Phasor-Based Control for Scalable Photovoltaic Integration

ENERGISE Kickoff Meeting
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Project Team

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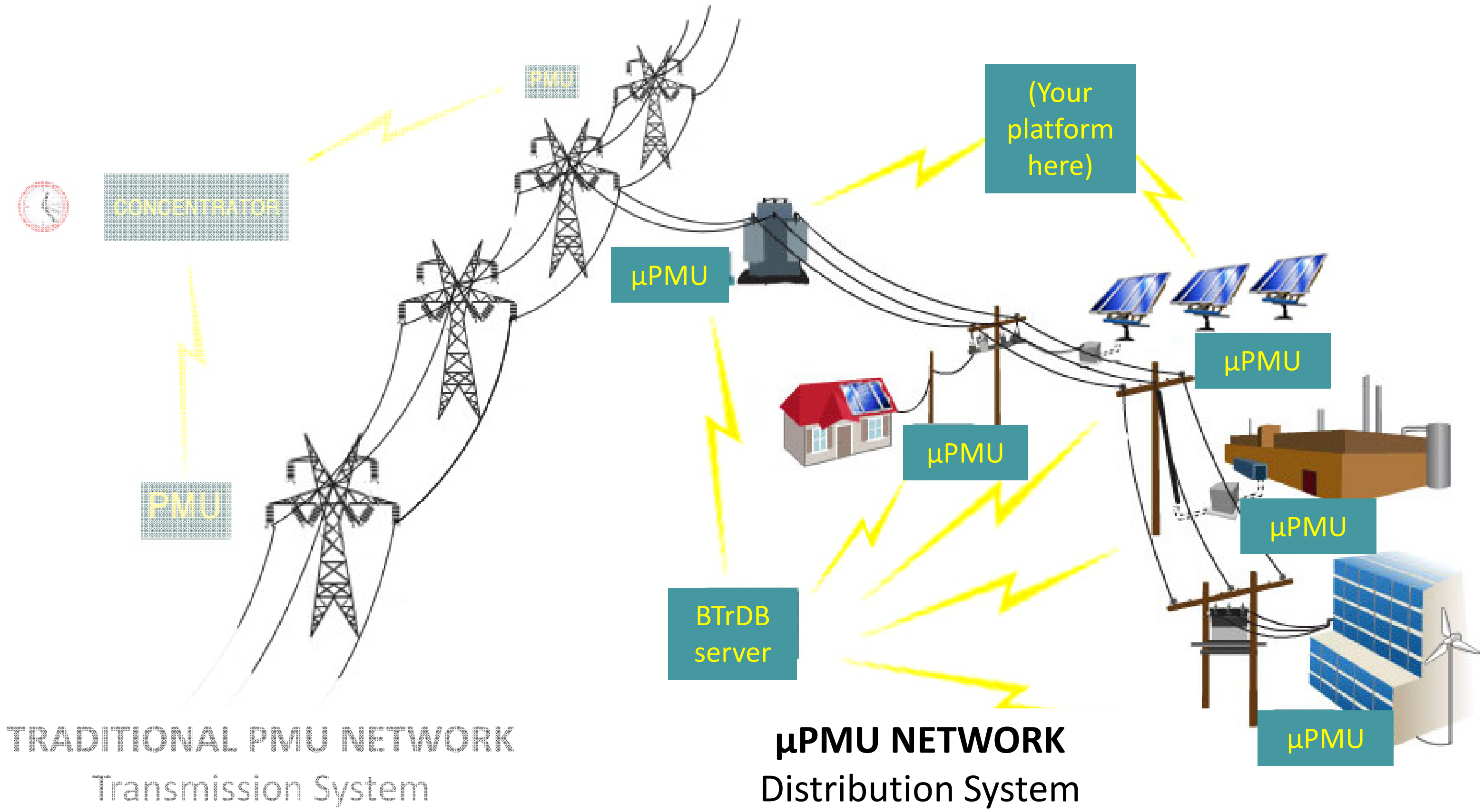
Project Goal

This project's goal is to develop a Phasor-Based Control (PBC) framework for grid resources that

- can manage arbitrarily high penetrations of variable DER
- is agnostic to devices, controllers, optimization criteria
- is completely scalable at both local and supervisory layers
- will meet or exceed all performance targets of ENERGISE FOA.

