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Electric Power Applications Enabled by Wide-Area Synchronized Time

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The Timing Subcommittee at the
63rd Meeting of the Civil GPS Service Interface Committee

Denver, CO

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Key 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 precision wide-area time synchronization should consider the integrity and robustness of their timing source in their design
- In the future, electric power grid applications will require higher availability and integrity for precise time synchronization as more applications dependent on this time synchronization are deployed

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Executive Order 13905 Requirements & Timeline

- *Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing (PNT) Services* issued in February 2020
- Sector-Specific Agencies developing plans to evaluate use of PNT services
  - U.S. Department of Energy (DOE) assigned to provide energy sector support
- Secretary of Commerce and Sector-Specific Agencies released initial PNT Profiles
- Department of Homeland Security (DHS) and Sector-Specific Agencies – plans to test PNT vulnerabilities
- DHS and Sector-Specific Agencies developing contractual language for PNT in Federal contracts
- DHS and Sector-Specific Agencies submitting reports to the Office of Science and Technology Policy (OSTP) on adoption of PNT Profiles

9359

Federal Register
Vol. 85, No. 32
Tuesday, February 18, 2020

Presidential Documents

Title 3—

The President

Executive Order 13905 of February 12, 2020

Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. *Purpose.* The national and economic security of the United States depends on the reliable and efficient functioning of critical infrastructure. Since the United States made the Global Positioning System available worldwide, positioning, navigation, and timing (PNT) services provided by space-based systems have become a largely invisible utility for technology and infrastructure, including the electrical power grid, communications infrastructure and mobile devices, all modes of transportation, precision agriculture, weather forecasting, and emergency response. Because of the widespread adoption of PNT services, the disruption or manipulation of these services has the potential to adversely affect the national and economic security of the United States. To strengthen national resilience, the Federal Government must foster the responsible use of PNT services by critical infrastructure owners and operators.

Sec. 2. *Definitions.* As used in this order:

(a) "PNT services" means any system, network, or capability that provides a reference to calculate or augment the calculation of longitude, latitude, altitude, or transmission of time or frequency data, or any combination thereof.

(b) "Responsible use of PNT services" means the deliberate, risk-informed use of PNT services, including their acquisition, integration, and deployment, such that disruption or manipulation of PNT services minimally affects national security, the economy, public health, and the critical functions of the Federal Government.

(c) "Critical infrastructure" means systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on national security, national economic security, national public health or safety, or on any combination of those matters.

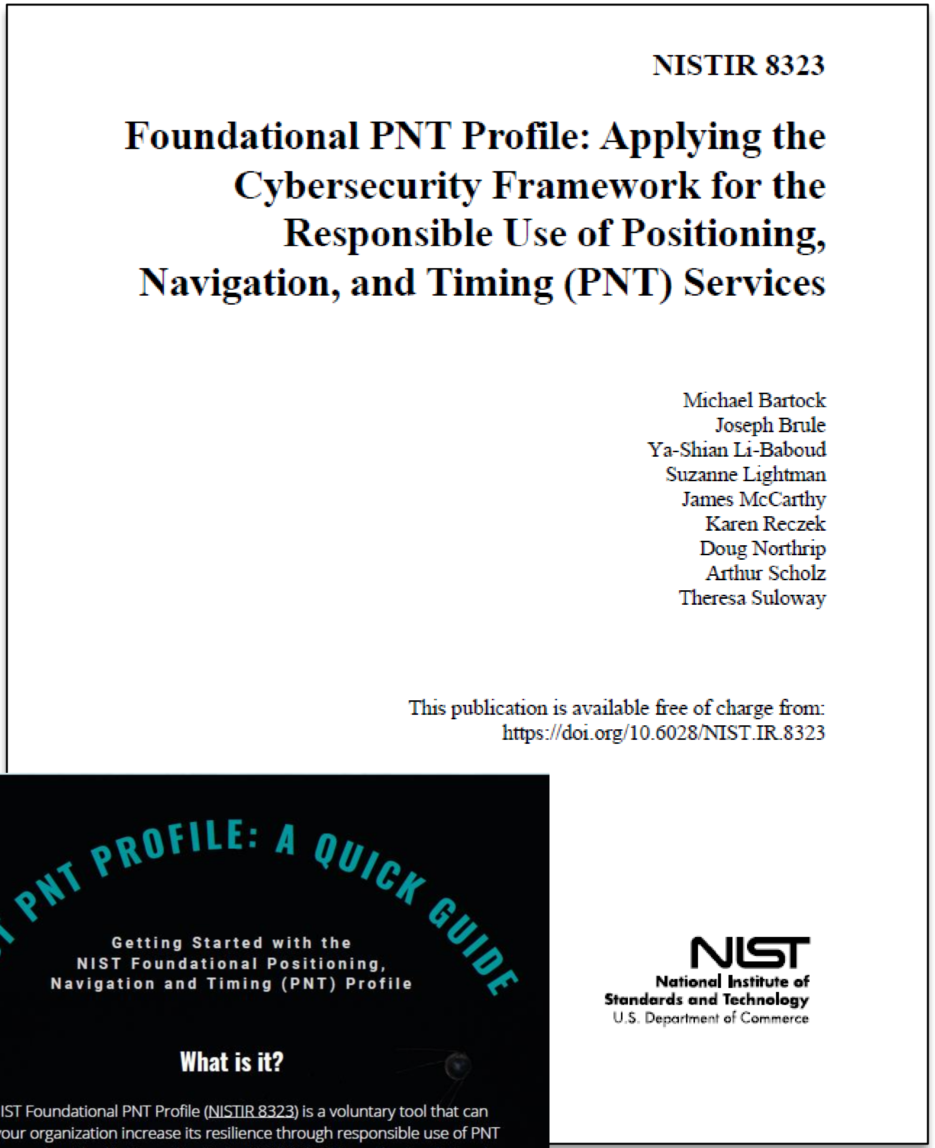
(d) "PNT profile" means a description of the responsible use of PNT services—aligned to standards, guidelines, and sector-specific requirements—selected for a particular system to address the potential disruption or manipulation of PNT services.

(e) "Sector-Specific Agency" (SSA) is the executive department or agency that is responsible for providing institutional knowledge and specialized expertise as well as leading, facilitating, or supporting the security and resilience programs and associated activities of its designated critical infrastructure sector in the all-hazards environment. The SSAs are those identified in Presidential Policy Directive 21 of February 12, 2013 (Critical Infrastructure Security and Resilience).

Sec. 3. *Policy.* It is the policy of the United States to ensure that disruption or manipulation of PNT services does not undermine the reliable and efficient functioning of its critical infrastructure. The Federal Government must increase the Nation's awareness of the extent to which critical infrastructure depends on, or is enhanced by, PNT services, and it must ensure critical infrastructure can withstand disruption or manipulation of PNT services.

DHS and NIST Issue Sector-Neutral PNT Profile

- February 12, 2021: NIST releases NISTIR 8323: *Foundational PNT Profile: Applying the Cybersecurity Framework for the Responsible Use of Positioning, Navigation, and Timing (PNT) Services*
  - Along with a 3-page Quick Start Guide
- Follows NIST Cyber Security Framework:
  - Identify, Protect, Detect, Respond, Recover
- Intended for all 16 critical infrastructure sectors
- Each Sector-Specific Agency is expected to develop their own PNT Profile that builds on NISTIR 8323, addressing the unique needs of their sector
  - DOE is responsible for the Energy Sector's PNT Profile



NISTIR 8323

Foundational PNT Profile: Applying the Cybersecurity Framework for the Responsible Use of Positioning, Navigation, and Timing (PNT) Services

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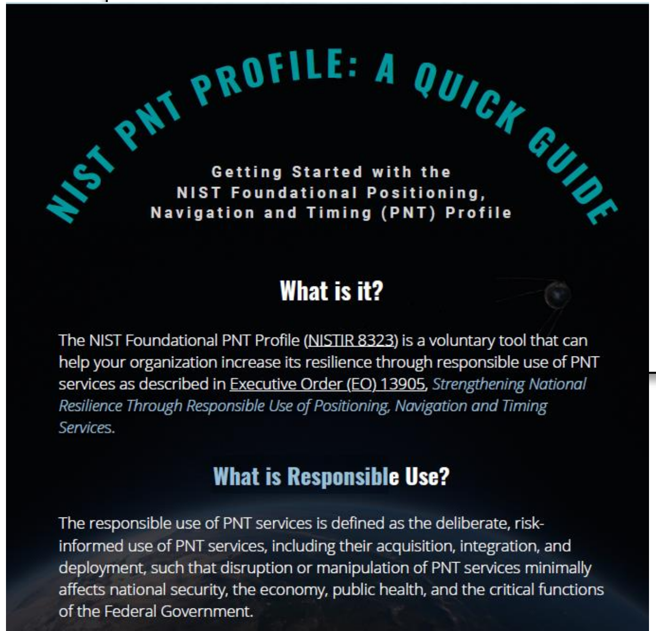
NIST
National Institute of Standards and Technology
U.S. Department of Commerce



NIST PNT PROFILE: A QUICK GUIDE

Getting Started with the
NIST Foundational Positioning,
Navigation and Timing (PNT) Profile

What is it?

