TIME SYNCRHONIZATION AND ITS IMPACT ON PMU APPLICATIONS

IV INTERNATIONAL WORKSHOP ON PMU APPLICATIONS

UFRJ – FEDERAL UNIVERSITY OF RIO DE JANEIRO

Rafael Fernandes
Suelaine Diniz
Alexandre Massaud
ONS - Brazil

Rio de Janeiro November, 29 2016

Motivation

- Time Synchronization Analysis – Impact on PMU Application by ONS-TSO;
- Data Validation in real time scenario – use of wireshark;
- ONS Technical Requirement - NT115/2014, Revision 2016;
- Irig-b Synchronism Protocol *Irig-b* / *Irig-b Extension Protocol* and IEEE C37.118 Standard;
- Synchronism Network and Error Mitigation.

Highlights Points

- Techniques of time synchronization with measurement techniques → opportunity of phasor measurement and angular change in real time;

- Growth of use Protection, Supervision and Control Systems (SPSC) → need to synchronize accurate and reliable sources → local (ad hoc) and non-integrated approach, each system with its own synchronism clock;

- Most clocks make use of GNSS (Global Navigation Satellite System) → proliferation of antennas in substation buildings. To these clocks are added the clocks used by the telecomunications systems;

- Local approach → low degree of reliability → Clocks used are based on low quality quartz and small holdover and not offer signal redundancy;

Highlights Points

- Synchronization problem, may not impact localized SPSC systems, but it can be one problem when it becomes to large area systems - such as the wide area synchronous grid;

- Analysis of IEEE C37.118 protocol by Wireshark software (actual ONS-TSO resource…) ➔ leap second verification with actual high voltage PMU data by openPDC-ONS;

- Verification of actual Satellite Systems (GNSS) from USA, Chine, Europe and Russia;

- Monitoring the Fracsec (Fraction of Second), sample counter (0 to 59) and the SOC (Second of Century) time variable ➔ check whether the time alignment of the phasors by the PDC (Phasor Data Concentrator) is in accordance with expected.

Local Synchronism: Ad-Hoc Approach

- Failure to receive the GPS system signal ➔ synchronization system migrates to local clock (internal equipments) - which is commonly based ➔ low quality clock.

Source: Furnas

- Excess of antenna;
- Clocks with low quality crystal quartz;
- Low holdover times;
- No redundancy;
- No centralized management;
- No proper accuracy;
- No quality tag (only available with Irig-b-Extended version) !!!

System GNSS: GPS (USA) + GLONASS (Russian) + BEIDOU (Chine) + GALILEO (Europe)

- Good accuracy in vector triangularization algorithm → minimum 3 satellites;
- GPS system (created in 1973 by US military) → world reference - first to compose the so-called GNSS - accuracy of a few nanosecond and has 31 satellites orbiting the Earth;
- The Russian positioning system GLONASS also has 24 satellites orbiting the Earth;
- The Chinese system (Beidou) has 14 satellites in orbit. In 2020 → 35 satellites (forecast);
- The European system (Galileo) only for civil purposes → Target for 2020 = 30 satellites;
- After all, how many GNSS systems are needed? ANSWER = only 1 (the minimum condition) → but without ignoring historical, political and economic realities involving systems that it depends of time reference…

Solar Storm x GPS Signal Interference

- On 9/11/2014 → The News Agency Reuters posted on its own website → an alert from the United States Weather Forecast Center (NOAA) that magnetically charged solar storms were in route to the Earth's orbit;

- Solar storms occur at a frequency of 100 to 200 times during a solar cycle (cycle of solar activities observation) - which repeats every 11 years;

- MAIN CONSEQUENCE: Highly energetic and magnetically charged solar particles → could reach the earth's magnetic field → disturbing the atmosphere, precisely on the layer where communication and GPS signals travel.

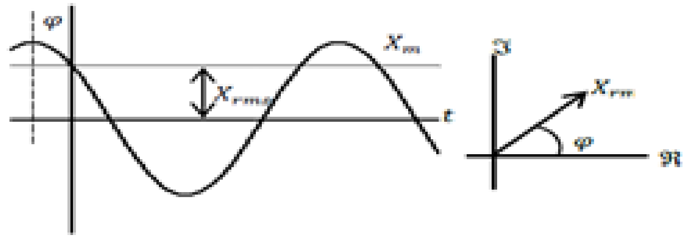
SVN-23 Sattelite Failure Problem

- PACWorld (March / 16) ➔ 26 January 2016, at 12:49 am (local time) ➔ a specific anomaly detected in the sync signals ➔ there was a deviation of 13 microseconds - compared to the atomic mass-hydrogen clock located in the city of Kirkkonummi - Finland. Initial cause ➔ aging (1990) of SVN 23 satellite of type II-IIA (North American legacy system);

- CONSEQUENCE: Drift clock (slip time) when the satellite was removed from the constellation of GPS satellites orbiting the earth;

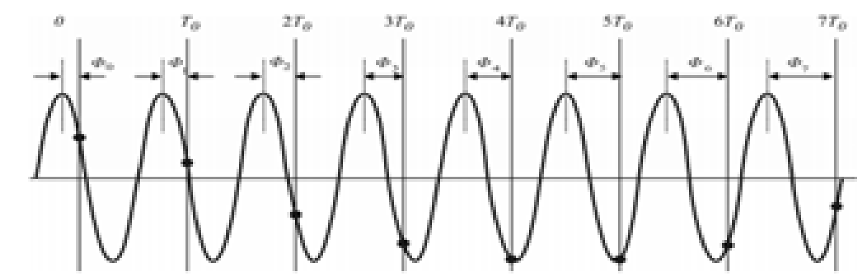
- Navigation systems ➔ operating normally BUT the UTC system (Coordinated Universal Time used for PMU, for example) were out for 13 microseconds !!!

- Phasor Notation: no relation with frequency ➔ $X_{rms}e^{j\varphi} = X_{rms} < \varphi$



- Synchrophasor Notation ➔ calculation from waveform sample measurement of measurement signal with time reference. Representation $\left(X_m/\sqrt{2}\right)e^{j\theta}$, polar representation ➔ $\left(X_m/\sqrt{2}\right)$ RMS waveform, e $\theta = 2\pi\Delta f t + \varphi$ is the instantaneous angular deviation.

- RESUME: If the acquired signal has a frequency different from the nominal reference, the phasor will have a constant magnitude, but the angle: $\theta = 2\pi(f - f_0)t$ of the phasor sequence will vary between -180 ° and + 180 °.



Source: IEEE C37.118 Standard

Basic Example: PMU Frequency Calculation

Table with Synchronized Measurement PMU extracted from ONS openPDC (only seven first frames).

IMPORTANT: 1 PMU LOAD THE NETWORK, IN AVERAGE, WITH 50kbits/s
➔ 540 Mbytes / day ➔ 0,2 Tbytes / year !!!

```
Tensão base: 303109 V
SOC inicial: 1473169380
SOC final: 1473169440
Taxa: 60 fasores/s

Tempo_(SOC)          VA_mod_(V)      VA_ang_(graus)   VB_mod_(V)      VB_ang_(graus)   VC_mod_(V)      VC_ang_(graus)
1473169380.0000      305795.500000   27.175090        305212.300000   -93.079110       303178.200000   147.127200
1473169380.0167      305783.400000   26.965010        305217.900000   -93.290600       303191.400000   146.914200
1473169380.0333      305789.300000   26.753460        305223.200000   -93.500890       303206.900000   146.703400
1473169380.0500      305802.900000   26.541630        305231.100000   -93.710640       303221.200000   146.493200
1473169380.0667      305810.100000   26.331810        305253.500000   -93.920330       303227.300000   146.281900
1473169380.0833      305809.000000   26.120300        305264.100000   -94.129840       303233.900000   146.070500
1473169380.1000      305807.700000   25.907780        305255.500000   -94.341080       303241.300000   145.859100
```

VA_ang_(graus)	Delta θ (graus)	$\Delta f = \frac{1}{2\pi} * \frac{\Delta\theta}{\Delta t}$	f(t) = f(t-1) +/- Δf	F medida PMU	Diferença %
27,17509					
26,96501	0,21008	0,033435	59,96656473	59,96471	0,003092946
26,75346	0,21155	0,033669	59,96633078	59,96491	0,002369289
26,54163	0,21183	0,033714	59,96628621	59,96492	0,0022783
26,33181	0,20982	0,033394	59,96660611	59,96499	0,002695022
26,1203	0,21151	0,033663	59,96633714	59,96481	0,002546665
25,90778	0,21252	0,033824	59,9661764	59,96456	0,002695512

$$\Delta f = \frac{1}{2\Pi} * \frac{\Delta\theta}{\Delta t}$$

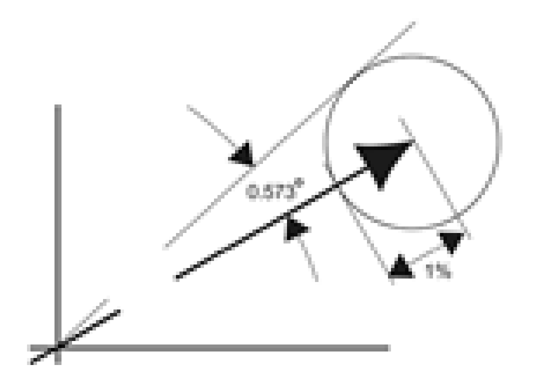
360° -- 60Hz

x° -- 0,03343 ==> x ≈ 0,21°

- How all the measurements have, theoretically, the same timebase and the same frequency reference (60Hz), the angle values can be determined and compared.
- The time synchronism accuracy – main focus of this presentation, is one important factor to the correct angle measurement and, consequentelly, the frequency determination of the measurement signal.

TVE: Total Vector Error

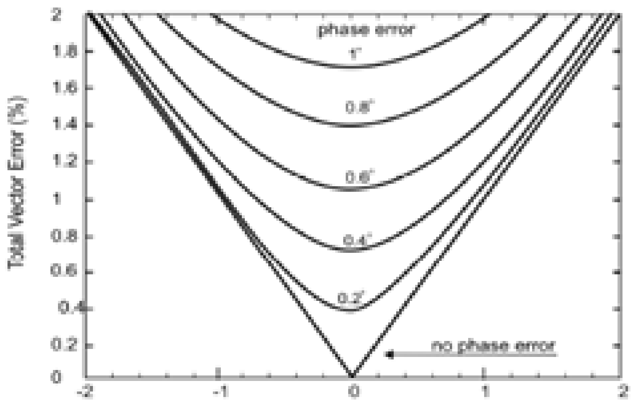
- Phase and Magnitude Error ➔ TVE determination (composed error in only one equation) is the difference in phasor values of what goes into pmu and what comes out of it.



