NASPI Webinar
Preparing for the December 31, 2016 Leap Second

Summary – why the leap second matters

- Recent timing events – including past leap seconds -- have revealed many different ways that timing systems fail. For synchrophasor systems, timing problems include poor clock processing of the leap second and erroneous PMU time-stamps.
- Past leap second events have caused PUC data losses, PDC crashes, random or jumpy phase angle measurements, and inaccurate analytical reports of grid conditions.
- Other IT systems don't always handle leap seconds effectively, which could compromise some of your IT or communications functionality.
- The next leap second insertion will occur at 23h:59m:60s UTC on December 31, 2016 (adjust for your time zone!).

Summary -- how to prepare for the leap second

1. **Ask your clock, GPS receiver, PMU and PDC vendors for firmware updates that will handle the leap second consistent with C37.118.1-2011. Implement the updates for every single PMU, GPS receiver and clock on your system.**
2. Consider using one or more independent, non-GPS clocks with a tested leap second solution as a back-up, correct timing source.
3. Have a plan for monitoring your synchrophasor system and other timing-dependent substation elements to spot any problems with leap second implementation. Start monitoring hours before the scheduled event.
4. Warn your engineering and control room staff about when the leap second will occur (time zone-adjusted). Educate them on possible signs that something on your system isn't handling the leap second event properly so they don't react to a false problem.
5. Know how to turn off or reset specific system elements if they mis-perform or fail due to a leap second problem.
6. Report any PMU data problems to your Reliability Coordinator immediately.
7. If you're using NTP in your substations or IT systems, ensure that your NTP software is updated to handle the leap second.
8. Prepare for the leap second on all of your IT and communications functions.
9. Please report any synchrophasor leap second problems to NASPI.

Introduction

- Electric systems use time distribution in many ways:
  - In substations to serve relays, PMUs, DFRs, traveling wave fault locators, and meters
  - Embedded throughout IT and communications systems
- Recent timing events – including past leap seconds -- have revealed many different ways that timing systems fail. These can compromise the performance of synchrophasor systems and other time-dependent systems.
- The next leap second insertion will occur at 23h:59m:60s UTC on December 31, 2016.

Timing users beware!

- International standards bodies decide when to insert the leap second and the U.S. GPS broadcasts the leap second correction information – but it’s up to users to assure that all their hardware and software recognize and manage the leap second correctly.
- We can reduce the number and causes of timing failures through better preparation. This will help make all timing-dependent uses – including synchrophasor systems -- more reliable and trustworthy.

Webinar agenda & presenters

- Intro – Jeff Dagle (PNNL)
- Leap second background – Dr. Marc Weiss (National Institute for Standards & Technology)
- NIST 2015 study of PMU leap second handling – D.J. Anand (NIST)
- Causes of leap second problems for synchrophasor systems – Robert Orndorff & Kyle Thomas (Dominion Virginia Power)
- Q&A
- Impacts of the leap second problem on synchrophasor analytics – "Frankie" Qiang Zhang (ISO-NE)
- Recommendations for synchrophasor system owners – Alison Silverstein (NASPI)
- Q&A

Background on the leap second

Dr. Marc Weiss

NIST

National Institute of Standards and Technology

Technology Administration, U.S. Department of Commerce

What and when is a leap second and how is it implemented

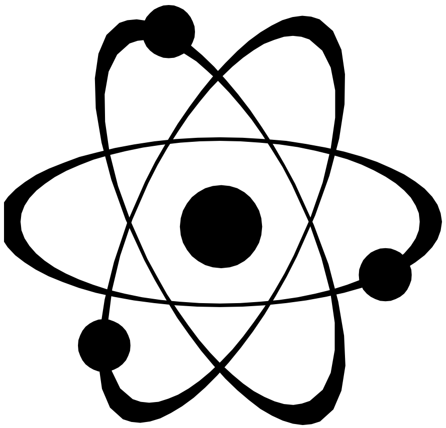
- Atomic Time vs. Earth Time produces leap seconds

- Officially, a leap second is the 61st second numbered #60 of a minute. Digital systems often have problems implementing this. There is a standard way for PMU's to implement it, but there can often be mistakes.

- The leap second on December 31, 2016 will happen simultaneously at 23:59:60 UT, hence at different hours in different time zones.

- GPS has a standard way of handling leap seconds.

