Steps toward the use of synchrophasors by the Brazilian System Operator - ONS

Operador Nacional do Sistema Elétrico

Rio de Janeiro - RJ

12/12/12

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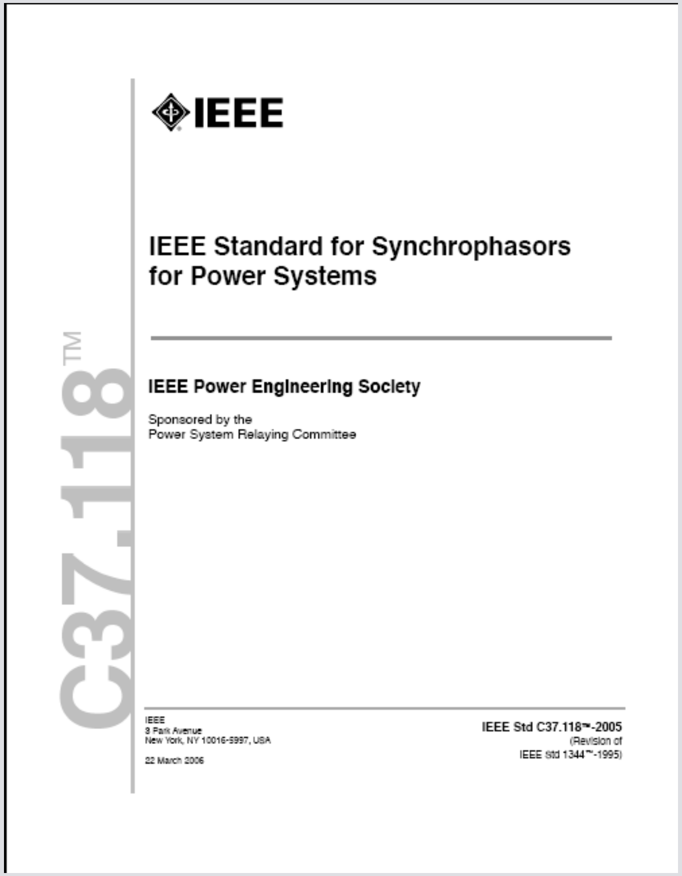
Definition


IEEE

IEEE Standard for Synchrophasors for Power Systems

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee

C37.118™

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

22 March 2006

IEEE Std C37.118™-2005
(Revision of
IEEE Std 1344™-1995)

Phasor:

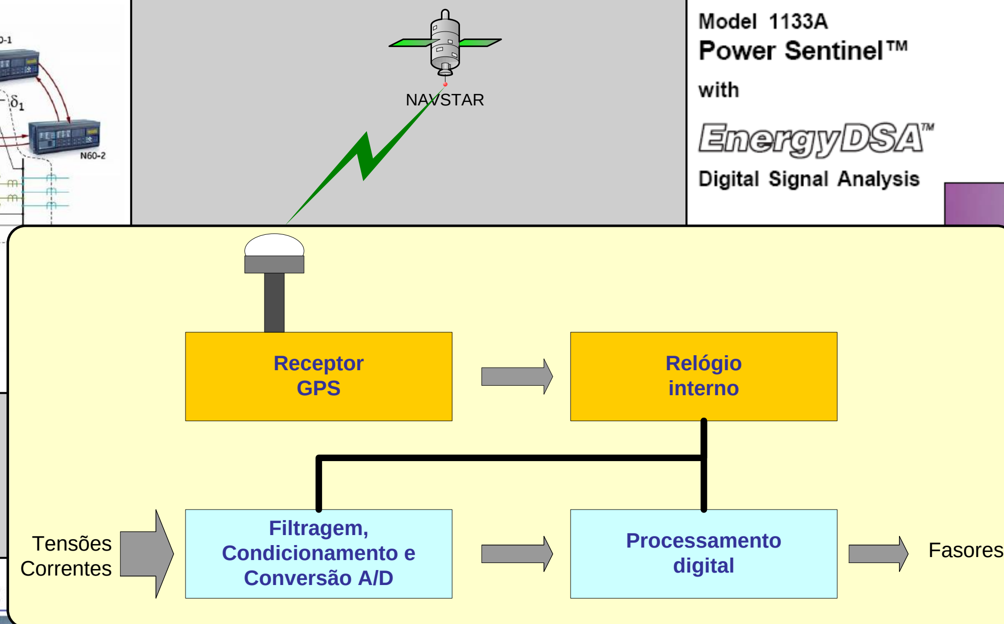
It is a complex number which represents the magnitude and angle of voltages and currents found on an electricity grid.