Distribution phasor measurement (micro-synchrophasor) infrastructure our team has already built and tested



Power Standards Lab micro-PMU

developed through ARPA-E funded project DE-AR 0000340

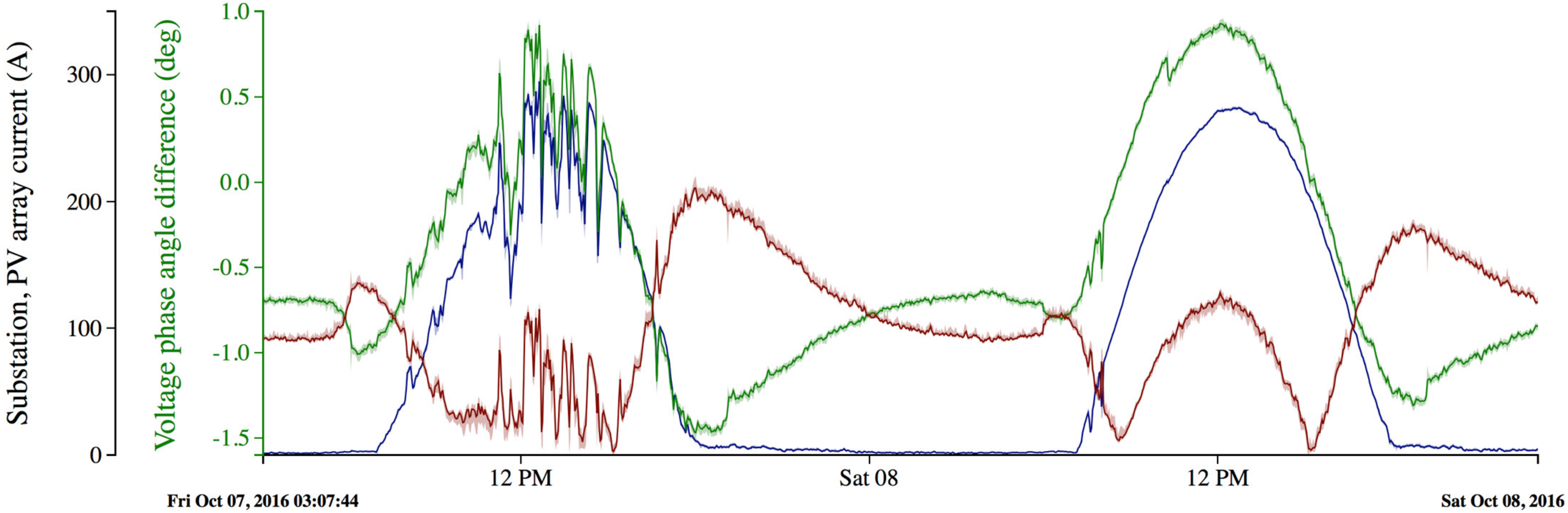


Illustration of PV current, substation current,
voltage phase angle difference
for a large PV array in Southern California

μPMU measurements viewed on Berkeley Tree Database (BTrDB) Multi-resolution Plotter