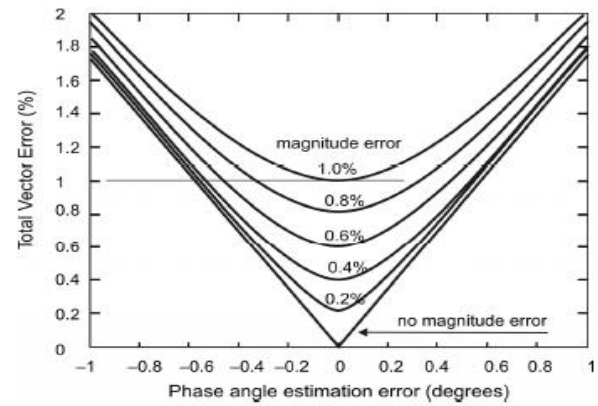
$$\rightarrow \quad TVE = \sqrt{\frac{[\hat{X}_r(n) - X_r(n)]^2 + [\hat{X}_i(n) - X_i(n)]^2}{[\hat{X}_r(n)]^2 + [\hat{X}_i(n)]^2}}$$

$$wt = 0{,}573° = 0{,}01\ rad \quad \longrightarrow \quad 2\pi f_{sinal}\Delta t = 0{,}573° = 0{,}01\ rad \quad \longrightarrow \quad \Delta t = 26\mu seg$$

TVE: Total Vector Error

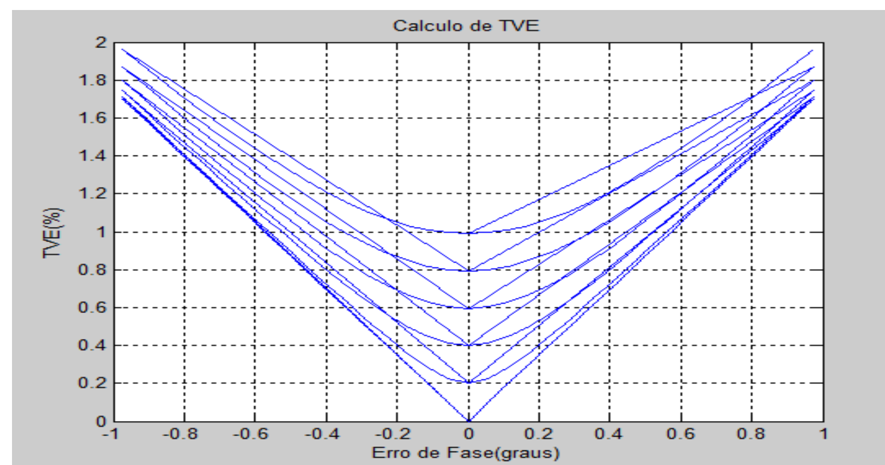


Magnitude Error Estimate (%) Source C37.118.1-2011



Phase Angle Error Estimate (%) Source C37.118.1-2011

$$TVE = \sqrt{\frac{\left[\hat{X}_r(n) - X_r(n)\right]^2 + \left[\hat{X}_i(n) - X_i(n)\right]^2}{\left[\hat{X}_r(n)\right]^2 + \left[\hat{X}_i(n)\right]^2}}$$



Source: Matlab

ONS - Technical Requirement / IEEE C37.118 Requirement

- Reliability and Quality Requirements (ONS 115/2014 Technical Note, Rev. 2016):

1) Timming accuracy of 26µs (Accuracy for maximum TVE = 1%);

2) Service Level Agreement (SLA) index = 99.98% → 1 hour and 45 minutes of unavailability / year (references - ITU standard and ONS Network Procedure 13.2);

3) Maximum Latency (considering the time interval between PMU measurement until ONS PDC) = 500 ms.

Time Quality: IEEE C37.118

"All message frames start with a 2-byte SYNC word followed by a 2-byte FRAMESIZE word, a 2-byte IDCODE, a time stamp consisting of a 4-byte second-of-century (SOC) and 4-byte FRACSEC, which includes a 24-bit FRACSEC integer and an 8-bit Time Quality flag described in 6.2.2".

- Quality Indication is critical ➔ PMU needs to know the quality of the sync signal they are receiving - since non-synchronized samples do not correctly translate phasor system alignment.

Table 4—4-bit Message Time Quality indication codes (MSG_TQ)

BINARY	HEX	Value (worst-case accuracy)
1111	F	Fault—clock failure, time not reliable
1011	B	Time within 10 s of UTC
1010	A	Time within 1 s of UTC
1001	9	Time within 10^{-1} s of UTC
1000	8	Time within 10^{-2} s of UTC
0111	7	Time within 10^{-3} s of UTC
0110	6	Time within 10^{-4} s of UTC
0101	5	Time within 10^{-5} s of UTC
0100	4	Time within 10^{-6} s of UTC
0011	3	Time within 10^{-7} s of UTC
0010	2	Time within 10^{-8} s of UTC
0001	1	Time within 10^{-9} s of UTC
0000	0	Normal operation, clock locked to UTC traceable source

Source IEEE C37.118

Time Quality: Irig-b Extended Protocol

- Attendance to quality indication requirement introduces greater complexity to the synchronization system → many protocols do not provide this quality marker;
- The Irig-b, only with extended version has the quality marker indication and monitoring!!! ;
- Few synchronization devices with the Irig-b protocol provide its extended version.

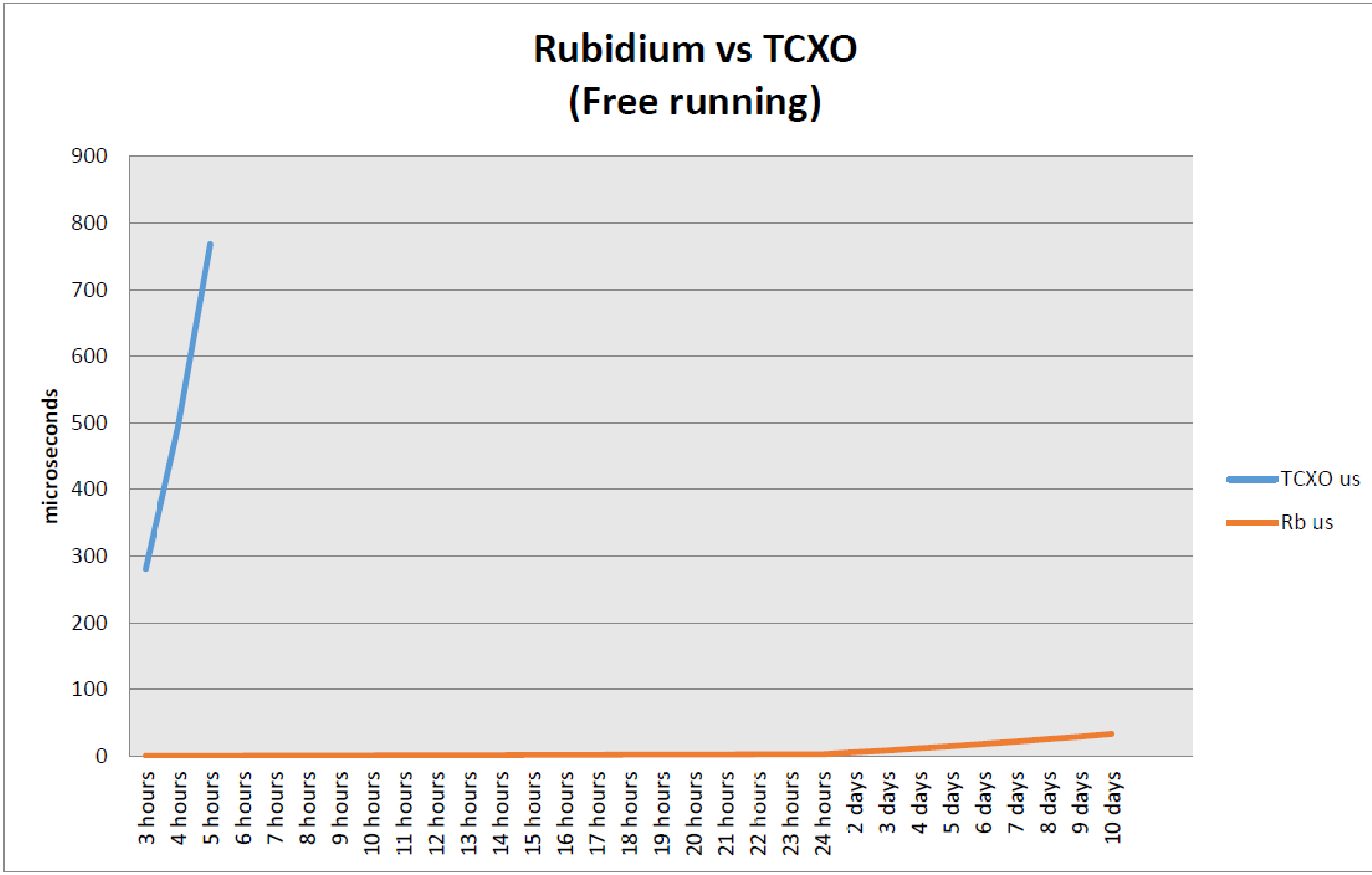
Time Quality: Clock Accuracy

- Relation of Clocks (different manufacturer): levels of precision, maximum holdover times , and presence of time quality marker.

				LOCKED			FREE RUN		
				CLOCK	PPS	TIME	TIME		C 37.118
MODEL	Type	Suport IRIG-B Extensão C37.118	Cost	Freq. Stability	Accuracy of PPS	Accuracy of Time	Accuracy of Time free run, one day (microsecs)	Accuracy of Time free run, one year (microsecs)	Hours to achieve accuracy of +/- 26 microsecs
A	Rubidium	IEEE1344-1995	$$$	1x10^(-12)	1x10^(-12)	±30ns RMS to UTC	1.66µs	0,6ms	375:54:13
	OCXO		$$	1x10^(-12)	1x10^(-12)	±30ns RMS to UTC	0,5ms	182,5ms	1:14:53
B	Rubidium	YES	$$$			±50ns RMS to UTC	10µs		62:24:00
C	TCXO	YES	$	1x10^(-9)	1x10^(-12)	<100ns to UTC	0,55ms	200s	1:08:04
	OCXO		$$	±1.0x10^(-9)	±50 ns to UTC	<100ns to UTC	15µs	10µs	41:36:00
D	Rubidium	NO	$$$	<0.01ppb	1x10^(-12)	<100ns to UTC	10µs	3.65ms	62:24:00
E	Rubidium	NO	$$$	<0.01ppb	1x10^(-12)	<100ns to UTC	2µs	0,73ms	312:00:00
	OCXO		$$	<0.01ppb	1x10^(-12)	<100ns to UTC	0,2ms	73ms	3:07:12
F	Rubidium	IEEE1344-1995	$$$	1x10^(-12)	1x10^(-12)	=100ns to UTC	3,33µs	1,21ms	187:23:15
	OCXO		$$						
G	Rubidium	IEEE1344-1995	$$$						
	OCXO		$$	1x10^(-12)	1x10^(-12)	=100ns to UTC	0,1ms	36,5ms	6:14:24
H	TCXO	YES	$		±40 ns to UTC		315 µs (Temp. CTE)		1:58:51
							36 µs (±1°C)		17:20:00
	OCXO		$$		±40 ns to UTC		5µs		124:48:00
I	Rubidium	NO	$$$	<0.01ppb	1x10^(-12)	<100ns to UTC	8µs	3.2ms	78:00:00
	OCXO		$$	<0.01ppb	1x10^(-12)	<100ns to UTC	0.53ms	194.66ms	1:10:38

Source - Furnas

Time Quality: Rubidium x TCXO – Free running (after lost GPS signal)



Source - Arsitec 2015

Standard: IEEE C37.118 x IEC 61850

"…IEEE Std C37.118-2005 was split into two parts, one with measurement requirements and the other with the data transfer requirements. This allows other communication protocols and systems to be used with phasor measurement systems supporting the original purpose of the standard. This split facilitates harmonization of IEEE Std C37.118-2005 with IEC 61850..."

IMPORTANT:

- Standard C37.118 provision the requirements of Supervision and Control, defined by the IEC61850 protocol- for future cases. Indicates harmonization between both standards ➔ integration of the synchronism system to attend both systems (Supervision and Control and Phasor Measurement) ➔ does not suggest division in local (ad hoc) and independent synchronism systems.

Standard: IEEE C37.118 x IEC 61850

- IEC61850 Standard indicate to have one more precise signal and with quality marker:
- IEC61850-90-4, item 14.2:

IEC 61850-90-4, item 14.2:

When absolute time distribution is critical, a substation should rely on two redundant time servers. Some substations loose the reference signal for a longer period due to their geographical location (e.g. in a deep valley). Also, GNNS jamming (intentional or not) can occur. Solar storms have disabled GPS satellites. Therefore, the two time servers should be of different types and it is recommended to use an atomic clock as a backup. Rubidium clocks are available at affordable prices. Several clock types can be used, provided the hierarchy between the clocks is the same for all devices.

