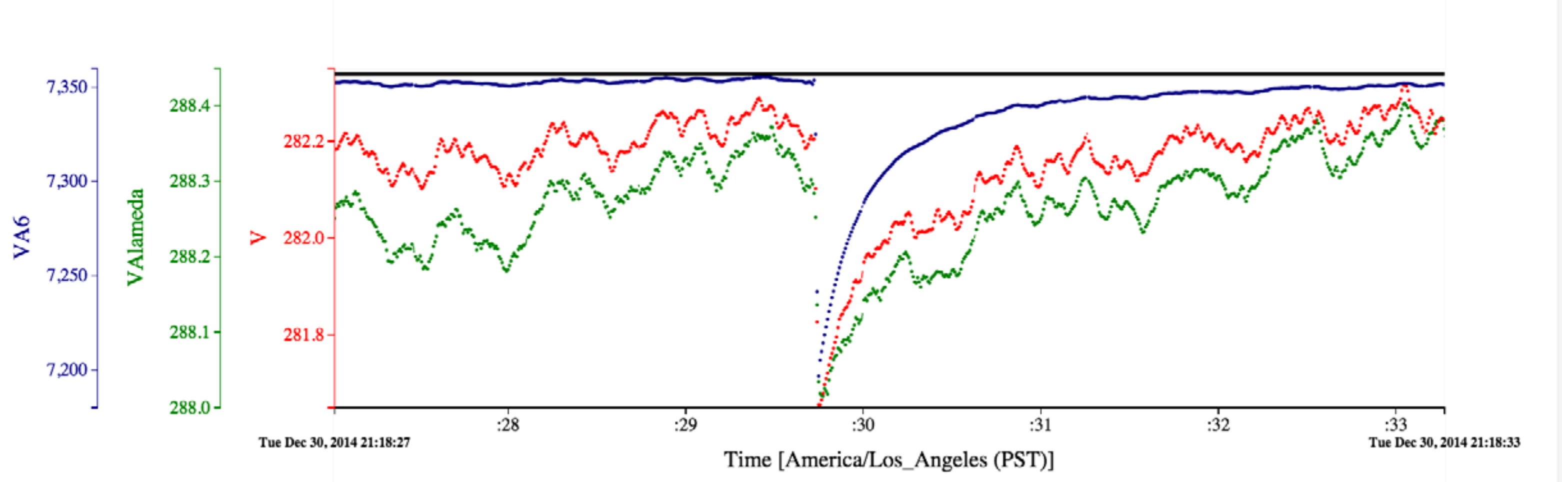
Time Series Synchronized Data Visualization from Distribution µPMUs



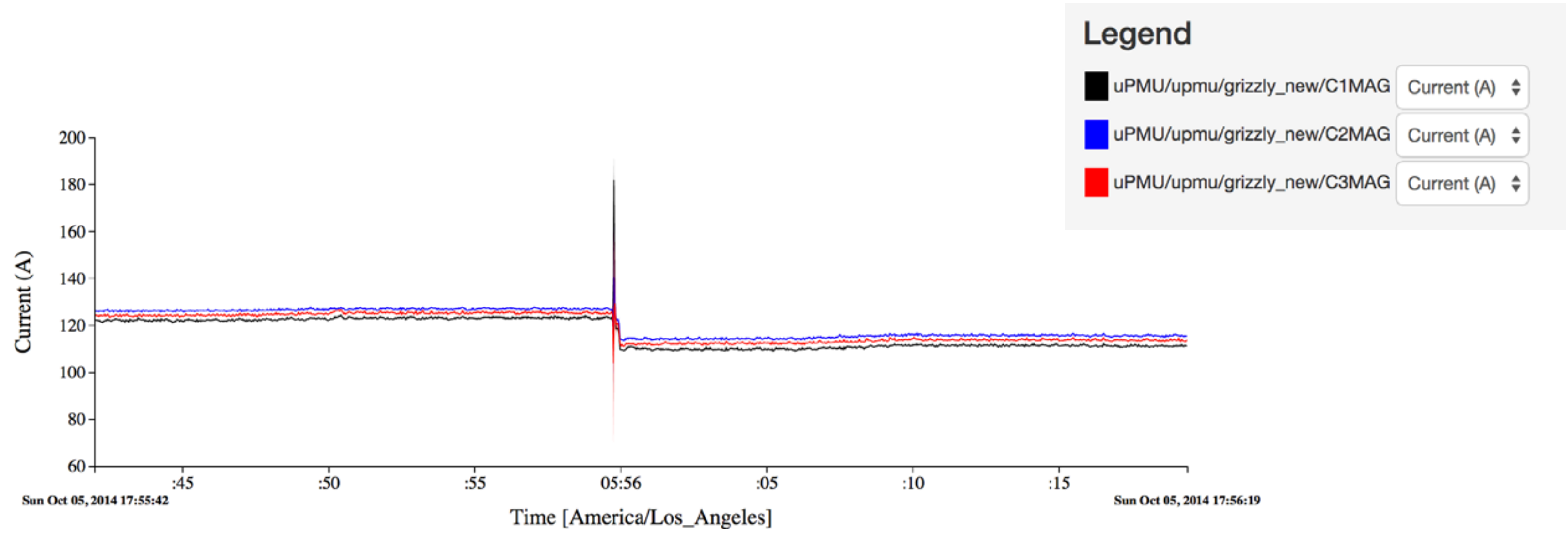
- Synchronized magnitude measurements reveal phenomena common to different measurement locations
- Distribution impacts can be visualized on the transmission system and vice versa
- Data can be utilized to characterize load and generation behavior precisely

