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Electric Power Applications of Wide-Area Time-Synchronized Measurements

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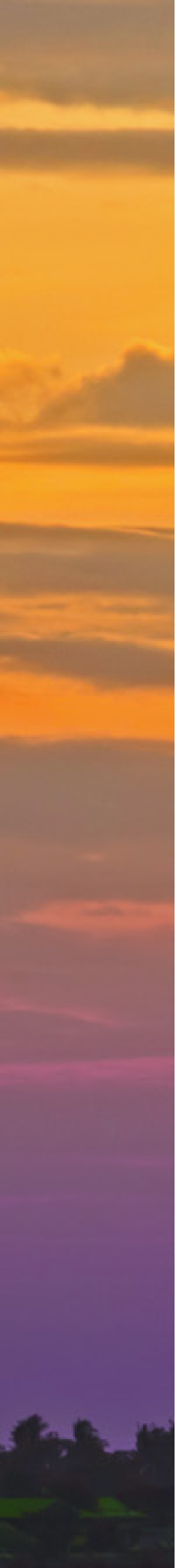


Major Takeaways

- An extended loss or degradation of satellite-based timing signals today would not be expected to result in a high-consequence reliability event
- Emerging measurement applications intended to increase reliability and enhance wide-area situational awareness could be impacted
- With the loss of wide-area time synchronization, utilities rely on the internal system clocks' holdover times
  - The stability of the clock's oscillator determines this holdover capability
- Control system applications that require wide-area time synchronization should consider the integrity and robustness of satellite-based timing signals in their design
- In the future, electric system operators will require higher availability, integrity, and redundancy for precise time synchronization

Power System Applications for Precise Timing

Application Area	Time Synchronization Requirement	Application Notes
Control Room Applications	1 s	Data acquisition, supervisory control, state estimation, etc.
Event Recording	1 ms	Sequence of events and disturbance reporting requirements
Synchrophasors	1 μs	Wide-area visibility
Advanced Protection	100 ns	Traveling wave fault location

Industry Standard for Disturbance Monitoring and Reporting Requirements

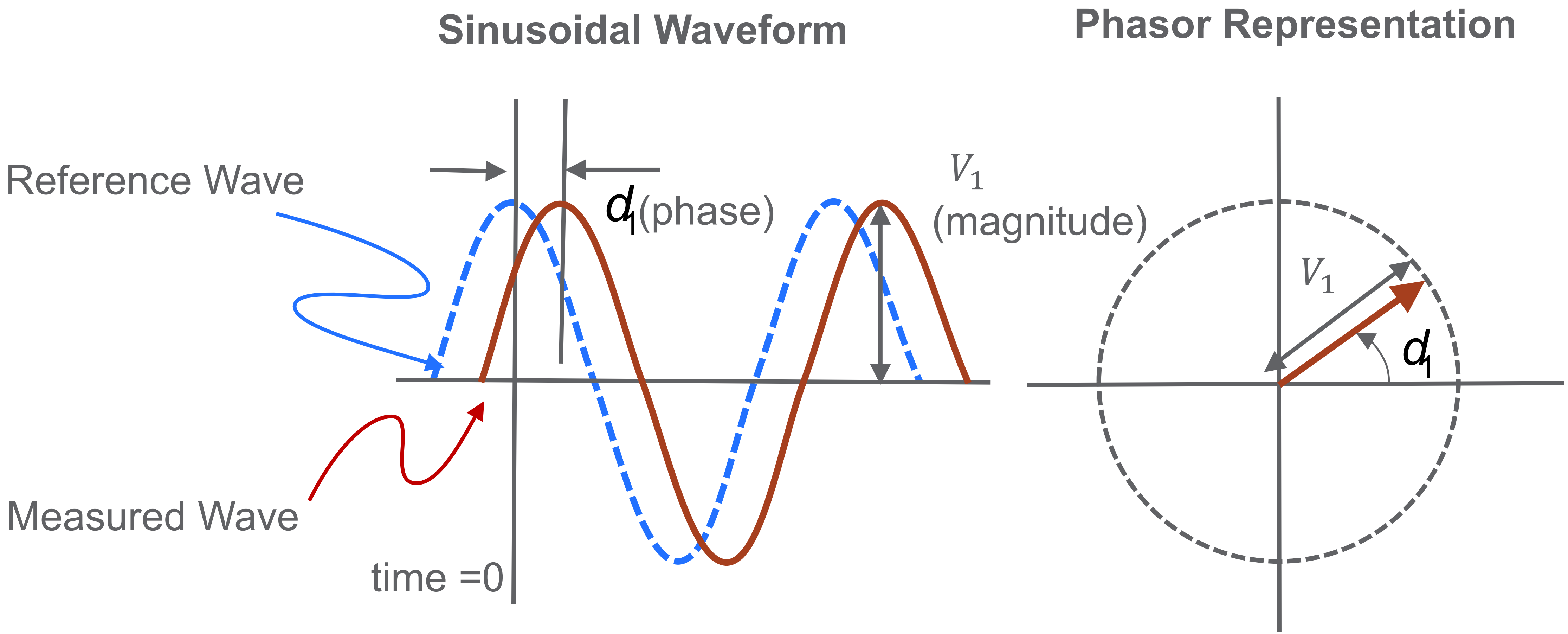
- The North American Electric Reliability Corporation (NERC) Standard for Disturbance Monitoring and Reporting Requirements
  - NERC Standard PRC-002-2

- For all sequence of events and fault recording data:
  - Requirement 10.2: Synchronized device clock accuracy within ± 2 milliseconds of UTC