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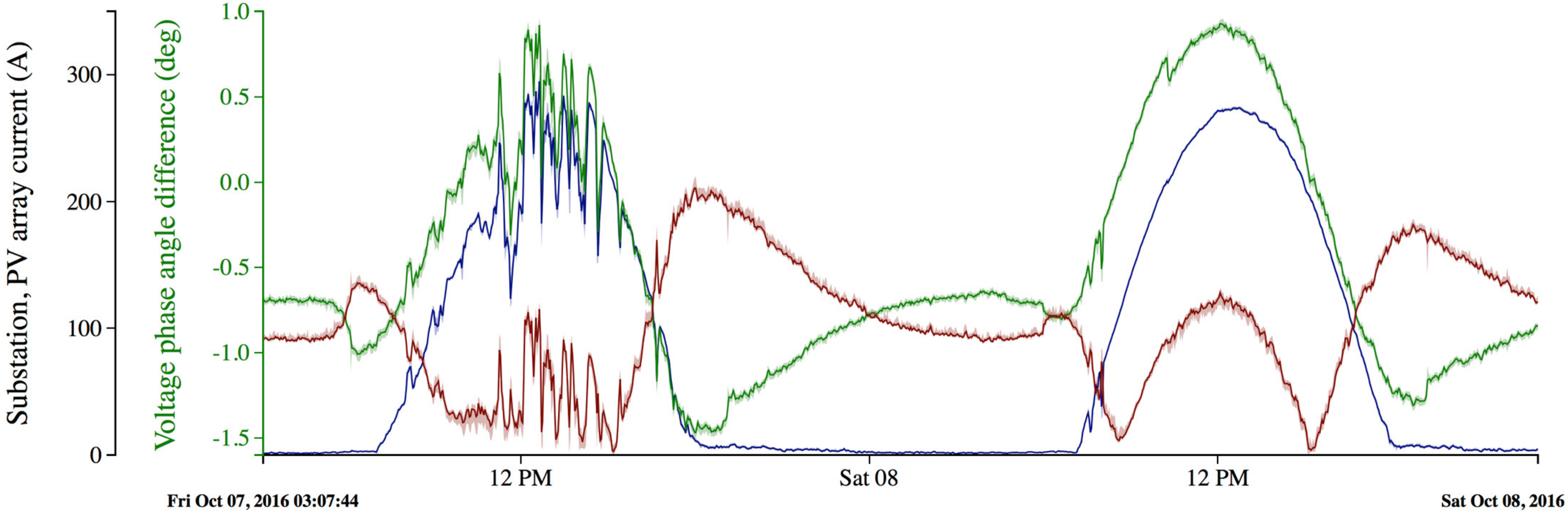

$$P \approx \frac{V_1 V_2}{X} \sin \delta_{12}$$

Conventional approximation in transmission context where X >> R relating real power flow to phase angle difference

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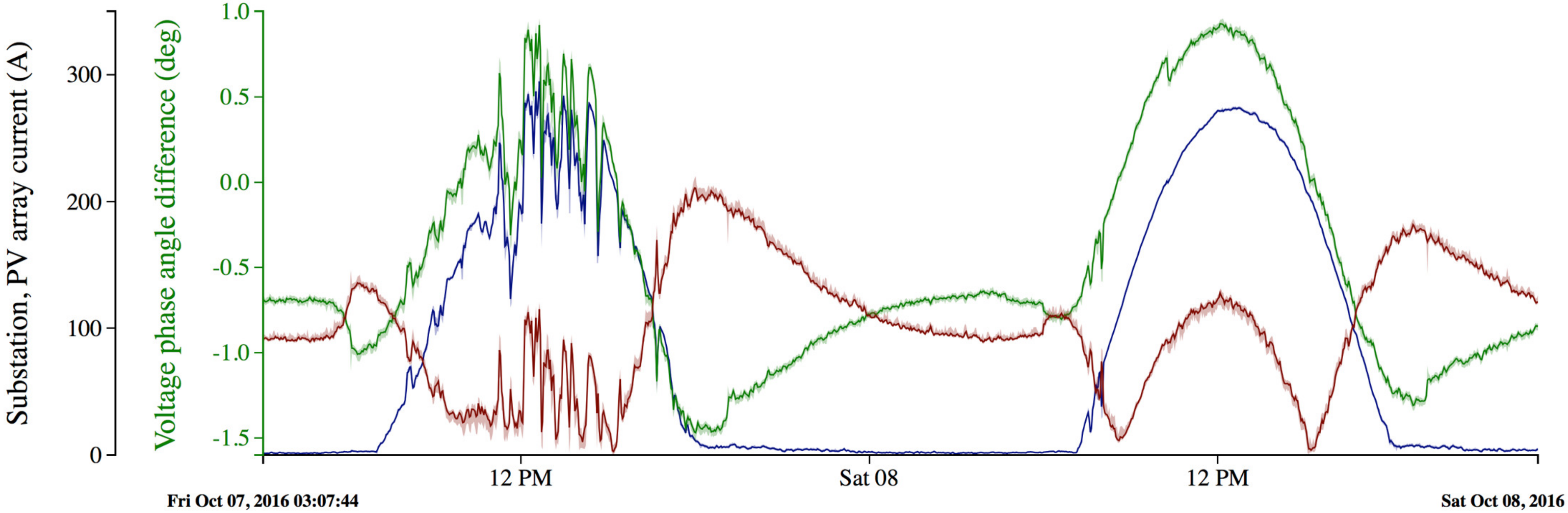
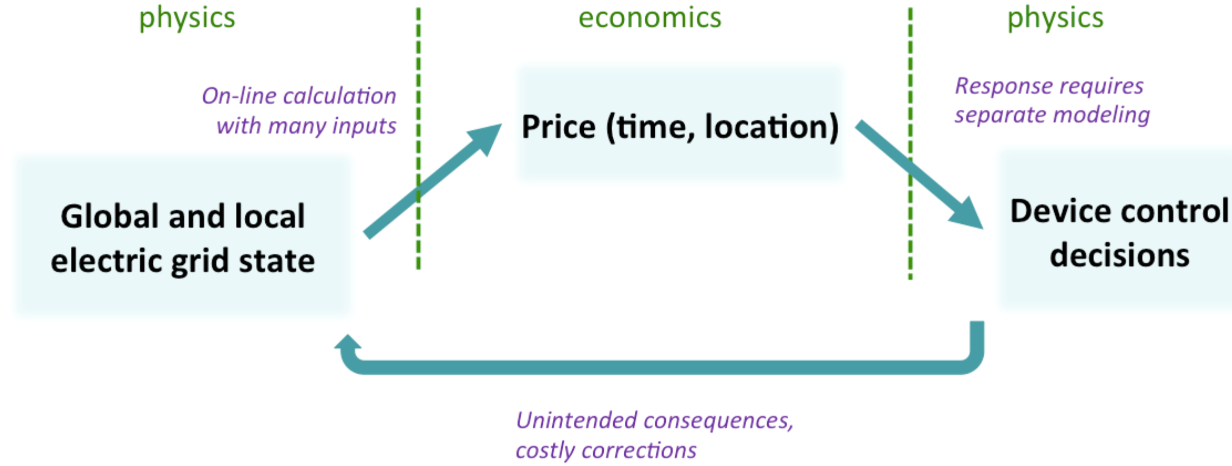