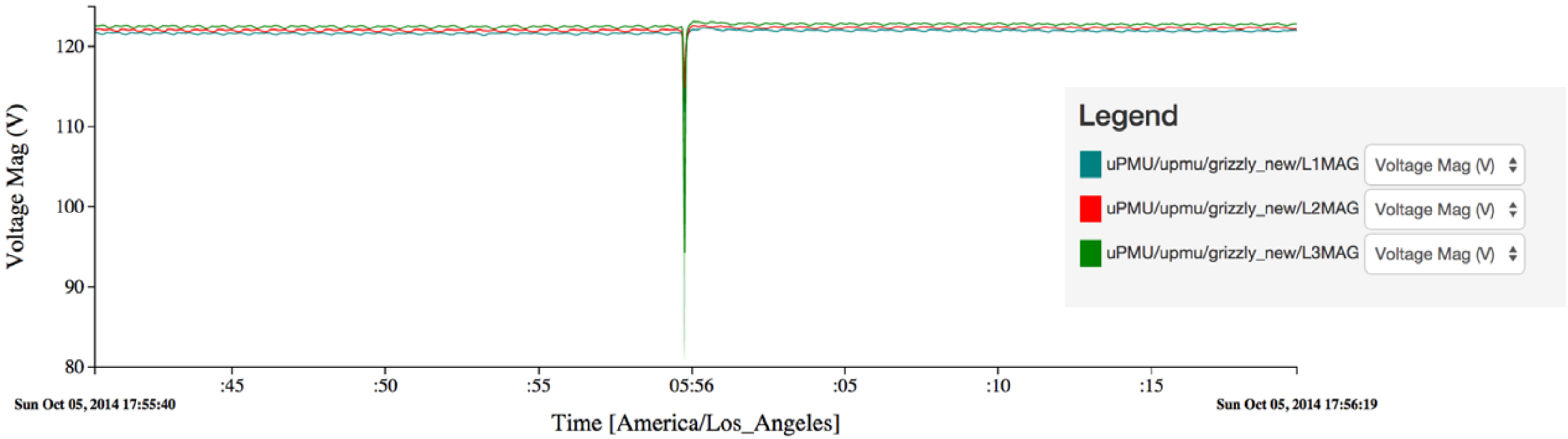
Example: What is this?