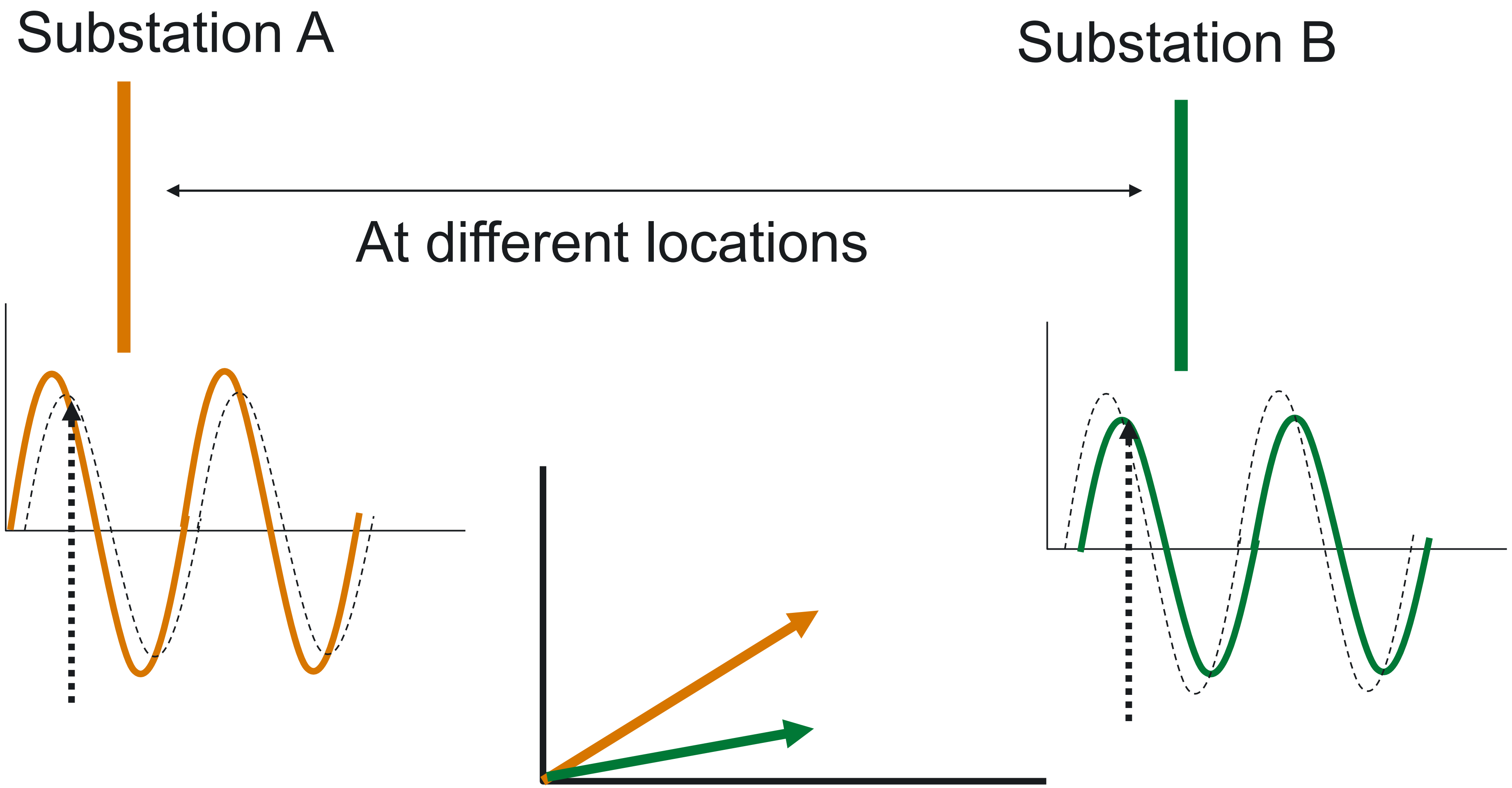
- This applies to all dynamic disturbance recording data that is required by the standard

What is a "Phasor"?