$$|V_{k-1}|^2 - |V_k|^2 \approx 2(R_k P_k + X_k Q_k)$$

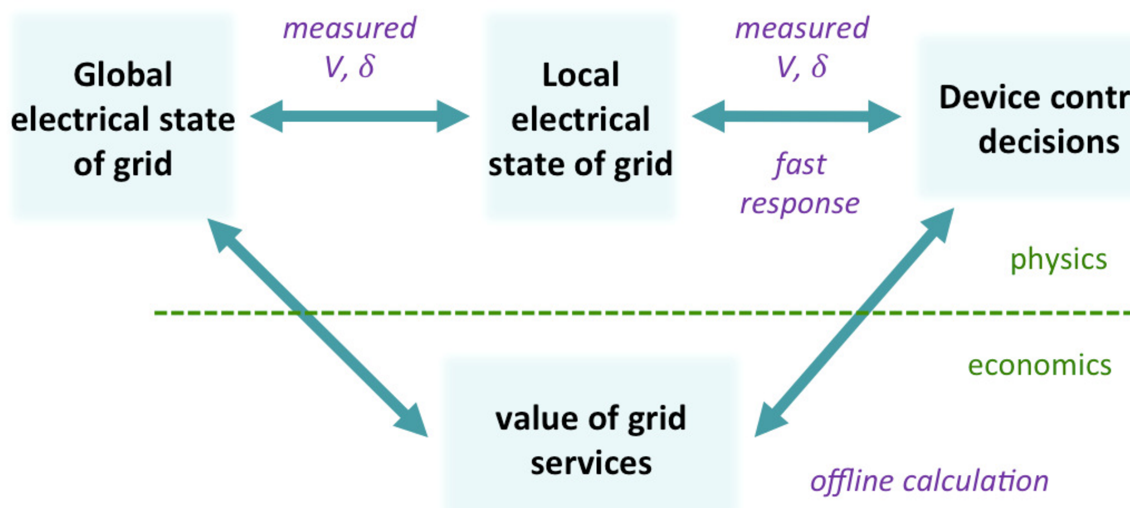
$$\delta_{k-1} - \delta_k \approx \frac{X_k P_k - R_k Q_k}{|V_k||V_{k-1}|}$$