Leap Seconds: Atomic vs. Earth Time



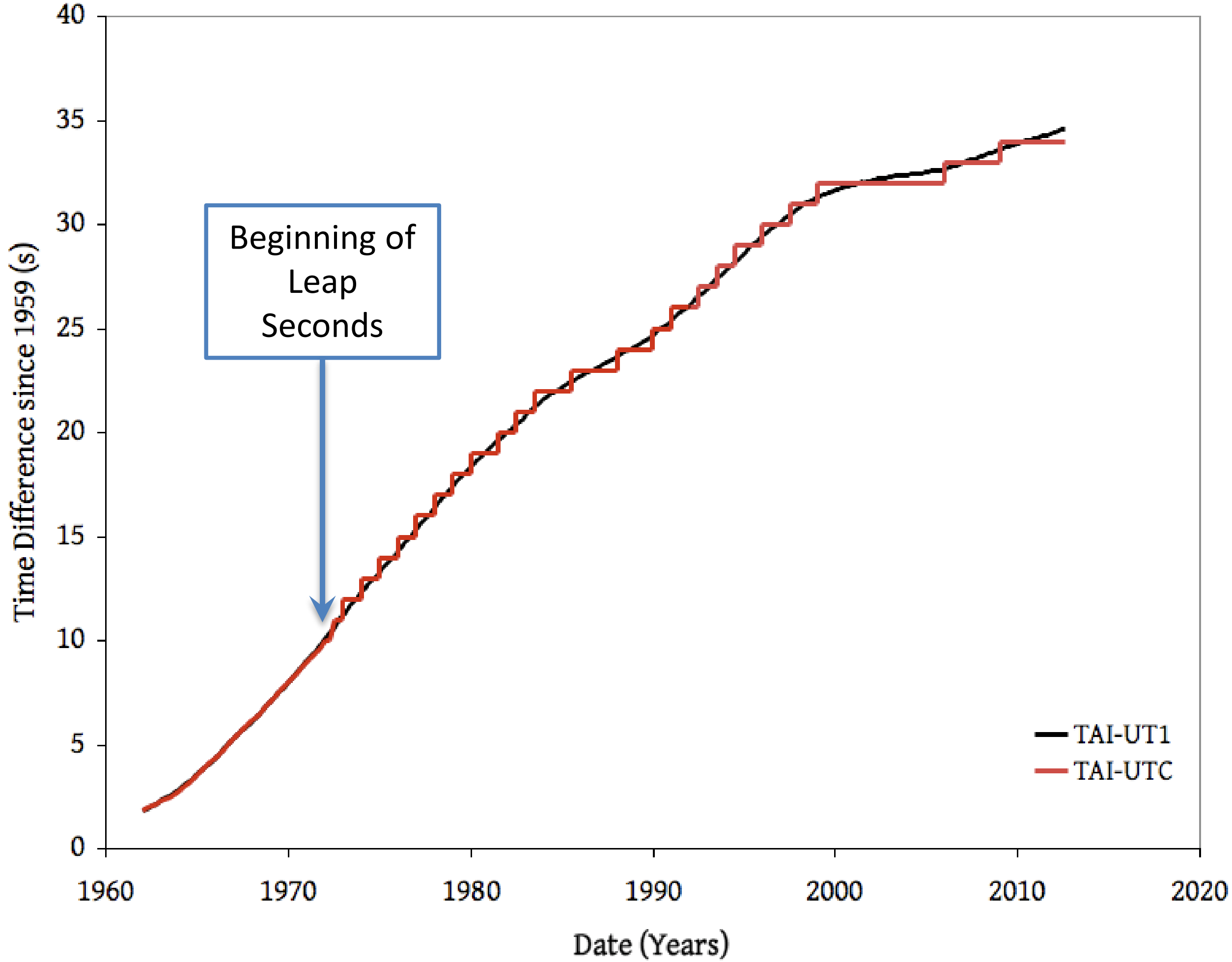
versus

- Coordinated Universal Time (UTC) year (based on atom) is about 0.9 s smaller than UT1 year (based on Earth).
- Leap seconds are added (or subtracted) to UTC as needed to keep |UT1 –UTC| ≤ 0.9 s

Leap Seconds Vary a Lot!

International Atomic Time (TAI) has no leap seconds

UTC is coordinated to have the rate of TAI, but stay close to UT1



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When will the leap second happen?

The next leap second will be inserted on December 31, 2016, at 23:59:60 UTC, to keep our official time of day close to the mean solar time of the Earth's rotation.

The sequence of dates and times will be:

- 2016 December 31, 23h 59m 59s UTC
- 2016 December 31, 23h 59m 60s UTC (this is the extra leap second)
- 2017 January 1, 0h 0m 0s UTC

When will the leap second occur for you?
December 31 23:59:60 UTC=

- 18:59:60 Eastern Standard Time (North America)
- 17:59:60 Central Standard Time (North America)
- 16:59:60 Mountain Standard Time (North America)
- 15:59:60 Pacific Standard Time (North America)

GPS Implementation of Leap Second

- GPS has two important time scales: GPS Time (no leap seconds, always TAI-19 s, i.e. UTC in Jan 1980) and UTC(USNO) via GPS
- GPS= UTC + 17 s now, will be +18 s on January 1, 2017, after UTC adds another leap second
- A message in the GPS data indicates a coming leap second, and its date
- Systems sometimes make mistakes in handling this information

Digital systems have problems implementing the 61st second

- A leap second is added as a 61st second numbered as second 60 at the end of either June or December (usually)
- A digital system that cannot represent second 60, may give the following time tags during a positive leap second:
- UTC — Digital System

UTC		Digital System
– Day N 23:59:58	C	(23:59:58)
– Day N 23:59:59	C+1s	(23:59:59)
– Day N 23:59:60	C+1s	(23:59:59)
– Day N+1 00:00:00	C+2s	(00:00:00)

- So a digital system may repeat time tags for second 59 over two consecutive seconds
- PMUs should follow standard IEEE C37.118.1-2011, though there are many ways mistakes can be made!

2015 NIST Investigation of PMU Response to Leap Second

DJ Anand
Allen Goldstein
Ya-Shian Li-Baboud

National Institute for Standards and Technology


NISTIR 8077

Investigation of PMU Response to Leap Second: 2015

Allen Goldstein
Dhananjay Anand
Ya-Shian Li-Baboud

This publication is available free of charge from:
http://dx.doi.org/10.6028/NIST.IR.8077

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

This publication is available free of charge from:
http://nvlpubs.nist.gov/nistpubs/ir/2015/NIST.IR.8077.pdf

Conclusions first:

When the 2015 leap second occurred:

- 8 PMUs and 1 GPS receiver were tested
- 4 of the PMUs got their time via IRIG from the GPS receiver
- The other 4 use internal GPS receivers.
- All of the PMUs had issues and were not in compliance with IEEE C37.118.2 immediately following the leap second.
- The GPS receiver also had an issue immediately following the leap second.

What happened to the Receiver?