- IEC61850-90-4, item 14.6.3:

IEC 61850-90-4, item 14.6.3:

14.6.3 IRIG-B

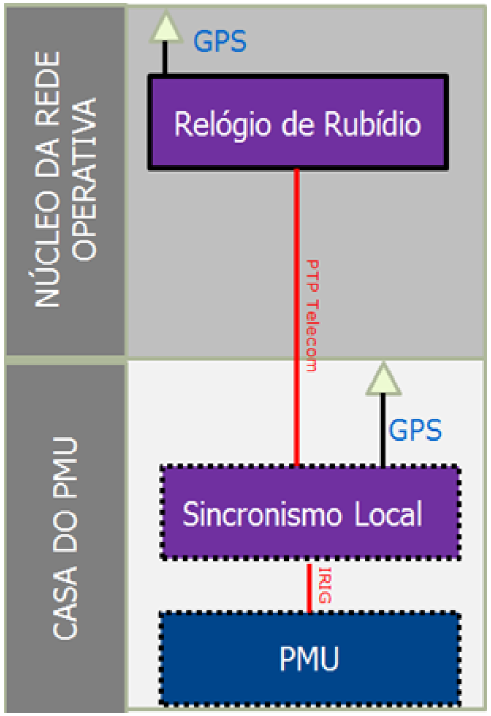
IRIG-B is a time synchronisation protocol which defines a train of pulses encoding the UTC date as BCD numbers, with additional indication of the clock traceability and quality. This train of pulses can be modulated over a radio signal, or sent as baseband over a simple twisted wire pair or optical fibre. Bus topologies and point-to-point are used with different kinds of links.

There exist several variants of IRIG-B. The synchrophasor measurement and transmission standards C37.118-1 and C37.118-2 (formerly IEEE 1344) define the use of IRIG-B 200-04 with the addition of a continuous time quality field that indicates the inaccuracy when the reference signal is lost. These documents contain an extensive description of the protocol.

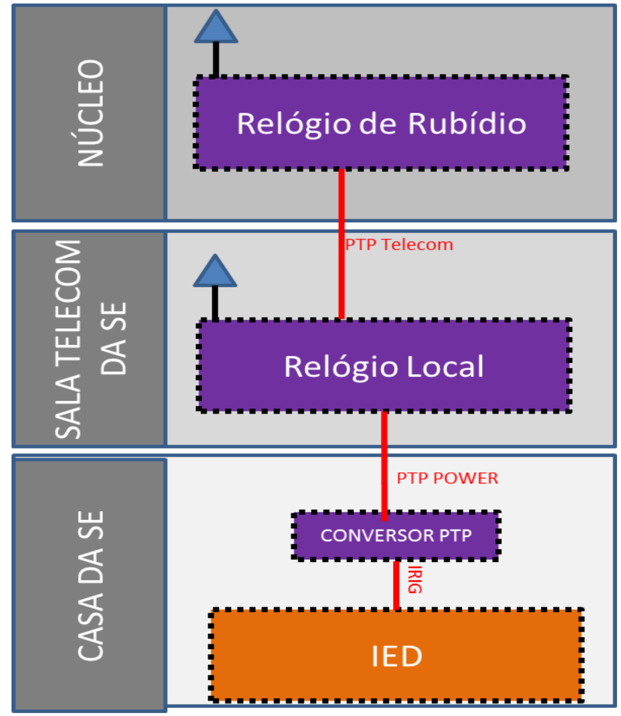
- Synchronism integration in only one network➔ in accordance with future view between protocols IEC 61850 and C37.118 ➔ its necessary redundancy of clocks and more precision.

PROPOSAL OF ARCHITECTURE TO THE SYNCHRONISM NETWORK INVOLVING TELECOM AND THE SPSC (SYSTEM INTEGRATION SOLUTION IN ONE NETWORK)

Proposal Suggestion of Two Architecture: Hybrid Solution



Source: Furnas

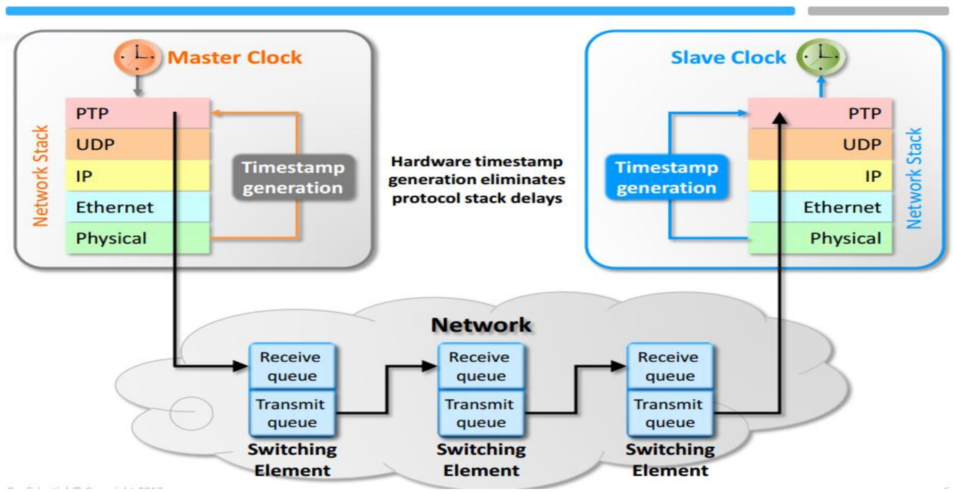


Source: Furnas (2016)

- Insert one clock with better quality (rubidium or quartz - OCXO) in the core of Operative Network and distribute the signal through PTP protocol PTP-Telecom until reach the equipment with the Irig-b extended protocol (hybrid solution).

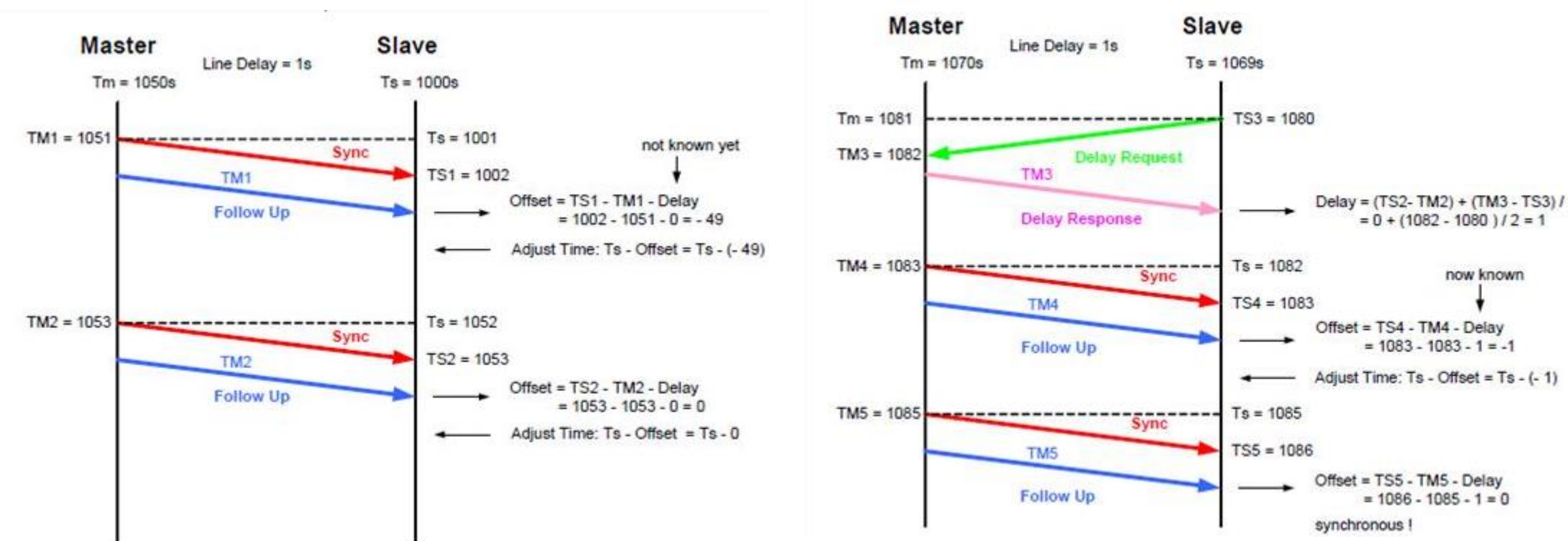
- The system can be use through equipment with local clock and signal distribution through PTP Power network with PTP converter to Irig-b protocol.

PTP Master – Slave Functionality:



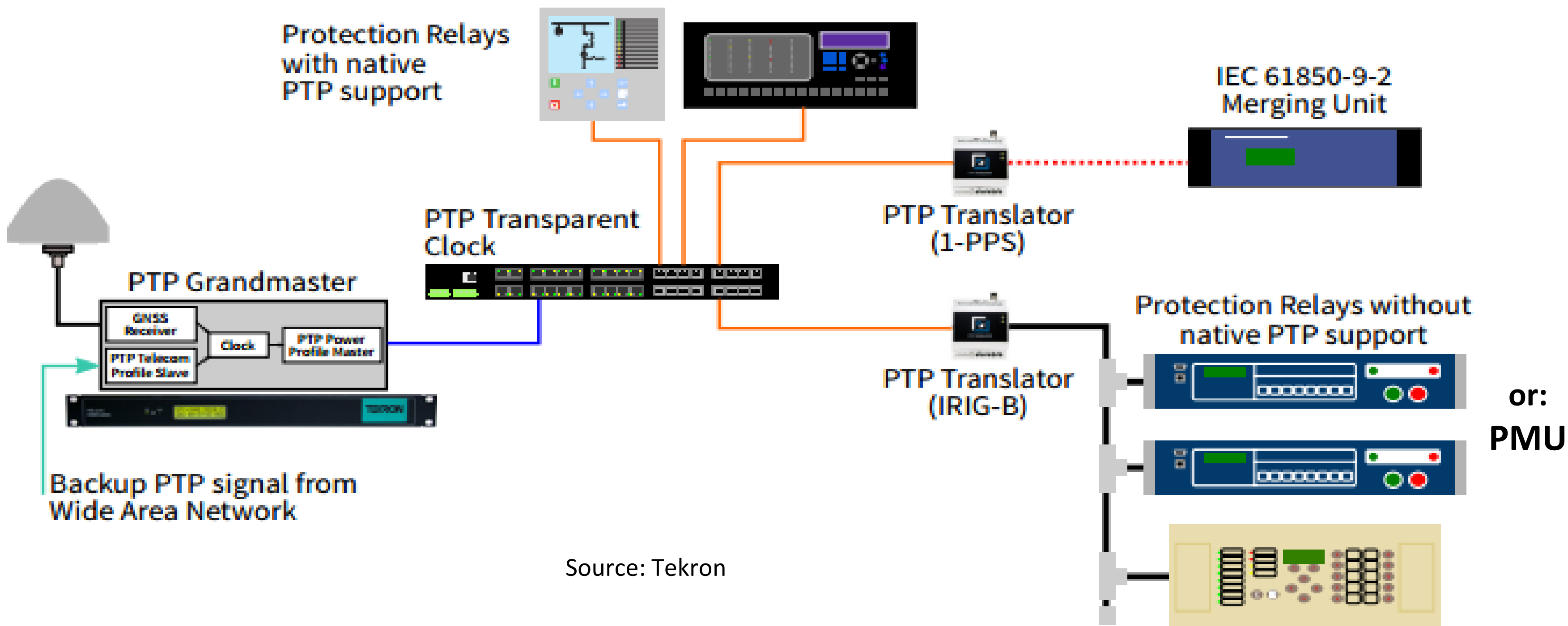
Source: Internet (2016)

- Synchronism Distribution Protocol can be transmitted by WAN network (PTP – Telecom) and by LAN network (PTP- Power). In function of jitter latency problem of subjacent network it recommends to use IEEE 1588 clock at the border of switches.



