Timing Challenges in the Smart Grid

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Application requirements in power systems

In the Fall of 2016, NIST and IEEE held a workshop to gather stakeholders to discuss application requirements, key timing challenges in the smart grid and identify research priorities. Stakeholders participating in the workshop coordination identified the wide area precision timing requirements necessary in measurement, protection and control applications.

Table 1 – Grid timing uses and timing requirements

Application	Time Accuracy Requirement
Traveling Wave Fault Detection and Location	100 to 500 ns
Synchrometrology (synchrophasors) Wide Area Protection Frequency Event Detection Anti-Islanding Droop Control Wide Area Power Oscillation Damping (WAPOD)	Better than 1 μs
Line Differential Relays	10 to 20 μs
Sequence of Events Recording	50 μs to ms
Digital Fault Recorder	1 ms
Communication Events	
Substation Local Area Networks (IEC 61850 GOOSE)	100 μs to 1 ms
Substation Local Area Networks (IEC 61850 Sample Values)	1 μs

Distributed measurement systems (Fig. 1)

- Phase and time of day alignment to synchronize the system's real-time clock (RTC) to a traceable reference to time-stamp data for merging data and establishing a clear sequence of events
- Phase and/or time of day alignment to trigger a measurement event (e.g. start recording)
- Provide a frequency reference for driving the analog digital converter (ADC) sampling at consistently spaced time intervals
- Measurement message latency

Fundamental time scales in power systems

- 60 Hz frequency
- Speed of electromagnetic waves: varies as a percentage of the speed of light (theoretical maximum based on Maxwell's Equations)

