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Phasor Measurement Units (PMU) and Wide Area Monitoring Systems (WAMS)

October 9, 2024

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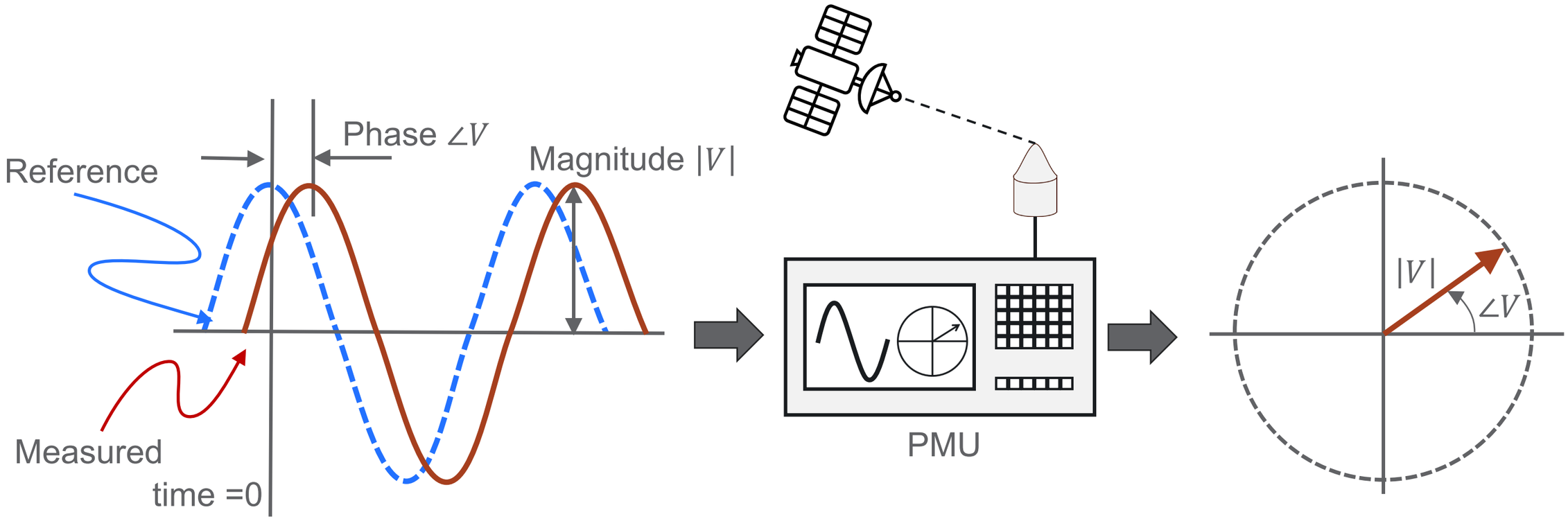
U.S. DEPARTMENT OF ENERGY BATTELLE

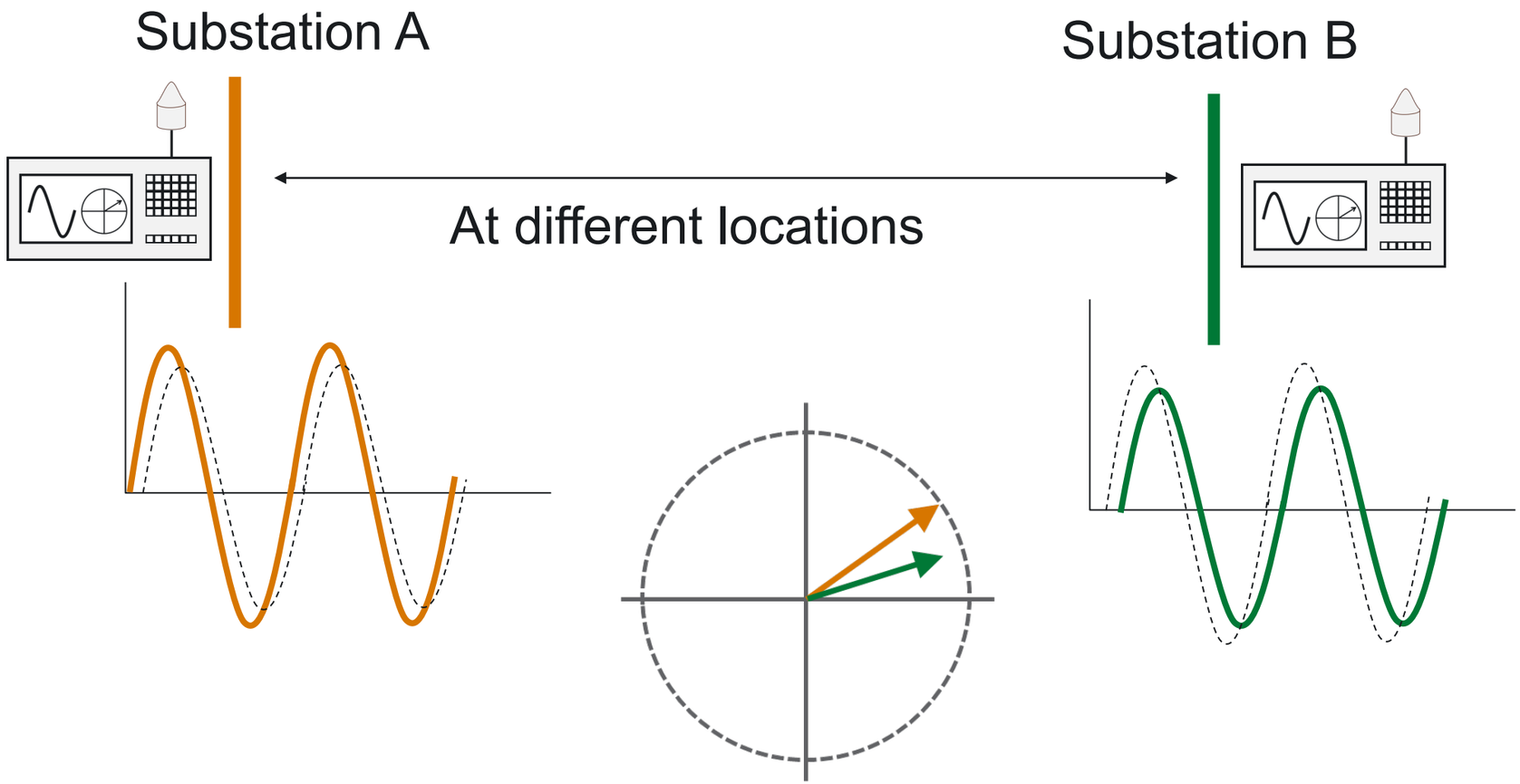
PNNL is operated by Battelle for the U.S. Department of Energy