Source: Internet (2016)

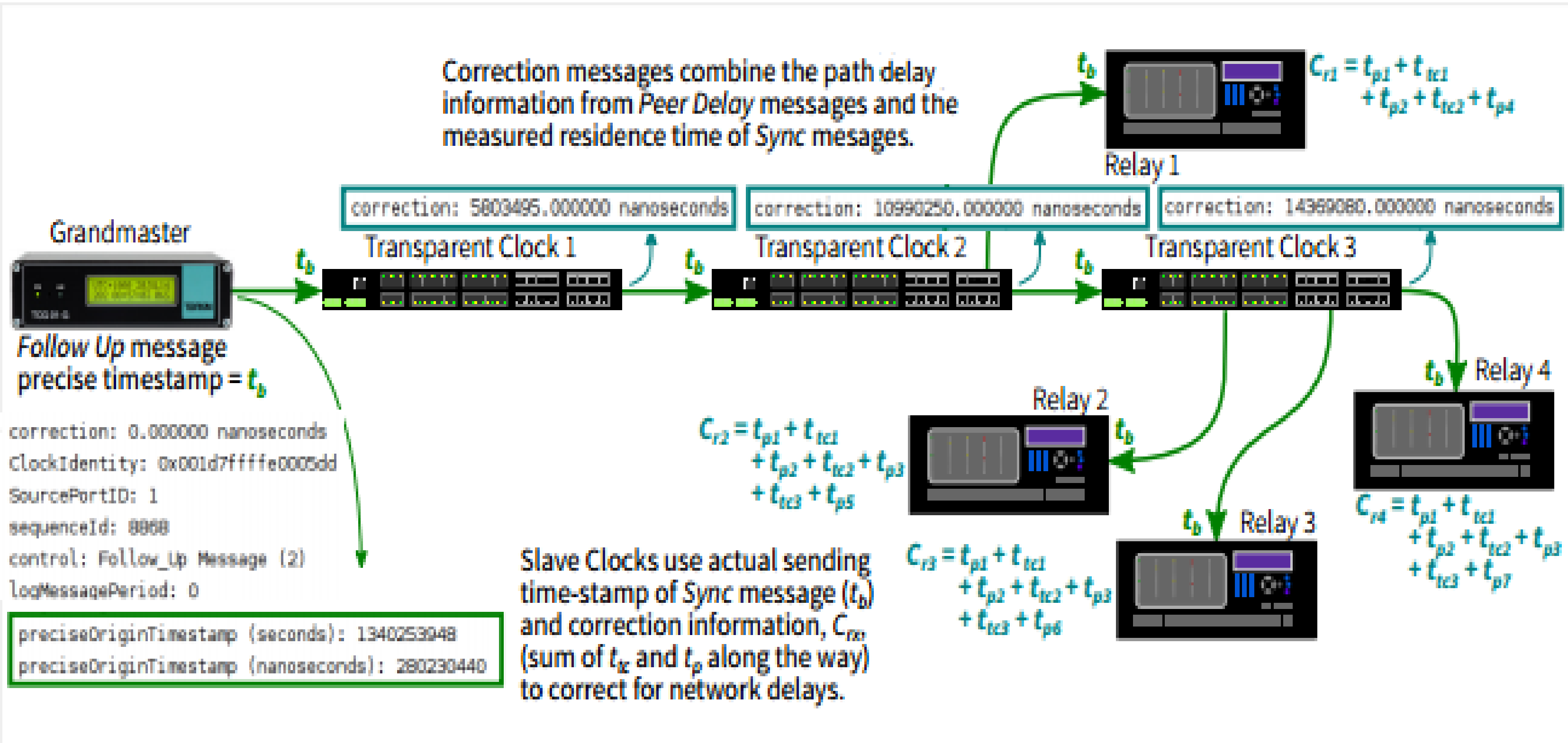
PTP Architecture:



Source: Tekron

- Grandmaster clock: the clock that is the ultimate source of time for synchronization using PTP, and usually has a GPS (or other satellite system) receiver built in;
- Master clock: a clock that is the source of time that other clocks on the network synchronise to;
- Slave clock: the end-user of PTP, which may be one IED (Intelligent Electronic Device) with native support for PTP or a translation protocol device that generates a legacy time synchronization signal such as IRIG-B or 1-PPS;
- Transparent clock: an Ethernet switch that measures the time taken for a PTP synchronization message to transit the device and provides this information to clocks receiving the PTP event message.

PTP Architecture:



Source: Tekron

ONS PMU ACTUAL NETWORK DATA CHECK RESOURCES

ONS PMU BRAZILIAN NATIONAL GRID LOCATION – STILL AN EXPERIMENTAL PROJECT – NOT START THE CCPMS PROJECT – WORLD BANK FUNDING

Data Check – IEEE C37.118:

IEEE Std C37.118.2-2011
IEEE Standard for Synchrophasor Data Transfer for Power Systems

Table 6—Word definitions unique to data frames

Field	Size (bytes)	Comments
SYNC	2	First byte: AA hex Second byte: 01 hex (frame is version 1, IEEE Std C37.118-2005 [B6])
STAT	2	Bit mapped flags. Bit 15–14: Data error: 00 = good measurement data, no errors 01 = PMU error. No information about data 10 = PMU in test mode (do not use values) or *absent data tags* have been inserted (do not use values) 11 = PMU error (do not use values) Bit 13: PMU sync, 0 when in sync with a UTC traceable time source Bit 12: Data sorting, 0 by time stamp, 1 by arrival Bit 11: PMU trigger detected, 0 when no trigger Bit 10: Configuration change, set to 1 for 1 min to advise configuration will change, and clear to 0 when change effected. Bit 09: Data modified, 1 if data modified by post processing, 0 otherwise Bits 08–06: PMU Time Quality. Refer to codes in Table 7. Bits 05–04: Unlocked time: 00 = sync locked or unlocked < 10 s (best quality) \01 = 10 s ≤ unlocked time < 100 s 10 = 100 s < unlock time ≤ 1000 s 11 = unlocked time > 1000 s Bits 03–00: Trigger reason: 1111–1000: Available for user definition 0111: Digital 0110: Reserved 0101: df/dt High 0100: Frequency high or low 0011: Phase angle diff 0010: Magnitude high 0001: Magnitude low 0000: Manual

Source: IEEE C37.118

1) DataIsValid (bit15) = Data Error;

2) Device Synchronization Error (bit13) = PMU Sync Error;

3) DataIsValid (bits 08-06) = PMU Time Quality.

ONS Medplot Real Time (UFSC) – Data Check

Source: Medplot Real Time

Medplot Real Time (UFSC) – Daily Data Check Report
Only DataIsValid (bit15) = Data Error