- The GPS receiver used in this investigation did not fully comply with IEEE-1344[1,2] in two ways:
  - The BCD second and SBS count repeated 23:59:59 and did not progress to 23:59:60 before going to 00:00:00[3].
  - The Leap Second Pending bit transitioned from 0 to 1 at 23:58:59, (one second early) and from 1 to 0 during the repeated 23:59:59, one second before the transition to 00:00:00 as specified.

1. IEEE-1344 is the common name for the extension to IRIG published in the PMU standard. The latest version of this is in Annex D of C37.118.1-2011.
2. Some technical changes happened between 1999, 2005, and 2011, use the 2011 standard!
3. Specified by IEEE-1344 but the IRIG standard is ambiguous on SBS behaviour.

What did the PMUs do?

Table 10: Summary of PMU response to leap second

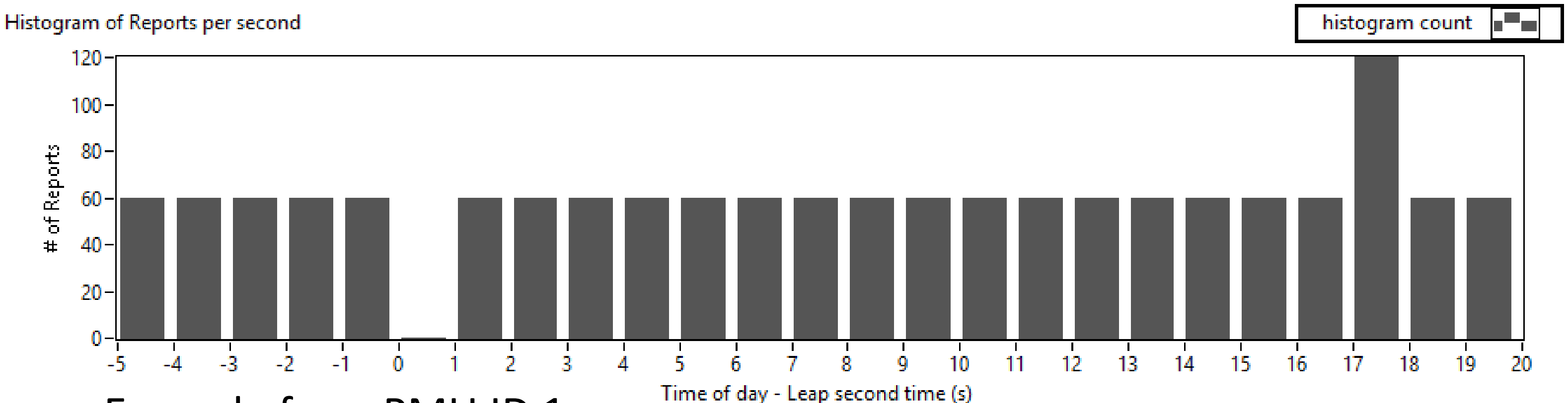
PMU ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Total period of time the SOC was not synchronized with UTC	17.000 s	47.000 s	4.000 s	0.150 s	1.933 s	4.000 s	2.000 s	3.000 s †
Pending bit was set at all	no	no	yes	yes	no	no	no	yes
Pending bit was set and cleared at the correct time	no	no	no	no	no	no	no	no
Occurred bit was set at all	no	no	yes	yes	no	no	no	yes
Occurred bit was set and cleared at the correct time	no	no	no	no	no	no	no	no
Number of seconds of TOD for which there were less the proper number of reports	1	1	many ††	1	1	1	1	1
Number of seconds of TOD for which there was more than the proper number of reports	1	1	1	1	1	1	1	1

† PMU ID 8 was not synchronized with UTC for 1 second beginning 59 seconds before leap second and for 2 seconds immediately following leap second.
†† PMU ID 3 Beginning at the leap second and continuing at the time of writing, PMU ID 3 has sporadic periods where there are only 46 reports during a second. 14 reports are missing during these seconds.

Of the 4 PMUs using IRIG, only one of their behaviors could directly relate to the GPS receiver's incorrect behavior, the other 3 had issues as not directly attributable to the problem in the IRIG

What happens when the time is not synchronized?

- "Missing" reports (the time never happened)
- "Duplicated" reports (reports that should have had a different time stamp)

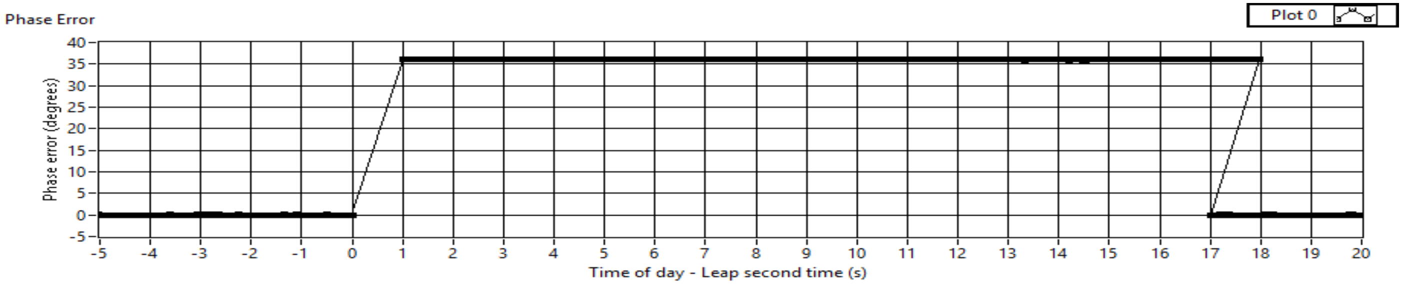


Example from PMU ID 1

What about the phase angles?