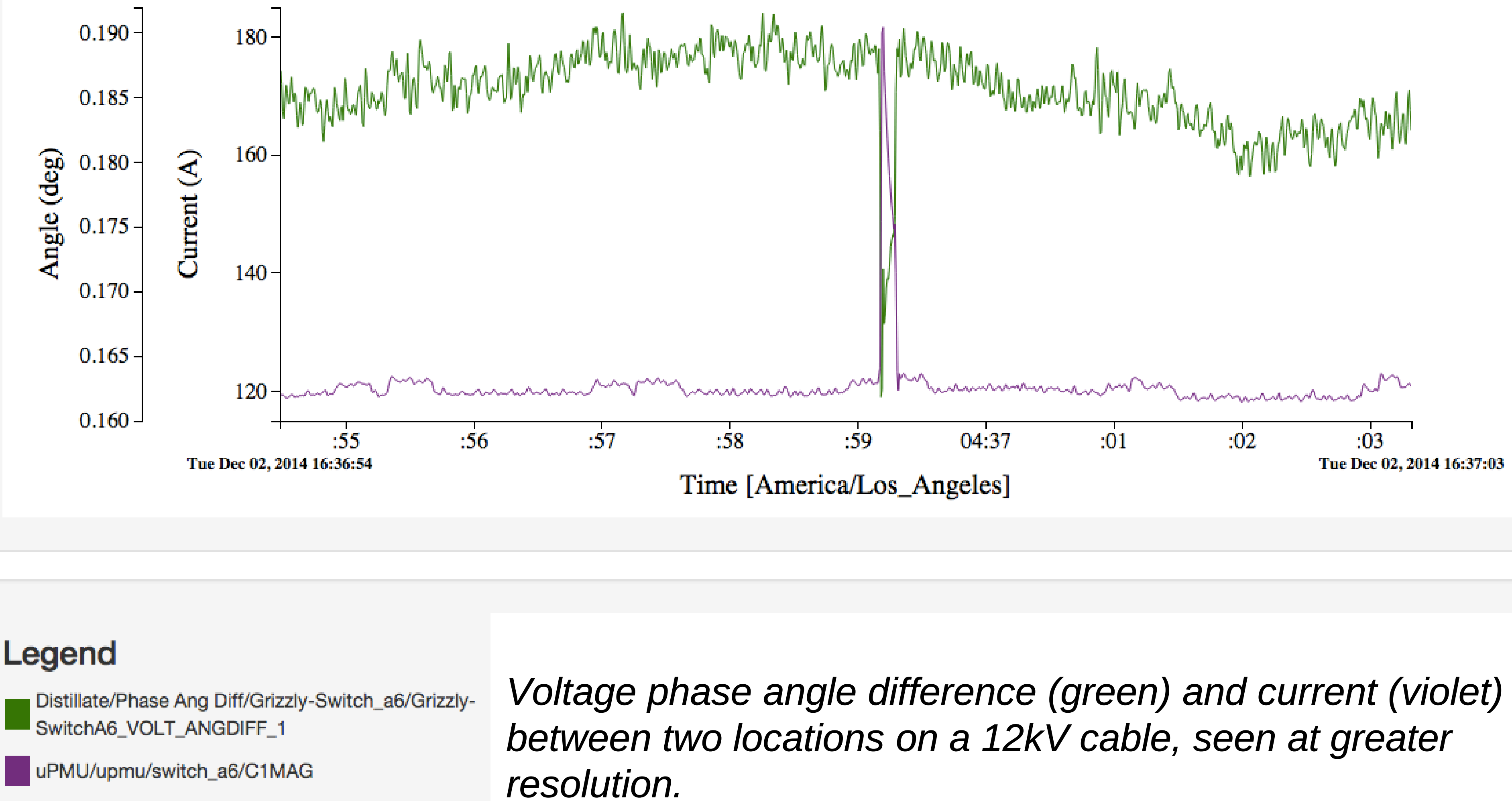




Orinda Fault (Oct 5) Grizzly V & I







Voltage phase angle difference (green) and current (violet) between two locations on a 12kV cable, seen at greater resolution.

In Progress

1st & 2nd Year Accomplishments

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

1st & 2nd Year Accomplishments

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

Final Year 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

Applications Being Studied

- Model Validation: compute impedances between instrumented locations and compare to circuit models
- Phase Identification: confirm ABC labels using phase angles and time-series correlations
- Load identification: Determine key parameters of distributed load for modeling
- Characterizing dynamic behaviors of loads, distributed generation and system interactions
  - *E Stewart, S Kiliccote et al., Addressing the Challenges for Integrating Micro-Synchrophasor Data with Operational System Applications, IEEE PES 2014.*
- State Estimation: integrate µPMU measurements with available SCADA and load data ("pseudo-measurements") in a fast, linearized method for estimating state variables at non-instrumented nodes
  - *L Schenato, G Barchi, D Macii, R Arghandeh, K Poolla, A von Meier: Bayesian Linear State Estimation using Smart Meters and PMU Measurements in Distribution Grids, IEEE SmartGrid Comm, 2014*
- Topology Detection: use characteristic signatures of time-series phasor measurements to recognize changes in topology, e.g. to confirm switch opening or closing.
  - *G Cavraro, R Arghandeh, G Barchi, A von Meier, K Poolla: Data-Driven Approach for Distribution Network Topology Detection, IEEE PES General Meeting, 2014.*
- Non-model based control of distributed resources: use phasor measurements for a robust indication of real and reactive power flows throughout the network
  - *Daniel B. Arnold, Matias Negrete-Pincetic, Emma M. Stewart, David M. Auslander, and Duncan S. Callaway. "Extremum Seeking Control of Smart Inverters for VAR Compensation." to appear in the 2015 Proceedings of the IEEE Power and Energy Society, Denver, CO*