1	Período de Análise		Percentual de Dados Recebidos																								
2	Início (UTC)	Término (UTC)	UFPA	UNIFEI	UNB	COPPE	UFC	USP_SC	UTFPR	UFSC	UNIR	UFMT	UNIPAMPA	UFMG	UFMS	UFPE	UFT	UFMA	UFJF	UFBA	UFRGS	UFAC	UFAM	UNIFAP	UFRR	PTI	UFES
3	21/11/2016 13:24:28.200	21/11/2016 14:00:00.000	99,97%	100,00%	90,19%	99,50%	0,00%	100,00%	99,95%	100,00%	99,99%	99,88%	99,97%	100,00%	99,71%	100,00%	99,95%	98,97%	100,00%	99,92%	0,00%	100,00%	4,50%	99,98%	0,00%	0,00%	100,00%
4	21/11/2016 14:00:00.000	21/11/2016 15:00:00.000	99,94%	100,00%	100,00%	99,27%	0,00%	100,00%	99,89%	99,97%	100,00%	99,89%	99,91%	100,00%	99,91%	100,00%	99,95%	99,08%	100,00%	99,90%	0,00%	100,00%	89,99%	100,00%	0,00%	0,00%	100,00%
5	21/11/2016 15:00:00.000	21/11/2016 16:00:00.000	99,98%	100,00%	100,00%	99,18%	0,00%	100,00%	99,95%	99,95%	99,99%	99,22%	99,84%	100,00%	98,75%	100,00%	99,97%	89,92%	100,00%	99,96%	0,00%	100,00%	98,83%	99,99%	0,00%	0,00%	100,00%
6	21/11/2016 16:00:00.000	21/11/2016 17:00:00.000	99,99%	100,00%	100,00%	99,15%	0,00%	100,00%	99,97%	99,92%	99,99%	99,90%	99,96%	100,00%	99,17%	100,00%	90,18%	98,66%	100,00%	99,91%	0,00%	100,00%	99,44%	100,00%	0,00%	0,00%	100,00%
7	21/11/2016 17:00:00.000	21/11/2016 18:00:00.000	99,97%	100,00%	90,73%	99,13%	0,00%	100,00%	99,97%	100,00%	99,99%	99,79%	99,99%	100,00%	99,05%	100,00%	99,85%	97,87%	100,00%	99,87%	0,00%	100,00%	98,15%	100,00%	0,00%	0,00%	100,00%
8	21/11/2016 18:00:00.000	21/11/2016 19:00:00.000	99,97%	70,13%	100,00%	99,06%	0,00%	100,00%	99,96%	100,00%	99,99%	99,78%	99,99%	100,00%	98,99%	100,00%	99,95%	98,41%	100,00%	99,93%	0,00%	100,00%	88,28%	100,00%	0,00%	0,00%	100,00%
9	21/11/2016 19:00:00.000	21/11/2016 20:00:00.000	99,97%	100,00%	100,00%	97,76%	0,00%	100,00%	99,97%	100,00%	99,89%	99,77%	99,98%	100,00%	94,87%	100,00%	99,89%	98,39%	100,00%	99,93%	0,00%	100,00%	94,91%	100,00%	0,00%	0,00%	100,00%
10	21/11/2016 20:00:00.000	21/11/2016 21:00:00.000	99,99%	99,72%	95,85%	97,33%	0,00%	100,00%	99,97%	100,00%	100,00%	99,93%	100,00%	100,00%	99,84%	100,00%	99,93%	99,41%	100,00%	99,99%	0,00%	100,00%	99,21%	100,00%	0,00%	0,00%	100,00%
11	21/11/2016 21:00:00.000	21/11/2016 22:00:00.000	99,98%	100,00%	94,09%	97,27%	0,00%	100,00%	99,95%	100,00%	99,99%	99,99%	99,99%	100,00%	99,93%	100,00%	99,95%	99,90%	100,00%	100,00%	0,00%	100,00%	99,60%	100,00%	0,00%	0,00%	100,00%
12	21/11/2016 22:00:00.000	21/11/2016 23:00:00.000	99,91%	100,00%	100,00%	98,40%	0,00%	100,00%	99,89%	100,00%	100,00%	99,97%	100,00%	100,00%	99,96%	100,00%	99,92%	99,89%	100,00%	100,00%	0,00%	100,00%	99,64%	99,02%	0,00%	0,00%	100,00%
13	21/11/2016 23:00:00.000	22/11/2016 00:00:00.000	99,99%	100,00%	100,00%	99,07%	0,00%	100,00%	98,60%	100,00%	99,99%	99,99%	100,00%	100,00%	99,94%	100,00%	99,98%	99,99%	100,00%	100,00%	0,00%	100,00%	99,76%	99,12%	0,00%	0,00%	100,00%
14	22/11/2016 00:00:00.000	22/11/2016 01:00:00.000	99,92%	100,00%	100,00%	99,53%	0,00%	100,00%	99,51%	100,00%	99,99%	100,00%	100,00%	100,00%	99,93%	100,00%	99,98%	99,92%	100,00%	100,00%	0,00%	100,00%	99,61%	97,98%	0,00%	0,00%	100,00%
15	22/11/2016 01:00:00.000	22/11/2016 02:00:00.000	99,97%	100,00%	100,00%	99,67%	0,00%	100,00%	96,30%	100,00%	99,99%	99,26%	100,00%	100,00%	99,90%	100,00%	99,99%	100,00%	100,00%	100,00%	0,00%	90,94%	98,17%	100,00%	0,00%	0,00%	100,00%
16	22/11/2016 02:00:00.000	22/11/2016 03:00:00.000	100,00%	99,59%	100,00%	99,33%	0,00%	100,00%	89,24%	100,00%	99,99%	99,14%	100,00%	99,54%	99,99%	100,00%	99,99%	100,00%	99,54%	99,60%	0,00%	100,00%	99,97%	100,00%	0,00%	0,00%	100,00%
17	22/11/2016 03:00:00.000	22/11/2016 04:00:00.000	100,00%	99,87%	100,00%	99,58%	0,00%	100,00%	91,06%	100,00%	99,99%	100,00%	100,00%	99,87%	99,82%	100,00%	100,00%	100,00%	99,87%	99,90%	0,00%	100,00%	99,98%	100,00%	0,00%	0,00%	100,00%
18	22/11/2016 04:00:00.000	22/11/2016 05:00:00.000	100,00%	99,88%	95,86%	99,84%	0,00%	100,00%	98,73%	100,00%	99,98%	99,29%	100,00%	99,88%	100,00%	100,00%	100,00%	100,00%	99,88%	99,90%	0,00%	100,00%	99,99%	100,00%	0,00%	0,00%	100,00%
19	22/11/2016 05:00:00.000	22/11/2016 06:00:00.000	97,95%	99,79%	100,00%	99,82%	0,00%	100,00%	92,39%	100,00%	99,99%	100,00%	100,00%	99,79%	100,00%	100,00%	100,00%	100,00%	99,79%	99,81%	0,00%	100,00%	98,97%	98,01%	0,00%	0,00%	100,00%
20	22/11/2016 06:00:00.000	22/11/2016 07:00:00.000	100,00%	99,85%	100,00%	99,88%	0,00%	100,00%	99,54%	100,00%	99,99%	100,00%	100,00%	99,82%	99,88%	100,00%	100,00%	100,00%	99,82%	99,87%	0,00%	100,00%	99,08%	99,08%	0,00%	0,00%	100,00%
21	22/11/2016 07:00:00.000	22/11/2016 08:00:00.000	100,00%	100,00%	100,00%	99,91%	0,00%	100,00%	99,14%	100,00%	99,99%	100,00%	100,00%	100,00%	99,71%	100,00%	100,00%	100,00%	100,00%	100,00%	0,00%	100,00%	100,00%	99,89%	0,00%	0,00%	100,00%
22	22/11/2016 08:00:00.000	22/11/2016 09:00:00.000	100,00%	100,00%	100,00%	99,86%	0,00%	100,00%	99,79%	100,00%	99,98%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	99,76%	100,00%	100,00%	0,00%	100,00%	100,00%	99,99%	0,00%	0,00%	100,00%
23	22/11/2016 09:00:00.000	22/11/2016 10:00:00.000	99,99%	100,00%	100,00%	99,60%	0,00%	100,00%	99,93%	100,00%	99,99%	100,00%	100,00%	100,00%	99,99%	99,99%	100,00%	99,85%	100,00%	100,00%	0,00%	100,00%	99,04%	98,95%	0,00%	0,00%	100,00%
24	22/11/2016 10:00:00.000	22/11/2016 11:00:00.000	99,97%	100,00%	88,82%	99,74%	0,00%	100,00%	94,62%	100,00%	99,98%	99,98%	100,00%	100,00%	98,77%	100,00%	99,99%	99,99%	100,00%	100,00%	0,00%	99,99%	92,44%	99,99%	0,00%	0,00%	100,00%
25	22/11/2016 11:00:00.000	22/11/2016 12:00:00.000	100,00%	100,00%	60,76%	98,50%	0,00%	100,00%	99,00%	100,00%	99,99%	99,91%	99,99%	100,00%	96,85%	100,00%	99,97%	99,89%	100,00%	99,99%	0,00%	100,00%	99,54%	100,00%	0,00%	0,00%	100,00%
26	22/11/2016 12:00:00.000	22/11/2016 13:00:00.000	99,92%	100,00%	0,00%	98,58%	0,00%	100,00%	99,73%	100,00%	99,99%	99,78%	99,99%	100,00%	99,81%	99,91%	99,98%	99,58%	100,00%	99,95%	39,34%	100,00%	95,67%	99,92%	0,00%	0,00%	100,00%
27	22/11/2016 13:00:00.000	22/11/2016 14:00:00.000	100,00%	100,00%	0,00%	99,07%	0,00%	100,00%	99,97%	100,00%	99,99%	99,77%	99,99%	100,00%	94,56%	100,00%	99,99%	99,17%	100,00%	99,92%	100,00%	100,00%	98,97%	100,00%	0,00%	0,00%	100,00%
28	22/11/2016 14:00:00.000	22/11/2016 15:00:00.000	99,92%	99,97%	0,00%	99,17%	0,00%	100,00%	99,97%	100,00%	99,99%	99,88%	99,99%	99,97%	99,73%	100,00%	99,97%	99,59%	99,97%	99,86%	100,00%	100,00%	99,21%	96,99%	0,00%	0,00%	100,00%
29	22/11/2016 15:00:00.000	22/11/2016 16:00:00.000	99,98%	100,00%	0,00%	99,00%	0,00%	100,00%	99,98%	100,00%	99,99%	99,28%	99,99%	100,00%	99,55%	100,00%	99,96%	99,72%	99,97%	99,97%	100,00%	100,00%	98,20%	97,97%	0,00%	0,00%	100,00%
30	22/11/2016 16:00:00.000	22/11/2016 17:00:00.000	99,99%	91,07%	0,00%	99,08%	0,00%	100,00%	99,99%	100,00%	99,97%	99,87%	99,98%	99,69%	99,68%	100,00%	99,94%	99,48%	99,69%	99,80%	100,00%	99,98%	98,63%	100,00%	0,00%	0,00%	100,00%
31	22/11/2016 17:00:00.000	22/11/2016 18:00:00.000	99,96%	99,99%	8,22%	98,70%	0,00%	100,00%	99,98%	100,00%	99,98%	99,73%	100,00%	82,90%	99,56%	100,00%	99,86%	98,57%	99,99%	99,92%	100,00%	100,00%	98,83%	99,98%	0,00%	0,00%	100,00%
32	22/11/2016 18:00:00.000	22/11/2016 19:00:00.000	99,97%	100,00%	100,00%	99,04%	0,00%	100,00%	99,98%	100,00%	99,99%	99,79%	99,99%	100,00%	99,54%	100,00%	99,91%	98,79%	100,00%	99,92%	100,00%	100,00%	99,02%	100,00%	0,00%	0,00%	100,00%
33	22/11/2016 19:00:00.000	22/11/2016 20:00:00.000	99,99%	100,00%	100,00%	99,15%	0,00%	100,00%	97,86%	100,00%	82,37%	99,77%	98,27%	93,10%	99,45%	100,00%	99,86%	98,02%	100,00%	99,96%	100,00%	82,38%	67,43%	100,00%	0,00%	0,00%	100,00%
34	22/11/2016 20:00:00.000	22/11/2016 21:00:00.000	100,00%	100,00%	100,00%	99,56%	0,00%	100,00%	94,15%	100,00%	0,00%	99,86%	100,00%	100,00%	98,88%	100,00%	99,77%	99,16%	100,00%	99,99%	100,00%	0,00%	99,10%	100,00%	0,00%	0,00%	100,00%
35	22/11/2016 21:00:00.000	22/11/2016 22:00:00.000	99,99%	100,00%	100,00%	99,66%	0,00%	100,00%	98,65%	100,00%	0,00%	99,99%	100,00%	88,72%	99,40%	100,00%	99,95%	99,73%	100,00%	100,00%	100,00%	0,00%	99,34%	98,93%	0,00%	0,00%	100,00%
36	22/11/2016 22:00:00.000	22/11/2016 23:00:00.000	99,88%	82,85%	99,93%	99,48%	0,00%	99,94%	95,58%	99,94%	19,72%	99,89%	99,94%	94,36%	99,66%	99,94%	99,87%	99,83%	99,93%	99,93%	99,94%	19,72%	99,62%	99,89%	0,00%	0,00%	99,94%
37	22/11/2016 23:00:00.000	23/11/2016 00:00:00.000	99,98%	100,00%	100,00%	99,40%	0,00%	100,00%	95,93%	100,00%	40,24%	100,00%	100,00%	100,00%	99,86%	100,00%	99,99%	99,98%	100,00%	100,00%	100,00%	40,24%	99,74%	100,00%	0,00%	0,00%	100,00%
38	23/11/2016 00:00:00.000	23/11/2016 01:00:00.000	100,00%	100,00%	100,00%	99,68%	0,00%	100,00%	97,38%	99,98%	99,99%	100,00%	100,00%	91,95%	100,00%	100,00%	99,99%	99,99%	100,00%	100,00%	100,00%	100,00%	99,85%	100,00%	0,00%	0,00%	100,00%
39	23/11/2016 01:00:00.000	23/11/2016 02:00:00.000	99,99%	100,00%	100,00%	99,58%	0,00%	100,00%	97,32%	100,00%	99,99%	99,27%	100,00%	100,00%	99,96%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	99,80%	100,00%	0,00%	0,00%	100,00%

Source: Medplot Real Time Data Check Report

openPDC Completeness Daily Report
DataIsValid (bit15) = Data Error + Device Synchronization Error (bit13) = PMU Sync Error

ONS

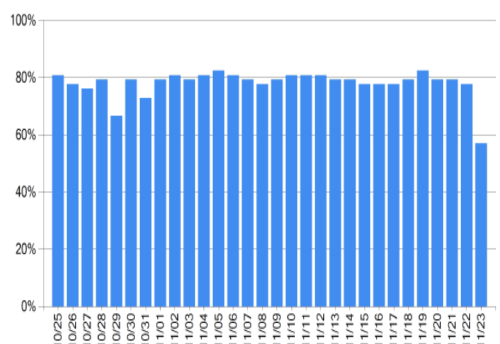
SEC_APP Completeness Report
ONS

quarta-feira, 23 de novembro de 2016

5-day Device Data Completeness

	11/19	11/20	11/21	11/22	11/23
L4: Good	47	47	47	31	29
L3: Fair	5	3	3	18	7
L2: Poor	2	4	4	6	18
L1: Offline	2	2	2	1	2
L0: Failed	7	7	7	7	7
Total	63	63	63	63	63

Percent of Devices with Acceptable Quality (30 days)



Definitions

Level 4: Good - Devices which are reporting as expected, with a completeness of at least 99% on the report date.

Level 3: Fair - Devices with a completeness of at least 90% on the report date.

Level 2: Poor - Devices which reported on the report date, but had an completeness below 90%.

Level 1: Offline - Devices which did not report on the report date, but have reported at some time during the 30 days prior to report date.

Level 0: Failed - Devices which have not reported during the 30 days prior to the report date.

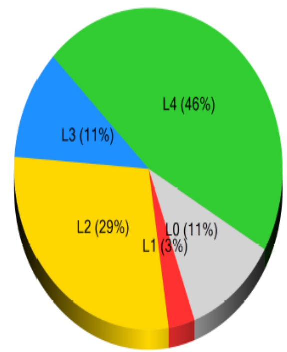
Completeness: Percentage of measurements received over total measurements expected, per device.