For reports with incorrect time stamps, the phase angle "error" depends on the system frequency

- At nominal frequency the phase angle is not changing.
- So we ran the test at a constant 59.9Hz system frequency so you can see the phase angle "error"



Again, an example from PMI ID 1

- For 17 seconds, it appears like 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.

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What should be done about this?

- IRIG standard is ambiguous about leap second responses so the ambiguities should either be clarified or vendors using IRIG will need to respond to every possible interpretation.
- All vendors need to test their devices for response to leap second.
  - This may mean expensive GPS simulation hardware will be needed for those devices with GPS receivers.
- Think hard about our critical infrastructure without testing of LS response.
- Read the NISTIR report and learn from the experiences of others.

Impact of June 2015 Leap Second on DVP Synchrophasor System

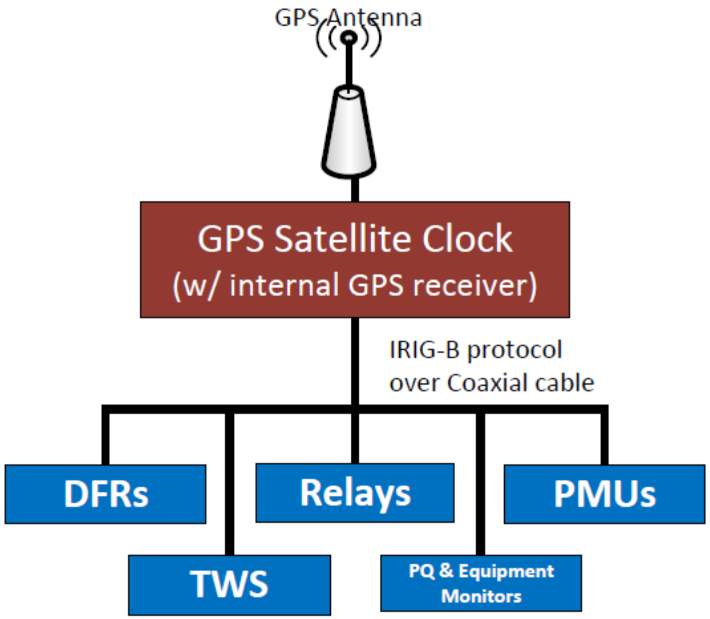
NASPI Leap Second Webinar
December 2, 2016

Robert M. Orndorff
Kyle Thomas

Dominion Virginia Power

Current Timing

- A GPS satellite clock installed at all Dominion transmission substations (100kV and above) and many distribution substations.
  - Located inside substation control houses, these are stand-alone GPS clocks, which have an internal GPS receiver chip
- Time synchronization is provided to many substation devices from the GPS clock via IRIG-B over coaxial cable
  - Includes Digital Fault Recorders (DFRs), protective relays, Phasor Measurement Units (PMUs), Traveling Wave fault locators (TWS), meters, and more