Approximations derived from DistFlow equations for radial feeders by Dan Arnold, Roel Dobbe and Michael Sankur, UCB

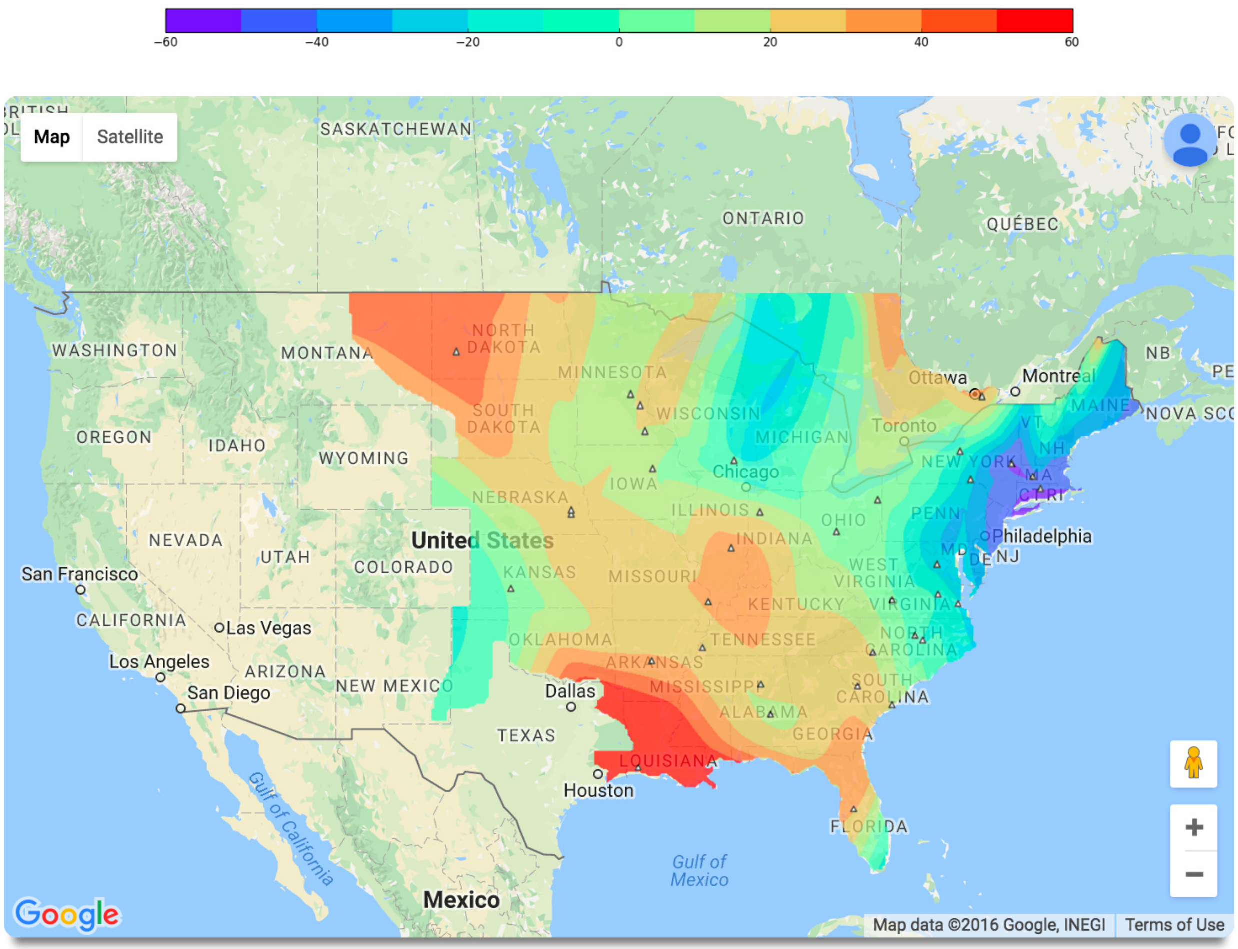
Conventional control paradigm



Phasor-Based Control



PBC in Context

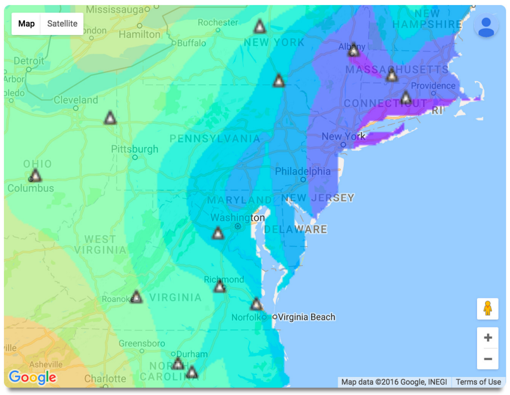


Visualization of voltage phase angle contours across the transmission grid

“Heat map” indicates system stress: power flows *and* network impedances

live map by University of Tennessee, Knoxville: fnetpublic.utk.edu

PBC in Context



Transmission system operators already think about power flow in terms of phasor profiles.

Distribution systems are becoming more like transmission networks.

We already control resources directly based on physical grid state, where feasible to date:

- *frequency droop control*
- *volt/VAR control (reactive power optimization)*

But we don't yet control based on phase angle because:

- *historically, there was no way to measure phasors directly*
- *energy value has dominated over capacity and stability constraints, so grid participants think of grid services in terms of kWh*

Work Plan: High-level summary by project year

Year 1

- validate PBC as a practical method for controlling multiple resources on a single distribution feeder
- design subsequent test cases

Year 2

- demonstrate scalability of PBC by extending simulation scenarios to increasing number of nodes on multiple interconnected distribution feeders
- develop S-PBC algorithms
- implement L-PBC on actual controller

Year 3

- test performance of physical devices in the control loop at FLEXLAB
- simulate PBC impacts on large network
- disseminate results
- commercialize local controller

Work in Progress as of October 2017

Defining Test Cases
Workshop held 19 Sept 2017 with 18 team members to gather requirements for PBC test cases.

PBC Objectives & Strategy Document
First draft is being prepared based on four distribution feeder test cases for supervisory control.

Build Test Models