Acceptable Quality: Devices which are in Level 4 or Level 3.

quarta-feira, 23 de novembro de 2016

Data Completeness Breakdown

Level 4	29
Level 3	7
Level 2	18
Level 1	2
Level 0	7



Level 0

Name	Completeness	Data Errors	Time Errors
03_BAU_CAV_1	0%	0	0
04_CAV_BAU_1	0%	0	0
QRDP	0%	0	0
RDP_CAV	0%	0	0
RDP_LT_REP	0%	0	0
RU-98012	0%	0	0
TU-98013	0%	0	0

Level 1

Name	Completeness	Data Errors	Time Errors
AT-98012	0%	0	0
UFC	0%	0	0

Level 2

Name	Completeness	Data Errors	Time Errors
01_ILS_BAU	73,36%	0	0
02_BAU_ILS_2	73,47%	0	0
05_CAV_BOJ	73,47%	0	0
AR2_RDP-CA1	73,4%	0	5.336
ARARAQUARA	73,4%	38	5.232
CPV_RDP-CA1	73,28%	2.729	2.875
LTCORG	65,69%	1.777.366	0
PR50_3RDP	73,45%	61	5.357
RDP-1	73,44%	1.824	1.817

quarta-feira, 23 de novembro de 2016

Level 2 (contd.)

Name	Completeness	Data Errors	Time Errors
RDP1_PMU	73,42%	0	0
RDP_2	73,44%	3.570	1.953
RDP_BAU	73,45%	31	14
RPV311_PMU	67,68%	0	0
RPV311_PMU2	8,36%	951	976
UFAC	86,3%	43	2
UFAM	71,99%	4	4
UFPA	88,83%	0	0
UNIR	76,71%	0	0

Level 3

Name	Completeness	Data Errors	Time Errors
CVO_525KV	98,51%	73	73
SCX_525KV	98,5%	2.598.645	608
SGD_525KV	98,51%	0	0
SSA_525KV	98,51%	0	0
STFI_500KV	98,51%	0	0
UNIFEI	98,76%	0	0
UTFPR	95,44%	0	0

Level 4

Name	Completeness	Data Errors	Time Errors
BTA525	320,14%	65	65
COPPE	99,47%	59	2
JGR_RDP1	99,54%	0	0
JGR_RDP2	99,45%	0	0
LTCOIT	99,98%	0	0
LTCOIZ2	99,87%	0	0
LTCOMC2	99,87%	0	0
LTIZCO2	99,9%	0	0
LTSMGU2	99,39%	0	0
LTSMSB3	99,39%	0	0
LTSMSD	99,41%	0	0
LT_IPZ_ACA_C1	99,86%	0	0
LT_PDD_ACA_C1	99,86%	0	0
RDP_CNO_ECTE	99,93%	0	0
UFBA	99,96%	57	1
UFES	99,99%	59	2
UFJF	99,98%	120	4
UFMA	99,66%	0	0
UFMG	99,31%	59	4
UFMS	99,42%	0	0
UFMT	99,8%	0	0
UFPE	100%	0	0

Source: openPDC Data Report

openPDC Completeness Daily Report

DataIsValid (bit15) = Data Error + Device Syncrhonization Error (bit13) = PMU Sync Error

Level 4 = "Good" - Devices which are reporting as expected, with a completeness of at least 99% on the report date.
Level 3 = "Fair" - Devices with a completeness of at least 90% on the report date.
Level 2 = "Poor" - Devices which reported on the report date, but had an completeness below 90%.
Level 1 = "Offline" - Devices which did not report on the report date, but have reported at some time during the 30 days prior to the report date
Level 0 = "Failed" - Devices which have not reported during the 30 days prior to the report date.
"Completeness" = Percentage of measurements received over total measurements expected, per device. PMU Data= 5184000 frames/day (60frames*24h*60min*60seg)
"Acceptable Quality" = Devices which are in Level 4 or Level 3.

First Week / October

Data	Circuit	Completeness	Data Errors [Frames]	Data Errors [%]	Time Errors	Level
10.17.16 (Monday)	COIT	99,99%	0	0,00%	0	4
	COIZ2	99,66%	7015	0,14%	2	4
	COMC2	99,66%	7015	0,14%	2	4
	CORG	95,03%	256961	4,96%	0	3
	IZCO2	99,73%	0	0,00%	0	4
	SMGU2	98,82%	5619	0,11%	1	3
	SMSB3	98,82%	5619	0,11%	1	3
	SMSD	99,28%	0	0,00%	0	4
	Average	98,87%	35278,625	0,68%	0,75	3,63

Data	Circuit	Completeness	Data Errors	Data Errors [%]	Time Errors	Level
10.18.16 (Tuesday)	COIT	99,99%	0	0,00%	0	4
	COIZ2	99,78%	0	0,00%	0	4
	COMC2	99,78%	0	0,00%	0	4
	CORG	99,99%	0	0,00%	0	4
	IZCO2	97,81%	0	0,00%	0	3
	SMGU2	99,23%	0	0,00%	0	4
	SMSB3	99,23%	0	0,00%	0	4
	SMSD	99,43%	0	0,00%	0	4
	Average	99,41%	0	0,00%	0	3,88

Second Week / October

Data	Circuit	Completeness	Data Errors	Data Errors [%]	Time Errors	Level
10.24.16 (Monday)	COIT	99,99%	0	0,00%	0	4
	COIZ2	99,74%	0	0,00%	0	4
	COMC2	99,74%	0	0,00%	0	4
	CORG	81,69%	948155	18,29%	0	2
	IZCO2	99,74%	0	0,00%	0	4
	SMGU2	99,60%	0	0,00%	0	4
	SMSB3	99,60%	0	0,00%	0	4
	SMSD	99,79%	5823	0,11%	2	4
	Average	97,49%	119247,3	2,30%	0,25	3,75

Data	Circuit	Completeness	Data Errors	Data Errors [%]	Time Errors	Level
10.25.16 (Tuesday)	COIT	95,38%	0	0,00%	0	3
	COIZ2	95,19%	0	0,00%	0	3
	COMC2	95,19%	0	0,00%	0	3
	CORG	95,38%	0	0,00%	0	3
	IZCO2	95,07%	0	0,00%	0	3
	SMGU2	95,07%	0	0,00%	0	3
	SMSB3	95,07%	0	0,00%	0	3
	SMSD	95,10%	9190	0,18%	2	3
	Average	95,18%	1148,75	0,02%	0,25	3

Source: openPDC – ONS PMU installed on high voltage side

SYNCRHONISM PROBLEM INVESTIGATION

PMU DATA RECEIVED FROM ONS OPENPDC

Wireshark: Latency, Framesize, SOC Time, FracSec, TimeBase and Leap Second

```
66500 2016-10-21 17:04:00.212661 200.195.129.2 192.168.254.11 SYNCHROPHASOR Data Frame
66544 2016-10-21 17:04:00.229855 200.195.129.2 192.168.254.11 SYNCHROPHASOR Configuration Frame 2
66545 2016-10-21 17:04:00.229882 200.195.129.2 192.168.254.11 SYNCHROPHASOR Data Frame

⊟ Frame 66544: 1206 bytes on wire (9648 bits), 1206 bytes captured (9648 bits)
    Arrival Time: Oct 21, 2016 17:04:00.229855000 E. South America Daylight Time
    Epoch Time: 1477076640.229855000 seconds
    [Time delta from previous captured frame: 0.000023000 seconds]
    [Time delta from previous displayed frame: 0.017194000 seconds]
    [Time since reference or first frame: 15.366050000 seconds]
    Frame Number: 66544
    Frame Length: 1206 bytes (9648 bits)
    Capture Length: 1206 bytes (9648 bits)
    [Frame is marked: False]
    [Frame is ignored: False]
    [Protocols in frame: eth:ip:udp:synphasor]
    [Coloring Rule Name: UDP]
    [Coloring Rule String: udp]
⊞ Ethernet II, Src: e8:39:35:10:2c:ed (e8:39:35:10:2c:ed), Dst: e0:db:55:0f:45:2c (e0:db:55:0f:45:2c)
⊞ Internet Protocol, Src: 200.195.129.2 (200.195.129.2), Dst: 192.168.254.11 (192.168.254.11)
⊞ User Datagram Protocol, Src Port: 21315 (21315), Dst Port: 4714 (4714)
⊟ IEEE C37.118 Synchrophasor Protocol, Configuration Frame 2
  ⊞ Synchronization word: 0xaa31
    Framesize: 1164
    PMU/DC ID number: 114
    SOC time stamp (UTC): 2016-10-21 19:04:00
  ⊟ Time quality flags
      .0.. .... = Leap second direction: False
      ..0. .... = Leap second occurred: False
      ...0 .... = Leap second pending: False
      .... 0000 = Time Quality indicator code: Normal operation, clock locked (0x00)
    Fraction of second (raw): 0
  ⊟ Configuration data, 6 PMU(s) included
      Resolution of fractional second time stamp: 1000000
      Number of PMU blocks included in the frame: 6
    ⊞ Station #1: "BTA_525kV        "
    ⊞ Station #2: "SGD_525kV        "
    ⊞ Station #3: "CVO_525KV        "
    ⊞ Station #4: "STFI_500kV       "
    ⊞ Station #5: "SCX_525KV        "
    ⊞ Station #6: "SSA_525KV        "
      Rate of transmission: 60 frame(s) per second
    Checksum: 0xe65e [correct]

0030  58 0a 66 a0 00 00 00 00  00 0f 42 40 00 06 42 54   X.f..... ..B@..BT
0040  41 5f 35 32 35 6b 56 20  20 20 20 20 20 20 03 e9   A_525kV        ..
0050  00 0f 00 00 00 00 00 00  00 00 00 00 53 47 44 5f   ........ ....SGD_
```

Source: ONS Wireshark

PDC Internal Calculation: Synchrophasor Alignment

- Variable SOC time in hexadecimal format: 580a66a0. Converting to decimal: 1477076640 (total of seconds since the first instant (time = 00h:00min:00sec:00msec) of 01/01/1970)
- Data Frame Flag Time: TIME = SOC + FRACSEC / TIME_BASE where, in this case: TIME_BASE = 1000000

Frame 1

```
66544 2016-10-21 17:04:00.229855 200.195.129.2 192.168.254.11 SYNCHROPHASOR Configuration Frame 2
66545 2016-10-21 17:04:00.229882 200.195.129.2 192.168.254.11 SYNCHROPHASOR Data Frame
66664 2016-10-21 17:04:00.248905 200.195.129.2 192.168.254.11 SYNCHROPHASOR Data Frame
⊞ Frame 66545: 502 bytes on wire (4016 bits), 502 bytes captured (4016 bits)
⊞ Ethernet II, Src: e8:39:35:10:2c:ed (e8:39:35:10:2c:ed), Dst: e0:db:55:0f:45:2c (e0:db:55:0f:45:2c)
⊞ Internet Protocol, Src: 200.195.129.2 (200.195.129.2), Dst: 192.168.254.11 (192.168.254.11)
⊞ User Datagram Protocol, Src Port: 21315 (21315), Dst Port: 4714 (4714)
⊟ IEEE C37.118 Synchrophasor Protocol, Data Frame
  ⊞ Synchronization word: 0xaa01
    Framesize: 460
    PMU/DC ID number: 114
    SOC time stamp (UTC): 2016-10-21 19:04:00
  ⊞ Time quality flags
    Fraction of second (raw): 0
  ⊞ Measurement data, using frame number 66544 as configuration frame
    Checksum: 0x759f [correct]
```

Frame [0] = 1477076640 + 0/1000000 = **0**

Frame [1] = 1477076640 + 16667/1000000 = **1477076640,01667**

Frame 2

```
66544 2016-10-21 17:04:00.229855 200.195.129.2 192.168.254.11 SYNCHROPHASOR Configuration Frame 2
66545 2016-10-21 17:04:00.229882 200.195.129.2 192.168.254.11 SYNCHROPHASOR Data Frame
66664 2016-10-21 17:04:00.248905 200.195.129.2 192.168.254.11 SYNCHROPHASOR Data Frame
⊞ Frame 66664: 502 bytes on wire (4016 bits), 502 bytes captured (4016 bits)
⊞ Ethernet II, Src: e8:39:35:10:2c:ed (e8:39:35:10:2c:ed), Dst: e0:db:55:0f:45:2c (e0:db:55:0f:45:2c)
⊞ Internet Protocol, Src: 200.195.129.2 (200.195.129.2), Dst: 192.168.254.11 (192.168.254.11)
⊞ User Datagram Protocol, Src Port: 21315 (21315), Dst Port: 4714 (4714)
⊟ IEEE C37.118 Synchrophasor Protocol, Data Frame
  ⊞ Synchronization word: 0xaa01
    Framesize: 460
    PMU/DC ID number: 114
    SOC time stamp (UTC): 2016-10-21 19:04:00
  ⊞ Time quality flags
    Fraction of second (raw): 16667
  ⊞ Measurement data, using frame number 66544 as configuration frame
    Checksum: 0x8116 [correct]
```