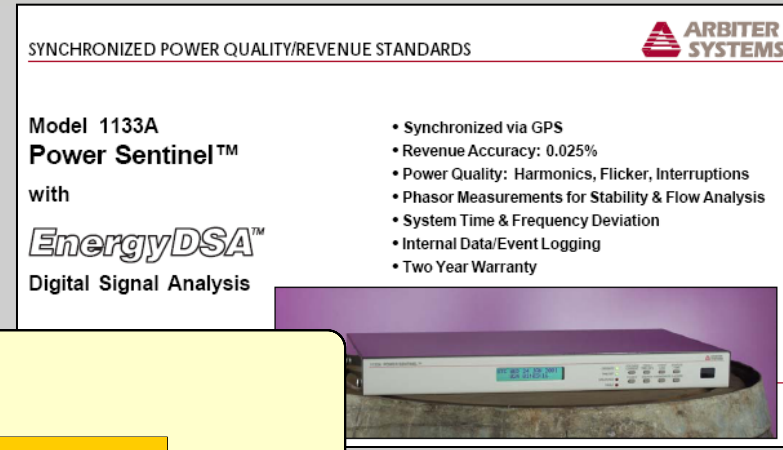
$$\hat{x} = x_r + j\,x_i = \frac{X_M}{\sqrt{2}} e^{j\phi} = \frac{X_M}{\sqrt{2}}\left(\cos\phi + j sen\phi\right)$$

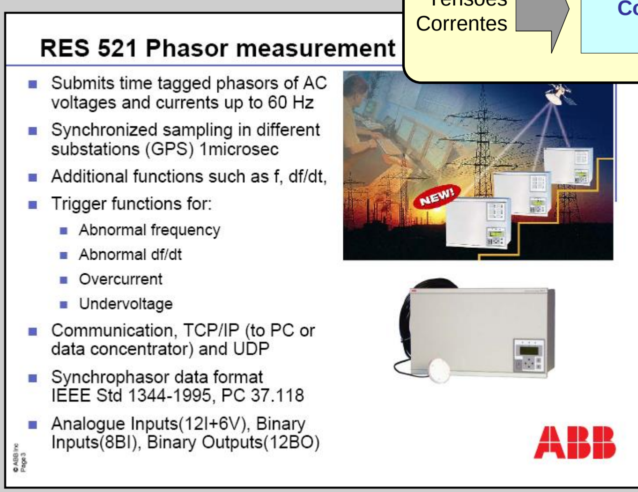
Synchrophasor:

It is a phasor measurement synchronized to a common time source (GPS radio clock). Since they are synchronized, they can be compared to assess power system conditions.