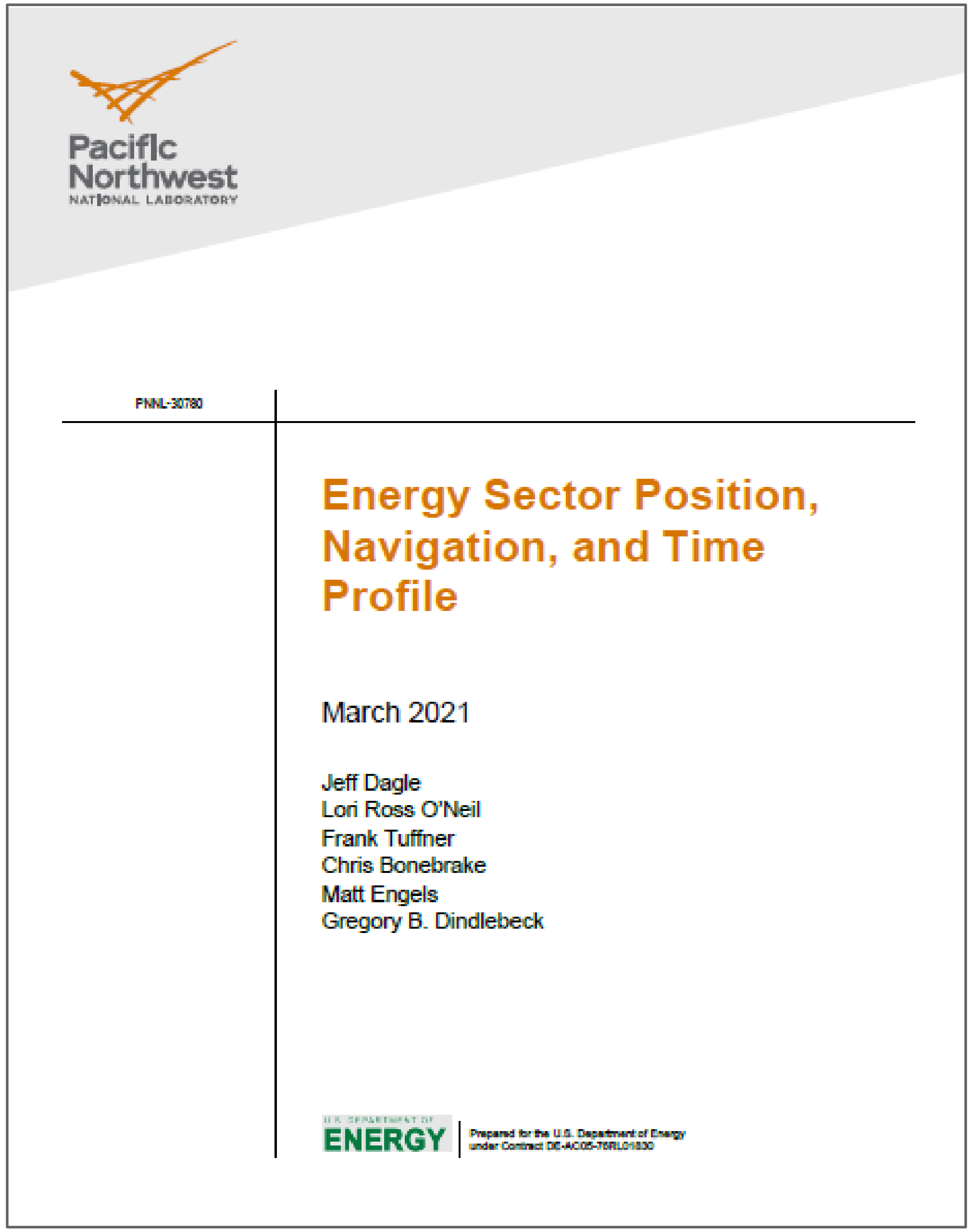
The NIST Foundational PNT Profile (NISTIR 8323) is a voluntary tool that can help your organization increase its resilience through responsible use of PNT services as described in Executive Order (EO) 13905, *Strengthening National Resilience Through Responsible Use of Positioning, Navigation and Timing Services.*

What is Responsible Use?

The responsible use of PNT services is defined as the deliberate, risk-informed use of PNT services, including their acquisition, integration, and deployment, such that disruption or manipulation of PNT services minimally affects national security, the economy, public health, and the critical functions of the Federal Government.

DOE’s Energy Sector PNT Profile – March 2021

- Addresses the unique needs of the Energy Sector
  - Electricity, oil and natural gas subsectors
- Profile focuses on timing. Positioning and navigation do not need precise time in electricity subsector
  - The Department of Transportation will address position and navigation aspects that may relate to asset management, field crew deployment, drone operations, etc.
- Profile focuses on electricity applications in the microsecond (μs) class of timing precision and accuracy
- Less accurate timing needs, which can be met via networks (NTP) or radio (e.g., WWVB), are declared out of scope
  - We determined that the oil and gas subsector does not require precise time with μs accuracy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PNNL-30780