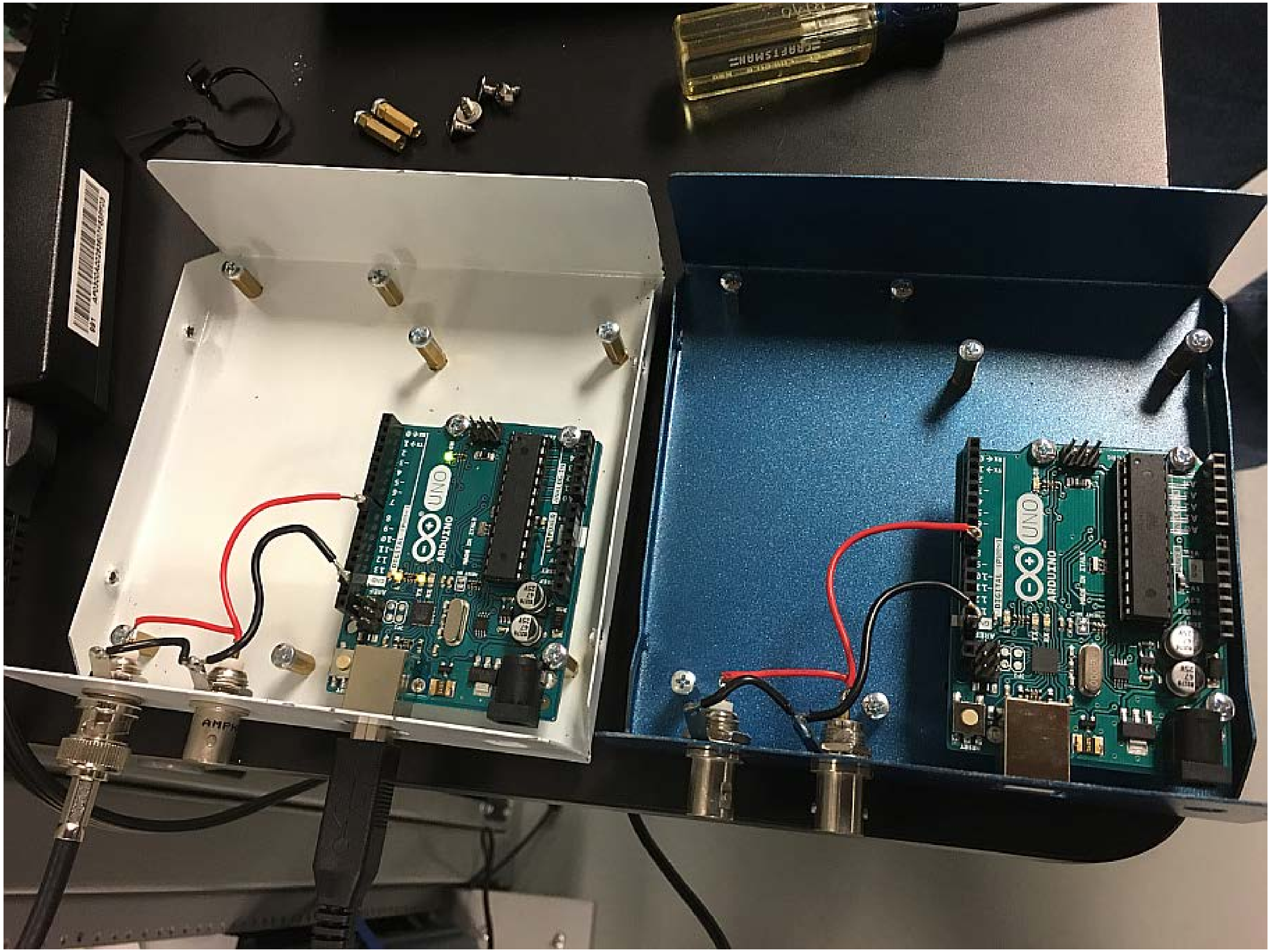
Current Timing

- Until recently, substation timing has been taken for granted – it hasn’t been as carefully scrutinized as other equipment.
- That is changing with the advent of new devices that are able to make use of precise timing.
  - Starting to see more issues and alarms than previously
- Early 2015 we began setting up lab/procedures to thoroughly test our substation clocks as new firmware upgrades came out

Discovering Timing Problems

- Monitoring and logging of the IRIG-B timing output is very insightful
  - Without monitoring IRIG-B output of clock, when time errors occur do not know if the problem is the clock or the end-device (PMU, DFR, etc.)
  - Most issues we have found are in the GPS clock firmware
- By decoding the IRIG data stream we learned a lot. This data was previously unavailable to us due to a lack of tools
- New IRIG monitoring tools are now on the market

$50 IRIG-B monitor



Impact of June 2015 Leap Second

- **First real event that we monitored was the June 2015 Leap Second**
  - Had no expectations of problems, monitored multiple clock firmware versions (including newest) that we have deployed in field
  - Monitored out of curiosity, and to test out the IRIG-B logger
- **First sign of problem – 30 seconds after Leap Second occurred**
  - Main synchrophasor PDC server went to 100% CPU and 100% RAM usage, crashing the server
  - Had to manually restart the PDC software entirely
  - Stopped all PMU data flow to downstream applications

Impact of June 2015 Leap Second

- **Discovered all our substation clocks had a firmware bug that performed the leap second late (5 seconds or longer)**
  - Caused all PMU data to be one second later compared to actual UTC time, for as long as it took clocks to eventually perform the leap second
  - Main Synchrophasor PDC setup with a “wait time” of one second to keep PMU latency low
  - All PMU data rejected as “late” data by the PDC (data was thrown out)
- **This did impact all substation devices that have time synchronization (DFRs, relays, etc.)**
  - No operational impact to protection functions
  - Data records did have inaccurate timestamps until clocks did the leap second

Time should have progressed as:

19:59:58
19:59:59
19:59:60
20:00:00
20:00:01
20:00:02
20:00:03
20:00:04
20:00:05

Time actually progressed as:

Year	Day	Time	LSP	LS
2015	181	19:59:58	1	0
2015	181	19:59:59	1	0
2015	181	20:00:00	0	0
2015	181	20:00:01	0	0
2015	181	20:00:02	0	0
2015	181	20:00:03	0	0
2015	181	20:00:04	0	0
2015	181	20:00:05	0	0
2015	181	20:00:05	0	0
2015	181	20:00:06	0	0

Timing Problems found to date

- Firmware/clock testing and monitoring
  - Problems surrounding the changeover from Standard time to Daylight time
  - Leap second handling
  - Year rollover issues
- Loss of signal/hardware issues
  - Cabling
  - Antenna mounting
  - Installation practices

Conclusions

- Timing in electric substations is becoming more important as more technologies become available that rely on accurate time.
  - With increased PMU deployment and the move towards operator decisions from PMU data and PMU-based control applications, timing becoming as critical as the PMU, relay, etc.
- Treat the timing system with the same thoroughness given to other substation systems.
- We need to keep up to date with industry developments in timing and the state of GNSS.

Future Timing Initiatives

- Evaluating new clocks and technologies. Our current clock model is >10 years old.
- Timing has been an afterthought
  - Not treated with the same importance as other substation equipment
- More rigorous testing of timing equipment. We have purchased a GPS simulator to test clocks and firmware updates.
- Improving timing architecture and products to ensure high availability of precise timing sources

Impacts of the leap second problem on synchrophasor analytics

"Frankie" Qiang Zhang
ISO New England

From End Users' Perspective

- Leap second effect travels through the whole data chain
  - Clock → PMU →
    Substation PDC → TO PDC →
    ISO PDC → Application
  - Involves
    - Hardware (clock, PMU, PDC, PC),
    - Software (PDC, OS, Application)
    - Human (settings, analyses)
  - End user (RC) doesn't own PMU assets
  - End user is most affected by the result: data
- Affects the analytical tools and human analyses