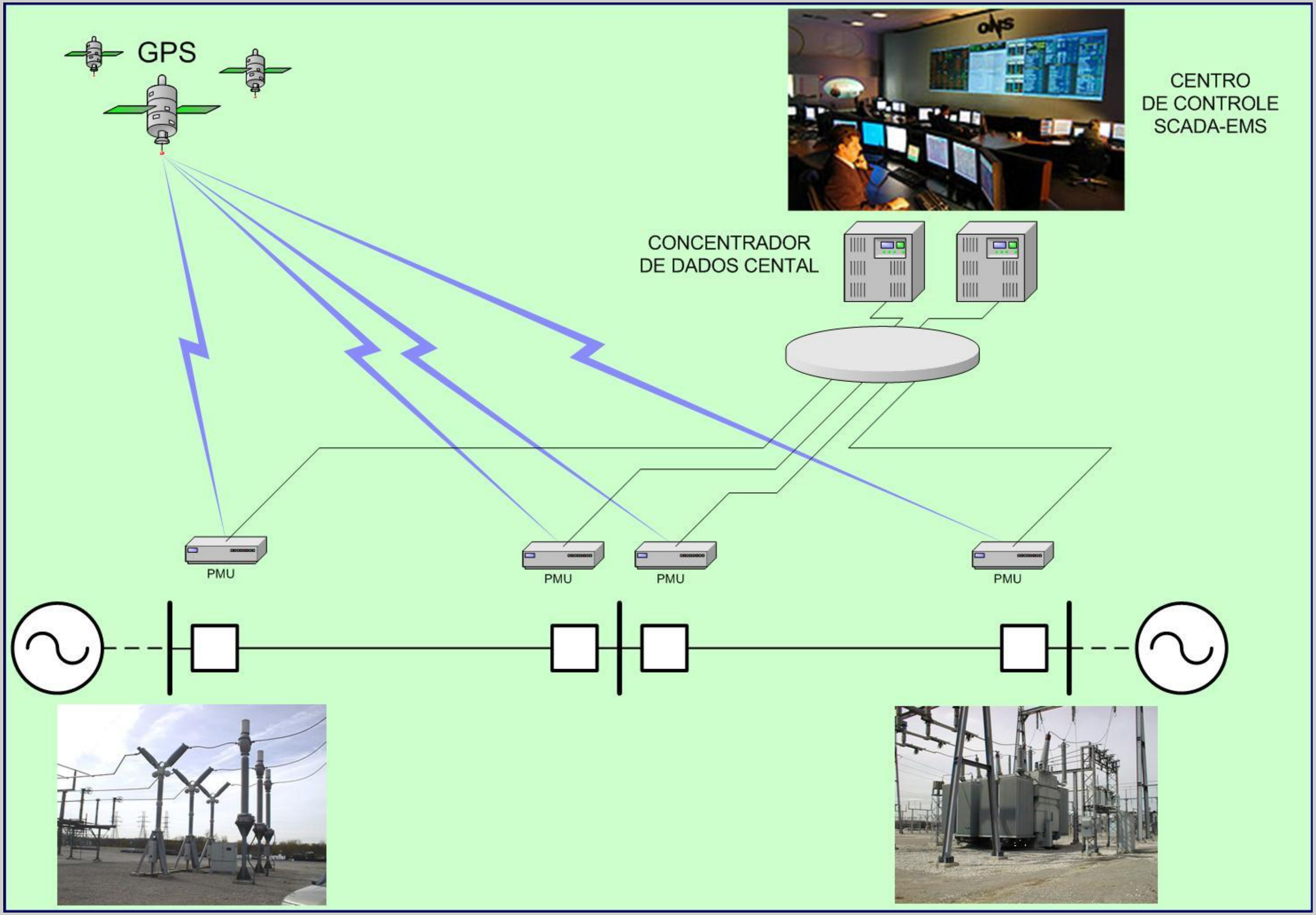
PMU – Phasor Measurement Unit



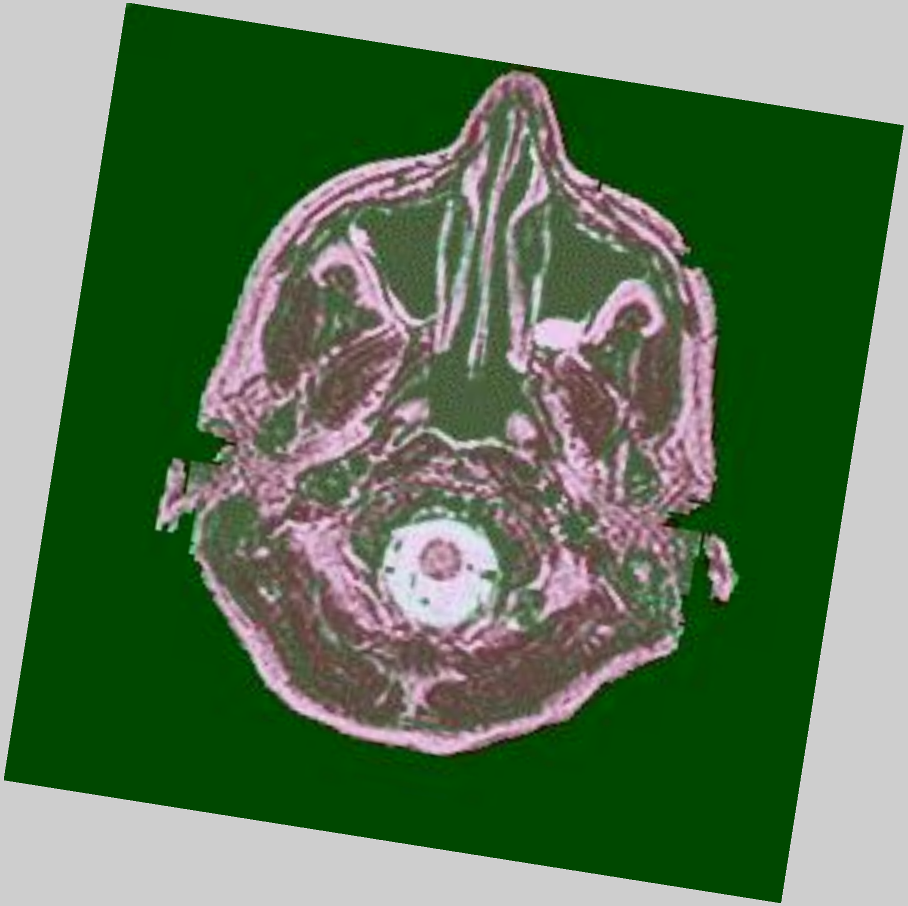




Synchronized Phasor Measurement System



Phasor Measurements: From X-Ray to MRI



MRI – Magnetic Resonance Imaging

SPMS in Brazil

National Interconnected Power System (NIPS) – SPMS

Motivation

Increase NIPS reliability using synchrophasors measuring technology for dynamic disturbance recording and real-time monitoring

Deployment of a Phasor Recording System

Install a synchronized phasor measuring system to record NIPS dynamic performance during long time wide area disturbances

This project will also define the whole system technical specifications, envisioning the future real-time applications

Phasor Measurement Technology Application to Support Real Time Operators Decision

Extend the application of the initial SPMS for real-time applications

Project Strategy

Work with Brazilian Regulatory Office to define a *top-down* approach, through an Authoritative Resolution

The ANEEL's Resolution (170/2005) states:

- ✓ **Utilities' duties**