Energy Sector Position, Navigation, and Time Profile

March 2021

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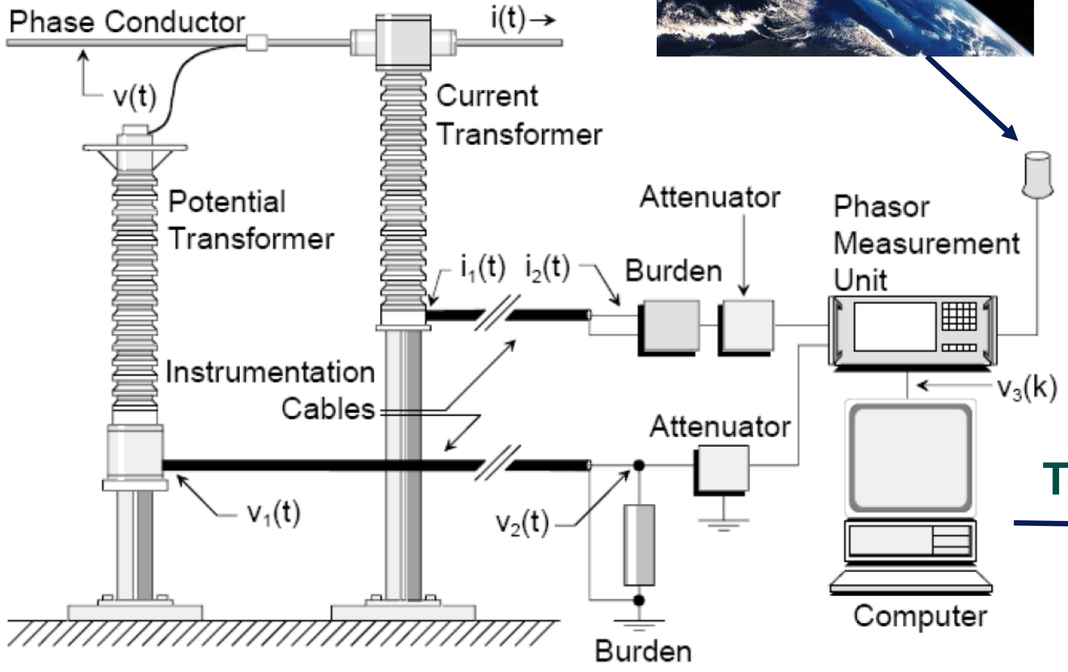
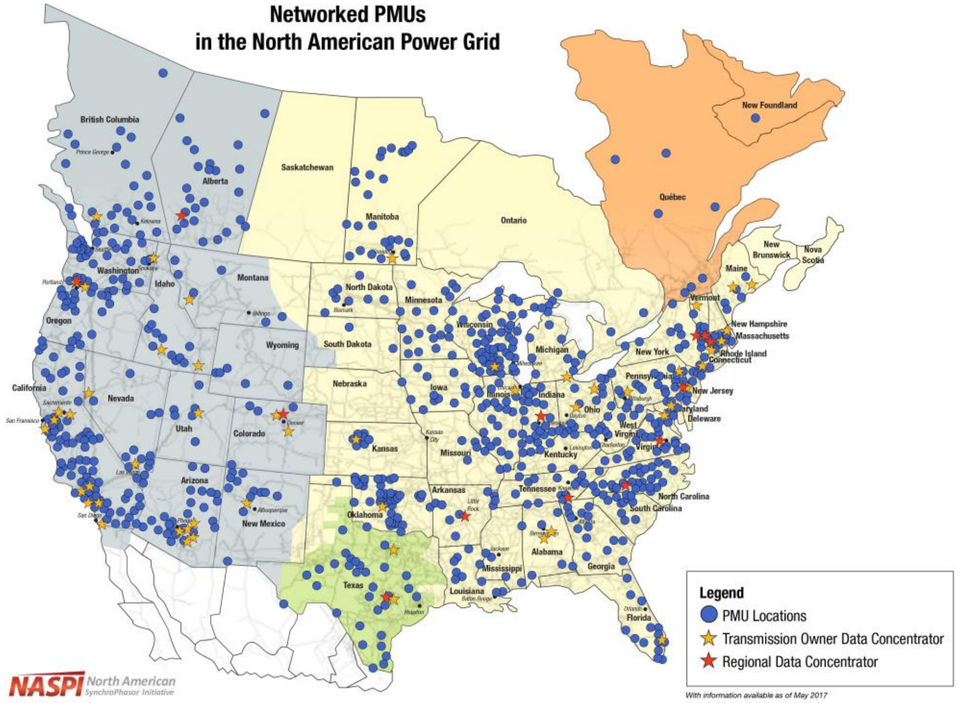
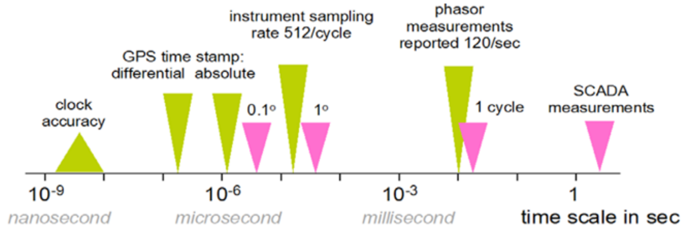
Wide Area Measurement System Overview

Wide Area Time Synchronization





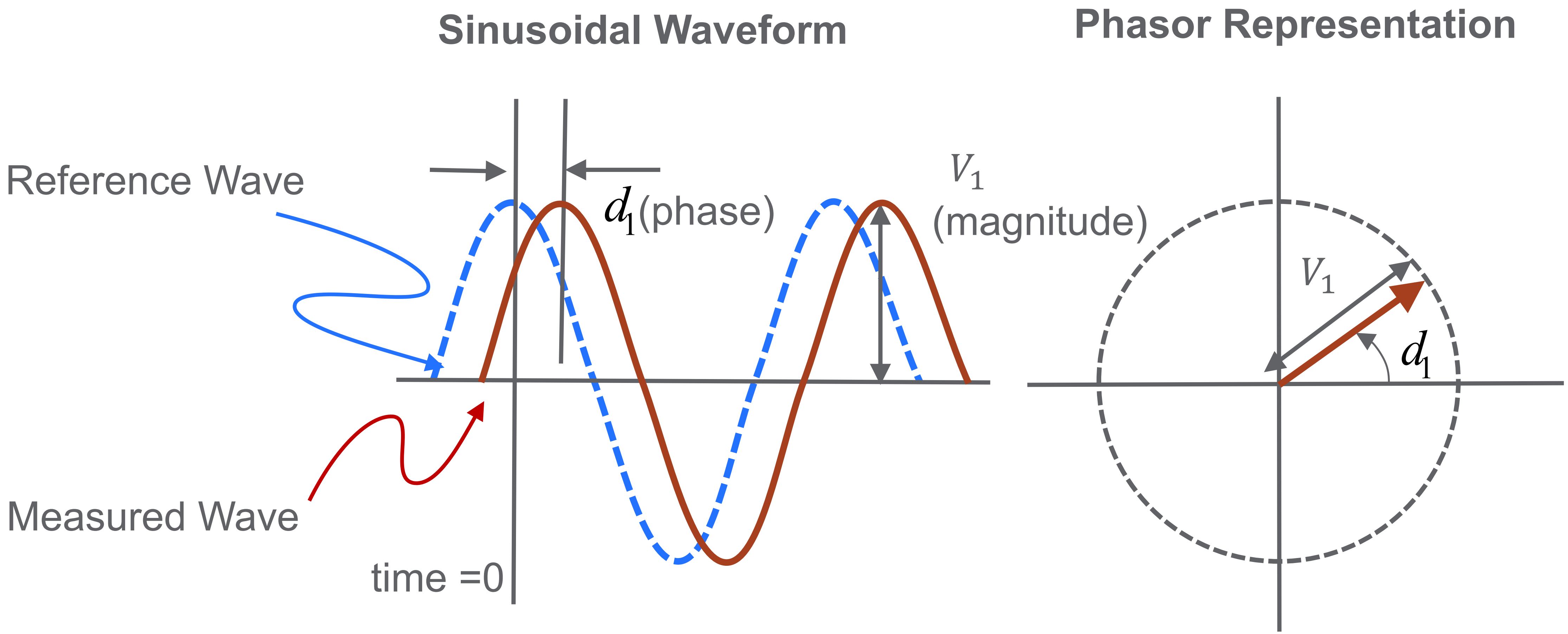
High Speed Telemetry



von Meier 2017

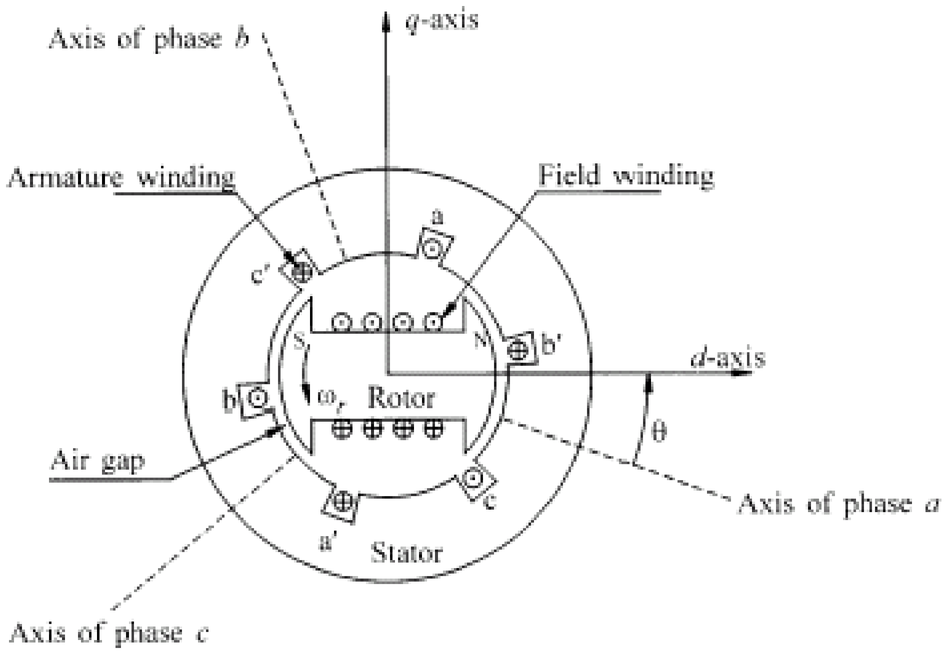
What is a "Phasor"?

