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Toward Micro-synchrophasors (µPMUs) for Distribution Networks

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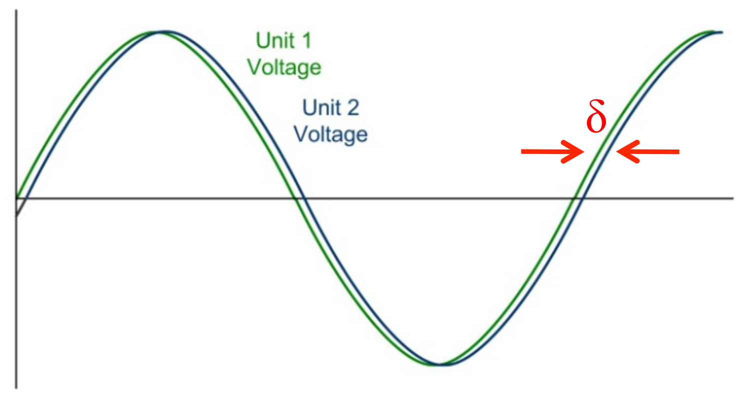
Micro-synchrophasors (µPMUs) for Distribution Networks Project

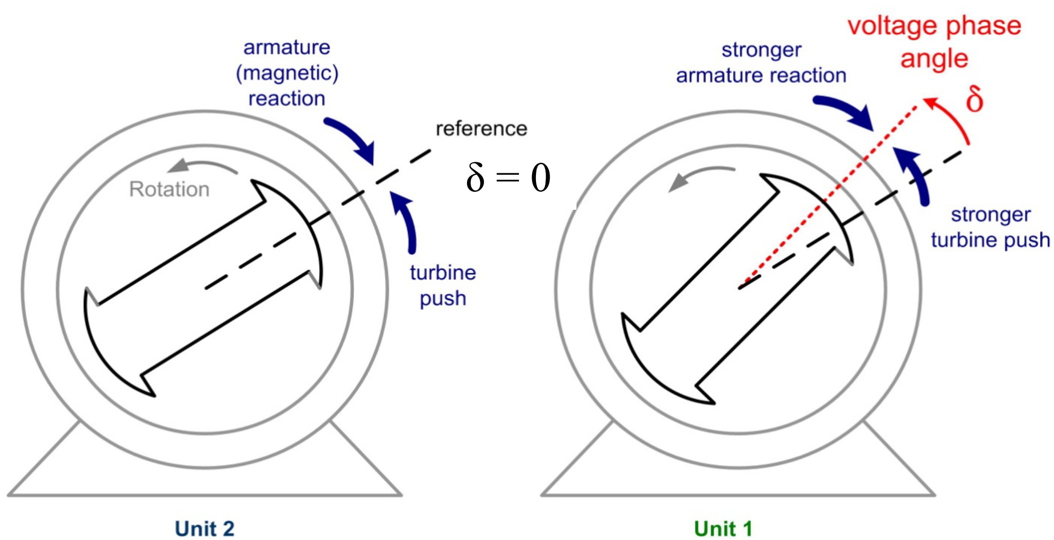
Research partners CIEE, UC Berkeley, LBNL, Power Standards Lab

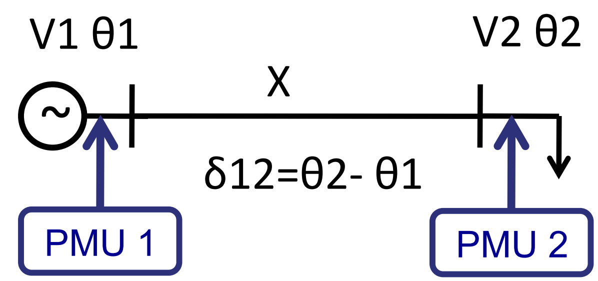
Why voltage phase angle ?



the small phase angle δ 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

Why measure Voltage magnitude and angle?

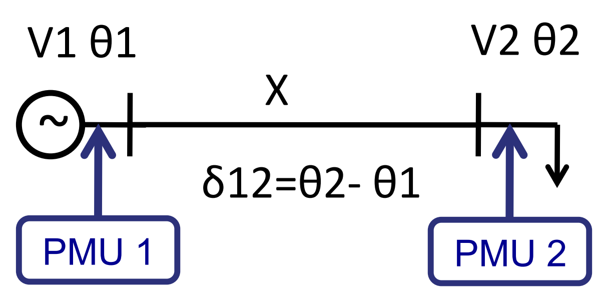
- Voltages are easier to measure than currents (PT vs. CT installation).
- By measuring change in voltage angle, we can get a proxy measurement for current flow and power flow.

We measure V1, V2 and δ12 with uPMU

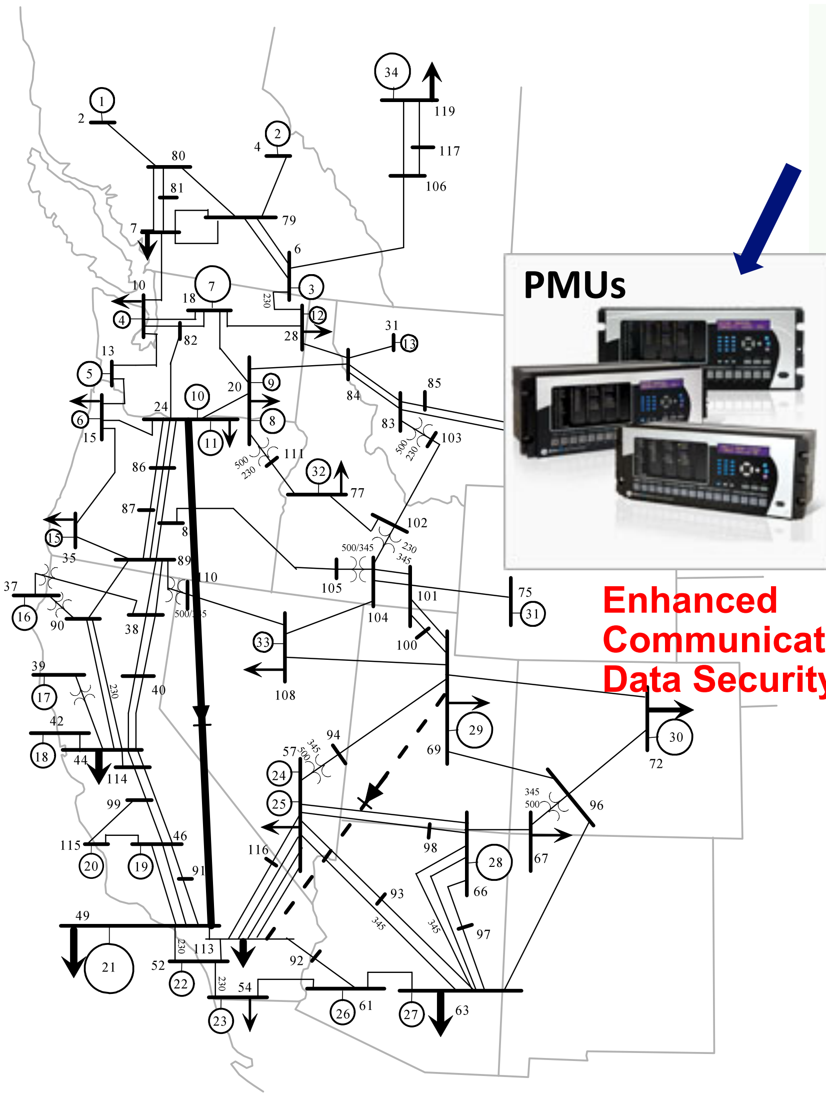
$$P \approx \frac{V_1 V_2}{X} \sin \delta_{12}$$