- A phasor *represents* magnitude and phase angle of a sinusoidal wave



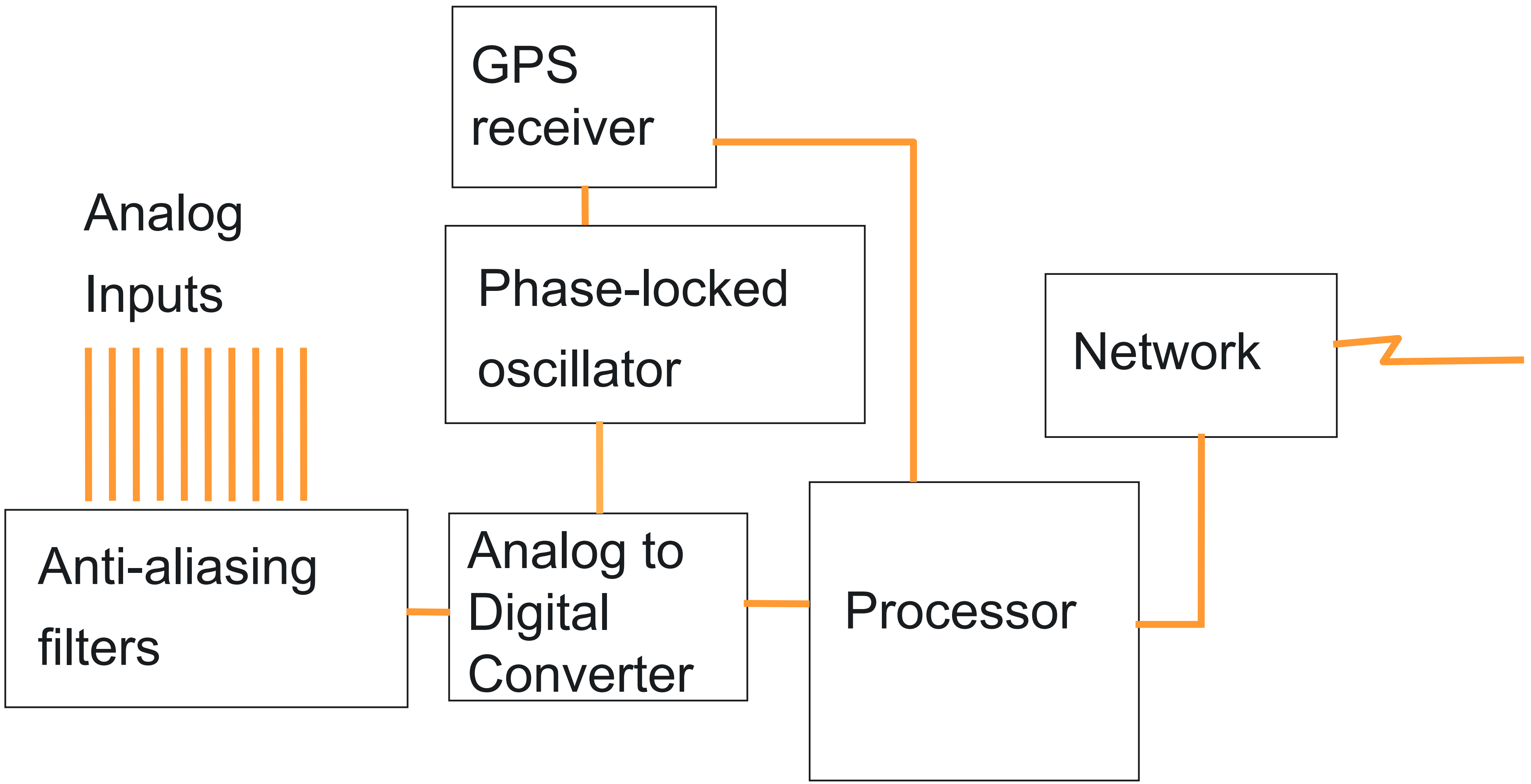
Time Synchronized Measurements



By synchronizing the sampling processes for different signals, which may be hundreds of miles apart, it is possible to put their phasors on the same phasor diagram.

Credit: A.G. Phadke

Phasor Measurement Unit (PMU)

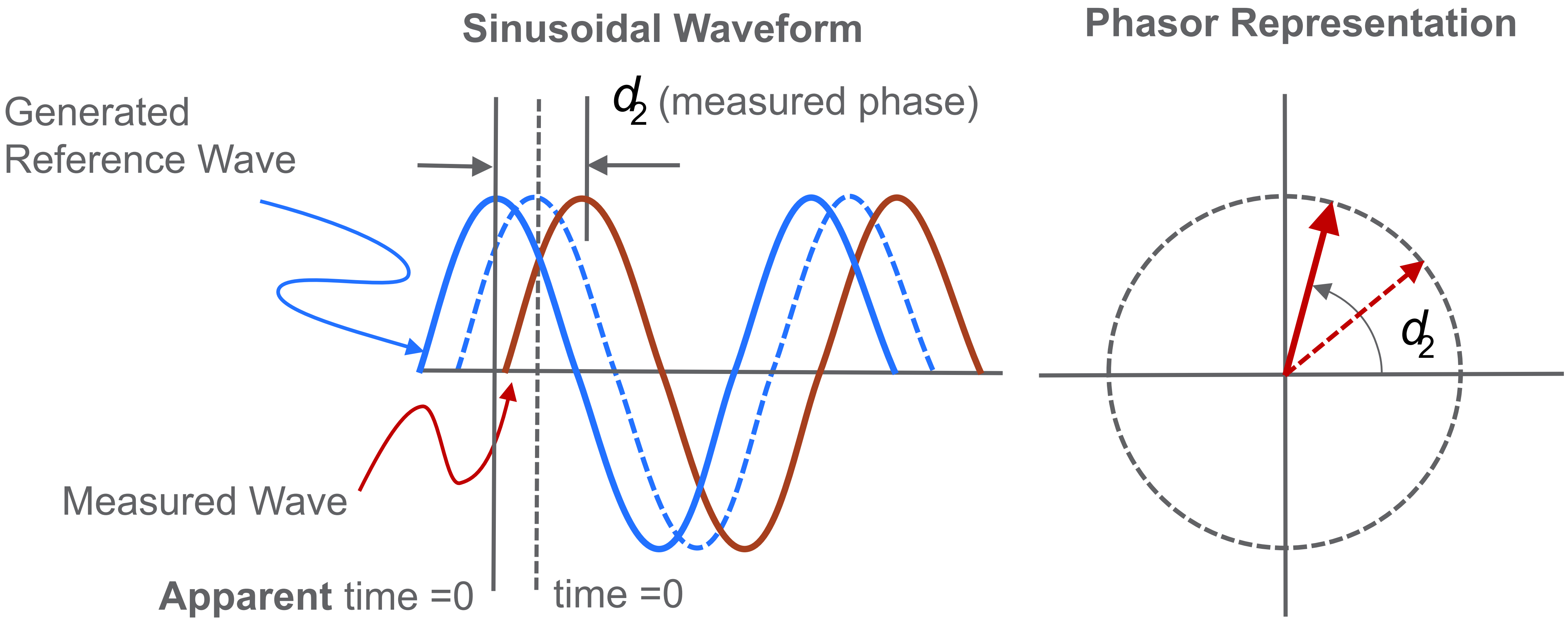


Except for synchronization, and some post processing, the hardware is the same as that of a digital fault recorder or a digital relay.