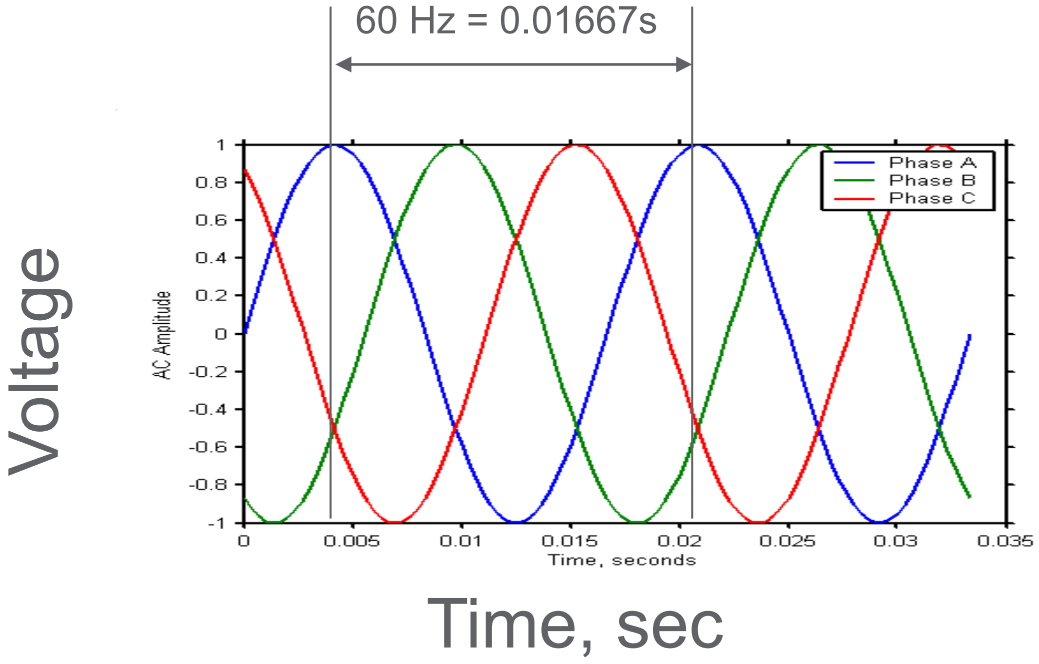
- A phasor *represents* magnitude and phase angle of a sinusoidal wave

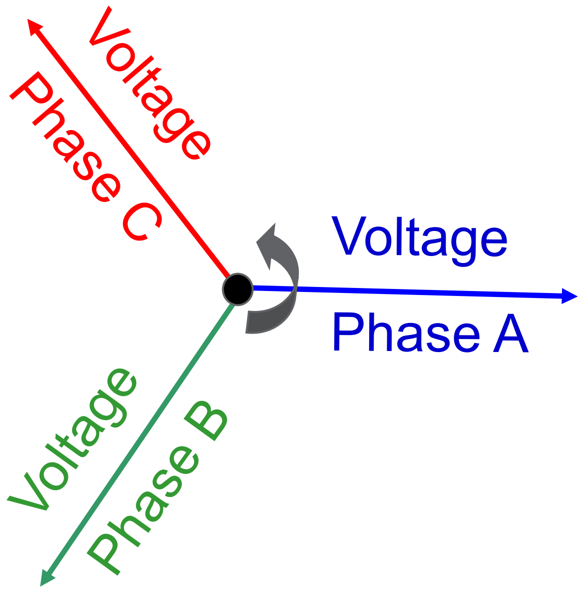


Conceptual Overview

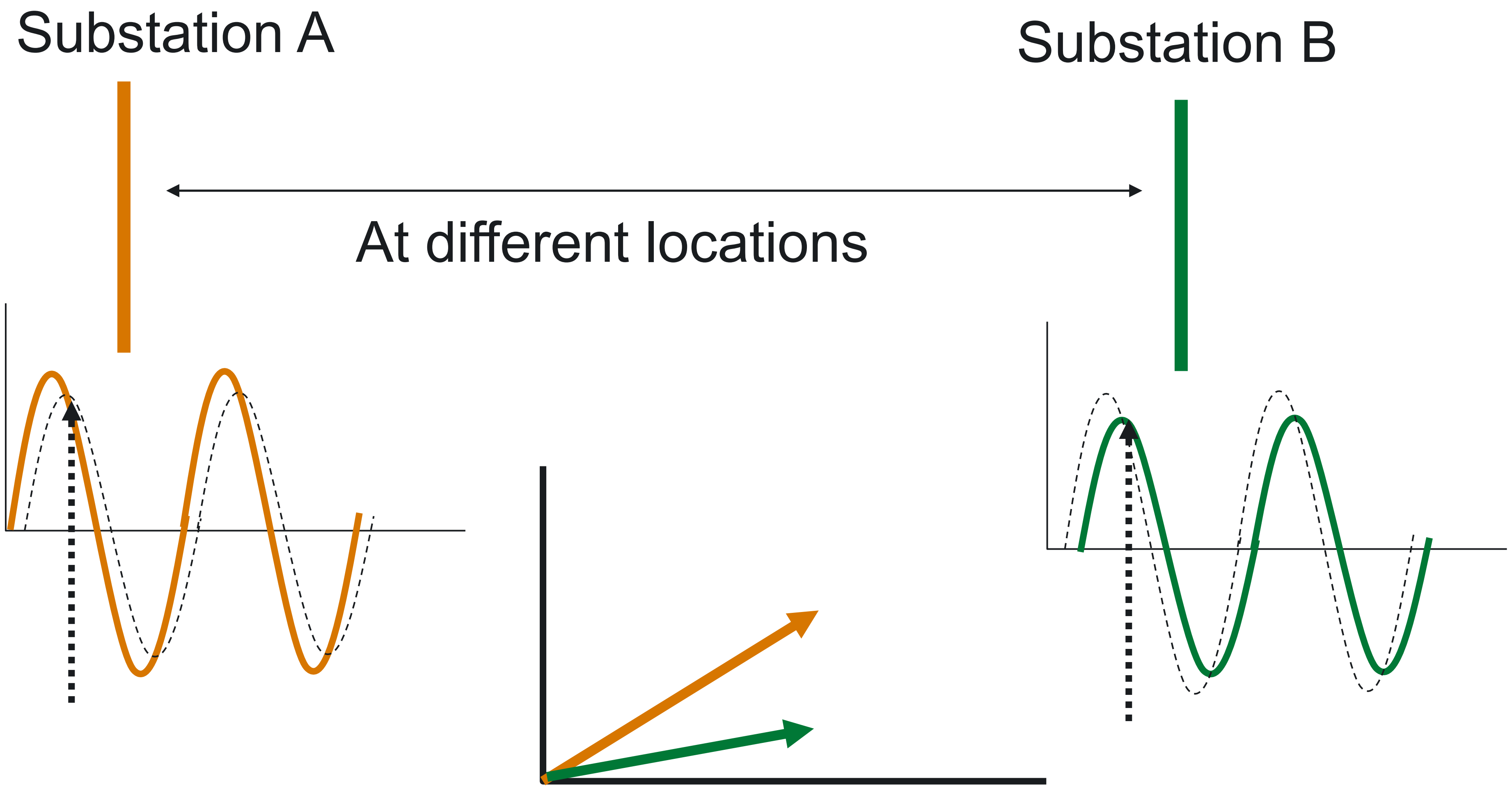
- Mathematical concept of physical quantities
- Reference phasors rotate counter-clockwise, each corresponding to a sinusoidal parameter (e.g., voltages)
- The rotating frame of reference can be modified (e.g., relative phase angle)