Other time scales

- Renewable generation variability (Fig. 2)
- Load variability

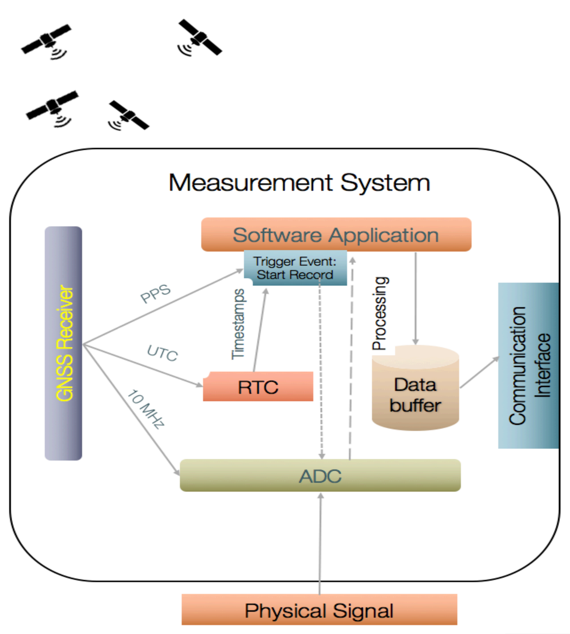


Figure 1. Uses of precision time in a measurement system

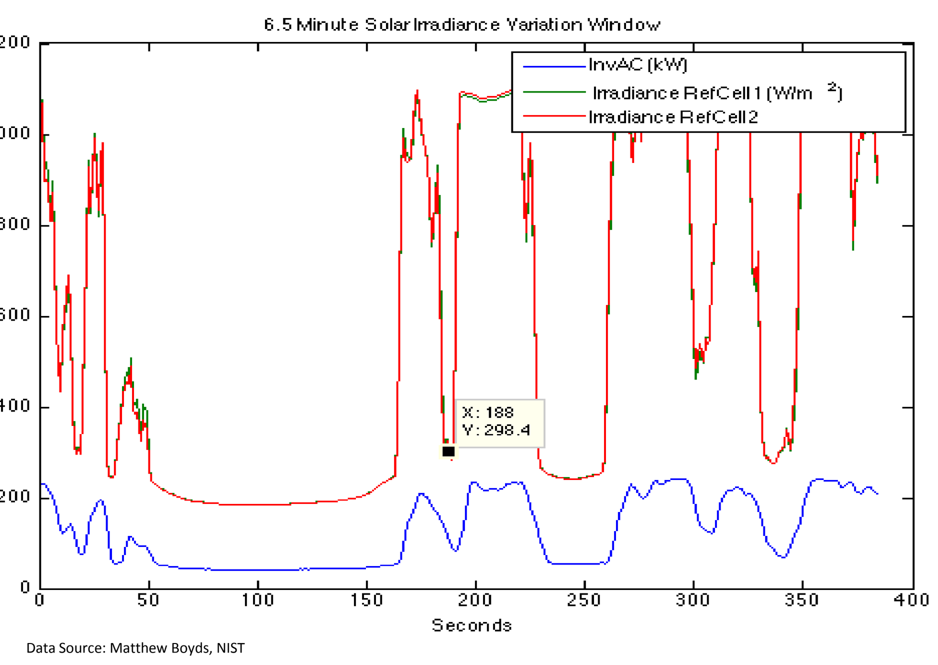


Figure 2. Photovoltaic generation variability

Temporal reasoning

Spatio-temporal analysis

Model validation and improvement

- Understanding location and time relationships in power systems models
- Electromechanical speed map: electromechanical waves propagate at different speeds and vary over time, etc.

Fault Detection and Location

- Goal to detect within 150 m (~500 ft).
- Speed of traveling wave is dependent on line parameters (an example is about 290 m / us)
- Ideal to have synchronization with accuracy of about 500 ns

Time frequency analysis

Expand signal processing from analyzing global regularity in time invariant frequency domain (Fourier) to time-frequency domain (short-time/windowed Fourier or Wavelets) , where local regularity can be analyzed for detection of singularities. In power systems, this equates to variations in power quality including voltage sags, momentary glitches, and other short duration transients.

Precision Timing Challenges

- **Time integrity assurance**
  Monitoring, detection and responsiveness to timing discontinuities and anomalies
  Accuracy measurements to traceable source
  Conformance of time information (GPS receivers, IRIG-B, PTP) in devices (device testing guidance)
  Interoperability (end-to-end system testing guidance)
  Security measures on devices restrict large time changes leading to challenges in testing leap second behavior, week rollovers, etc.
  Multiple sources of traceable reference time when the industry will need to rely for automated systems.
- **Resolving multiple time scales and handling time discontinuities**
  Resolving TAI, UTC and local time scales at the application level. System response to leap seconds, GPS week rollovers, etc.
- **Pertinent time performance metrics and impact analysis**
  Research to understand how time performance (accuracy, stability, etc) can impact power systems application performance in transmission and distribution applications
  Additional time performance metrics for devices in addition to time error may need to be reviewed (clock stability, holdover, etc.)
- **Business challenges:** Affordability, flexibility, and sustainability

Impact of timing errors on measurement uncertainty

Synchrophasor technology uses phasor measurement units (PMUs) synchronized to UTC to measure voltage and current waveforms, calculate, time-stamp, and send data at 30 to 120 reports per second to data concentrators and archives. In 2015, there were about 1800 PMUs in North America.

PMUs must be capable of receiving time signals synchronized to a traceable reference (UTC) with an accuracy of ± 1 µs.