Credit: A.G. Phadke

PMU Time Synchronization Accuracy

- The *measured* angle is determined by the time reference
- At 60Hz, 1° phase angle precision corresponds to 46 µs
- Magnitude and frequency are not affected



Different Types of PMUs

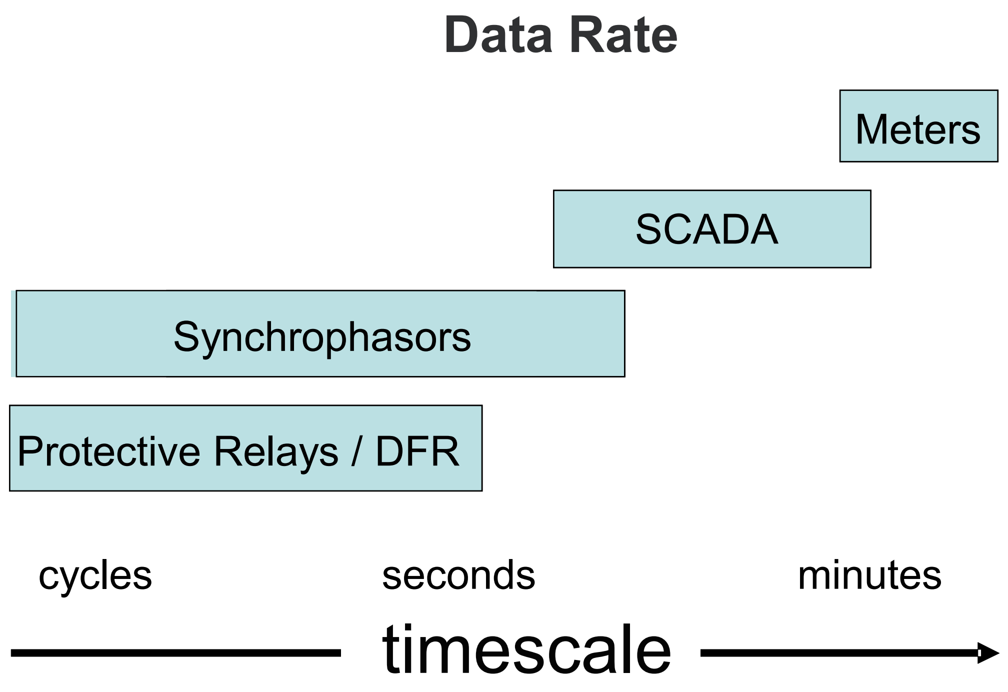
Governed by IEEE Standards:

- P class (protection)
  - Minimal filtering
  - Possible aliasing of higher frequency components
  - Less delay in estimation
  - Important for real-time controls requiring minimum delay

- M class (measurement)
  - Better anti-alias protection
  - More filtering deceases effect of higher frequencies, noise
  - Latency longer (depends on reporting rate)
  - Important for situations with higher frequencies present

Technology to Meet Emerging Industry Needs

- Synchrophasor technology is being rapidly deployed by utilities throughout the world
- Both on-line and off-line applications are emerging, particularly those that require faster time-synchronized measurements than are available from existing technology
- Vendors are providing new solutions including measurement technology, networking, and applications



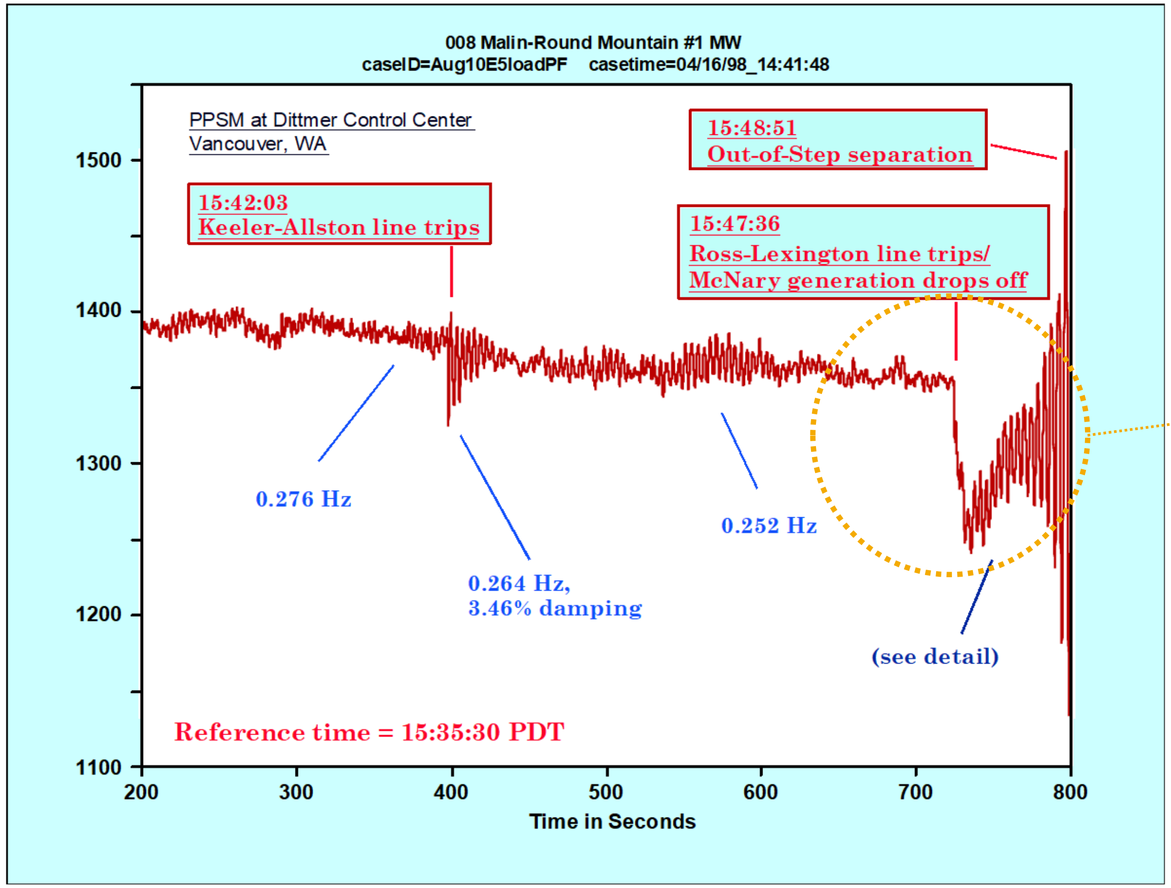
Time synchronized data can be gathered at reporting rates much faster than traditional supervisory control and data acquisition (SCADA) systems

They provide the “missing link” between localized digital fault recorders (DFR) and SCADA systems.