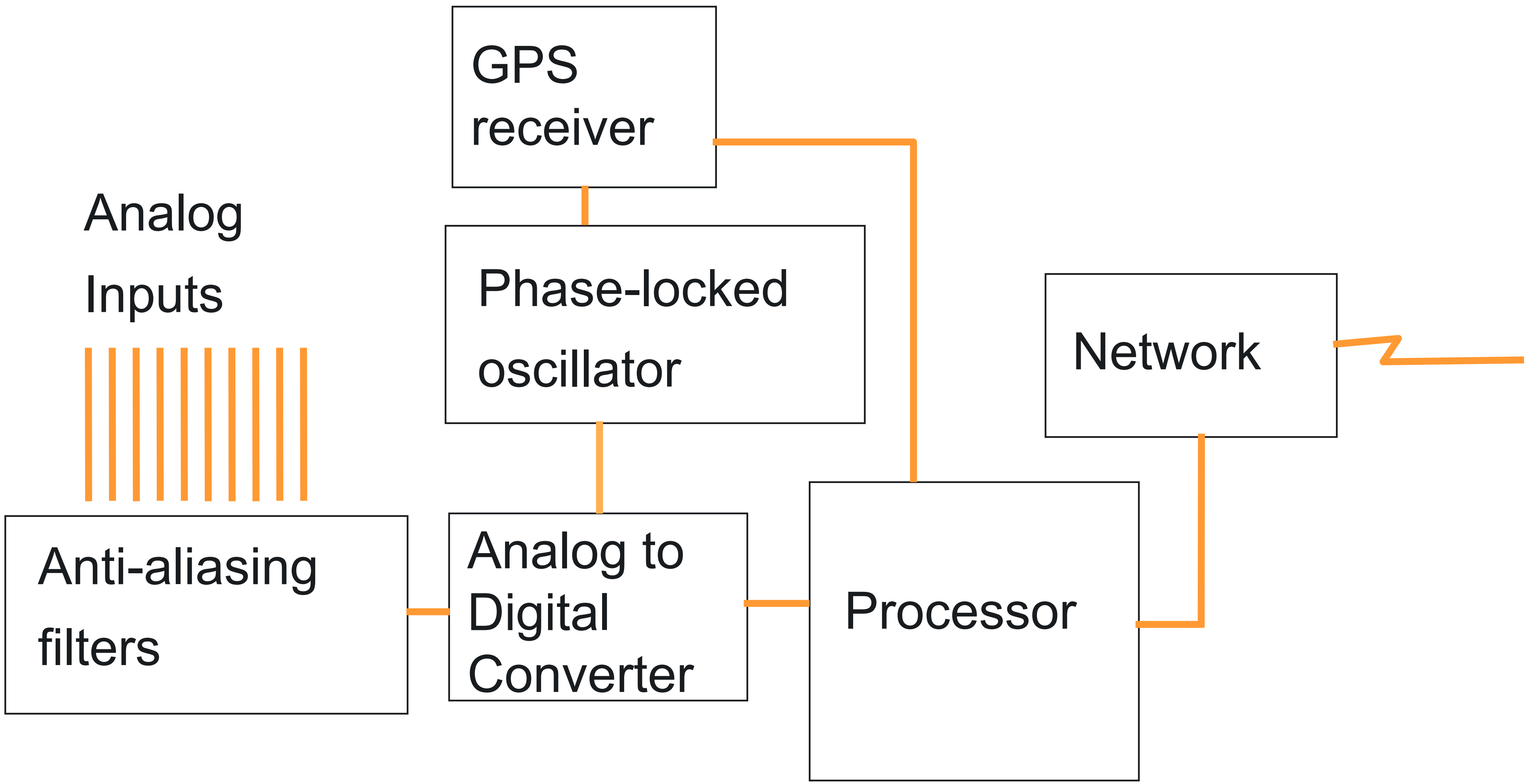
Time Synchronized Measurements



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)

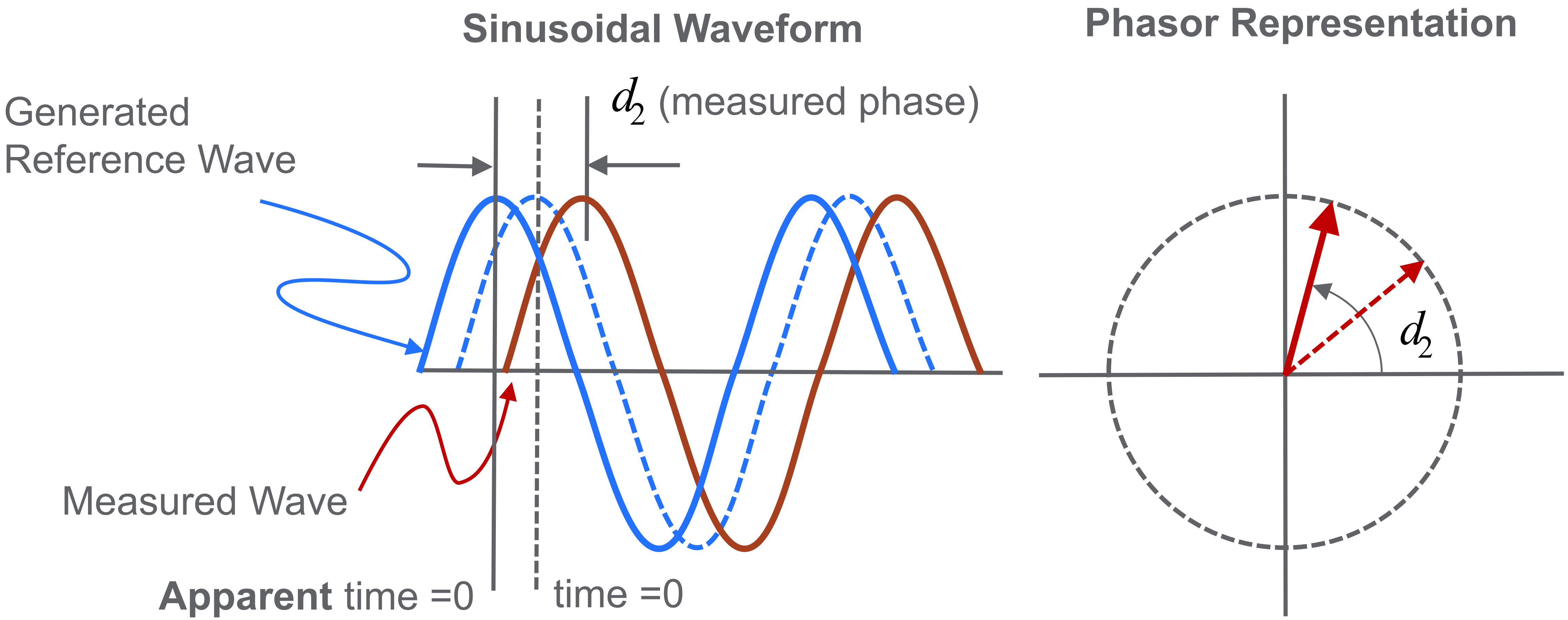


Except for synchronization, and some post processing, the hardware is the same as that of a digital fault recorder or a digital relay.

Credit: A.G. Phadke

PMU Time Synchronization Accuracy

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



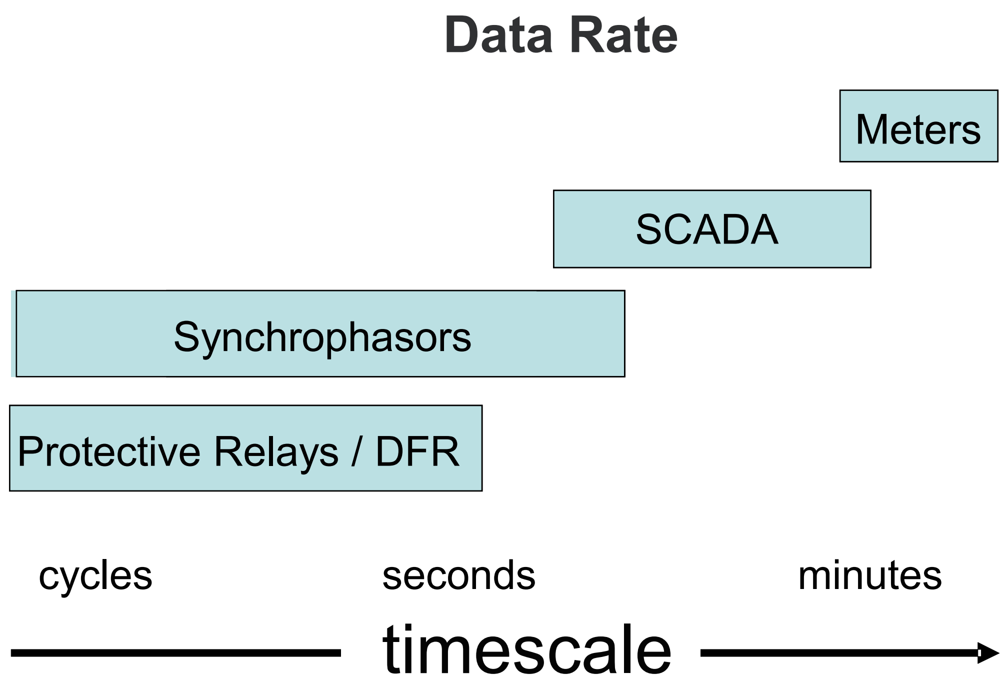
Different Types of PMUs

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 decreases 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