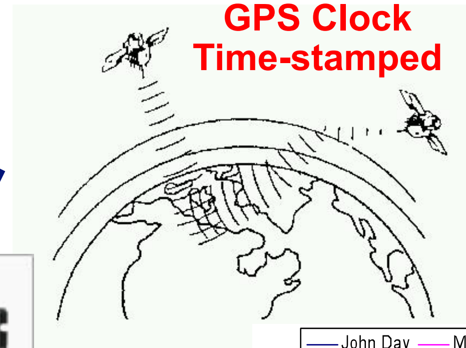
We calculate Power flow

We know X from distributing line physical construction

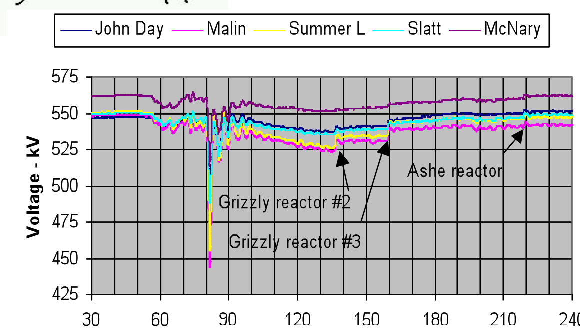


Synchrophasors (PMUs) in Transmission Networks

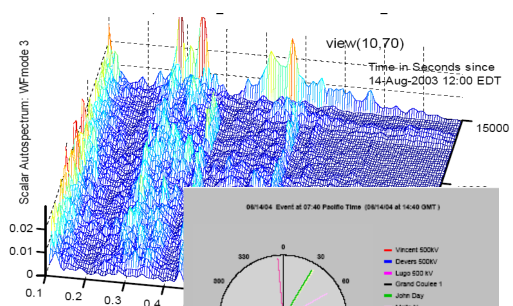


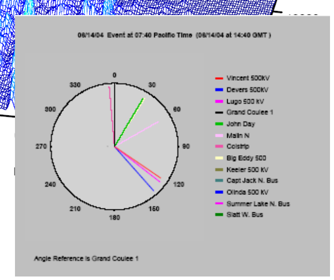


Enhanced Communications and Data Security



Synchronized Measurements





useful high quality and real-time information for system operators

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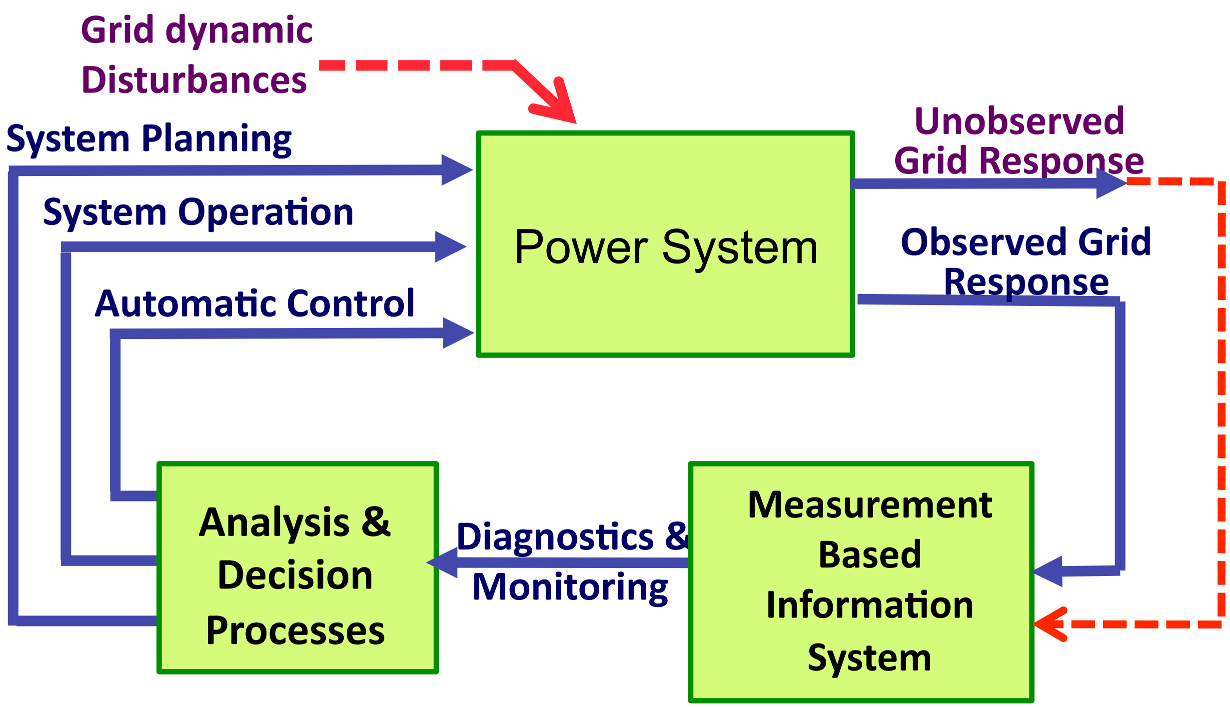
SCADA vs. PMU

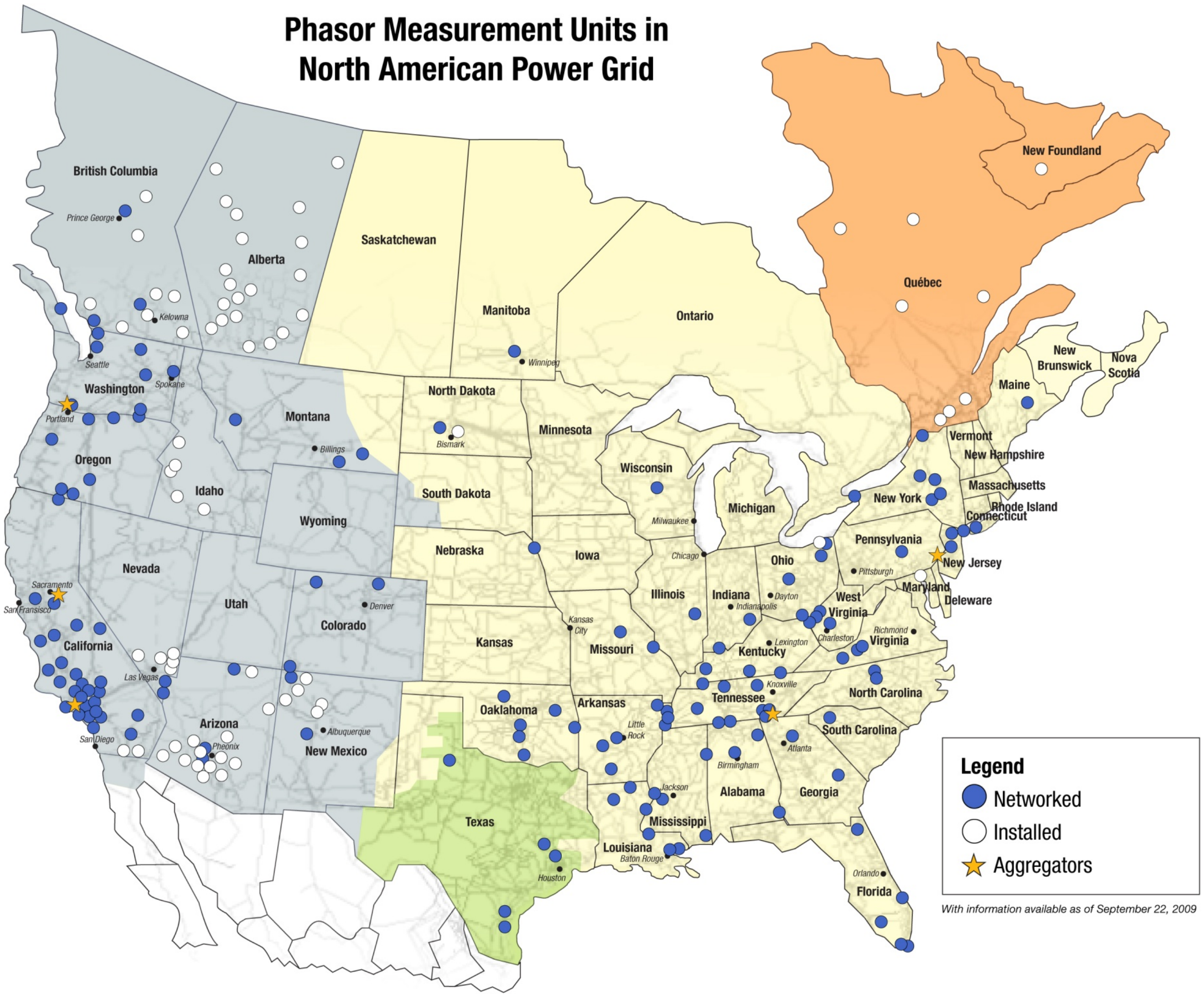
Traditional SCADA Real-Time Data Rate	4 seconds
PMU Real-Time Data Rate	30-60/second