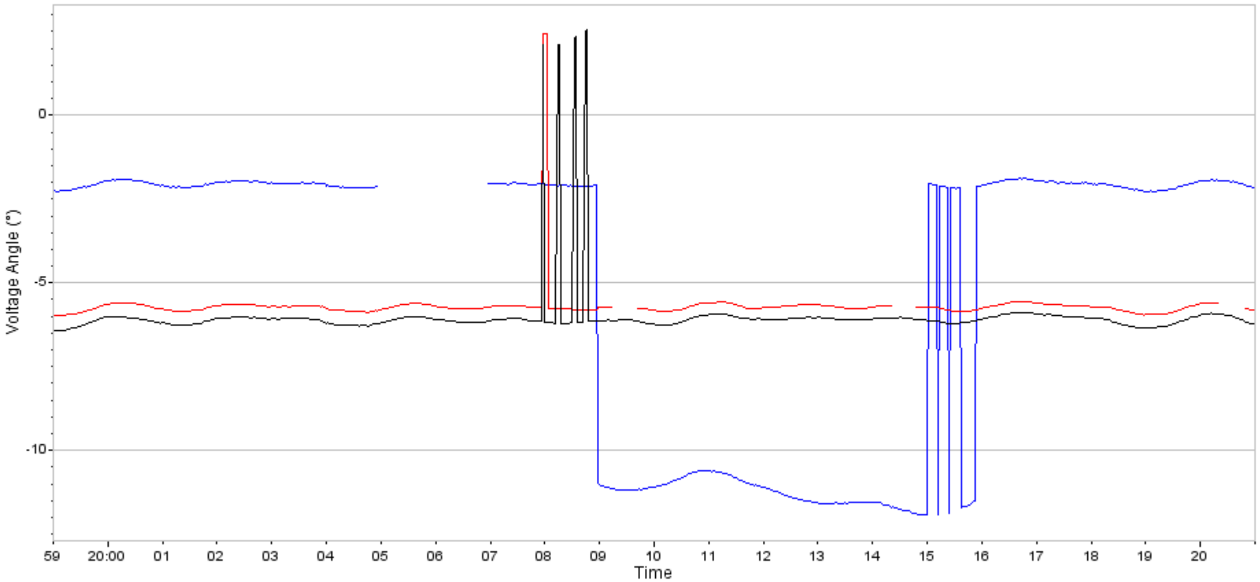
Leap Seconds in 2012 & 2015
General Experience

- Hardware is the frontline and source
  - Clock & PMU
- Different clock & PMU pairs reacted differently
  - Adds complexity to the problem
- PDC late leap
  - Increased latency →
    exceed wait time setting →
    data loss

- No leap second timestamps / data points
  - E.g., 23:59:60.xxx UTC don't exist in the historian
  - Needs investigation

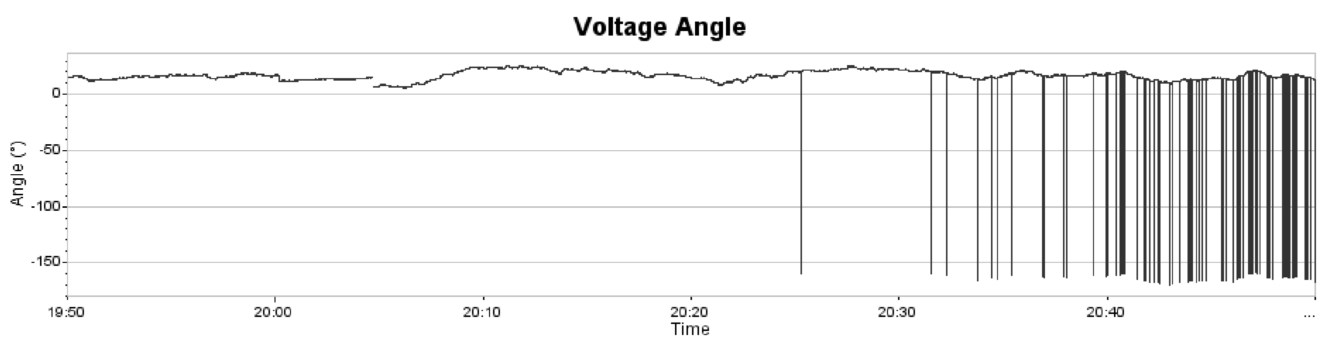
Leap Seconds in 2012 & 2015
Different Leap Behavior

- Late leap, missing data, back and forth jumps.



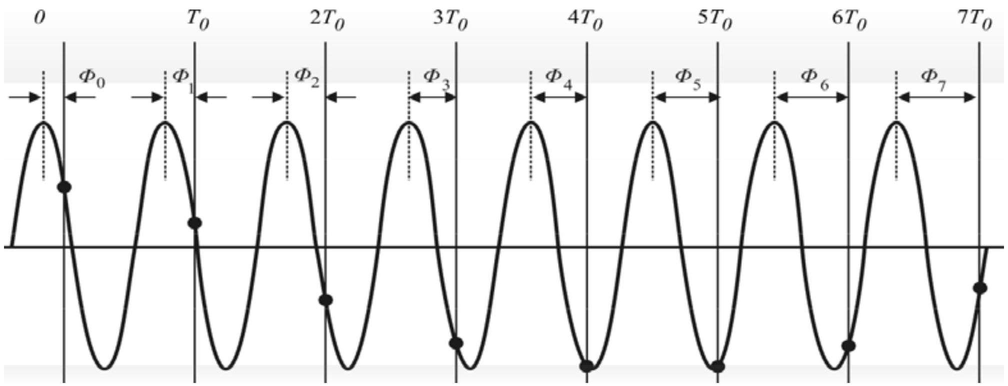
Red and **black** data are from same clock/PMU make/model

- Unstable



How Are Phasor Angles Defined?