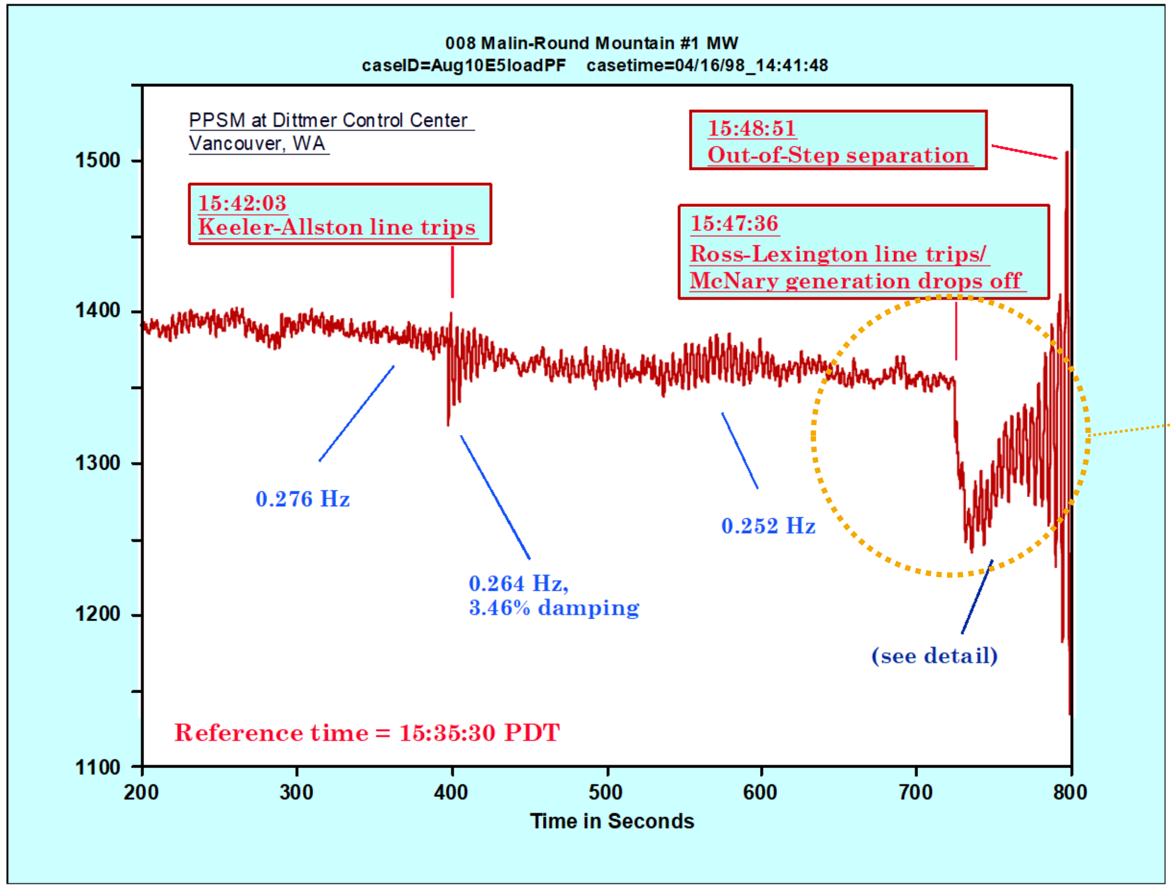
Time synchronized data can be gathered at reporting rates much faster than traditional supervisory control and data acquisition (SCADA) systems

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

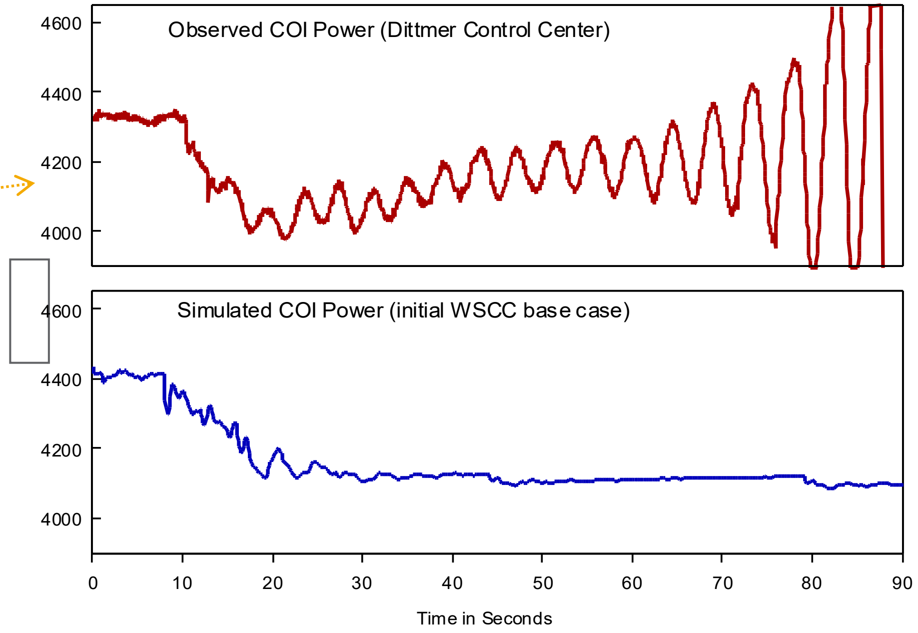
Unlike most SCADA systems, these emerging wide-area measurement technologies utilize Internet protocols to exchange measurement information.

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



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

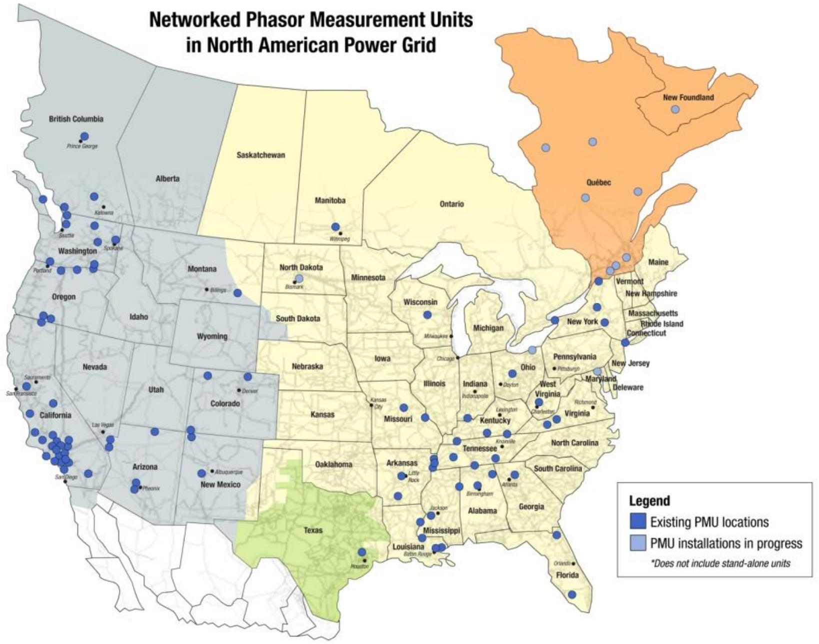
The North American SynchroPhasor Initiative (NASPI)

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.

