# Electric Power Systems and GPS

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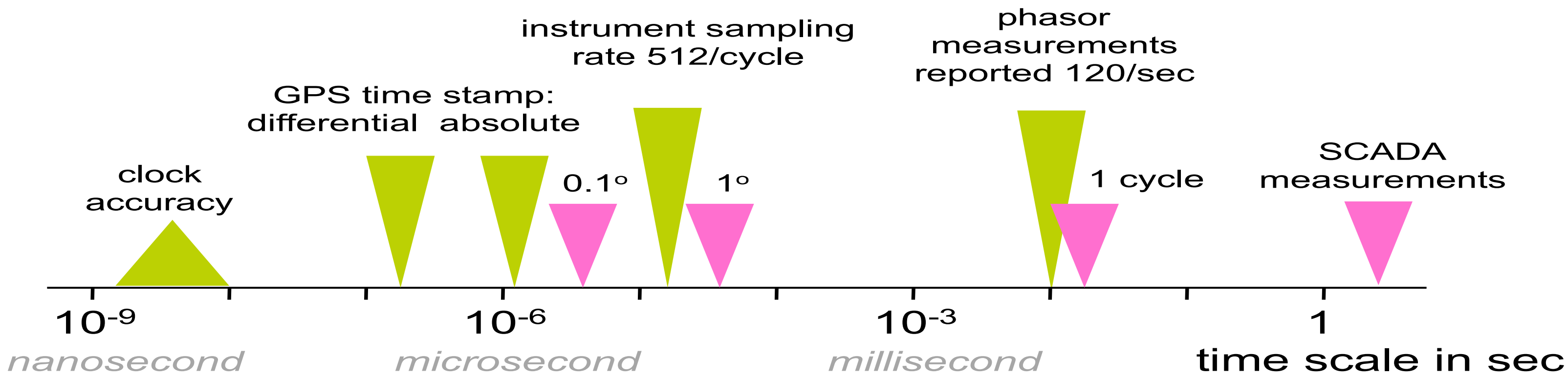
NASPI North American SynchroPhasor Initiative

# Overview and punchlines

- Power system owners and operators use GPS for navigation, position and timing.
- If we lose GPS today, it will complicate (higher cost, longer duration, lower efficiency), but not kill, grid operations.
- GPS and alternate time sources (and the ways we deliver and use them) need to become more reliable for time-synchronized applications to become mission-critical in the future.

# Time & power measurement resolution




Micro-PMUs sample at 512 samples/cycle

Grid standards require event time data synchronized at 2 ms accuracy

Phasor measurement units sample 30 to 120 samples per second

SCADA samples every 4 to 6 seconds

60 Hertz (Hz) = 60 cycles/second = frequency of alternating current sine waves on the North American power system

1 cycle = 1/60$^{th}$ second = 16.67 milliseconds = duration of one sine wave cycle at 60 Hz

Lightning strikes (frequent cause of line faults) last a few microseconds

Voltage sags last from a few milliseconds to several cycles

Relays operate in 1 to 1.5 cycles and breakers interrupt current in 1.5 to 3 cycles, so total fault clearing time could be up to a few hundred ms

Household clocks blink after momentary line interruptions up to two seconds long

# Key grid timing use technologies

Most grid time-using devices use GPS antennas as the timing source, and distribute time within the substation primarily using copper cabling (IRIG-B), with growing use of Ethernet (IEC 1588).