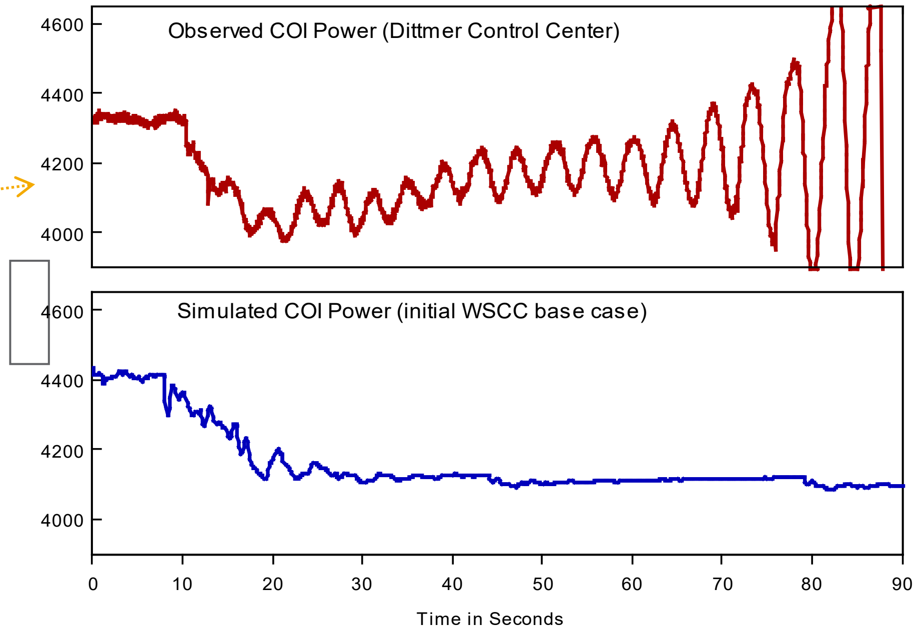
Unlike most SCADA systems, these emerging wide-area measurement technologies utilize Internet protocols to exchange measurement information.

Lessons Learned from the August 10, 1996 Western Blackout

High-speed, time-synchronized data was essential to support the blackout investigation



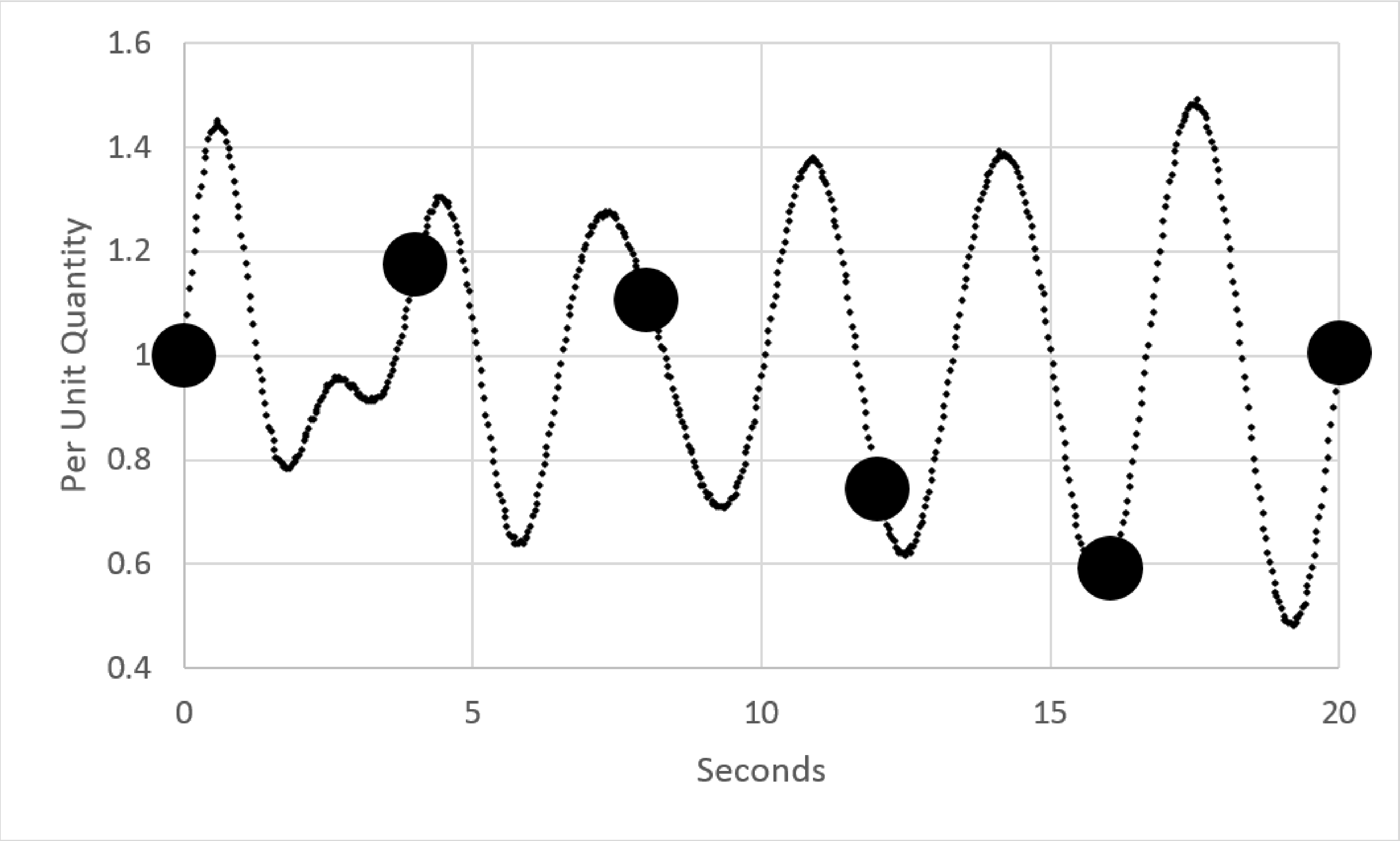
The need for better model validation was demonstrated