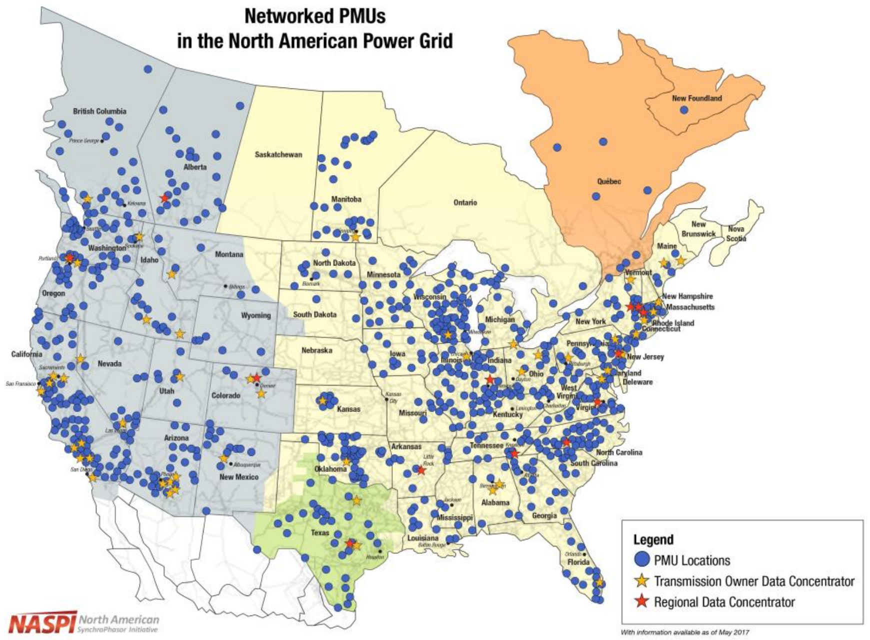
Current and emerging areas of emphasis/focus for NASPI:

- 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

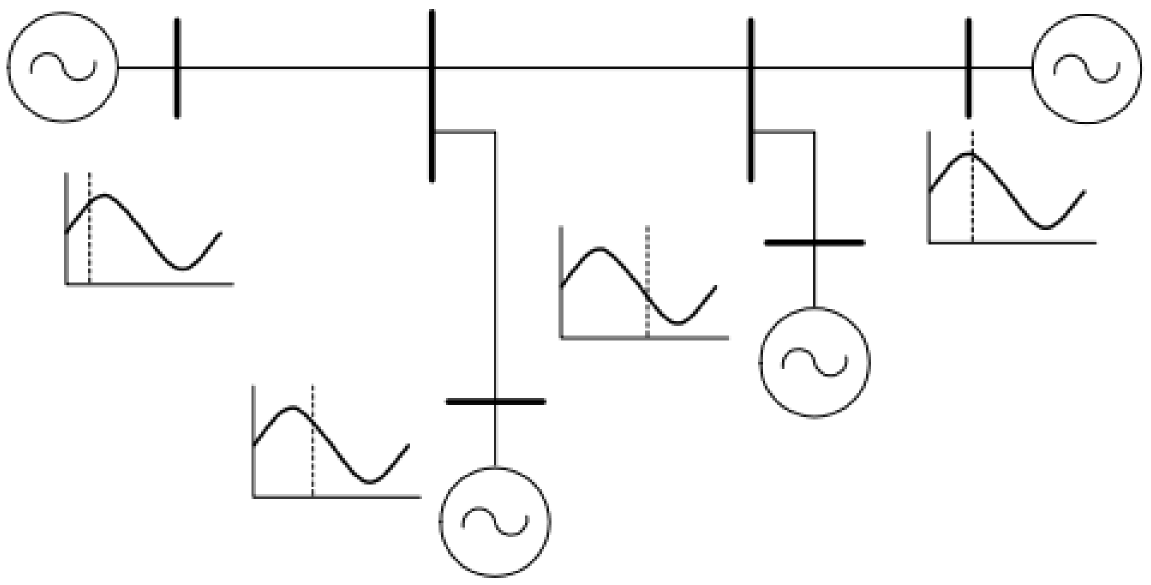


"Better information supports better - and faster - decisions."

NASPI Current Status

- Technical Task Teams (comprised of, and led by, key industry stakeholders)
  - Control Room Solutions
  - Data & Network Management
  - Distribution
  - Engineering Analysis
- Work Group Meetings
  - Most recent: April 2023, Phoenix AZ
  - Upcoming: September 26-27, Charlotte NC
    - ✓ Hybrid meeting option
- Monthly webinar series
- Information available at naspi.org

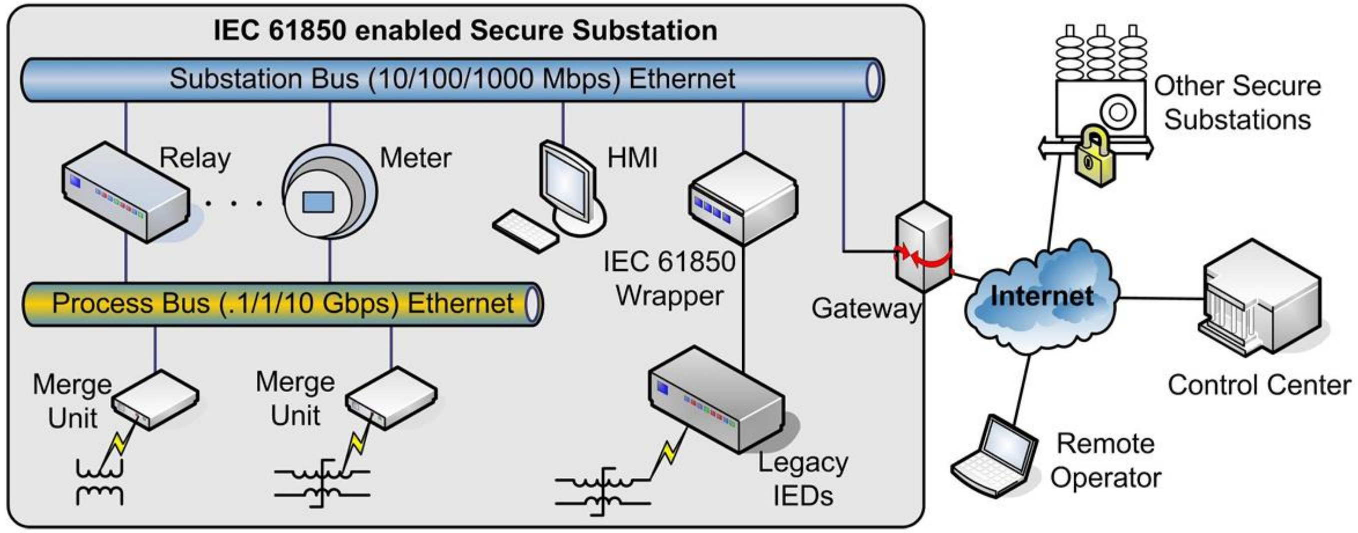
Synchrophasor Summary



- Time-synchronized voltage and current measurements that include the phase angle for the fundamental system frequency across a wide area
- Accuracy requirements (directly related to timing precision) are governed by IEEE and IEC standards
  - IEEE/IEC 60255-118-1-2018 (replaces IEEE C37.118.1)
  - Accuracy required: tens of microseconds
- The resilience consequences are highly dependent on how the measurements are being utilized:
  1. Feedback control (including protection)
  2. Feed-forward controls (e.g., state estimation)
  3. Situational awareness and visualization
  4. Off-line applications (e.g., event and engineering analysis)
- The criticality of these measurements have been increasing over the past several years