What is a Phasor Measurement Unit (PMU)?

A device that produces *synchrophasors*: synchronized measurements of voltage and current phasors (magnitude and phase) based on a common time source



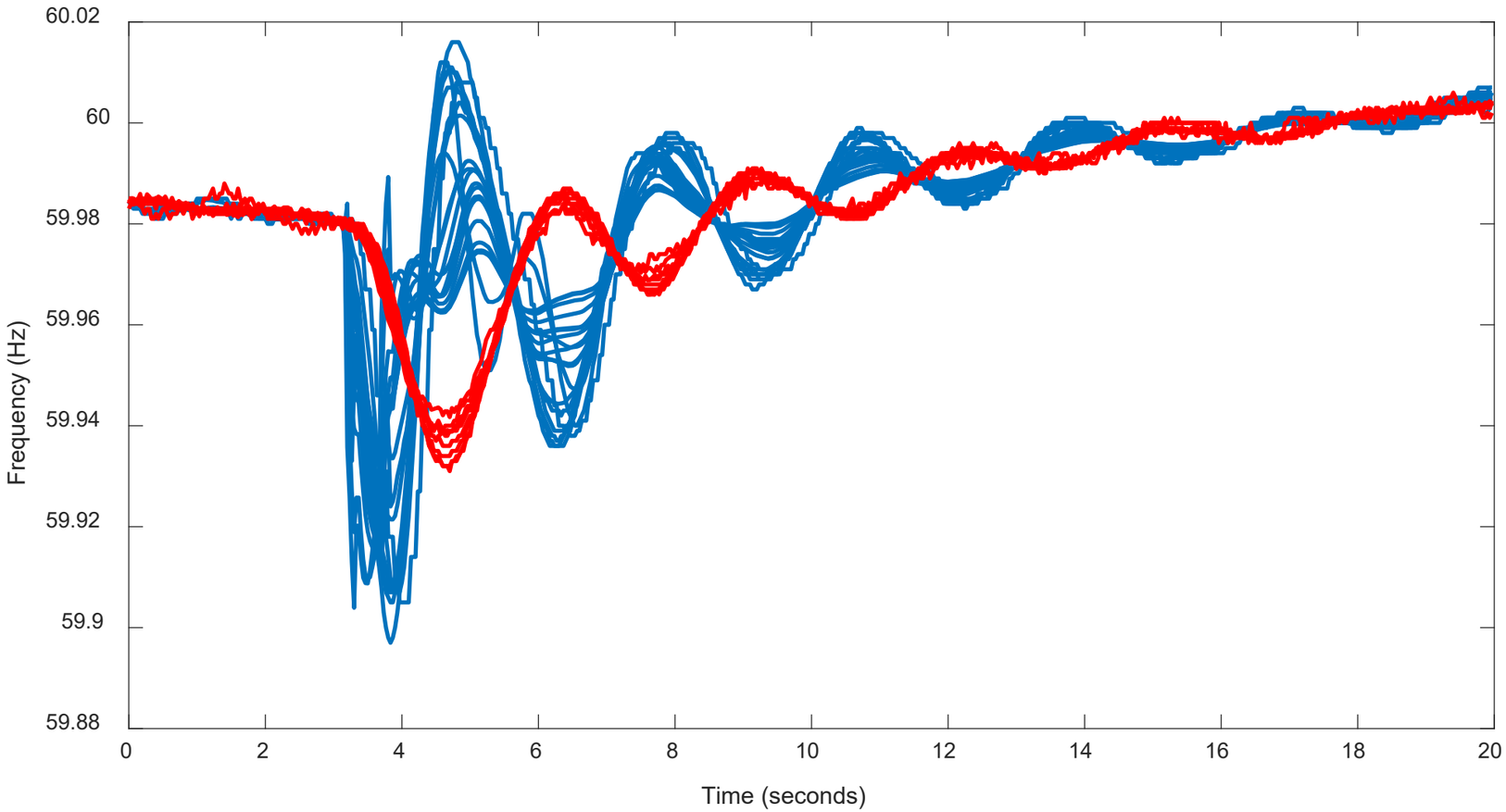
Why PMUs? Synchronization



By synchronizing the sampling processes for signals hundreds of miles apart, we gain a wide-area view of the system