- High Resolution
- Accuracy
- Time-Stamped Data
- Angle Measurements
- Over the Horizon Views

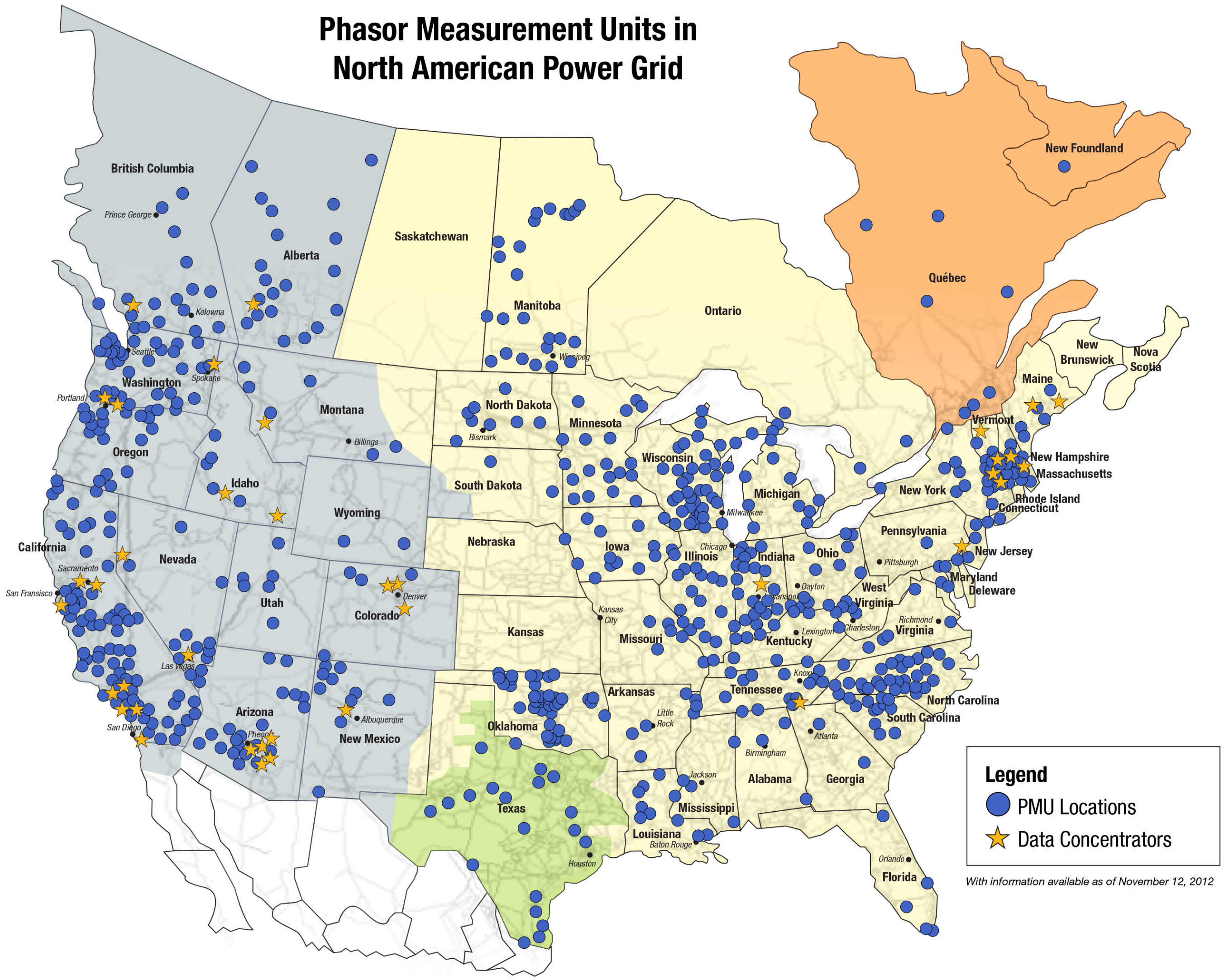
Synchrophasor wide-area real-time monitoring capabilities are beginning to show up in modern transmission control rooms around the world.