Notional representation of the difference between synchrophasors and traditional SCADA measurements

Supervisory Control and Data Acquisition (SCADA): every 4 seconds

Synchrophasors: typically 30 measurements per second



Synchrophasor Applications for Wide-Area Monitoring, Analysis, and Control

Monitoring	Analysis	Control
• Frequency • Voltage • Oscillation Detection • Wide-Area Visualization • Operator Decision Support • State Estimation (hybrid or linear state estimation / state measurements) • Renewables Integration	• Post-Event Analysis • Model Validation • State Estimation	• Adaptive Islanding • Adaptive Relaying • Power System Stabilizing / Power Oscillation Dampers • Black-Start Restoration • Automated Remedial Action Schemes

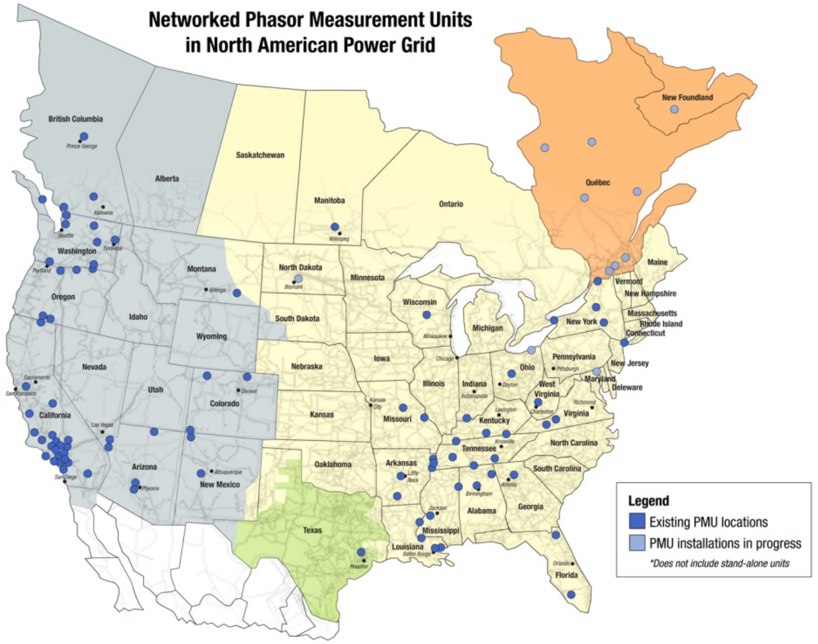
The North American SynchroPhasor Initiative (NASPI)

The U.S. Department of Energy (DOE) and EPRI are working together closely with industry to enable wide-area time-synchronized measurements that will enhance the reliability of the electric power grid through improved situational awareness and other applications.

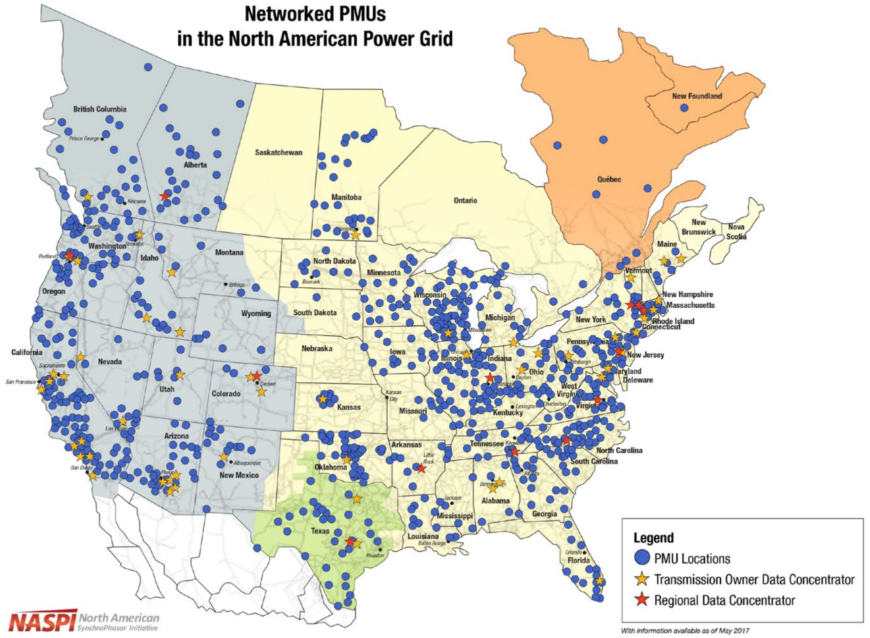
Current and emerging areas of emphasis/focus for NASPI:

- Networking and communications technologies (advanced architectures)
- Statistical analysis and deep learning for extracting actionable information from large datasets
- High-resolution sensors to characterize the transient behavior of inverter-based resources and other fast-acting phenomena

April 2007



May 2017



"Better information supports better - and faster - decisions."