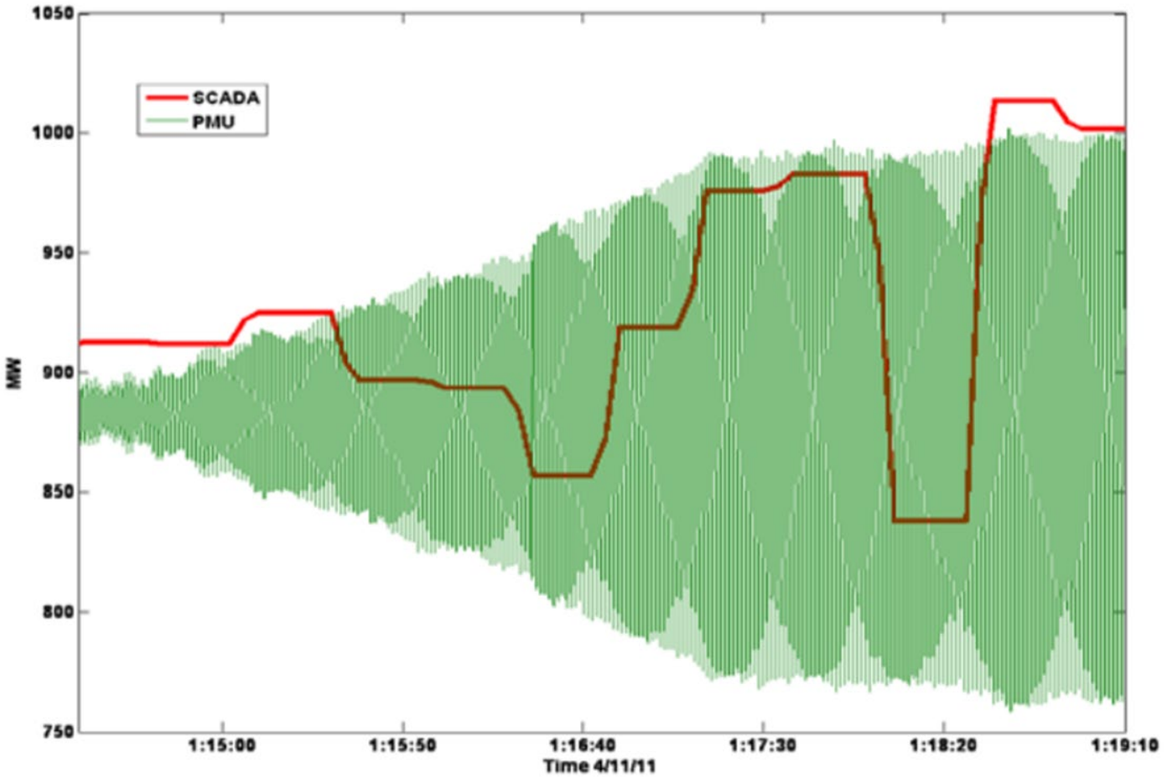
Credit: A.G. Phadke, inventor of the PMU

Why PMUs? Synchronization



Why PMUs? High-Speed Streaming

- PMUs provide the “missing link”
- Digital Fault Recorder (DFR)
  - Locally triggered waveform recording
  - Thousands of measurements per second for short duration
- Supervisory Control And Data Acquisition (SCADA)
  - Report once every 1-4 seconds
  - Timestamped upon arrival
- PMU
  - Continuously stream phasors 30-60 times per second
  - Streaming is critical for many high-value applications



Source: Dominion Energy

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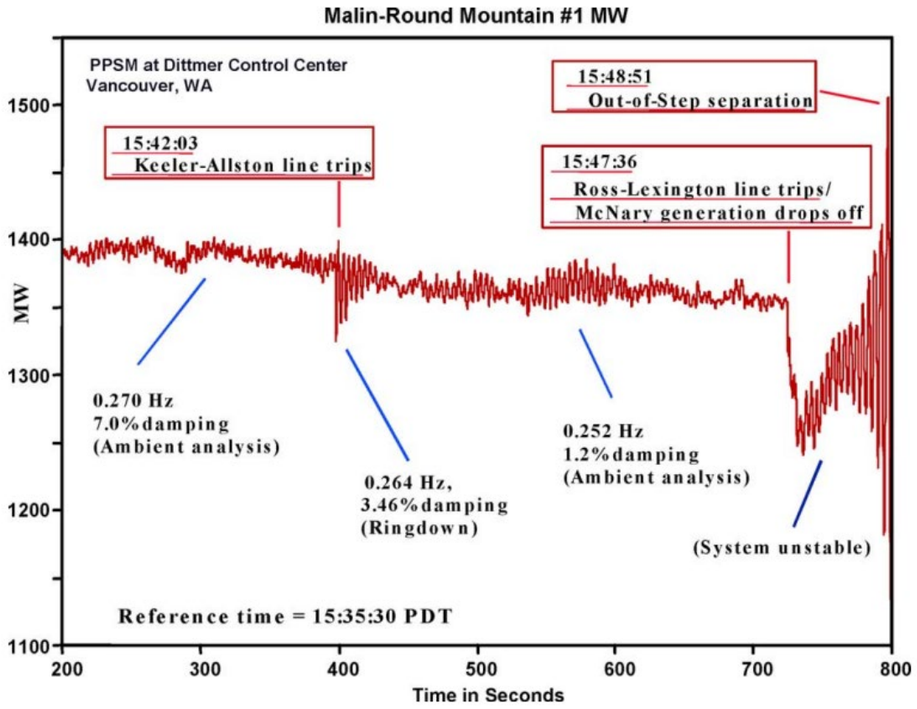
Use Cases