Transmission PMUs in North America



NASPI
2010

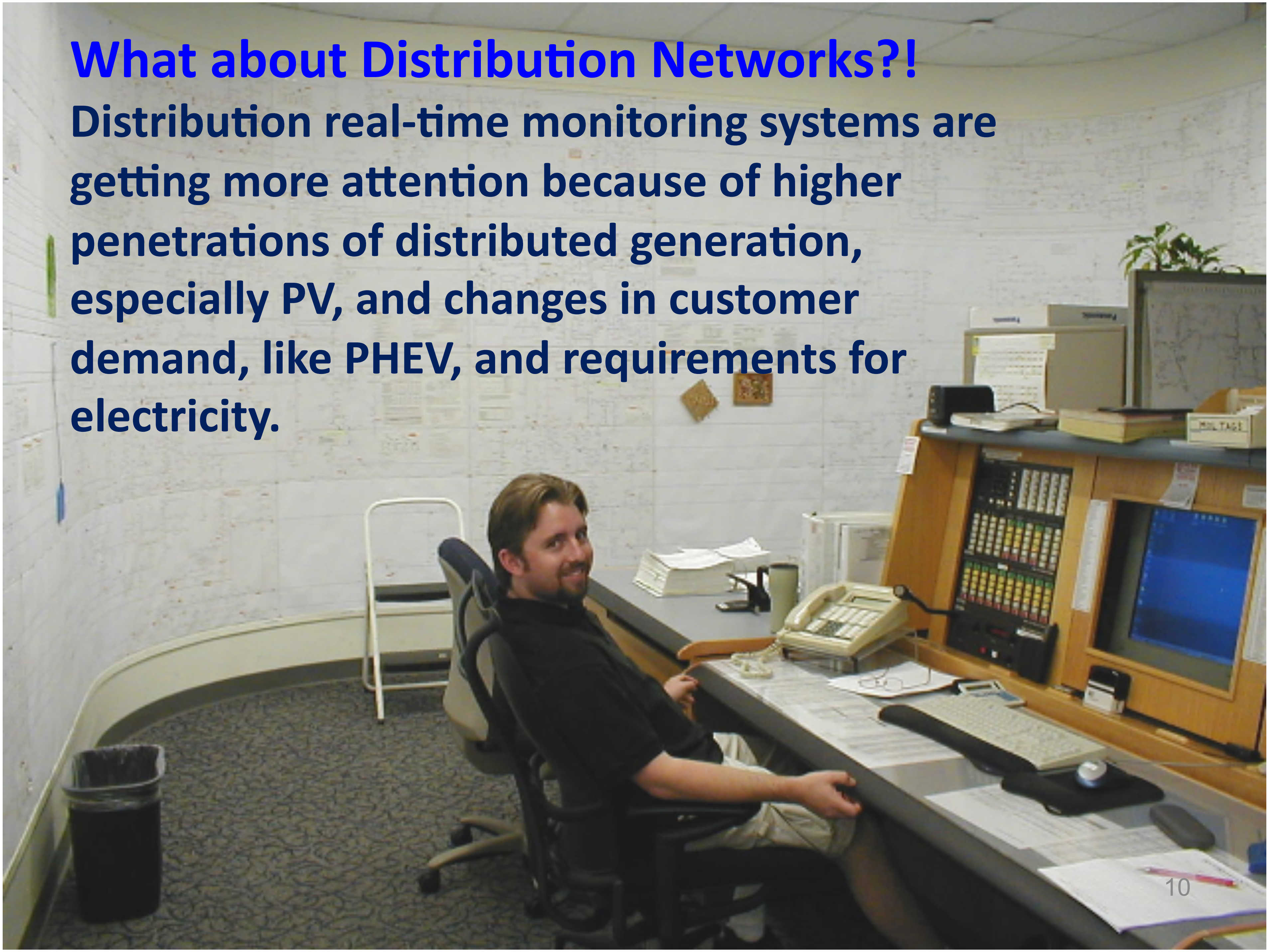
Transmission PMUs in North America



NASPI
2012

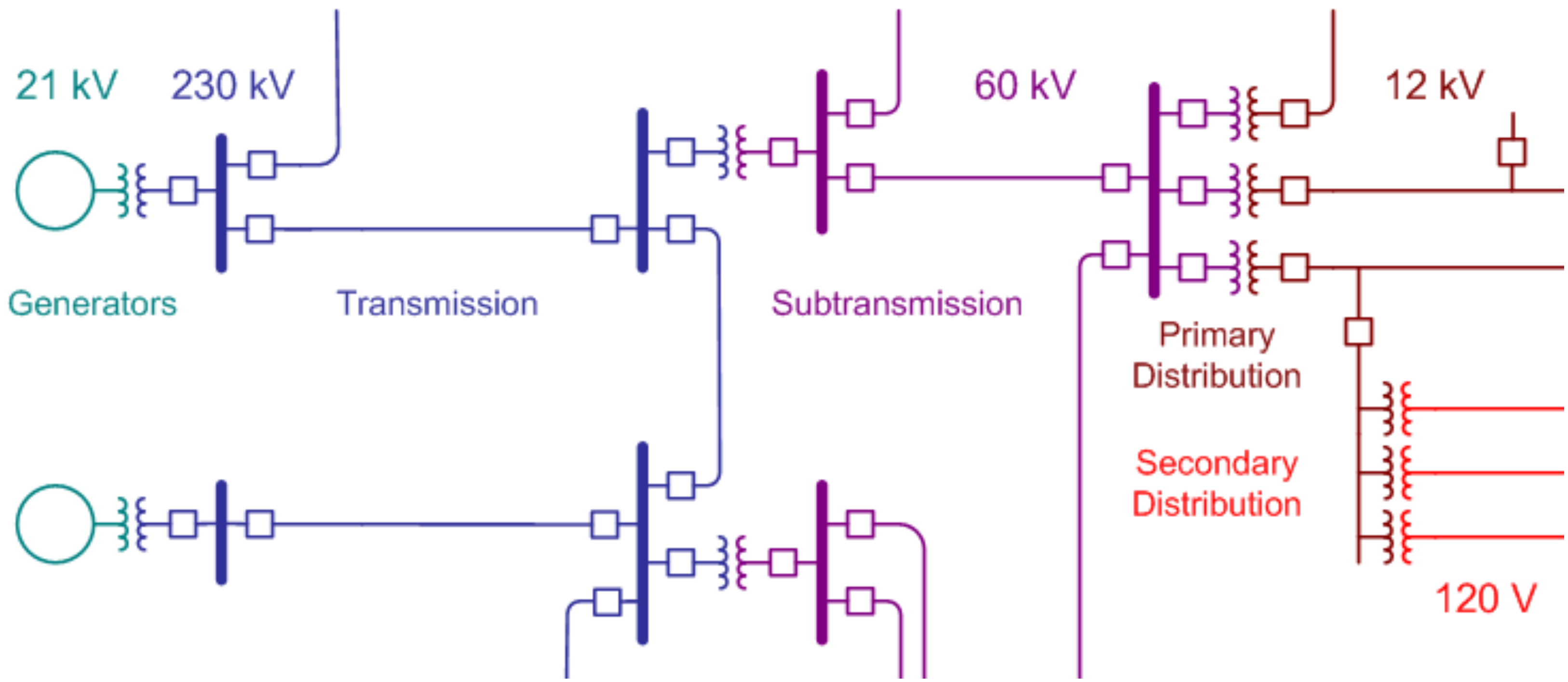
What about Distribution Networks?!

Distribution real-time monitoring systems are getting more attention because of higher penetrations of distributed generation, especially PV, and changes in customer demand, like PHEV, and requirements for electricity.



Distribution vs. transmission – important differences:

- mostly radial architecture
- unbalanced and asymmetrical
- diversity among circuits
- subject to more external influences
- less observability for operators



Why PMUs mostly on transmission, not distribution?

- 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

but this is changing…

What is the µPMU device (PSL product)?

- very low cost: piggy-back on existing distribution instrument, Pqube
- sync with power quality recordings
- local data storage on SD card as low-cost backup
- µPMU can connect to single- or 3-phase, secondary distribution, substation PT, or outlet!

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PSL

μPMU vs. PMU:

- higher resolution than conventional PMUs: aiming for 0.01° vs. PMU 1°
- 512 samples per cycle vs. PMU 1 sample per cycle
- phase-locked sampling for power quality measurements and time-based sampling for synchronized measurements