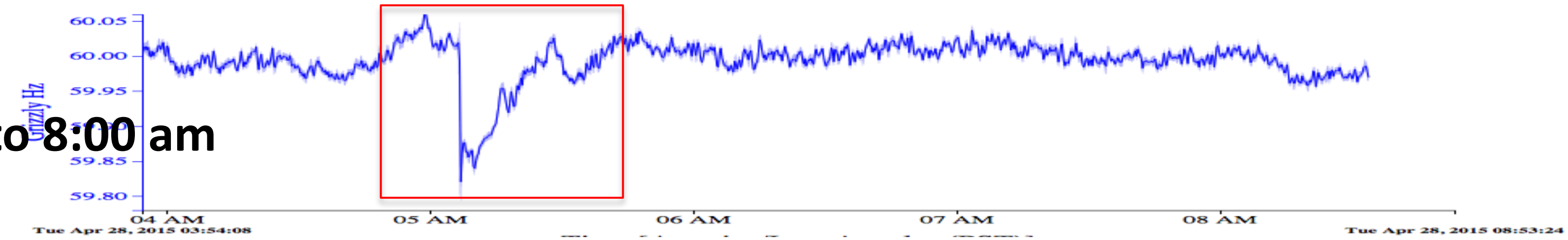
- Relays – system protection workhorse. Monitors local grid conditions down to the microsecond, and actuates control operations (including breaker operation) for line trips and other system protection measures. Time-synchronized with GPS (mostly) or SONET over fiber.
- Synchrophasor technology – Phasor Measurement Units (PMUs) do high-speed grid monitoring, time-synchronized to UTC with microsecond accuracy. Used mostly at transmission level. Now sampling at 30 to 120 samples/sec; timing must be accurate within 1 µs. When timing delivery mechanisms become more reliable, synchrophasor technology can become a mission-critical tool.
- Micro-PMUs being developed for distribution system monitoring, analysis & control.

# Power system GPS (or PNT) uses

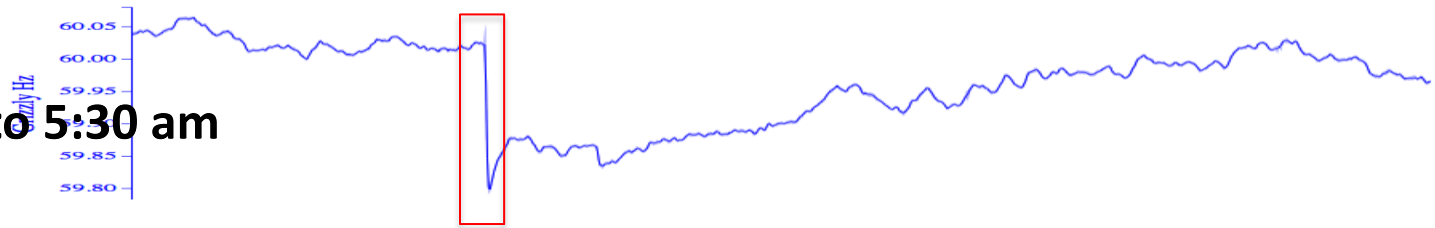
- Position & navigation
  - Fleet direction and tracking
  - Mobile crew management
  - Customer information systems
  - Physical asset tracking & management
  - LIDAR for vegetation management
  - LIDAR and 3D modeling for substation and line construction
- Timing
  - Absolute time – system protection, including fault location and fault clearing
  - Synchronized time – see slide 8
- Also heavy telecom and IT network dependence, which rely on timing delivery services