Background on Oscillations

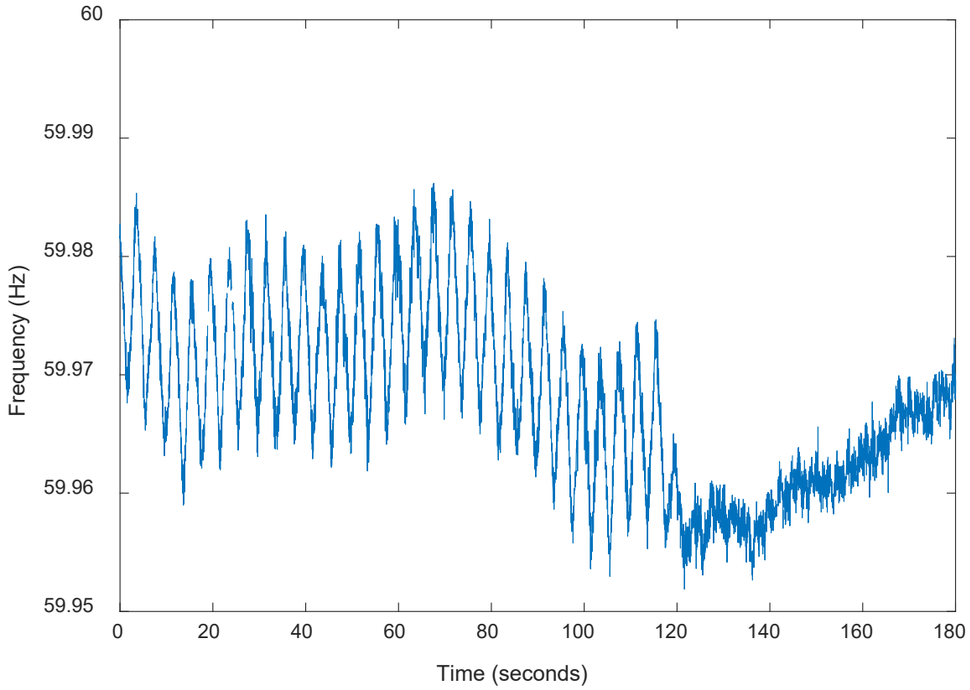
Several PMU applications are related to analysis of low frequency (< 15 Hz) oscillations in power and system frequency