PSL

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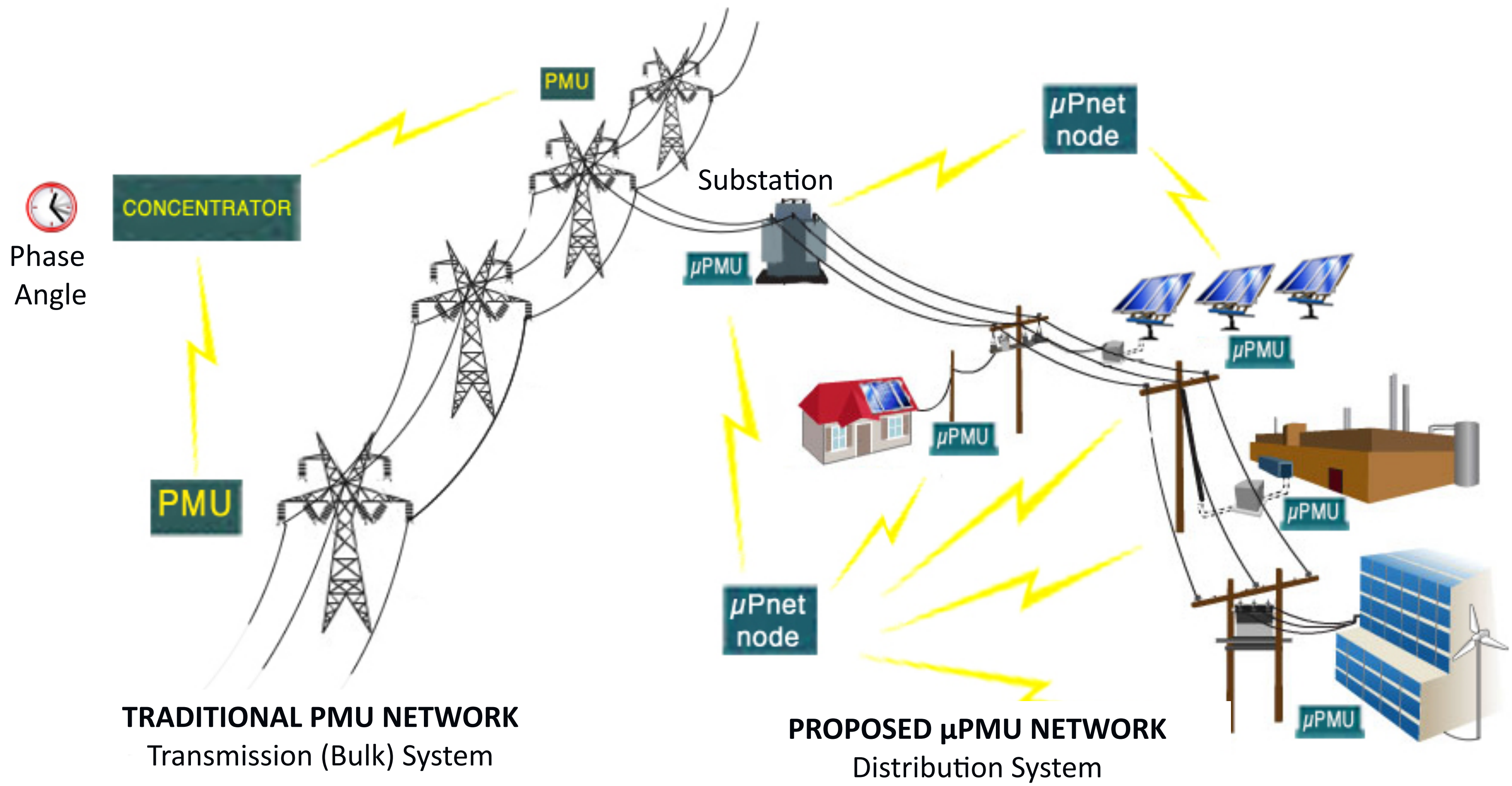
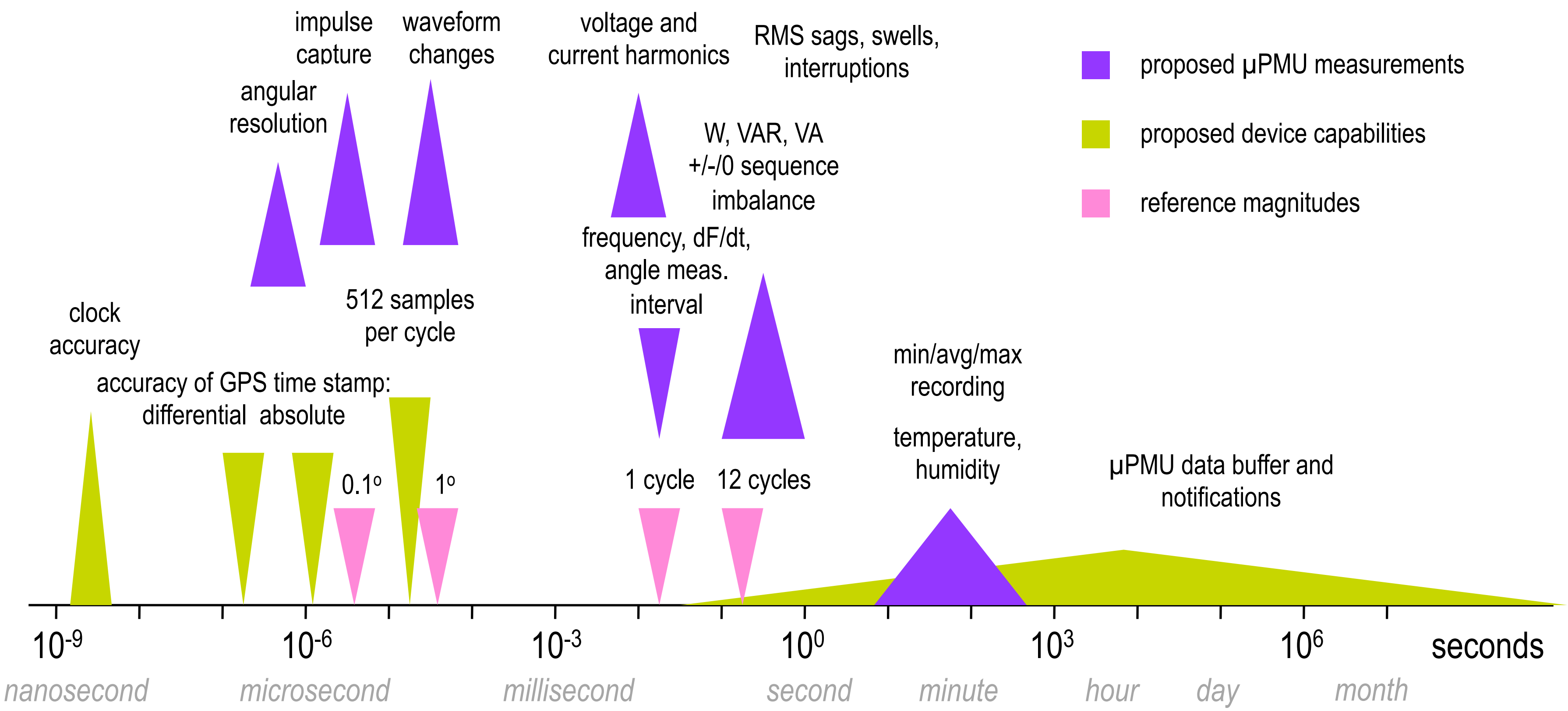
µPMU and µPnet concept



Time horizon for μPMU Applications



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PSL

Some interesting problems at the micro-scale

- Need to separate signal from noise

  Combine phase angle and frequency with info about disturbances, harmonics, lightning strikes…

- Need sampling rate consistent with frequency of phenomena to be observed

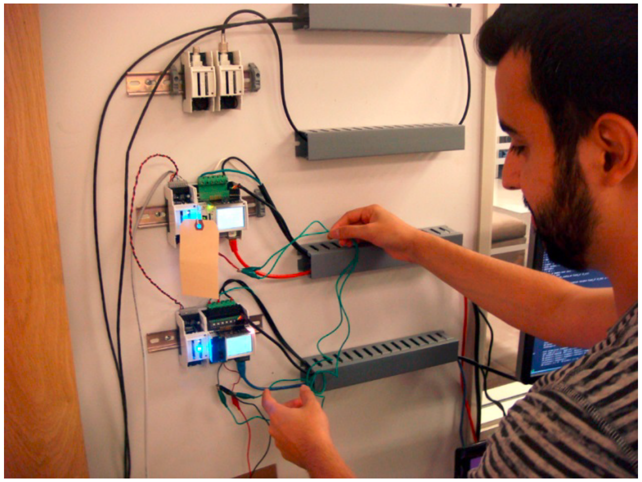
  Find angular sampling rate required to observe relevant behavior on the scale of inverter control loops (> 10 kHz)

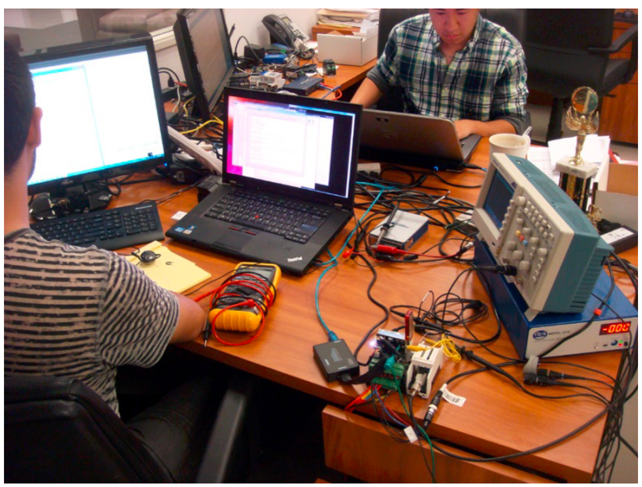
- How to define “frequency” and “phase angle” when signal < single cycle?