# Why time resolution matters on the grid -- same event, four time slices

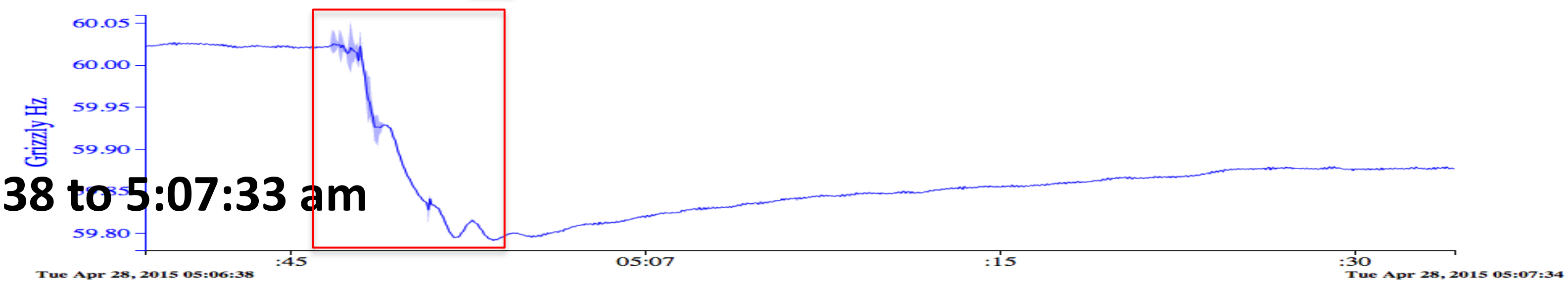
4:00 to 8:00 am



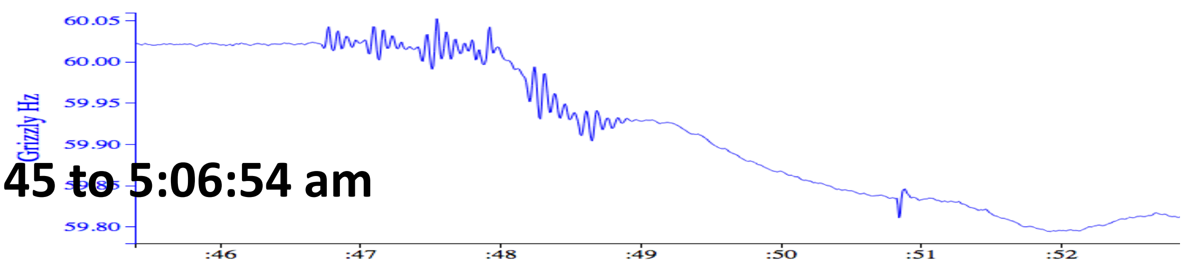

4:58 to 5:30 am




5:06:38 to 5:07:33 am




5:06:45 to 5:06:54 am




micro-PMU data from Lawrence Berkeley National Laboratory, viewed through the Berkeley Tree Database (BTrDB) plotter at different time resolutions

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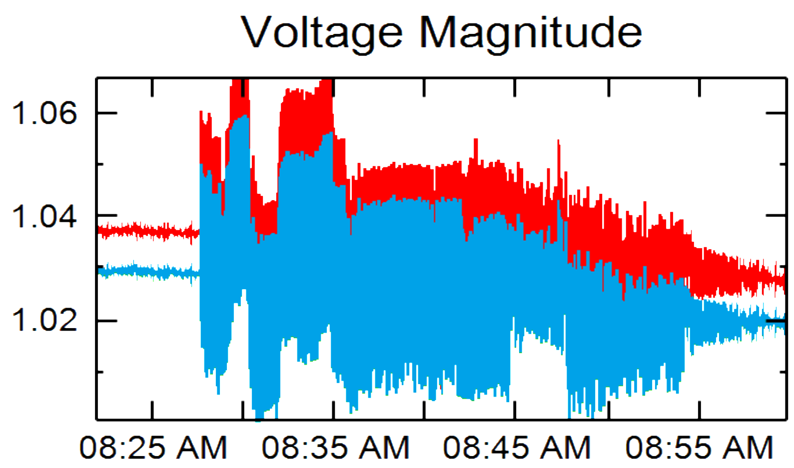
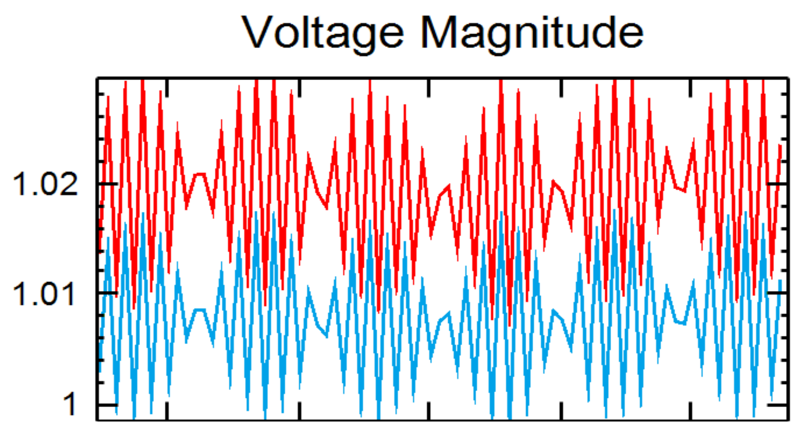
# Why time resolution matters on the grid – same event, two time slices




(35 minutes)