Natural (Modal):
A System Stability Problem

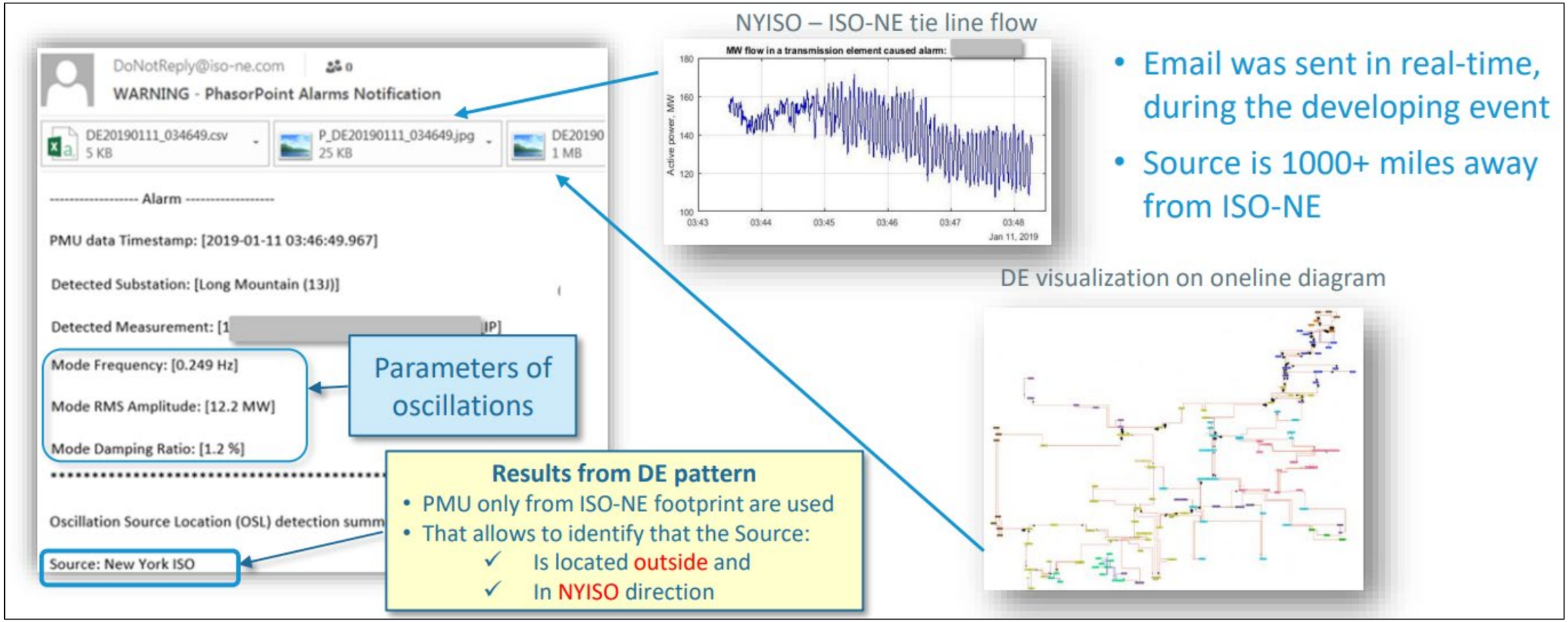


Source: Dan Trudnowski, 10.1109/TPWRS.2008.919415

Forced:
An Equipment Problem Impacting a Wide Area

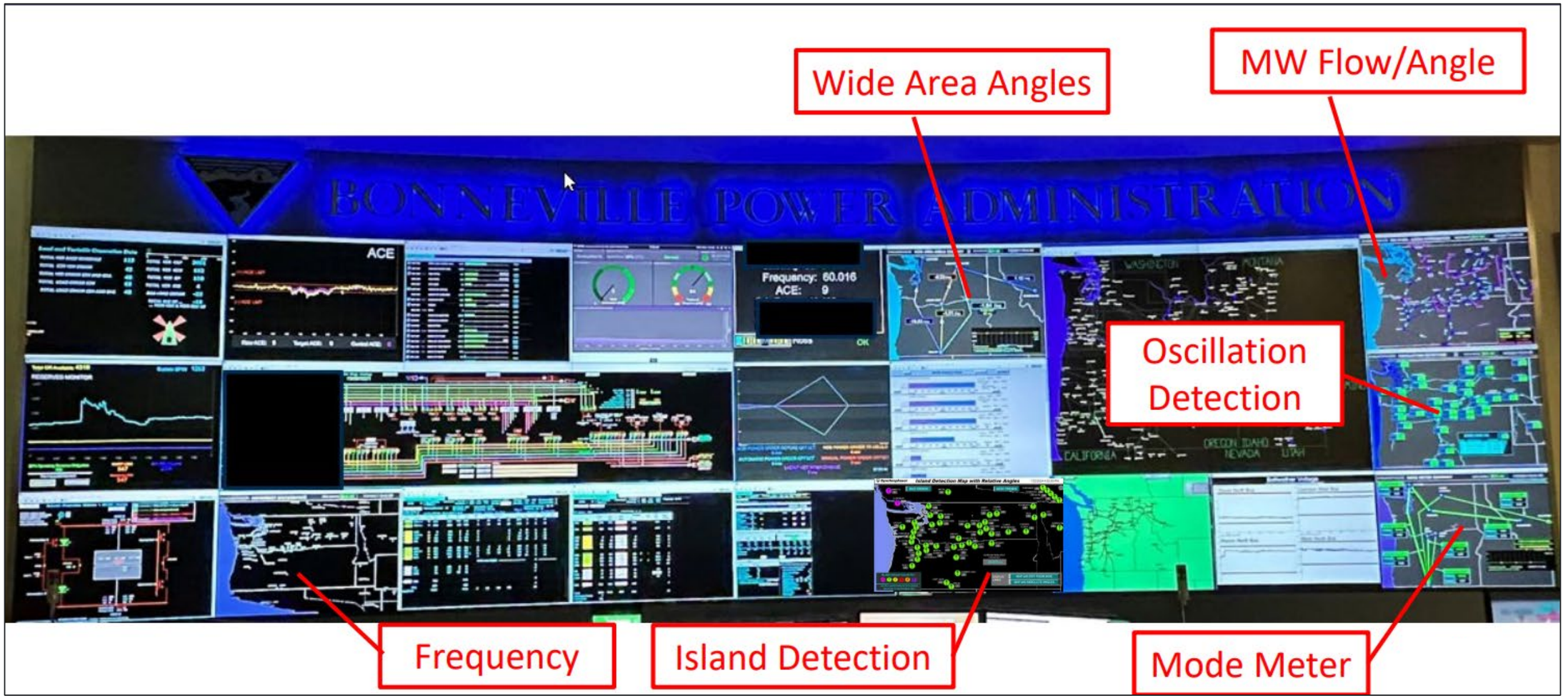


Oscillation Source Localization at ISO New England



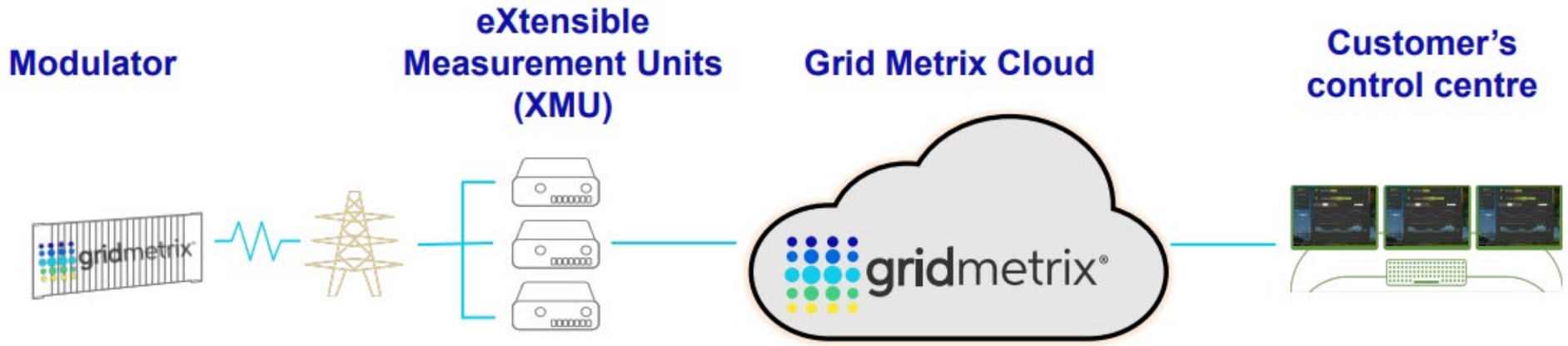
Source: ISO-NE, https://www.esig.energy/download/session-1-experience-with-oscillations-in-iso-new-england-slava-maslennikov/

Control Room Operations at Bonneville Power Administration (BPA)