Impact of Accuracy in DG Models and Related Barriers

Inaccurate distribution circuit models over- or underestimate DG impacts, resulting in

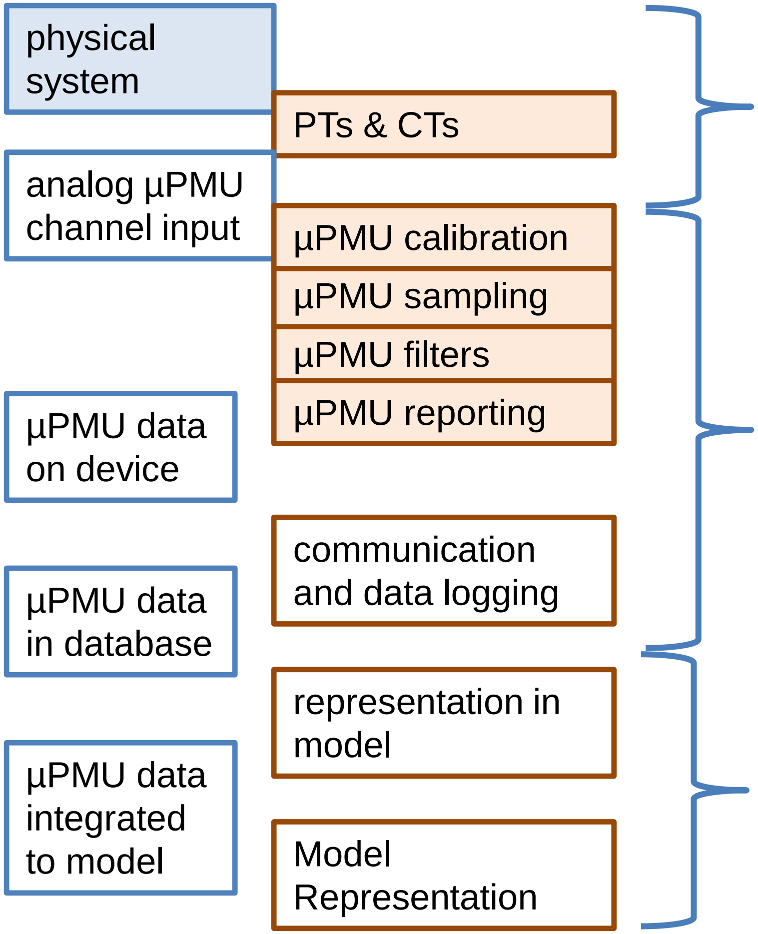
- Excessive cost to utilities and customers from unnecessary mitigation measures
  - *Example: modifications to protection systems, voltage regulation and power quality management to compensate for presumed impacts*
- Inhibited DG deployment
  - *Example: presumed feeder hosting capacity is reached*
- Compromised safety and power quality
  - *Example: DG presumed harmless actually results in voltage violations, reverse power flow and/or disruption of utility protection scheme*

From a planning analysis standpoint, there are three related barriers to the integration of renewables to the distribution grid:

- The lack of tools to adequately represent high penetration levels and advanced control strategies for distributed resources;
- The lack of accuracy and trustworthiness of models , often due to limited availability of data for their validation; and
- The limited accuracy of measured data sources in and of themselves, for control and validation purposes

Error Sources

Possible sources of signal and noise



physical system

PTs & CTs

analog µPMU channel input

µPMU calibration

µPMU sampling

µPMU filters

µPMU reporting

µPMU data on device

communication and data logging

µPMU data in database

representation in model

µPMU data integrated to model

Model Representation

Normal Accuracy for Relay and Instrumentation
0.3 Class PT
1.2 Class CT

High accuracy device and logging
1% TVE, 0.02 magnitude

0.5% magnitude error

Expected data requirements for key applications

	Sampling Rate (per cycle)	**Angle Resolution (milli-deg)**	**Spatial Resolution (placement)**	**Data Volume (bandwidth)**	**Communication Speed**
Topology/Connectivity	1	50-300	Sparse but selective	Low	Low for validation, high for security
Steady State Circuit Behavior (e.g. voltage profile)	1-2	10-300	Sparse	Medium but continuous	Typically low but depends on application
Dynamic Circuit Behavior (e.g faults and motor starting)	2-512	10-50	Dense	High but intermittent (triggered on event)	Typically but depends on application