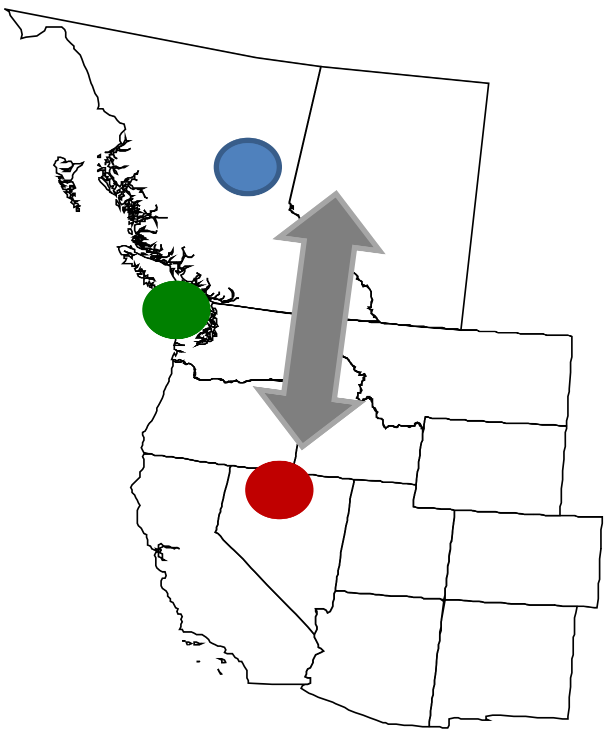


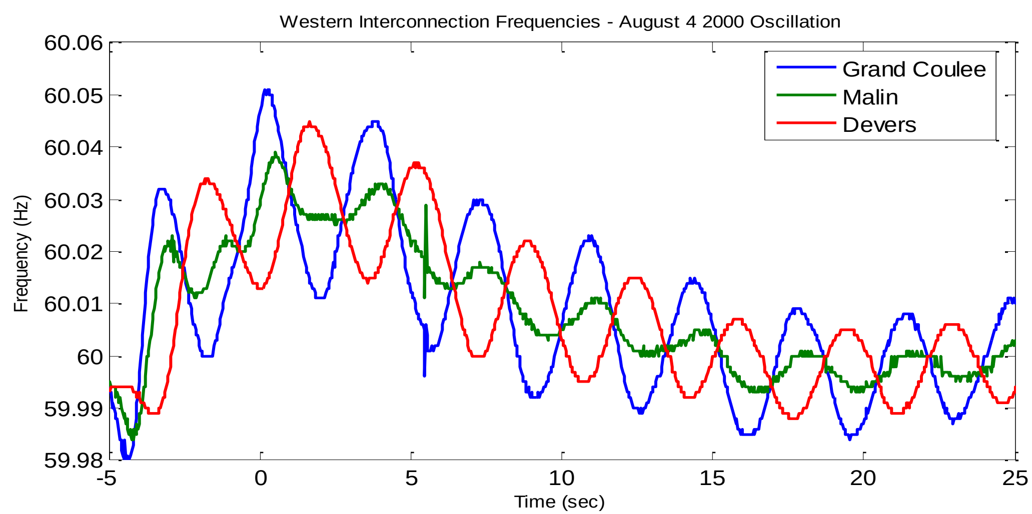

(2 seconds)

Source: OG&E, "Synchrophasors at OG+E," Austin White, IEEE PES GM 2016

# Inter-area oscillations in Western Interconnection

Aligning synchronized wide-area measurements from multiple locations reveals the power system's dynamic state; you can't see and analyze these oscillations from slower SCADA data or from unsynchronized local PMU measurements.  Timing errors cause false conclusions about grid conditions.





# Power system uses of time-dependent data

## On-line, real-time uses (current and emerging uses)

Absolute time

- Fault detection & location (100 ns)*
- Fault clearing
- Lightning correlation (1 ms)
- Synchronize a generator to the grid

Synchronized time

- Frequency management
- Voltage management*
- Wide-area situational awareness
- Automatic event detection & notification*
- Oscillation detection
- Islanding control
- Black-start system restoration
- Integrate distributed resources, including rooftop PV and EVs*
- Dynamic line management*
- Remedial action schemes (<50 ms)*