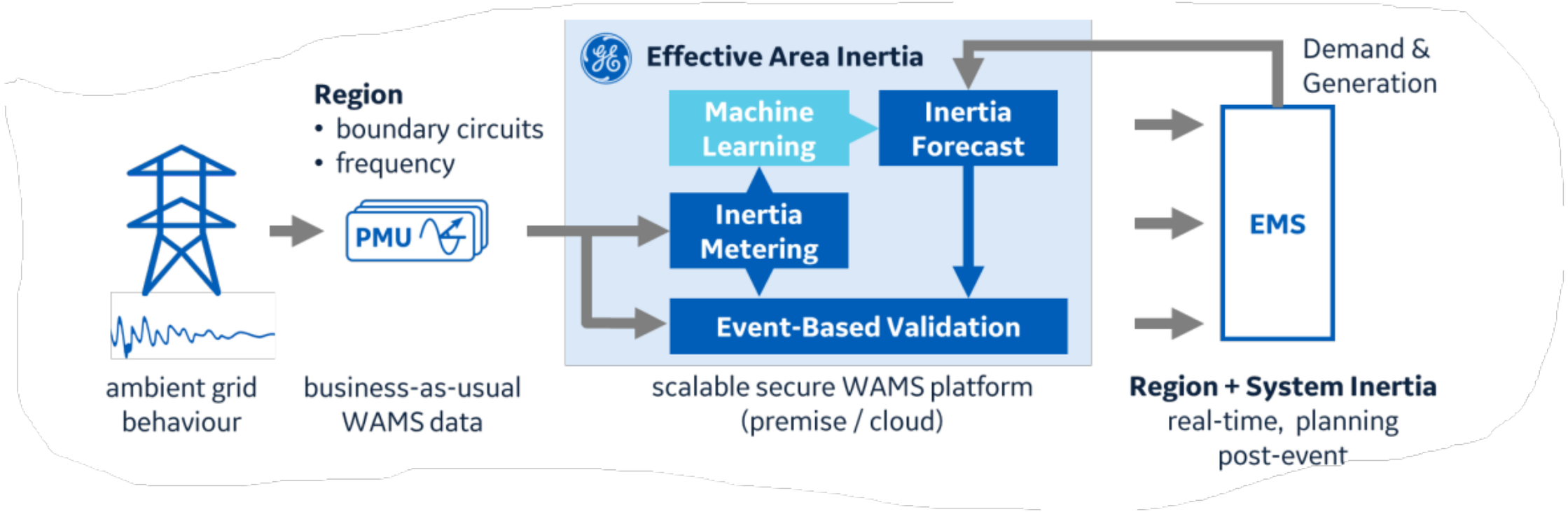
Source: BPA, https://www.naspi.org/sites/default/files/2024-04/D2_S07_P01_Goodrich_Hopson_BPA_20240417.pdf

Inertia Monitoring at National Grid (UK)



Source: National Grid, https://www.naspi.org/node/898

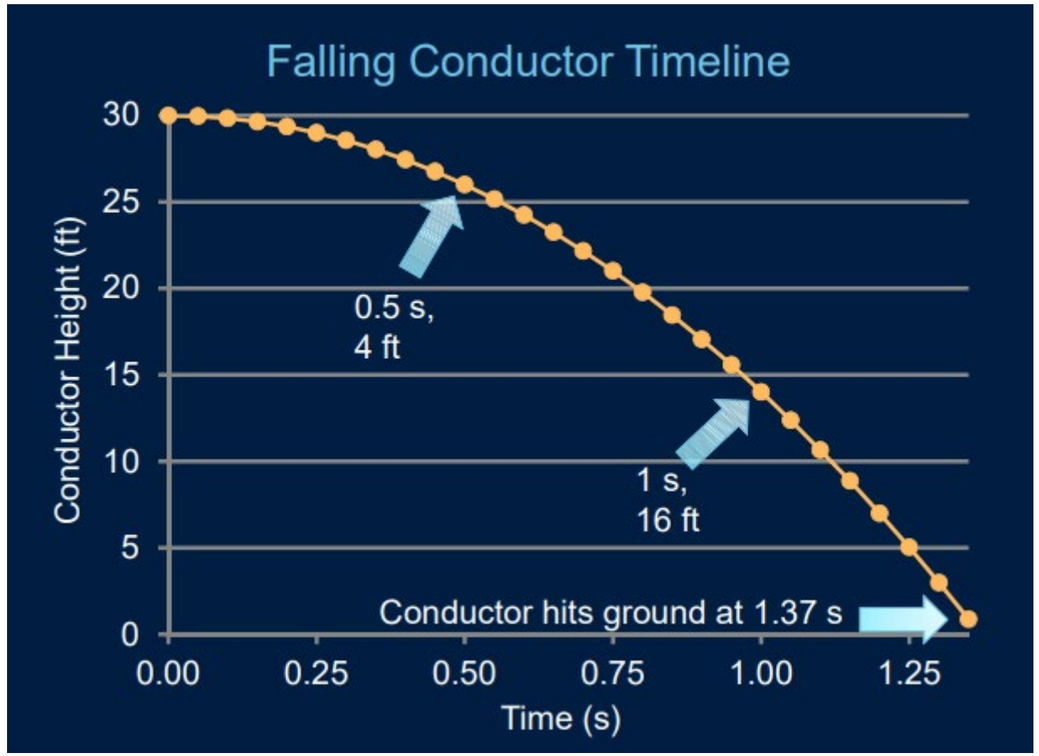
Inertia Monitoring at National Grid (UK)



Source: National Grid, https://www.naspi.org/node/898

Broken Conductor Tripping at San Diego Gas and Electric (SDG&E)