Sampled Values

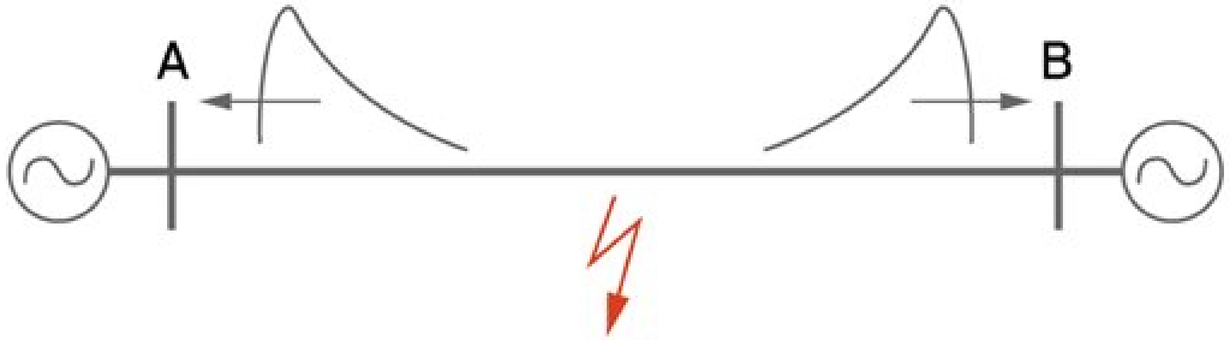
- Deployment of IEC 61850 for substation automation applications (emerging in North America) defines a protocol for information exchange between intelligent electronic devices and merging units with digital representations of analog quantities (e.g., voltages, currents)
  - Mostly intended for localized applications within a substation



- Time accuracy requirement: application-dependent, on the order of microseconds
  - IEC 61869-9 defines accuracy requirement ± 1 microsecond
- The protocol includes a description for sampled value measurements
  - Publisher/subscriber approach for sending time-stamped messages
- Global synchronization is necessary when information is coming from multiple clocks
  - Local applications may be possible without a global time reference
- Mis-operation of this scheme could have impacts on smart substation applications, including false operation of circuit breakers, etc.

Traveling Wave Fault Location (and Protection)

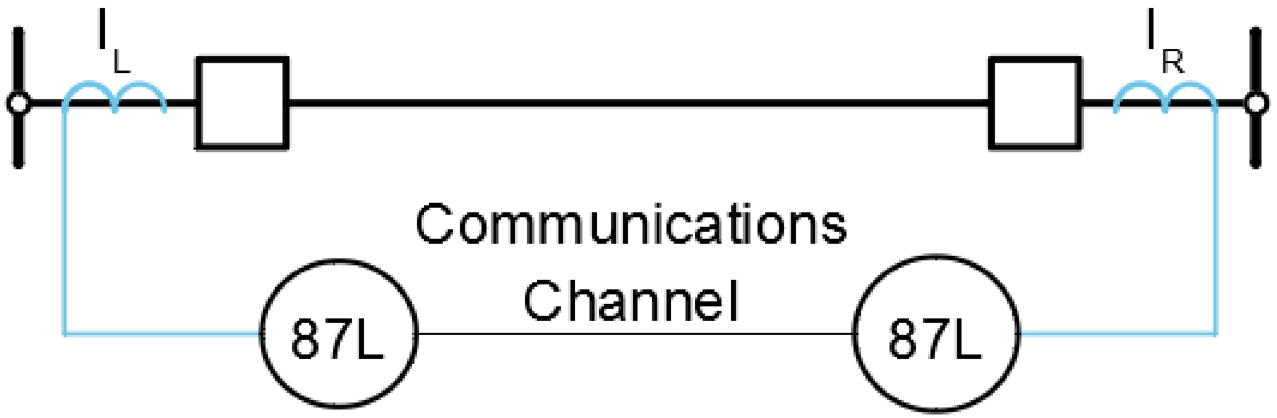
- Advanced protection scheme that determines the location of a transmission line fault by comparing the arrival time of the fault-induced transient at each terminal



- The scheme requires precise time synchronization; each nanosecond of error results in approximately 0.3m uncertainty resolving the location of the fault
  - Traveling waves propagate at approximately 98% of the speed of light
  - Accuracy requirements: approximately 500 ns to resolve within a tower-tower span distance
- Traveling wave location and/or protection schemes require synchronization between each end of the line (achieved through dedicated fiber optic links); accuracy to global time is less consequential

Line Current Differential Protection

- Protection scheme that utilizes highly reliable and low latency communications links between substations
- Compares time-stamped current measurements on each terminal of a transmission line, and operates protection scheme when a line fault is determined based on mismatch

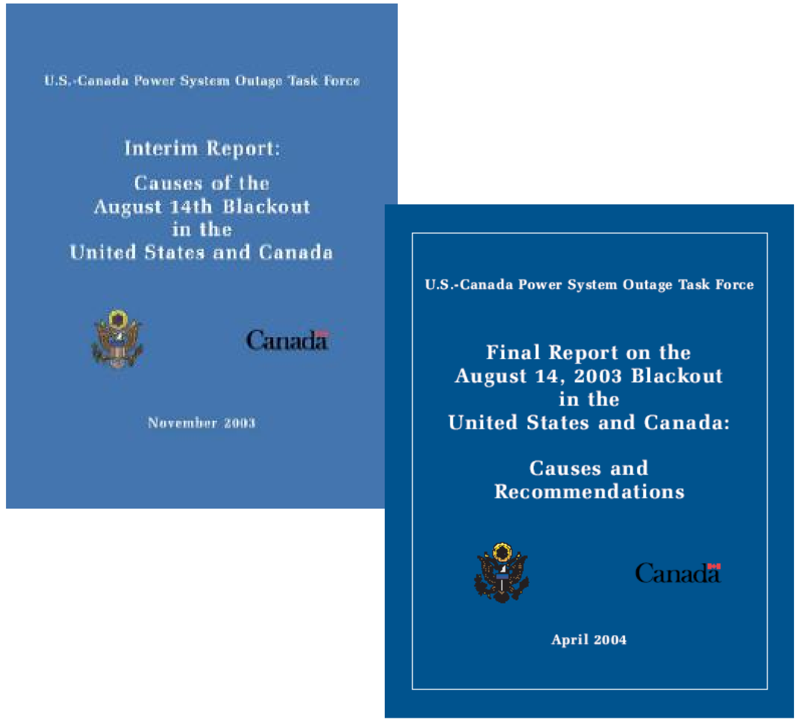


Line differential relays (device 87L) compare the local line current (I_L) and remote line current (I_R) to determine whether a line fault (i.e., short circuit) has occurred.

- The scheme depends on reliable time synchronization between substations
- There are schemes that depend on timestamp accuracy (typically resolved to the microsecond)
  - Potential for mis-operation with clock error

Disturbance Measurement

- Accurately determining the sequence of events is critical for event analysis (i.e., event analysis, or blackout investigations)
  - When multiple utilities are involved, time-aligning the data is critical
- In North America, the North American Electric Reliability Corporation (NERC) Protection and Control (PRC) reliability standard NERC PRC-002 requires better than ±2ms accuracy with respect to Coordinated Universal Time (UTC)
- Other jurisdictions also require adherence to this requirement



Next Steps

- Test and evaluate the effectiveness of alternatives to Global Navigation Satellite Systems (GNSS) for precision timing for critical applications
- Network-based timing (IEEE standard 1588: Precision Time Protocol) is rapidly emerging as a viable alternative for wide-area time synchronization
  - Commercial off-the shelf solutions are being tested and demonstrated for suitability for widespread scale-up
- Terrestrial radio (e.g., LORAN) has desirable characteristics, but is expensive to maintain and operate the transmitting towers
  - Opportunities may exist to leverage other Federal agencies
  - Recent tests have been undertaken by DHS, the Air Force will be conducting additional tests this winter
- Other commercially available satellite-based systems are available but have similar concerns related to jamming and spoofing as GNSS-based solutions
- Other technology options exist (e.g., cesium and rubidium clocks), but their affordability and effectiveness need to be demonstrated

Benefits to the Energy Sector

- This effort will serve as a lighthouse to help the energy industry solve a challenging problem
  - Vulnerabilities in time synchronization relying on GNSS are well documented
  - However, common industry practice continues to be reliance on GNSS for precision time synchronization applications in the energy sector
- Through testing and demonstration, the DOE will illustrate viable alternatives based on commercial off-the-shelf technology that can be implemented in the short term
- The results of this testing and demonstration will be broadly shared with industry as a catalyst to demonstrate the viability of robust alternatives to GNSS for critical timing applications
- Broader government-industry partnerships to standardize technology deployment alternatives will benefit from this testing and demonstration effort

Conclusions

- Precise timing is widely used to support synchrophasor applications in the electric power sector
- 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
- Other protection and control applications are increasingly reliant on wide-area precision timing
- Increased robustness of wide-area time synchronization is required to support these emerging applications

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Thank you