## Off-line uses

- Power system modeling
  - Generators
  - Loads
  - System model
- Event reconstruction and analysis (1 ms)
- Equipment mis-operations identification and diagnosis
- Baselining (statistical event characterization) to develop operator decision support tools*
- Disaggregate distributed generation from loads behind the meter*

*** = emerging uses**

# The power system today and tomorrow

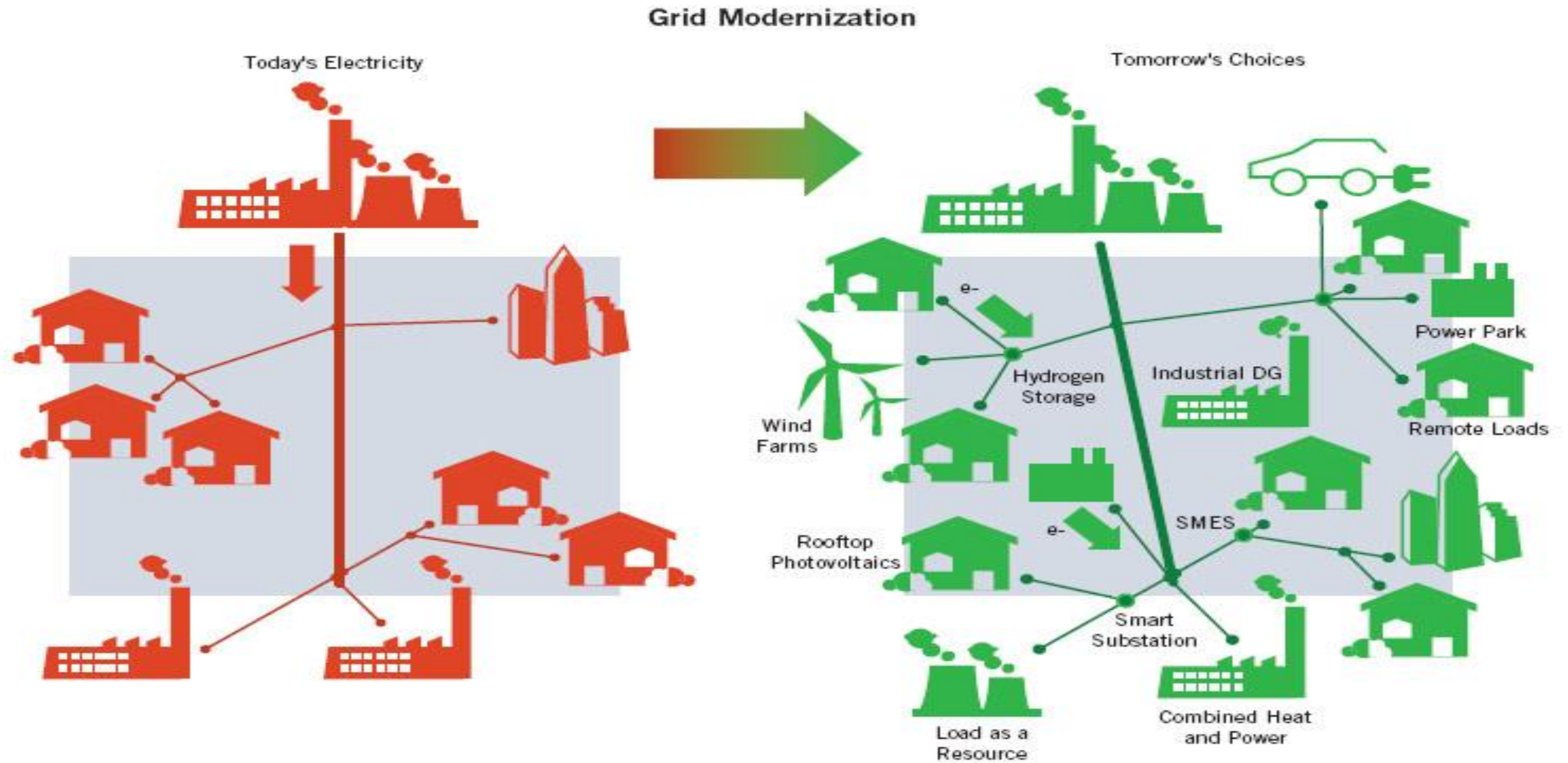



**Fig. 1. The IEEE's version of the Smart Grid involves distributed generation, information networks, and system coordination, a drastic change from the existing utility configurations.**