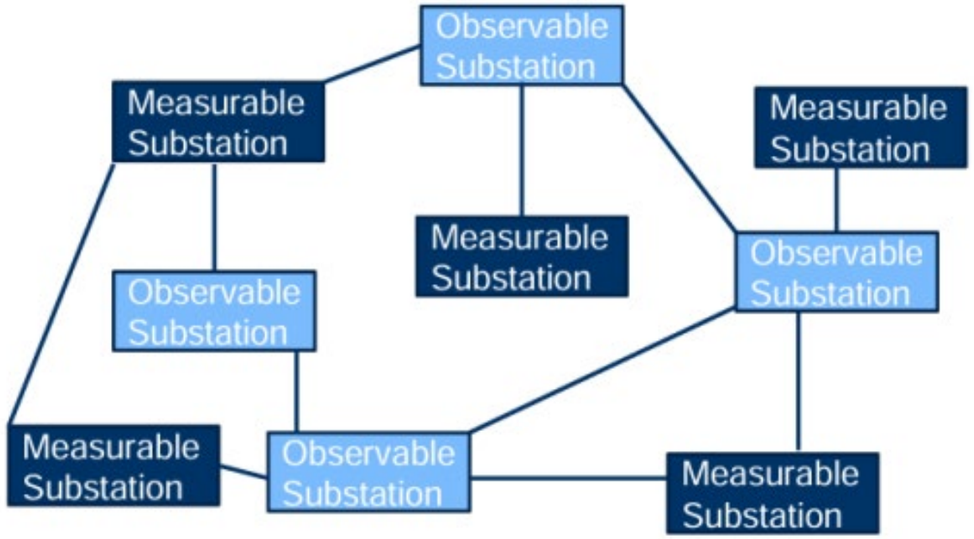
- Fires caused by falling conductors are a significant concern for SDG&E
- They pioneered a method of detecting and tripping falling conductors while still in the air using PMUs
- A commercial solution is now available



Source: SDG&E, https://www.naspi.org/sites/default/files/2019-10/04_SDGE_Dietmeyer_20191029.pdf

Linear State Estimation (LSE) at Tennessee Valley Authority (TVA)

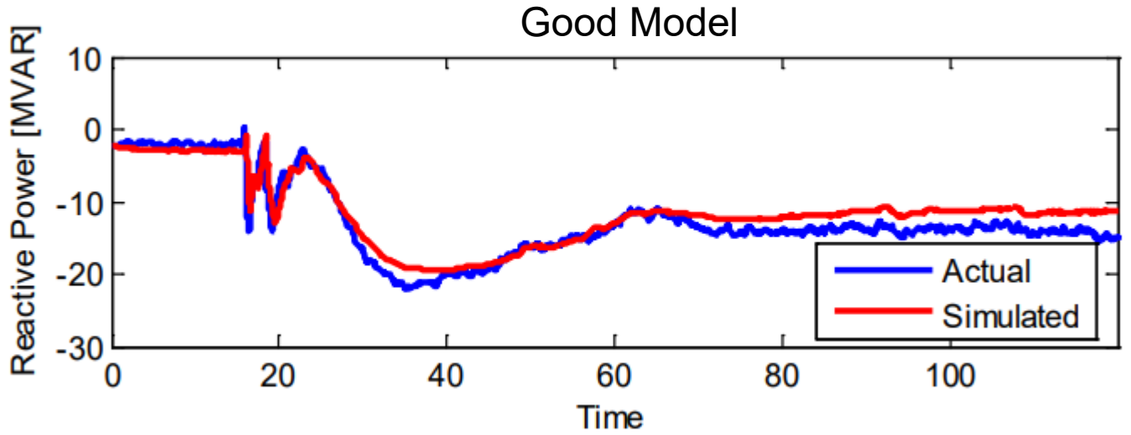
- State estimation is fundamental to power system operation
- Due to synchronization, PMUs directly observe the system's state at the buses they are monitoring
- Linear equations are solved without iteration at the PMU reporting rate to increase system observability
- The LSE feeds a variety of applications

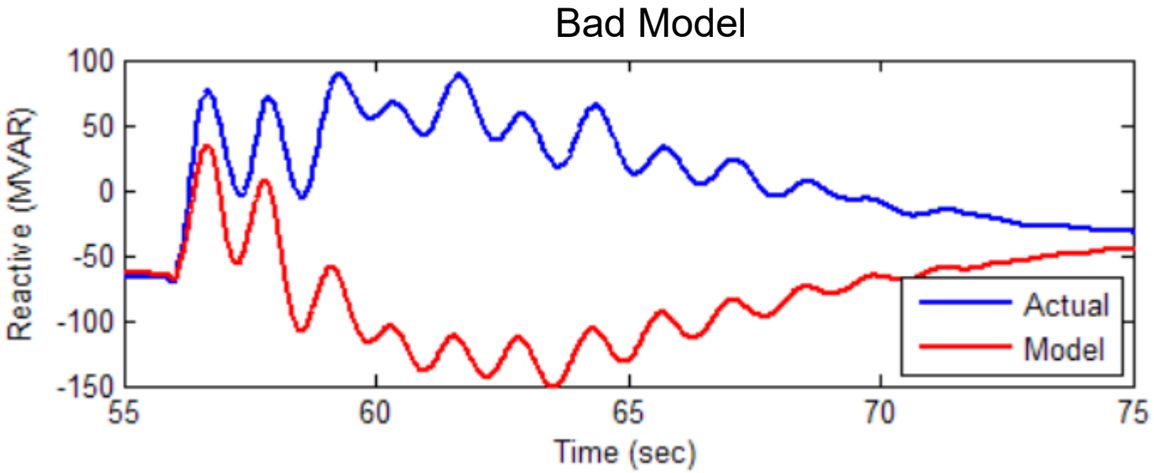


Source: EPG and TVA, https://www.naspi.org/sites/default/files/2024-05/D1_S01_P02_Nayak_EPA.pdf