Expected Outcomes

- ARPA-E project completion – April 2016
- CEDS – just started
- Demonstrate empirical µPMU data provide useful, actionable intelligence about the distribution system
- Exercise topology detection and state estimation algorithms with field data, evaluate performance
- Integrate C37.118 µPMU data stream with OSIsoft PI server, compatible with existing tools, and commonly used at utilities
- 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

Conclusions

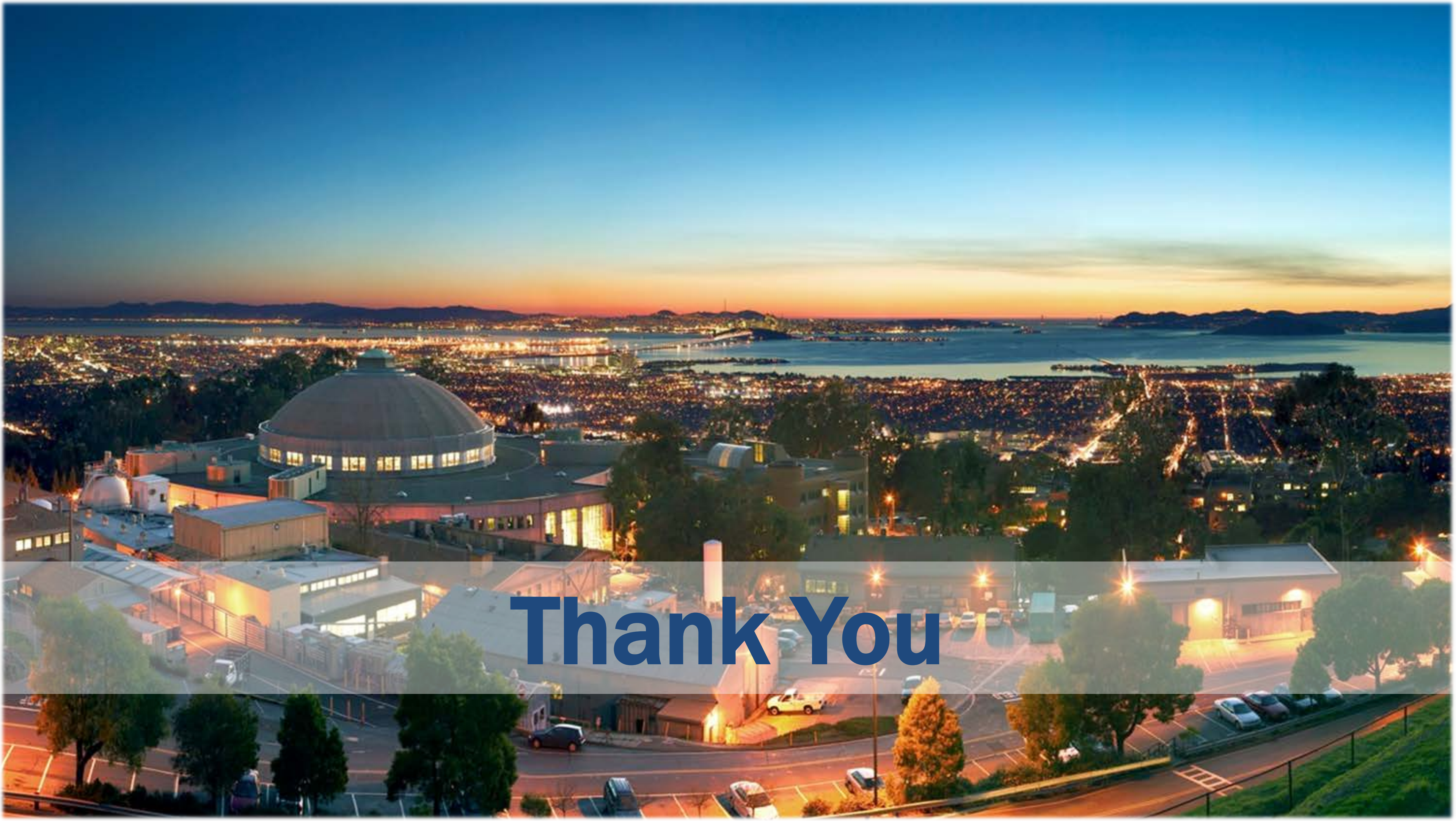
Distribution synchrophasors are an idea that is resonating well throughout research community and industry, esp. in California

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



Thank You

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