- Relative to a reference, per C37.118:
  - A cosine function
  - At nominal system frequency: 60 Hz
  - Synchronized to UTC



- Angle changes with non-nominal frequency
  - Increases when f > 60 Hz
  - Decreases when f < 60 Hz

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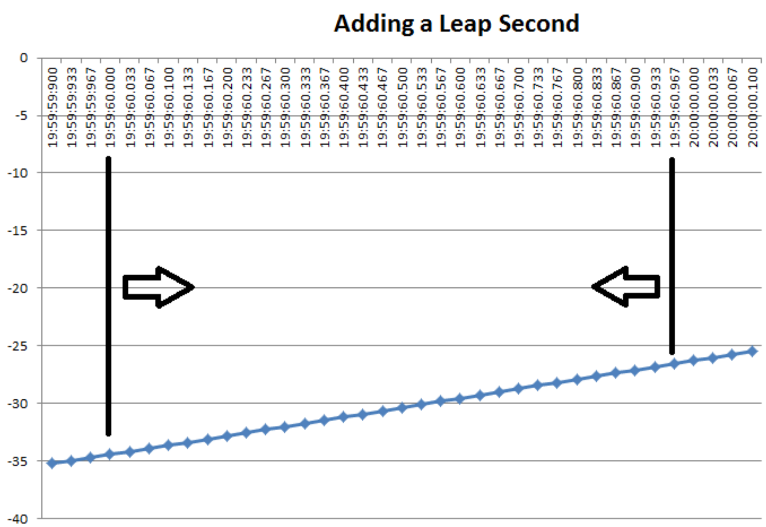
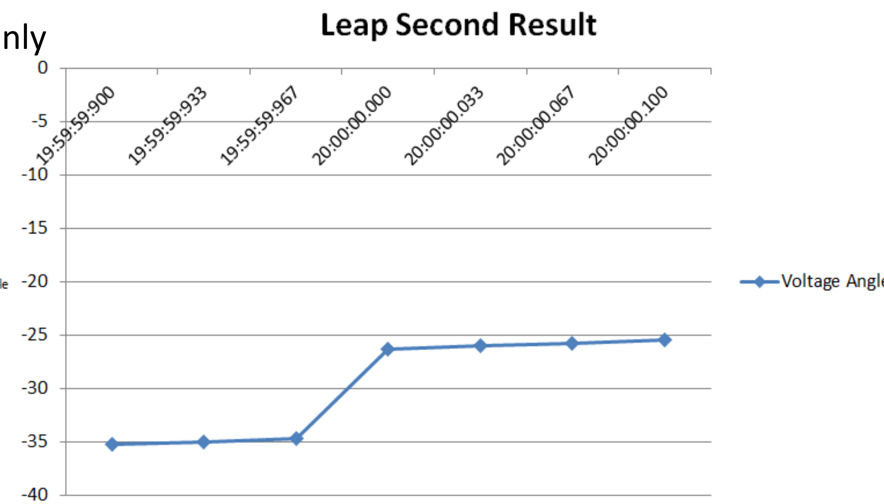
How Does Leap Second Change Phasor Data?

- Missing leap second data → Phasor Angle jump
- Hence the frequency and ROCOF jumps



Demo only



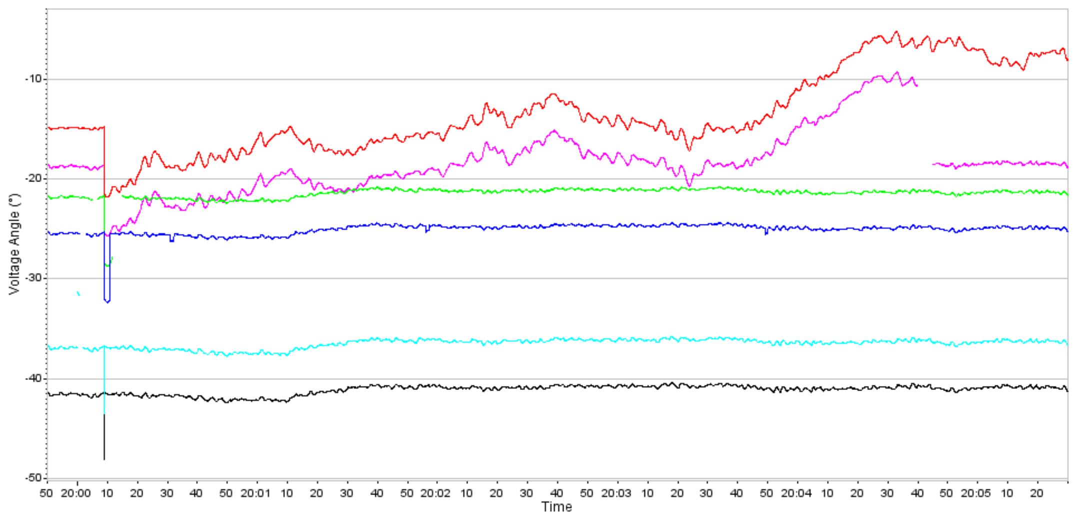
$$\delta^{After} = \delta^{Before} + \delta^{Leap} = \delta^{Before} + (f - 60) \times \text{Leap} \times 360$$

f is system frequency at the time, usually not nominal (60 Hz)