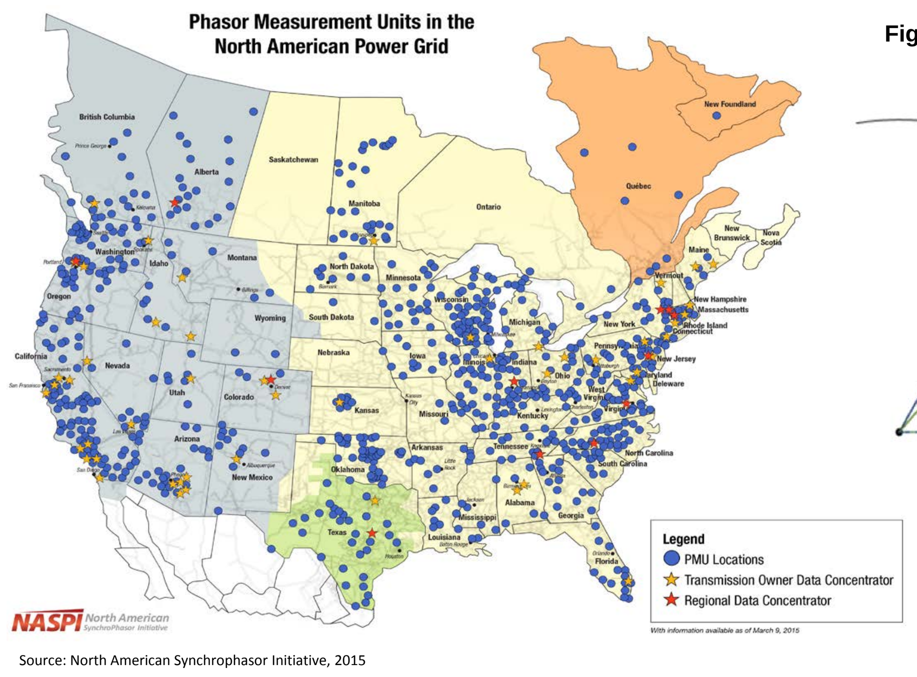


Figure 3. Total Vector Error Computation

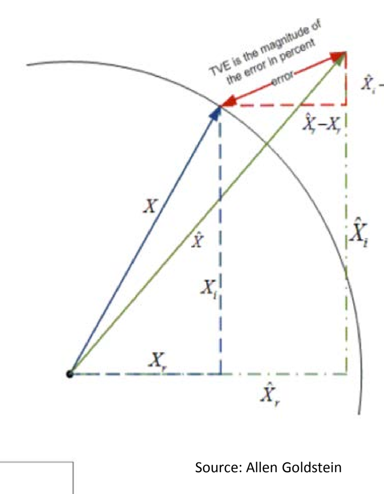
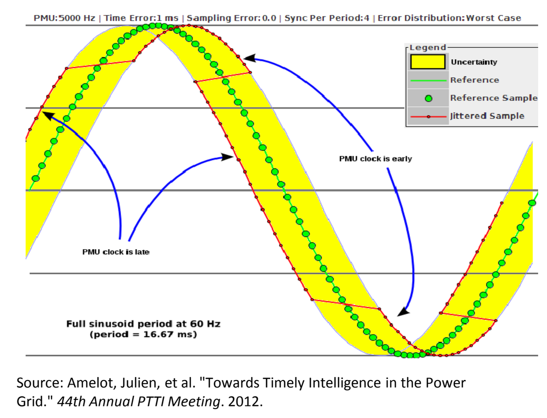


Figure 4. Time errors and impact on phase estimation uncertainty



Phasor Data Concentrators: Phasor data concentrators (PDCs) aggregate and time-align the phasor data from multiple PMUs. Since the data are time-aligned, they can be used to calculate real-time phase angles, oscillations, and dynamic grid events. This time-aligned, wide-area data is useful for monitoring and visualization, alarms and alerts, and off-line analysis.

A *phasor* is a representation of a voltage or current sinusoidal waveform used in alternating current (ac) power system analysis, where t represents an instant in time, ω is the angular frequency, X_m is the magnitude of the waveform, 110 volts for example, and ϕ depends on the time scale as shown in Equation 1 (IEEE C37.118.1-2011).

Equation 1 $$x(t) = X_m \cos(\omega t + \phi)$$

A PMU outputs time-stamped, estimated phasor representations to allow analysis of the electrical waveforms in downstream applications. Comparing other phasors in the electrical system must be done with the same time scale and frequency. Therefore, a *synchrophasor* is defined as the instantaneous magnitude, X_m, and phase angle, ϕ, relative to a cosine function at 60 Hz, the nominal frequency in North American systems, synchronized to the Universal Time Coordinated (UTC) time scale (IEEE C37.118.1-2011).