Frame [1] = 1477076640 + 33333/1000000 = **1477076640,03333**

And so on...

where: Δt = 16,67 msec

Source: Wireshark

PDC Internal Calculation: Synchrophasor Alignment

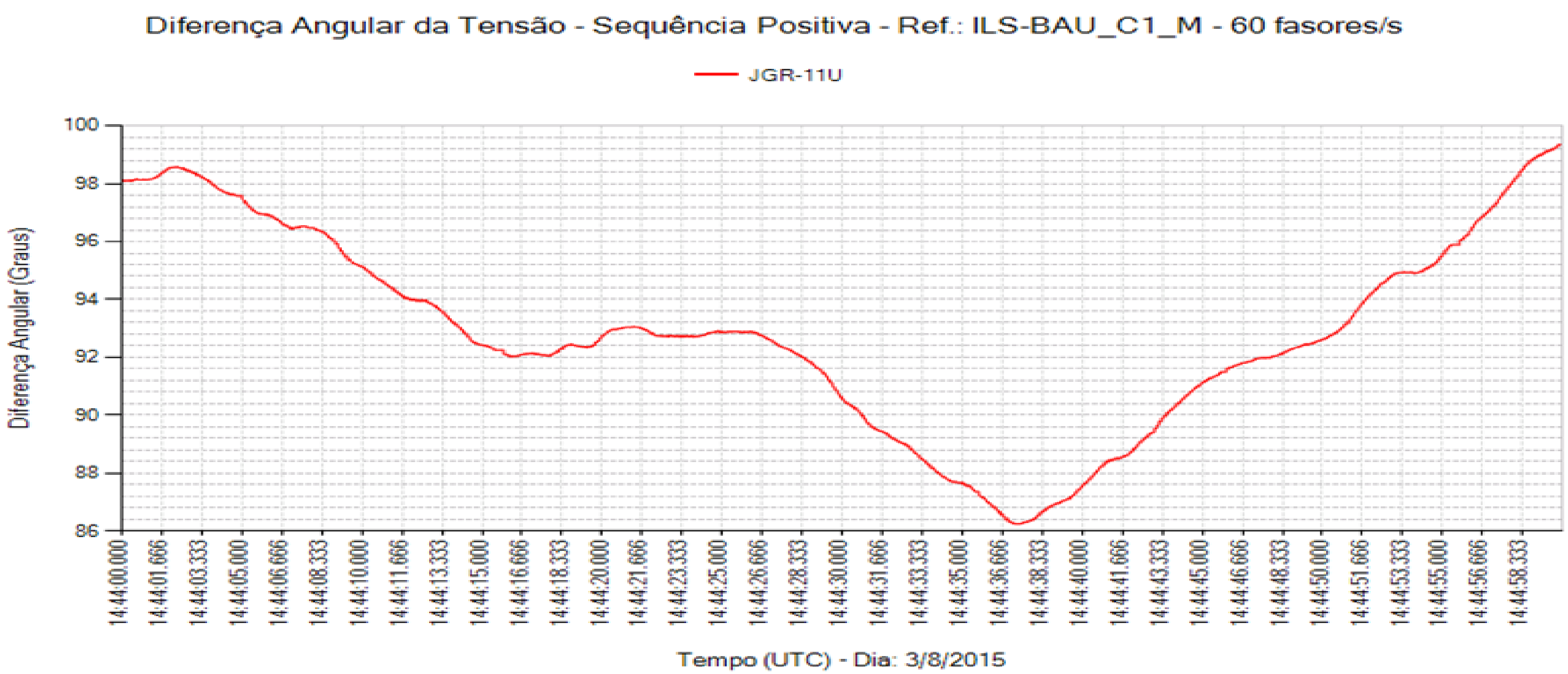
Count	Tempo_(SOC)	VA_mod_(V)	VA_ang_(graus)	VB_mod_(V)	VB_ang_(graus)	VC_mod_(V)	VC_ang_(graus)	Frequência
0	1477076640,0000	309139,1000	-112,9359	309418,5000	126,7619	308156,7000	6,8692	59,9693
1	1477076640,0167	309138,2000	-113,1200	309425,8000	126,5803	308168,2000	6,6856	59,9695
2	1477076640,0333	309138,8000	-113,3030	309421,0000	126,3992	308170,2000	6,5039	59,9698
3	1477076640,0500	309133,1000	-113,4857	309421,7000	126,2167	308168,9000	6,3193	59,9694
4	1477076640,0667	309142,5000	-113,6696	309421,9000	126,0329	308176,0000	6,1357	59,9693
56	1477076640,9333	309204,8000	-123,7484	309465,7000	115,9495	308212,0000	-3,9414	59,9666
57	1477076640,9500	309201,1000	-123,9497	309463,9000	115,7479	308210,3000	-4,1430	59,9664
58	1477076640,9667	309195,9000	-124,1535	309461,7000	115,5471	308213,1000	-4,3464	59,9661
59	1477076640,9833	309179,1000	-124,3570	309451,0000	115,3457	308204,8000	-4,5502	59,9662
60 0	1477076641,0000	309135,3000	-124,5595	309426,2000	115,1471	308194,9000	-4,7534	59,9665

- After 60 frames (0 – 59) ➔ increment variable SOC = 1477076640,9833 to SOC = 1477076641,0000 and the counter should return number 0 ➔ **OK!!!**

Problem Detected: Angle Difference between PMU Cemig x Cteep

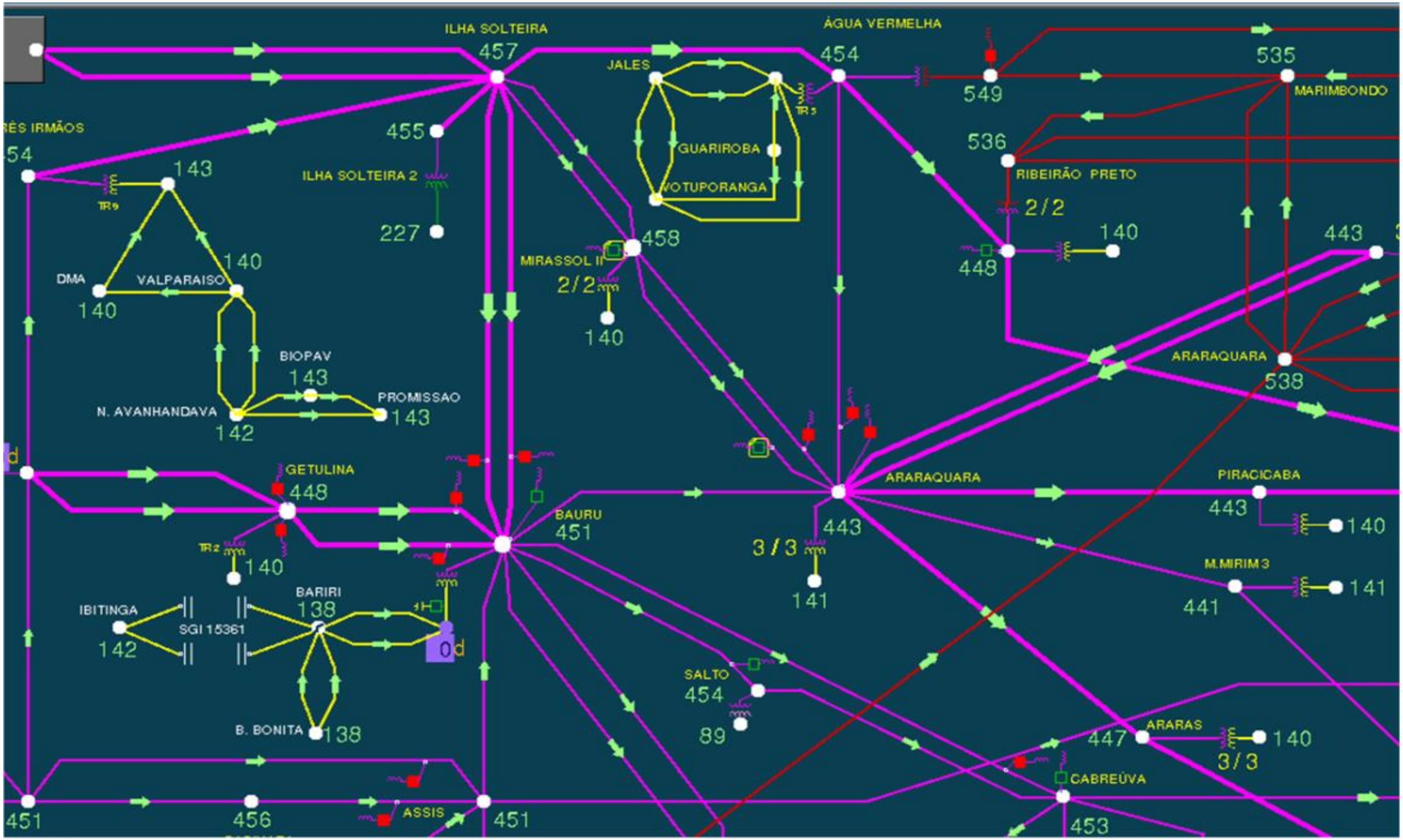
- On August of 2015 were evaluated the angle difference between PMU of high voltage (Cemig – Jaguara and Cteep – Ilha Solteira);

- Angle variation higher than expected, even in short time period and with the SIN (Brazilian Network) in normal condition (with no reported disturbance).