E.g., in 2015, most NE PMUs added 8.64° because f ≈ 60.024 Hz

Leap Second Impact on Analyses

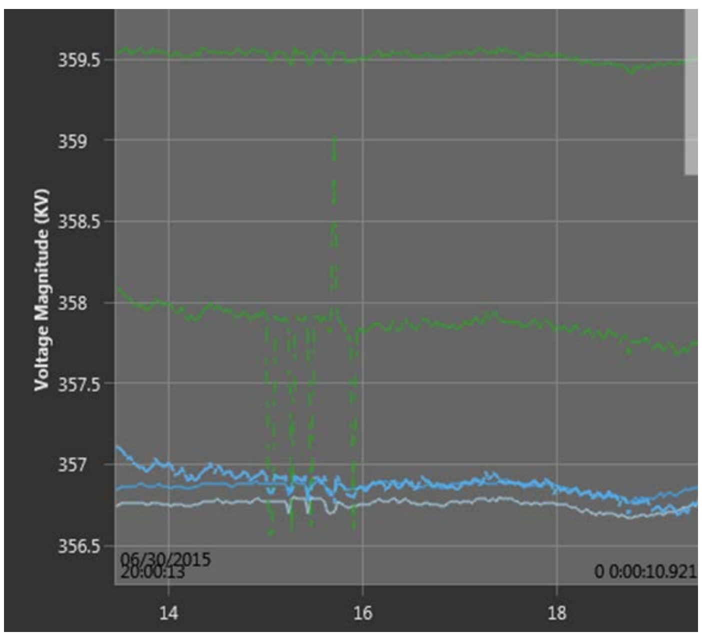
- With no leap second in time records
  - Angle jumps across the leap second
  - Fake **dynamics** – not an event!
- Leaped at different times
  - **Voltage angle difference changed**
  - No problem for **steady state** analyses if leaped at the same time

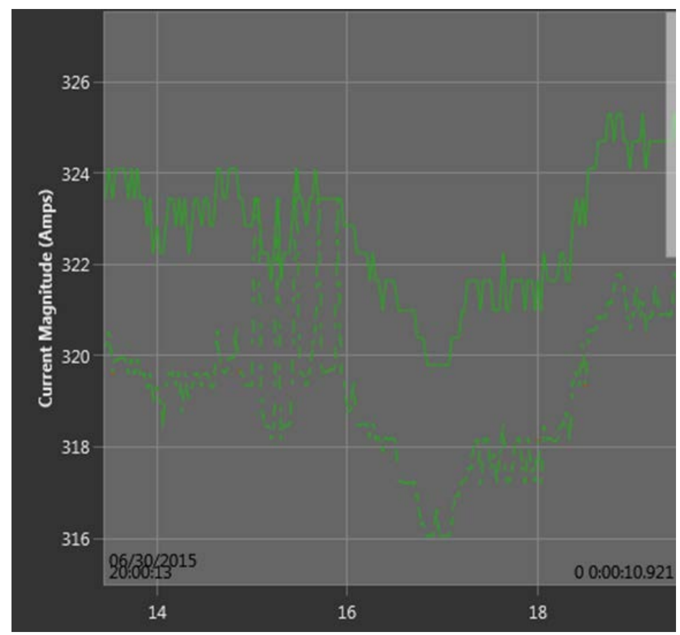


- Good news!
  - P & Q remain intact
  - Same change in VA and IA in the same PMU

Leap Second Impact on Applications

- Linear State Estimator
  - Affects the estimation results
    - Solid lines are raw data, dashed lines are estimated values
    - Errors propagated to magnitudes





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Conclusions

- Need the leap second data points
- Dynamical analyses
  - Need to skip the moment if:
    - Leap second is missing from the timestamps
    - System frequency is not nominal (60 Hz)
- Steady-state analyses
  - Wrong voltage angle profile during changes
  - No problem after all PMUs leaped
- Calculate P & Q using V and I from same PMU

Recommendations for how to prepare for the leap second

Alison Silverstein
NASPI project manager

Things you can do to prepare for the 2016 leap second event

1. **Ask your clock, GPS receiver, PMU and PDC vendors for firmware updates that will handle the leap second consistent with C37.118.1-2011. Implement the updates for every single PMU, receiver and clock on your system.**
2. Consider using one or more independent, non-GPS clocks with a tested leap second solution as a back-up timing source, so you have at least one reference clock on your system that you know will be correct.
3. Have a plan for monitoring your synchrophasor system and other timing-dependent substation elements to spot any problems with leap second implementation; start monitoring your system at least a day ahead of the leap second implementation in your time zone.

More recommendations

4. Warn your engineering and control room staff about when the leap second will occur (time zone-adjusted). Educate them on possible signs that something on your system isn't handling the leap second event properly so they don't react to a false problem.

   Things to watch for:

   - Crashed PDC
   - Bouncing, random or sudden phase angle shifts
   - Jumps or drops in PMU time-stamps
   - Sudden PMU failure

5. Know how to turn off or reset specific system elements if they mis-perform or fail due to a leap second problem; have IT and engineering staff standing by to handle any problems.

More recommendations

6. Report any PMU data problems to your Reliability Coordinator immediately.
7. If you're using NTP in your substations or IT systems, ensure that your NTP software is up to date and verify with your NTP server vendors that their leap second solution will handle the leap second correctly. (See DHS-CERT brief and other sources for more information)
8. All the above recommendations are intended for synchrophasor systems – but they can and should be used to prepare other systems, including critical IT and communications functions.

And if something does go wrong….

Please share details about any leap second problems with NASPI by February 1, 2017, to help the industry learn from this event.

Email details to alisonsilverstein@mac.com,

cc naspi@pnnl.gov

For more information

- NASPI Technical Report – Leap Second Effects on Synchrophasor Systems https://www.naspi.org/File.aspx?fileID=1914
- DHS ICS-CERT Best Practices for Leap Second Event Occurring on 31 December 2016 https://ics-cert.us-cert.gov/Best-Practices-Leap-Second-Event-Occurring-31-December-2016
- NISTIR 8077 Investigation of PMU Response to Leap Second: 2015 https://www.naspi.org/Badger/content/File/FileService.aspx?fileID=1547
- NERC Security Guideline for the Electricity Sector: Time Stamping of Operational Data Logs (http://www.nerc.com/comm/CIPC/Security%20Guidelines%20DL/Timestamping_Guideline_009-11-11_Clean.pdf)

Any questions?