- Need to account for signal latencies everywhere

- What do you mean, “real time”?

Testing prototype µPMUs at PSL





ARPA-E Research Project Plan

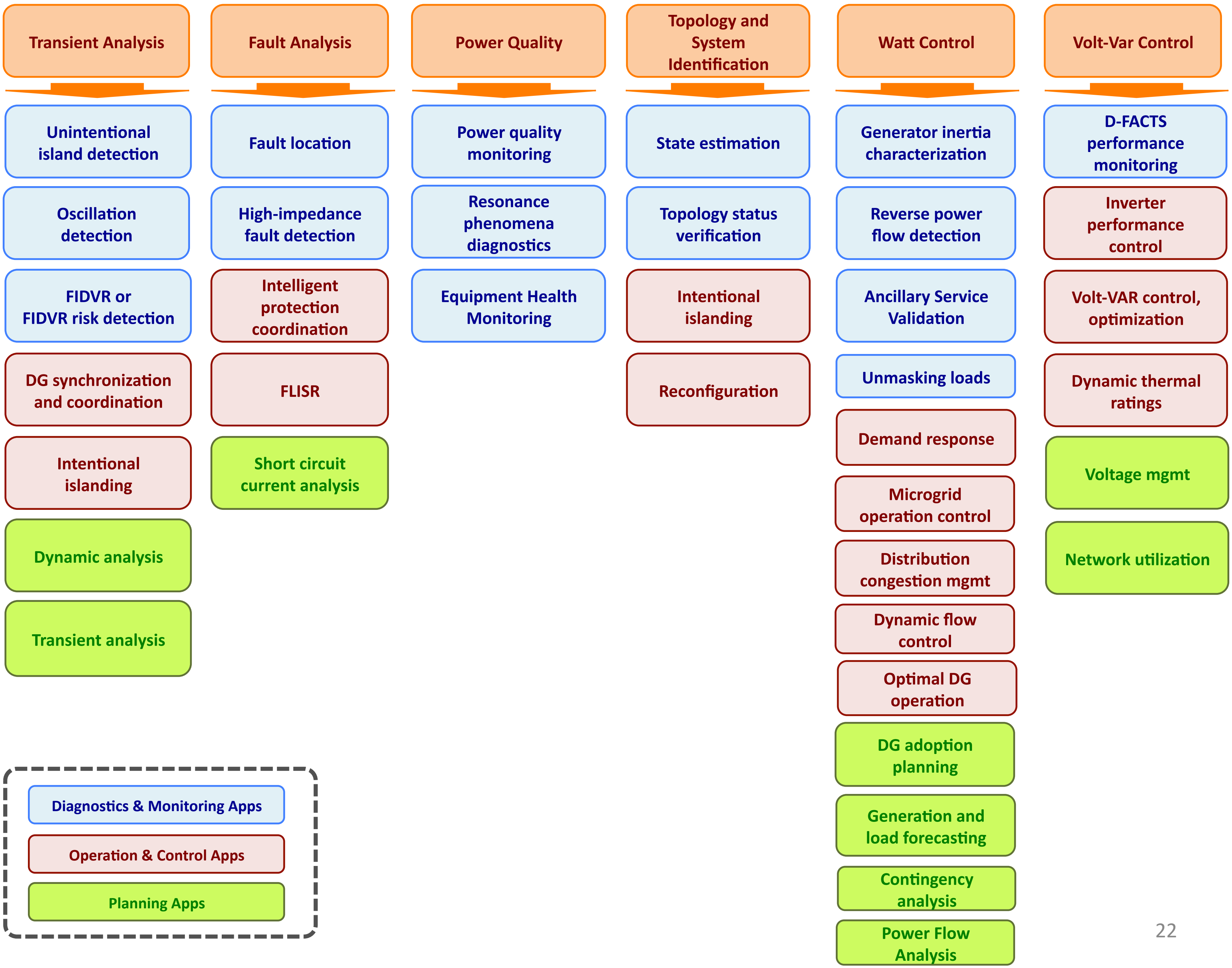
- Validate µPMU performance
- Develop µPnet: implement communications, data analysis based on sMAP (simple Measurement and Actuation Profile)
- Install µPMUs and µPnet at pilot site on UC Berkeley campus to make first empirical observations of voltage angle at very high resolution
- Collaborate with partner utilities to install µPMUs and µPnet on selected distribution feeders
- Study the promise of voltage angle as a state variable
- Examine diagnostic and control applications for µPMU data

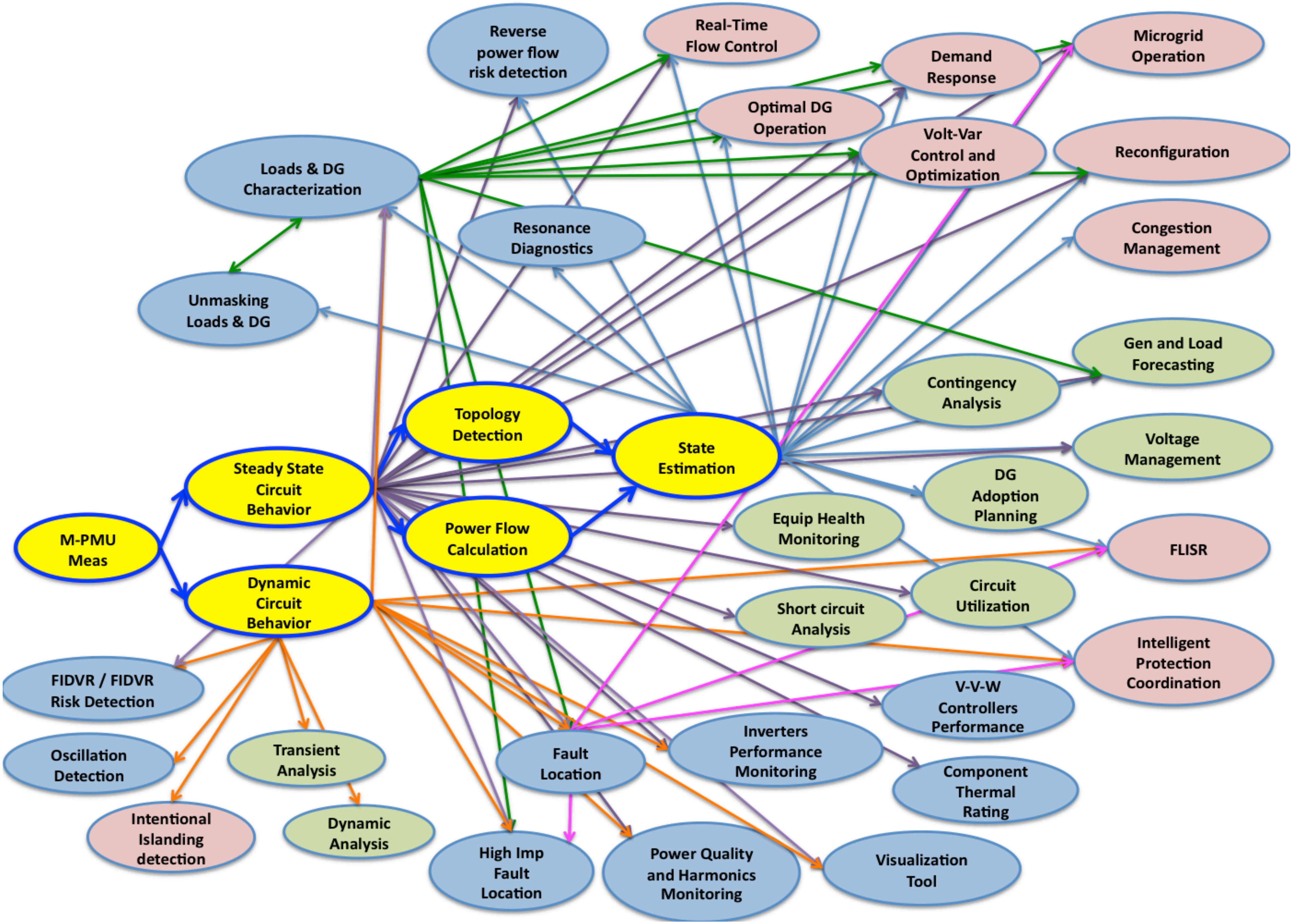
Possible diagnostic applications for µPMU data:

- unintentional island detection
- fault location
- high-impedance fault detection
- state estimation
- reverse power flow detection
- renewable generation monitoring
- oscillation detection
- characterization of DG Inertia

Possible control applications for µPMU data:

- protective relaying
- Volt-VAR optimization
- microgrid coordination
- seamless intentional islanding and re-synchronization of microgrids
- creative recruitment of distributed resources for ancillary services


Transient Analysis
Unintentional island detection
Oscillation detection
FIDVR or FIDVR risk detection
DG synchronization and coordination
Intentional islanding
Dynamic analysis
Transient analysis
Fault Analysis
Fault location
High-impedance fault detection
Intelligent protection coordination
FLISR
Short circuit current analysis
Power Quality
Power quality monitoring
Resonance phenomena diagnostics
Equipment Health Monitoring
Topology and System Identification
State estimation
Topology status verification
Intentional islanding
Reconfiguration
Watt Control
Generator inertia characterization
Reverse power flow detection
Ancillary Service Validation
Unmasking loads
Demand response
Microgrid operation control
Distribution congestion mgmt
Dynamic flow control
Optimal DG operation
DG adoption planning
Generation and load forecasting
Contingency analysis
Power Flow Analysis
Volt-Var Control
D-FACTS performance monitoring
Inverter performance control
Volt-VAR control, optimization
Dynamic thermal ratings
Voltage mgmt
Network utilization
Diagnostics & Monitoring Apps
Operation & Control Apps
Planning Apps

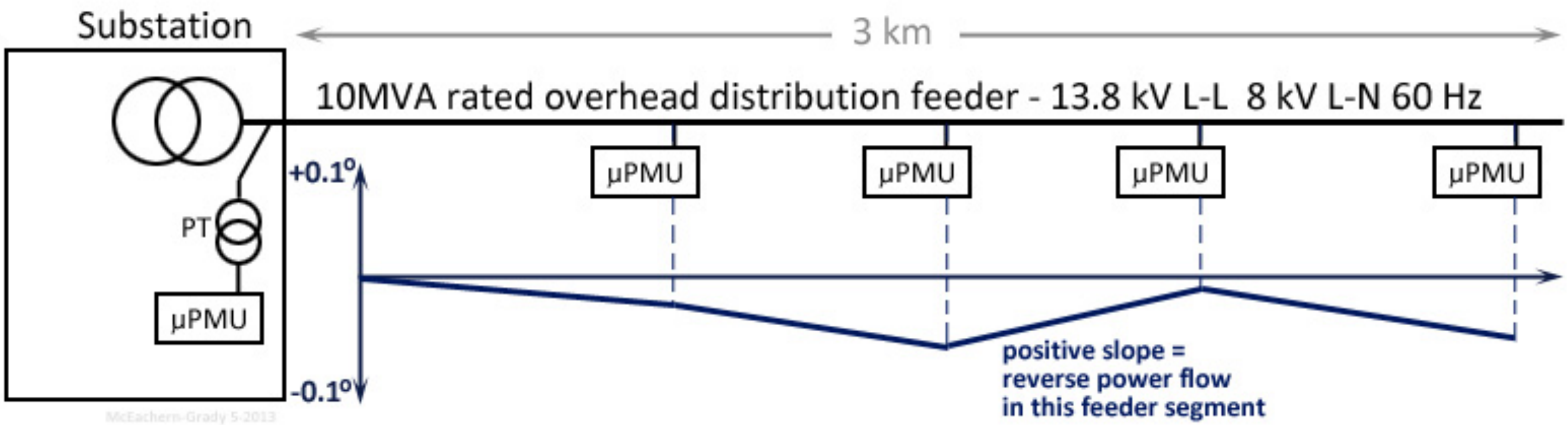


Reverse power flow risk detection
Real-Time Flow Control
Microgrid Operation
Demand Response
Optimal DG Operation
Volt-Var Control and Optimization
Reconfiguration
Loads & DG Characterization
Resonance Diagnostics
Congestion Management
Unmasking Loads & DG
Gen and Load Forecasting
Contingency Analysis
Topology Detection
State Estimation
Voltage Management
Steady State Circuit Behavior
DG Adoption Planning
M-PMU Meas
Power Flow Calculation
Equip Health Monitoring
FLISR
Dynamic Circuit Behavior
Circuit Utilization
Short circuit Analysis
Intelligent Protection Coordination
FIDVR / FIDVR Risk Detection
V-V-W Controllers Performance
Oscillation Detection
Transient Analysis
Fault Location
Inverters Performance Monitoring
Component Thermal Rating
Intentional Islanding detection
Dynamic Analysis
High Imp Fault Location
Power Quality and Harmonics Monitoring
Visualization Tool