Starting with the IEEE 13 node model, we are identifying modifications in the Opal-RT and GridLAB-D implementations. Looking to incorporate solar PV and battery storage into the IEEE 13 node models on both platforms.

Cybersecurity and Interoperability Plans
In progress, system architecture drafted.

Define L-PBC
Identified battery operating parameters and constraints, with preliminary simulation underway for local PBC.

Compatibility Assurance
Investigating L-PBC algorithm requirements and compatibility with Opal-RT and the DG:IC platform capabilities.

FLEXLAB

Four exterior testbeds in front of Building 90

- Provide space for HIL testing with easily accessible power, teledata, and data acquisition infrastructure
- Leverage existing µPMU sensor infrastructure on LBNL campus

https://flexlab.lbl.gov/

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FLEXLAB

Risks and Mitigation:
General risks for DER optimization

Risk: Inadequate distribution system model information

Mitigation by PBC:

- *adaptive control to accommodate unknowns*
- *high-precision µPMU sensing increases network observability*

Risk: Loss of communications; Cyber-attacks

Mitigation by PBC:

- *minimal number of communication points*
- *safe and stable local control in absence of supervisory updates*

Specific Risks and Mitigation

Risk: μPMU accuracy compromised by transducer errors
Mitigation: *online transducer calibration*

Risk: Cost of sensor infrastructure, since required number and optimal locations of μPMUs is still unknown
Mitigation:
- *reduce installation cost by allowing secondary-side sensor nodes*
- *theoretically investigate optimal and minimal placement strategies*

Risk: Robustness of linearized, approximate OPF
Mitigation: *assess limitations of OPF algorithm early and systematically*

Risk: Complexity of adaptation with multiple controllers under system changes
Mitigation: *Simulation-based studies of controller priorities*

Risk: Controlled phasor partitioning for large systems is a completely new concept and may be prone to error propagation
Mitigation: *techniques for minimizing errors from numerical integration*