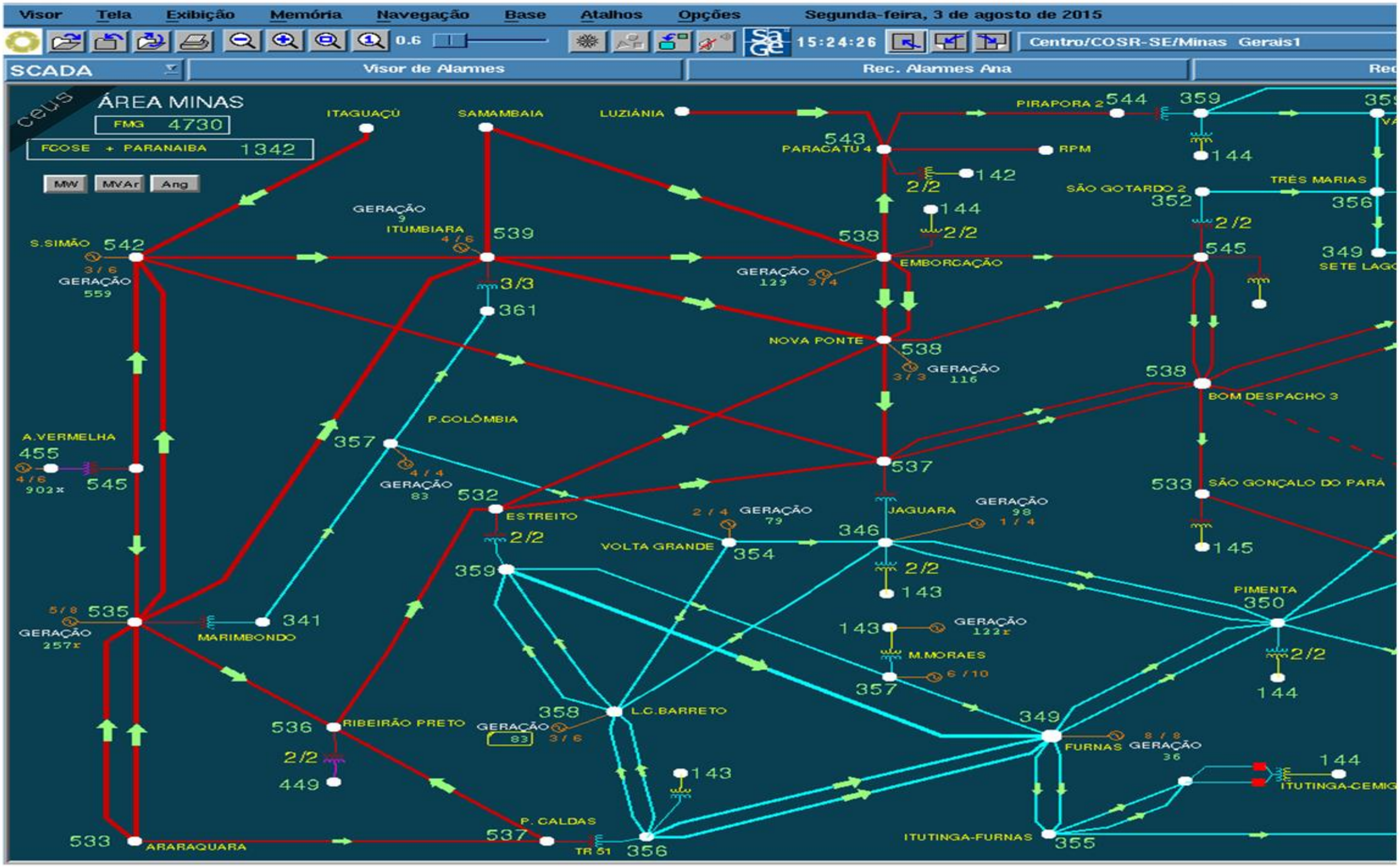
Source: Medplot Offline - UFSC

Software CEUS/SAGE: São Paulo Area



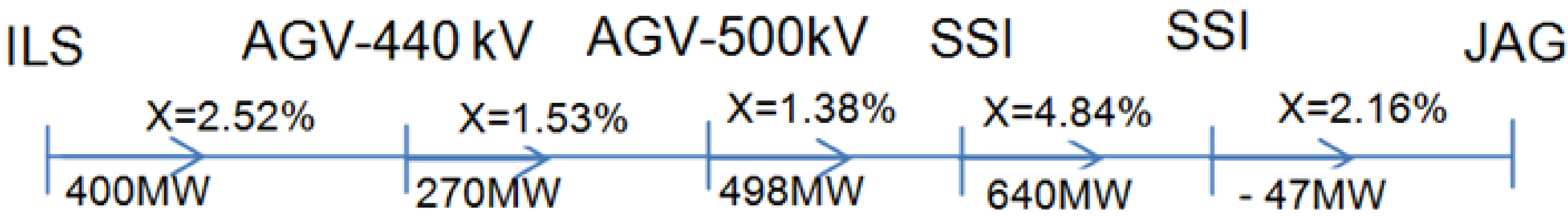
Source: Sage/CEUS

Software CEUS/SAGE: Minas State



Source: Sage/CEUS

Angle Difference: Cemig // Cteep – Linearized Power Flow



The angle difference between the two substations: Ilha Solteira (Cteep) and Jaguara (Cemig) was determined by:

$$\theta_{ILS} = -0.47 * 0.0216 + 6.06 * 0.0484 + 4.98 * 0.0138 + 2.7 * 0.0153 + 4 * 0.0252$$
$$\theta_{ILS} = -0.0494 rad * 57.3 = -28.3°$$

Verifying by Anarede Software (Power Flow) with Medium Loading Scenario (2015), thus:

$$\theta_{ILS} = -28°.$$

- Leap Second is the time setting → occasionally applied to the UTC reference. UTC → keep the daily time close to the average solar time (UT1). Without this correction, in function of earth rotation irregularities, the UTC reference would drift away from atomic time. The correction system were implemented in 1972 → already occured 26 leap seconds;

- Insertion of UTC leap second → determined every six months by IERS (International Earth Rotation and Reference Systems Service), to ensure that the time difference between UTC and UT1 does not exceed more than 0.9 seconds.

Tabel 5 – Leap Second in accordance with IEEE Standard

Bit #	Description
7	Reserved
6	Leap Second Direction—0 for add, 1 for delete
5	Leap Second Occurred—set in the first second after the leap second occurs and remains set for 24 h
4	Leap Second Pending—shall be set not more than 60 s nor less than 1 s before a leap second occurs, and cleared in the second after the leap second occurs
3–0	Message Time Quality indicator code—see Table 4.

Tabel 6 – Last 5 leap second

Data UTC	Tempo UTC	Diferença TAI x UTC
31/12/2005	23:59:60	33 seg
31/12/2008	23:59:60	34 seg
30/06/2012	23:59:60	35 seg
30/06/2015	**23:59:60**	**36 seg**
31/12/2016	**23:59:60**	**37 seg**

Finding the problem : ONS Real Case

Tabel 7 – Verification of the leap second

ID Code PMU	NumChPhasor	Time	Count	Magnitude	Angle
3	0	1438815299	58	277449	38,0897
3	0	1438815299	59	277447	38,2056
3	0	1438815299	60	277443	38,3244
3	0	1438815300	1	277440	38,4451
3	0	1438815300	2	277444	38,5652
3	0	1438815300	3	277446	38,6847

- Yellow line indication → problem with the time tagging of the data frames. The first frame of the first second was tagged with the SOC time of the previous second (1438815299) and COUNT = 60. The correct would be current SOC (1438815300) and COUNT = 0;

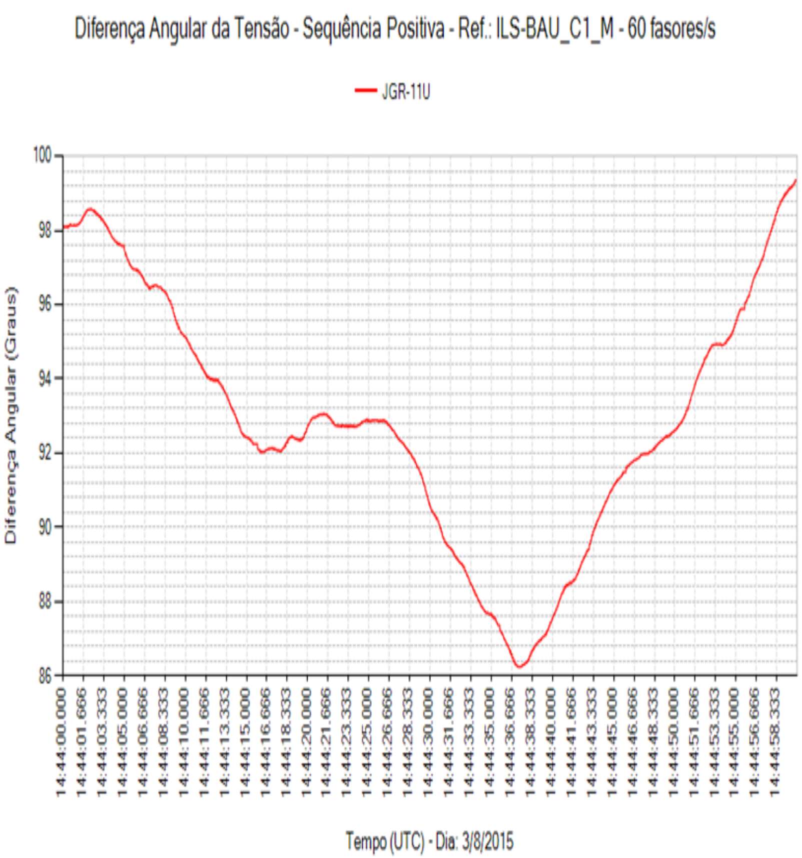
- This problem with time tagging alignment → resulted in inconsistent analysis, including the angle difference;

- As a post event analysis was performed, it was not possible to verify the leap second flag via the wireshark software, this software captures real-time information, which reinforces the need for registration and indication the leap second indications by the PDC.

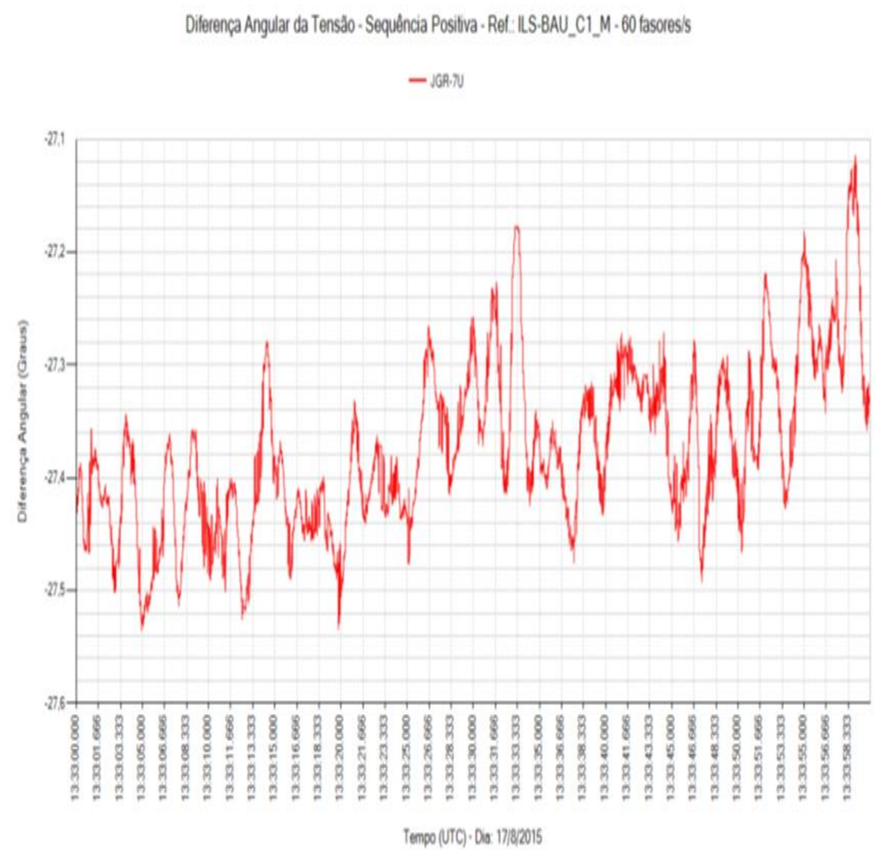
Problem Solution:

SOLUTION ➔ Changing PMU Firmware version➔ Leap Second problem solution.

Old Firmware Version



New Firmware Version



Conclusion:

- About GNSS sytem, small part of failures (0.25%) → loss of primary reference signal → longer period than one hour. Majority of failures → momentary impact signal oscillations;
- Equipment failures, they were not the object of study but greater times of unavailability → impact directly by the performance of the maintenance teams;
- Important → Fault management centered, if possible, on reliability → notify occurrences;
- Essential → integrated system → needs redundancy about synchronism system.

Conclusion:

- Synchronism failure ➔ problem of analysis in the electrical system, such as angular difference ➔ CONSEQUENCE ➔ wrong decision in real-time operation team ➔ reinforcing the need to monitor the synchronization signals;

- CONSEQUENCE ➔ frequency calculation, since it is obtained by the first derivative of the angle and the ROCOF, obtained by the second derivative of the angle, respectively;

- Improve communications architecture, equipment and time synchronization protocol ➔ essential task during initial project design ➔ must meet criteria of NT115 / 2014 Rev.16;

- Greater interaction between IEEE standards C37.118 and IEC61850 ➔ mainly with regard to synchronization systems. A strong trend ➔ PTP IEEE 1588 usage and / or hybrid solutions.

THANKS FOR ATTENTION!

Rafael Fernandes – ONS
rafael.fernandes@ons.org.br
+5521-3444-9475