Automated Power Plant Model Validation at ISO New England

- PMU-based power plant model validation is widely deployed
- Compares measured and simulated responses to disturbances
- Cost-effective approach to meet model verification requirements
- At ISO New England, PMU-based model validation has been automated
  - Detects system disturbances
  - Emails results when poor performance identified





Source: ISO-NE, https://www.naspi.org/sites/default/files/2018-05/01_Wu_AutomatedPowerPlant_20180426.pdf

Source: BPA, https://www.naspi.org/sites/default/files/2016-10/bpa_kosterev_power_plant_model_validation_20152014.pdf

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Deployment Considerations

PMU Placement

- It's more a question of *where* than *how many*
  - Small number of PMUs can have a big impact
  - Organizations find value with partial observability while gradually adding PMUs
- The needs of intended applications should be the primary determining factor
  - Oscillation source localization: generation sites, tie-lines between regions
  - Mode metering: locations participating in the oscillation
  - State estimation: extends system observability
- Additional factors can be used to rank potential locations[1]
  - Bus Voltage
  - Line Flow
  - Line Length
  - Generation Capacity
  - Number of Lines
  - Tie-Lines
  - Average Load
  - Variable Generation
  - Synchronous Condensers

[1] https://www.spp.org/documents/55159/spp%20members%20pmu%20planning.pdf

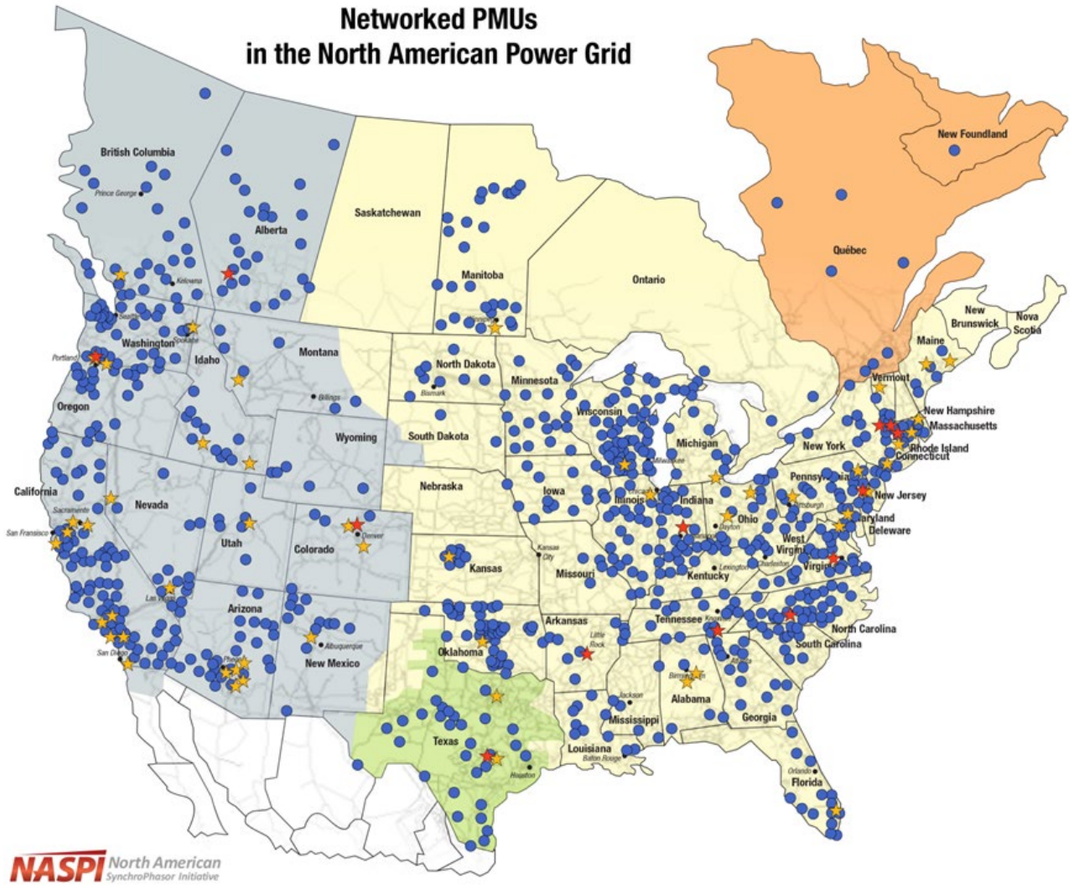
Installation Costs and Participation from Transmission Service Providers (TSPs)

- A 2014 DOE study found costs per PMU installation ranged from $40,000 to $180,000[1]
- Cost drivers in order of importance
  - Communications – highly dependent on existing infrastructure
  - Security – particularly CIP compliance
  - Labor – reduced if coordinated with other planned outages
  - Equipment – typically < 5%
- Many Reliability Coordinators and Independent System Operators have struggled gaining voluntary support from their TSPs
  - Several now require PMU installation at new generation facilities and upgraded substations
  - Requirements have successfully allowed the TSPs to justify investment
  - CIP is an important consideration, whether requiring compliance or not

[1] https://www.smartgrid.gov/files/recovery_act/PMU-cost-study-final-10162014_1.pdf

PMU Status and Future Needs

- PMUs are widely deployed with an ever-increasing list of applications
- Integration of inverter-based resources (IBRs) is driving increased need and interest in advanced measurement systems



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Thank you.