One-way power flows, limited resource diversity, centralized management moving toward two-way power flows serving diverse loads and resources with high coordination and IT and communications requirements

Source: IEEE via https://smartgrids.wikispaces.com/Smart+Grid+Future+Capabilities

# Some of the ways timing goes bad from the grid user's perspective

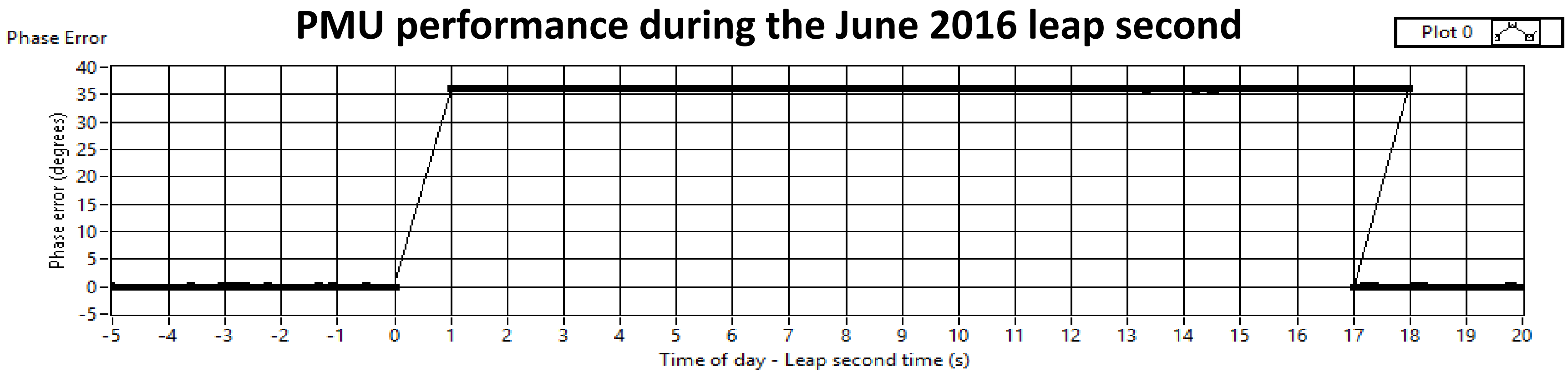
- From space
  - Ionospheric problems – sunspots, geomagnetic disturbances
  - Events – leap seconds, satellite constellation changes
- On-site
  - GPS receiver – poor quality, software bugs, no firmware updates, bad location, local jamming or spoofing or other radio interference, lost wire to the PMU, no correction for PNT broadcast problems
  - PMU – poor interoperability with GPS receiver, slow firmware patches, lost wire to GPS receiver, sloppy program for time-handling, no detection of timing problems, no back-up time source
  - In substation timing delivery (rare) – problems with cabling or ethernet distribution of time signal to slave clocks
- Phasor Data Concentrator and applications – inadequate detection of timing anomalies or gaps and computational errors resulting from those problems. Also sometimes inadequate timing standards and protocols…

# What happens to synchrophasor measurements if GPS goes bad?

- If there is an error or spoof of the time signal to a phasor measurement unit (PMU), that error will cause false calculations of phase angle and mis-alignment of measured grid conditions relative to other PMUs
- In the case of the leap second:
  - Where the GPS clocks skipped the second or were early/late, PMU measurements were too early or too late, causing PDCs to ignore the PMU measurements
  - Where there were duplicate time stamps, there were "duplicate" PMU measurements
  - Phase angle error depends on accurate time information; bad time stamps mean erroneous phase angle calculation

*** These are all PMU or PMU-clock problems, not GPS problems – but the user doesn't recognize that…

# Calculating phase angle with a time error




- Above -- for 17 seconds, it appears that the phase has a 36 degree error (at 59.9Hz)
- Note that there are no reports for the second immediately following the leap second, and there are two sets of reports for the second between 17 and 18 seconds after.
- And different PMU models handled the leap second differently.
- Due to inconsistent time-determination methods (below), some PMUs in India reported wildly fluctuating phase angles.