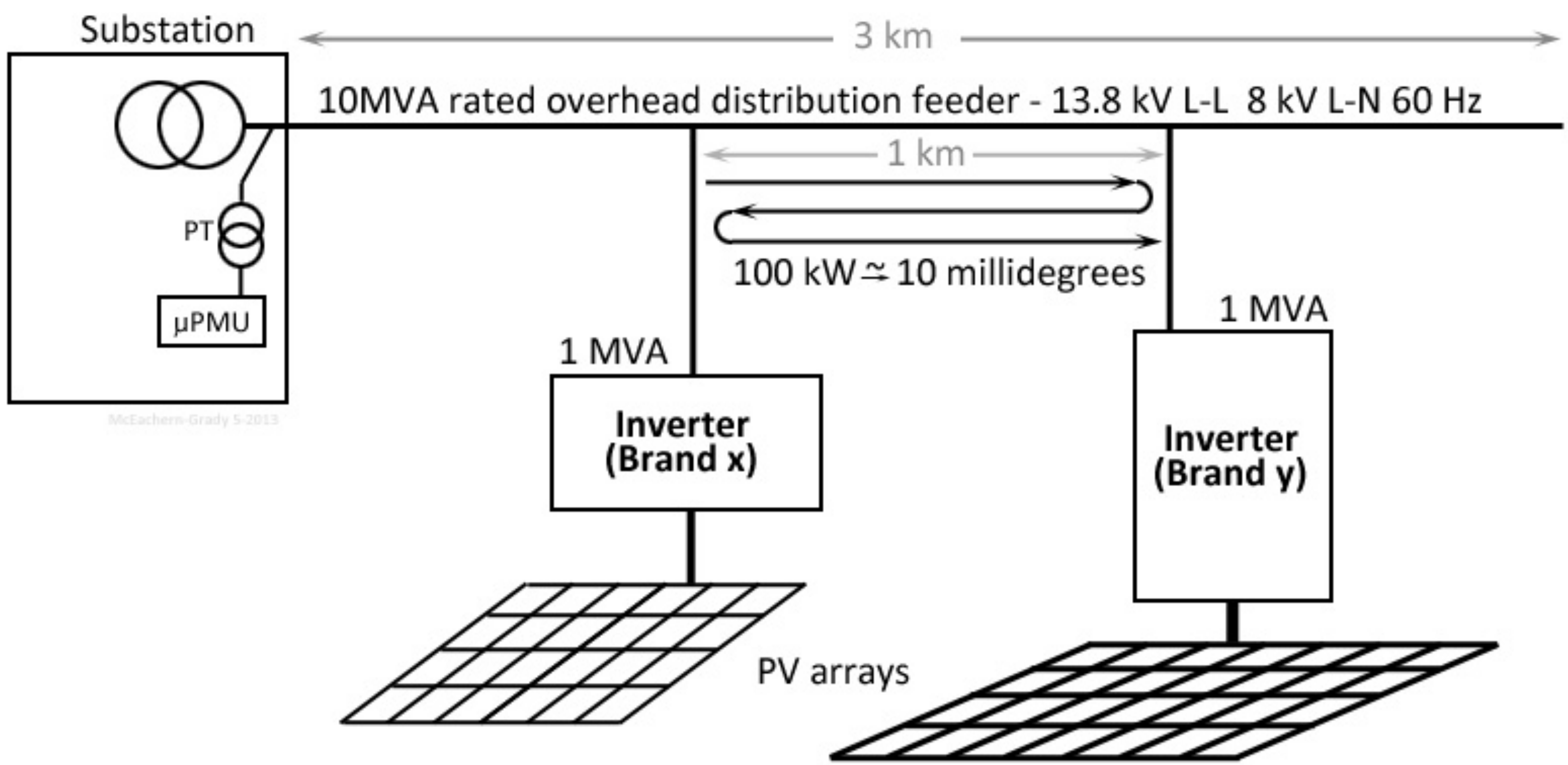
Data requirement for different class of μPMU appellations

	Sampling rate (per cycle)	Angle resolution (milli-deg)	Spatial Resolution (placement)	Data volume (Bandwidth)	Comm Speed
Steady-state circuit behavior	1-2	10-300	Sparse	Medium but continuous	usually low
Dynamic circuit behavior	2-512	10-50	Dense	High but could be intermittent	usually high

Sample Application: Detect Reverse Power Flow



Sample Application: Detect Oscillations

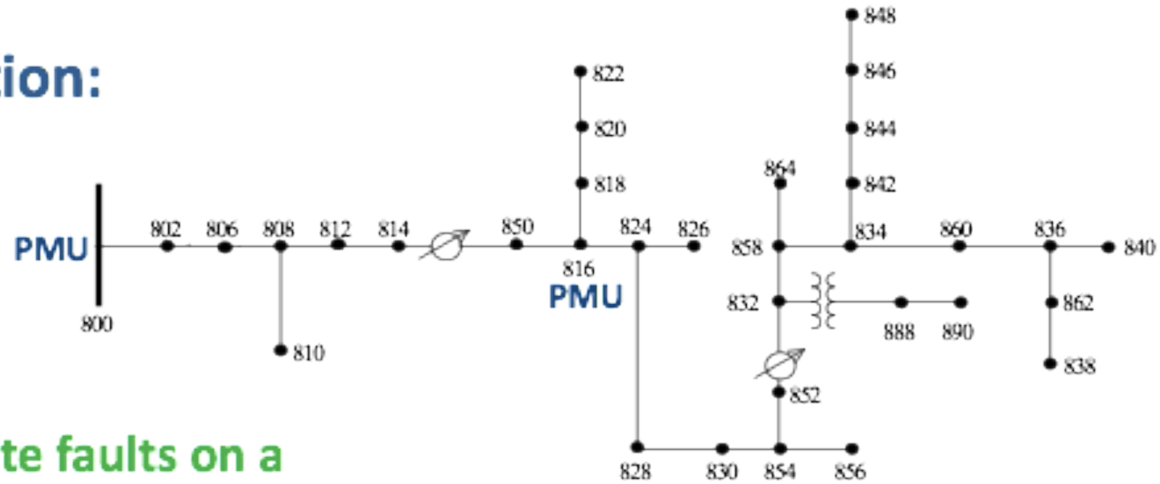


Sample Application:

Fault Location

Can angle help locate faults on a long feeder?

IEEE 34 Bus Test System

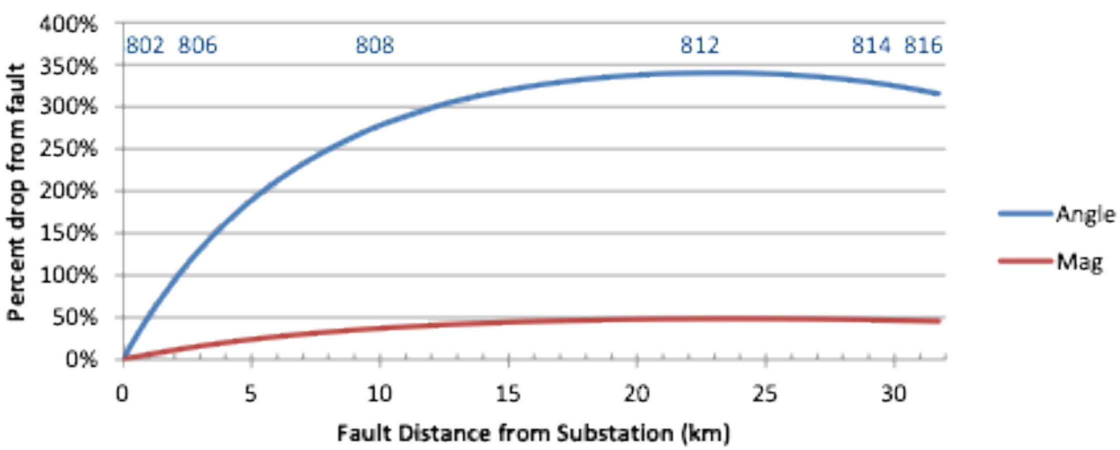


For a shunt fault, the change in angle is sensitive to the distance from the fault.

Angle appears to be much more sensitive than magnitude.

What determines the shapes of these curves exactly…? Loads and topology!

μPMU Reading at Node 816



Sample Application:

Unmasking load behind net metered DG

Benefits

- Identify exposure to fast DG ramps or loss of DG
- Facilitate forecasting of net load by understanding its composition

Traditional Obstacles

Separate physical measurements of DG and load are needed to reveal how much load is "masked" by generation behind the meter, but may be constrained by access and/or cost.

μPMU measurements *might* allow remote inference of load/DG cancellation behind meter by intelligently combining

- time series net load data

- insolation measurements taken inexpensively at μPMU

- power quality measurements (such as harmonic content and other signature characteristics of load and/or DG)

Conclusion:

Directly observing voltage phase angle should enable:

- better visibility and situational awareness for operators
- avoided outages and faster service restoration
- better understanding of unintended impacts of distributed energy resources (solar PV, electric vehicles)
- Adoption of distributed energy resources (DG, storage, demand response…) for grid services

For the first time, we will be able to actively *manage* distribution systems with a precise image…

Thank You!

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