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 $\delta$ 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.
**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.

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

- We measure \( V_1, V_2 \) and \( \delta_{12} \) with uPMU
- 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

GPS Clock Time-stamped

PMUs

GPS

John Day
Malin
Summer L
Slatt
McNary

Enhanced Communications and Data Security

useful high quality and real-time information for system operators

GPS Clock Time-stamped
SCADA vs. PMU

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

Grid dynamic Disturbances
System Planning
System Operation
Automatic Control

Analysis & Decision Processes

Power System

Measurement Based Information System

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
Transmission PMUs in North America

Phasor Measurement Units in North American Power Grid

Legend
- PMU Locations
- Data Concentrators

With information available as of November 12, 2012

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!
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
μPMU and μPnet concept

TRADITIONAL PMU NETWORK
Transmission (Bulk) System

PROPOSED μPMU NETWORK
Distribution System
Time horizon for μPMU Applications

- **Time horizon** for μPMU Applications
- **Accuracy of GPS time stamp:** differential/absolute
- **Angular resolution:** 0.1°/1°
- **512 samples per cycle**
- **Waveform changes**
- **Voltage and current harmonics**
- **RMS sags, swells, interruptions**
- **W, VAR, VA**
- **+/−/0 sequence imbalance**
- **Frequency, dF/dt, angle meas. interval**
- **Min/avg/max recording**
- **Temperature, humidity**
- **μPMU data buffer and notifications**

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

Power Quality
- Power quality monitoring
- Resonance phenomena diagnostics
- Equipment Health Monitoring
- Short circuit current analysis

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

Volt-Var Control
- D-FACTS performance monitoring
- Inverter performance control
- Volt-VAR control, optimization

Diagnostics & Monitoring Apps

Operation & Control Apps

Planning Apps

Power Flow Analysis

Contingency analysis

Generation and load forecasting

Optimal DG operation

DG adoption planning

Network utilization

Demand response

Microgrid operation control

Distribution congestion mgmt

Dynamic flow control
Data requirement for different class of \( \mu \)PMU appellations

<table>
<thead>
<tr>
<th></th>
<th>Sampling rate (per cycle)</th>
<th>Angle resolution (milli-deg)</th>
<th>Spatial Resolution (placement)</th>
<th>Data volume (Bandwidth)</th>
<th>Comm Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady-state circuit behavior</td>
<td>1-2</td>
<td>10-300</td>
<td>Sparse</td>
<td>Medium but continuous</td>
<td>usually low</td>
</tr>
<tr>
<td>Dynamic circuit behavior</td>
<td>2-512</td>
<td>10-50</td>
<td>Dense</td>
<td>High but could be intermittent</td>
<td>usually high</td>
</tr>
</tbody>
</table>
Sample Application: Detect Reverse Power Flow
Sample Application: Detect Oscillations

Substation

10MVA rated overhead distribution feeder - 13.8 kV L-L 8 kV L-N 60 Hz

PT

µPMU

3 km

1 km

100 kW ~ 10 millidegrees

1 MVA

Inverter (Brand x)

1 MVA

Inverter (Brand y)

PV arrays
Sample Application: Fault Location

Can angle help locate faults on a long feeder?

IEEE 34 Bus Test System

μPMU Reading at Node 816

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!
**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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