Source: "2015 NIST Investigation of PMU Response to Leap Second", Allen Goldstein, DJ Anand & Ya-Shian Li-Baboud, NIST, March 2016


Source: POSOCO, P.K. Agarwal, "Encounter with the Leap Second," NASPI Work Group, March 23, 2016

# Power system punchlines

- Timing errors from the time source can cause incorrect synchrophasor data
  - Such errors can create false analytical conclusions and in the future could drive undesirable and possibly dangerous automated grid operations with synchrophasor-based controls
- The power sector needs to protect future grid operations  with better timing tools and practices to improve robustness and resilience
  - We need to assume that PNT could be unreliable at both source and receiving points
  - We need to start implementing measures to assure accurate, reliable time stamps against multiple failure modes

# Some timing remedies and options

At the PNT level:

- Improved signal robustness checks
- Multi-frequency – L1 C/A, L2C, L5 (but multi-frequency receivers are expensive)
- Multi-system – GPS, GLONASS, GALILEO, eLoran, good internal oscillators
- Multiple receivers
- Jamming, spoofing and interference detection and/or prevention

GPS-independent networks:

- Telecom network is capable of time transfer -- avoids dependence on satellites and transmitter sites and requirement for large receiver network installation and maintenance
- Network-distributed time can receive accurate time from multiple sources (GPS, NTP, CDMA, PTP), some IRIG-B
- Distributed clock networks, some IEEE 1588
- Holdover clocks in key devices for short-term back-up

# What we're doing about it – NASPI Time Synchronization Task Force

Scope – Time synchronization awareness and problem-solving for electric sector, with synchrophasor focus

- Document problems of current PNT solutions
- Identify specific, near-term solutions and mitigations that can address multiple failure causes (redundant timing sources, better installation and maintenance practices, detection of bad or anomalous time signals, specs for good-quality equipment, etc.)
- Develop and share how-to information for these solutions
- Recommendations for longer-term research needs (timing problem detection, equipment interoperability, standards updates, etc.) within grid sector and beyond

# Questions?

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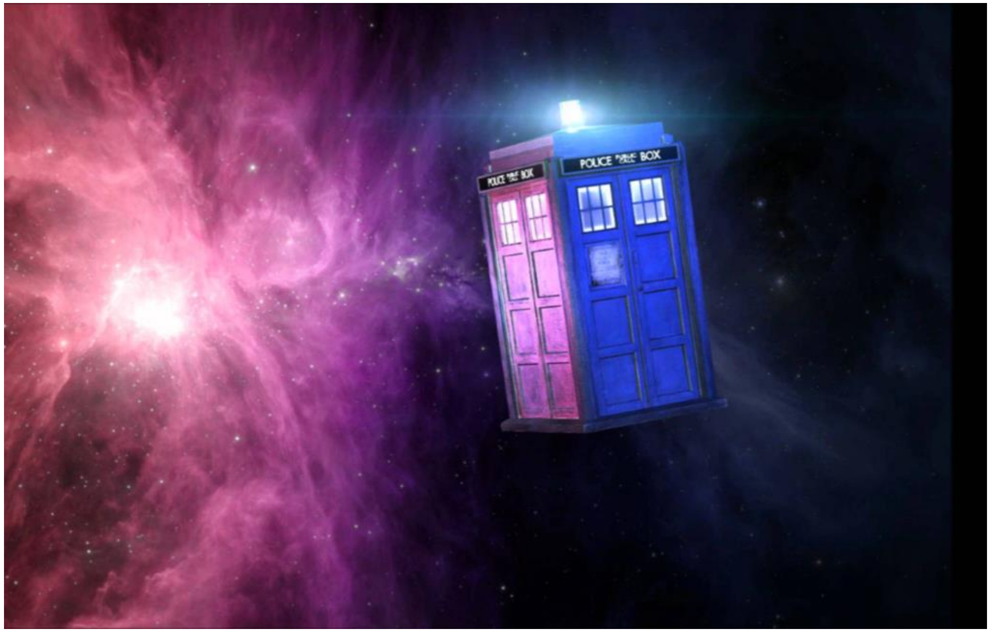


Source: BBC