NASPI Current Status

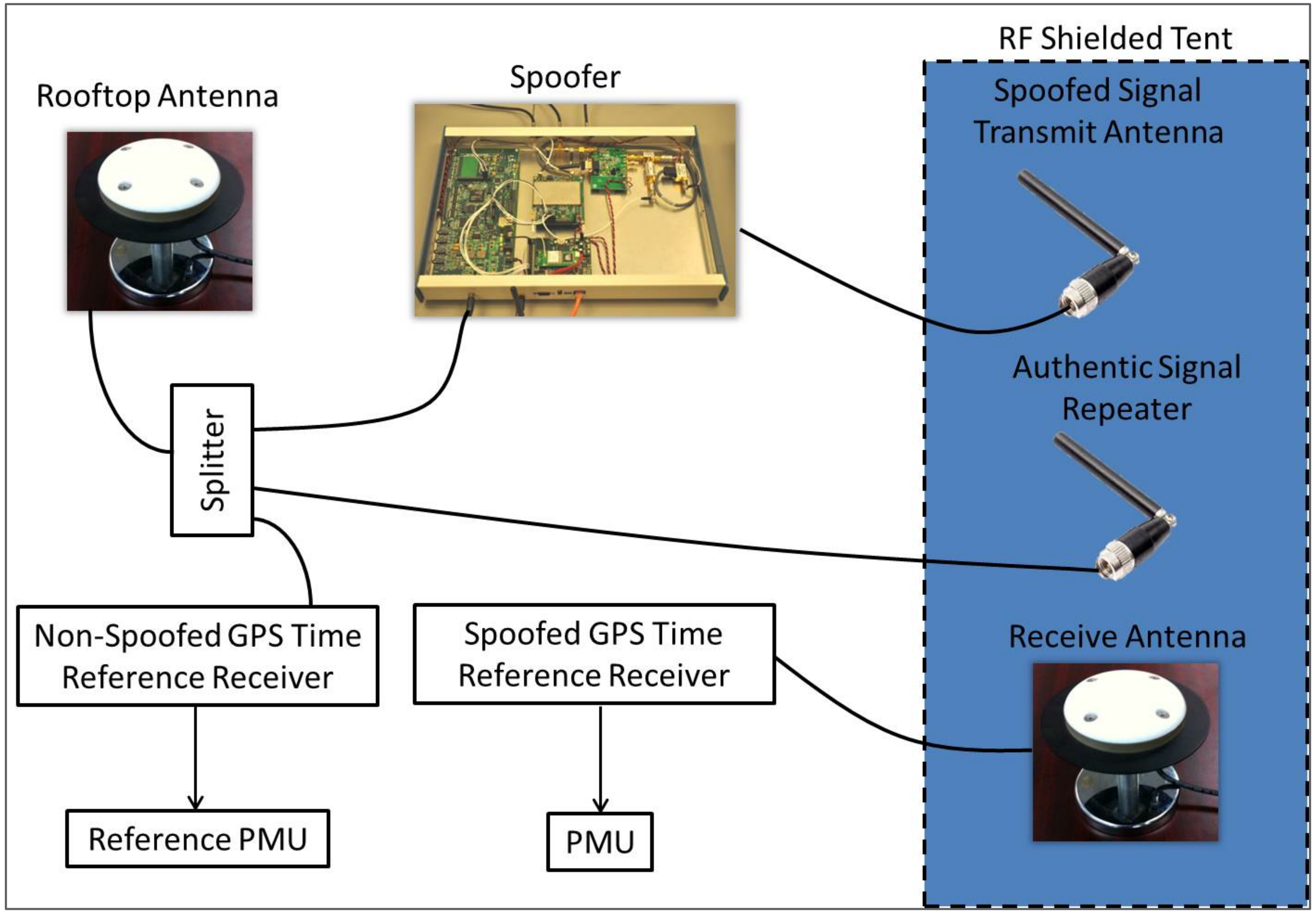
- Technical Task Teams (comprised of, and led by, key industry stakeholders)
  - Control Room Solutions
  - Data & Network Management
  - Distribution
  - Engineering Analysis
  - Performance Requirements, Standards & Verification
- Work Group Meetings
  - Most recent: October 2019 in Richmond, VA
    - ✓ Train the trainer workshop
    - ✓ Sharing best practices and lessons learned
    - ✓ Vendor exhibits, poster session, organization updates, and other technical presentations
  - April 2020 meeting converted to four one-hour webinars on 4/15-16
  - Upcoming: November 4-5, 2020 in Minneapolis, MN
- New monthly webinar series initiated

Testing Vulnerabilities Associated with Satellite Clocks for Precision Timing Applications in the Power System

Test Objectives:

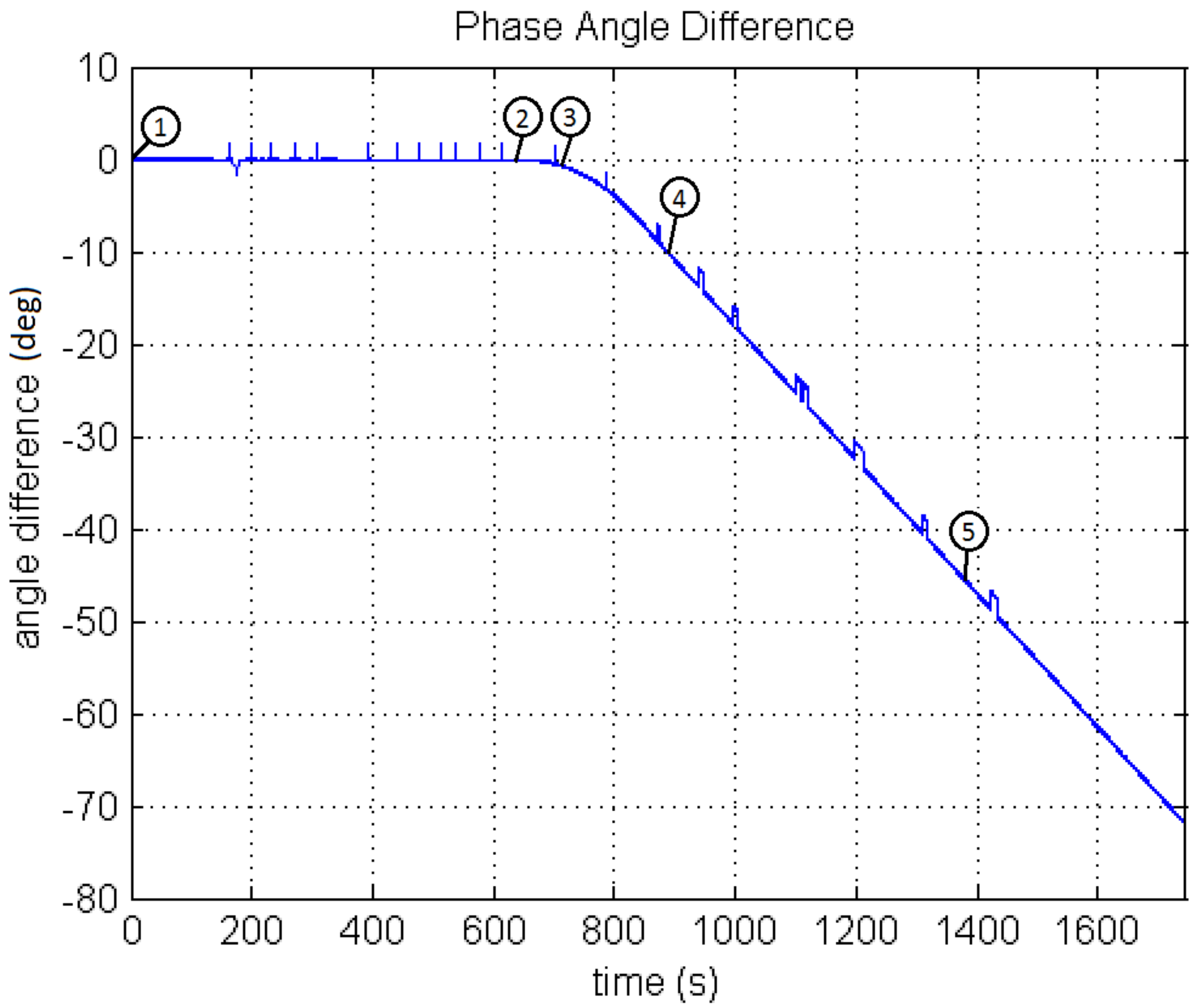
- Determine the susceptibility of GPS satellite clocks to spoofing that could undermine the accuracy of Phasor Measurement Units (PMU)
- Tests carried out at the PNNL Electricity Infrastructure Operations Center (EIOC) December 2011 with Northrop Grumman and University of Texas-Austin
- Three different satellite clocks were utilized in the testing

Schematic of the Test Setup



RF Shielded Tent

Spoofing Test Result: Impacting the Phase Angle Measurement by Manipulating the Time Reference



Test Results

- All three satellite clocks that we tested were susceptible to GPS spoofing
  - Some differences in the rate of change that could be implemented (defeating the internal error checking algorithms)
  - Some differences in how the clocks responded when the spoofing signal was turned off
- Recommending an alternative method for time synchronization associated with control applications that require robust and secure time synchronization

Jamming Satellite Clocks

- Jamming is easier to accomplish than spoofing
- Consequences are much less impactful:
  - Clocks will reliably set the “loss of synchronization” error flag
  - Time error will be based on internal clock holdover accuracy
  - Resulting timing errors will be somewhat random
  - Predictable behavior of the clock when jamming signal removed

Options for Increasing Time Synchronization Robustness

- Enhancing the satellite-based timing system
- Improved holdover oscillator accuracy
- Atomic clocks at substations
- Alternative radio-based technology (e.g, eLORAN)
- Network-based time synchronization
  - For example: Precision Time Protocol (IEEE Standard 1588)

NASPI Path Forward

- Continue to support and liaison with industry
  - Various IEEE Standards activities
  - North American Electric Reliability Corporation
    - ✓ Synchronized Measurement Subcommittee
  - Western Electricity Coordinating Council
    - ✓ Joint Synchronized Information Subcommittee
- Anticipating no substantial structural changes to the NASPI leadership team, industry-led task teams, or meeting tempo (plan to resume twice per year)
  - Maintain approximately equal representation among utilities, vendors, and academia, which has been a unique attribute and key value proposition for NASPI
- Current and emerging areas of emphasis/focus for NASPI:
  - Networking and communications technologies (advanced architectures)
  - Statistical analysis and deep learning for extracting actionable information from large datasets
  - High-resolution sensors to characterize the transient behavior of inverter-based resources and other fast-acting phenomena

New NASPI White Paper

High-Resolution, Time-Synchronized Grid Monitoring Devices

- Power system planners and analysts see growing opportunities in the use of higher-resolution, time-synchronized grid data for a variety of applications
- This paper defines high-resolution measurements as those based on samples obtained at rates faster than 256 samples/second, ranging up to a million samples/second (1 MHz)
  - Reviews the types of devices that can make such measurements
  - Addresses the more valuable applications for high-speed, time-synchronized use cases and considers where on the grid such applications might best be implemented.

Available on the NASPI website: https://www.naspi.org/node/819

Conclusions

- Synchrophasors have long been used for important applications, such as validating power system dynamic models
- There are emerging applications being deployed that utilize synchrophasors for operational applications
- Various deployment initiatives are underway that will continue to introduce advanced technology to solve planning and operational challenges
- There is an emerging need to support higher availability, integrity, and redundancy for precise time synchronization

Pacific Northwest NATIONAL LABORATORY

NASPI North American SynchroPhasor Initiative

https://www.naspi.org/

Thank you