Equation 2 $$X = \left(\frac{X_m}{\sqrt{2}}\right) e^{j\phi} = \left(\frac{X_m}{\sqrt{2}}\right)(\cos\phi + \mathrm{j}\sin\phi) = X_r + \mathrm{j}X_i$$

Industry Priorities

Testing and Certification
- Device conformity
- End-to-end system interoperability
- Test methods development
- Conformity (IEEE ICAP) and interoperability test events (UCAIUG)

Monitoring and anomaly detection
- Real-time monitoring against traceable reference
- Characterize normal behavior
- Low-latency detection

Metrics and Impact analysis
- Protection control systems
- Measurement systems
- Microgrids
- Establish and parameterize performance metrics and requirements

Alternative sources and security
- Satellite (GNSS, Iridium)
- Ground-based radio (eLORAN, WWVB)
- Network (PTP, NTP)
- Time signals (IRIG-B, PPS)
- Chip scale atomic clocks
- Ensembling multiple sources

Achieving Resilient and Assured Timing

Standards

- IEEE PSRC and IEC TC 57 standards and guidance efforts in timing, including plug-fests and interoperability testing events
- IEC 61850-9-3 PTP Utility automation profile and UCA International Users Group Interoperability Test Event
- IEEE C37.238 PTP Power Profile and CASC
- IEEE C37.237 Draft standards requirements for time tags created by Intelligent Electronic Devices (IEDs)
- Certification Program (IEEE Conformity Assessment Program)

Industry Guidance

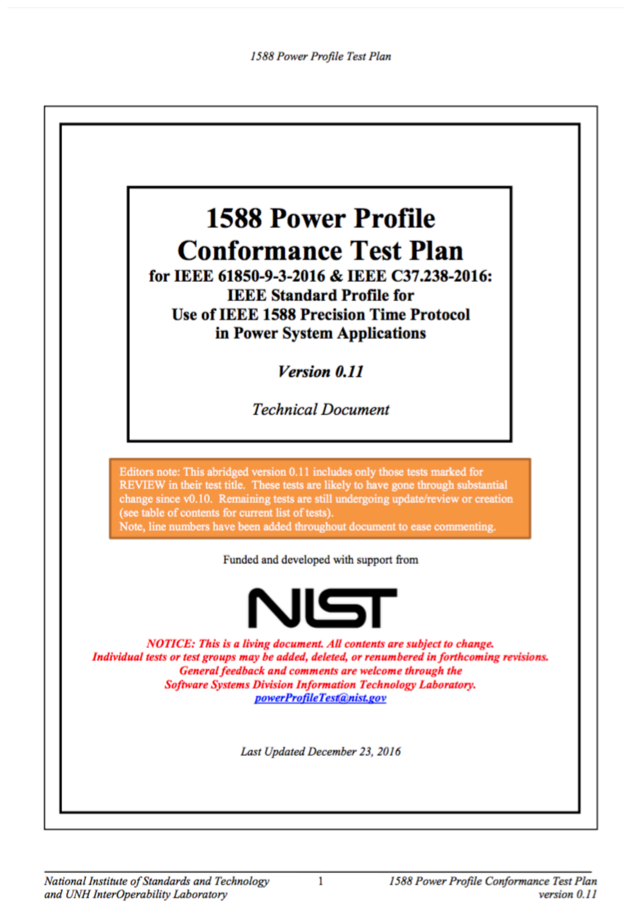
- PNNL/NASPI guidance for synchrophasor applications through the Time Synchronization Task Force (TSTF)
- Secure and resilient time distribution (DHS, NIST)
- Leap second guidance (DHS, NASPI, NIST)

Conformance and Interoperability Testbeds

- PTP Power Profile and Time Sensitive Networking Conformance and Interoperability Testbed (University of New Hampshire / InterOperability Laboratory)
- Power Systems Applications Hardware/Software Standards Interoperability (PNNL)
- Microgrid Standards Interoperability (NIST)

Time Aware Systems Enabling Correct-by-construction

- Distributed CPS Timing Testbed (Arizona State University)


1588 Power Profile Test Plan

1588 Power Profile Conformance Test Plan
for IEEE 61850-9-3-2016 & IEEE C37.238-2016:
IEEE Standard Profile for Use of IEEE 1588 Precision Time Protocol in Power System Applications
Version 0.11
Technical Document

NIST

Last Updated December 23, 2016

References:

NIST/IEEE Timing Challenges in the Smart Grid Workshop

NIST Special Publication SP 1500-08 Timing Challenges in the Smart Grid Workshop Report