  - Utilities shall purchase, install, operate and maintain the PMU placed in theirs substations. They also shall supply the communication links to ONS' Phasor Concentrators, *complying with technical requirements, specifications and schedules coordinated by ONS*

- ✓ **ONS' duties**
  - Define and specify the SPMS architecture
  - Specify, acquire and install the ONS' Phasor Concentrators
  - Define PMU placement
  - Define the schedule and coordinate the PMU installation by utilities

Project History

Year	Activity
2005	Technical Studies for PMU Location
2006/2007	Synchronized Phasor Measurement System Technical Specification
2008	Technical Studies for Application of Phasor Measurements Technology for Real Time Decision Making
2009	PMU Certification Process
2011	MME/BIRD understandings for funding SPMS
2012	Manufacturer’s Benchmark
2013	*PDC Infrastructure Acquisition*
2014	*Beginning of Operation*

PMU Placement

PMU Locations – 2 PMUs in each station

31 Substations

Área Rio de Janeiro
Angra 500 kV
Cach. Paulista 500 kV

Área Sul
Areia 500 kV
Bateias 500 kV
Campos Novos 500 kV
Itá 500 kV
Ivaiporã 500 kV
Nova Santa Rita 500kV

Área Minas Gerais
Itumbiara 500 kV
Jaguara 500 kV
Ouro Preto 345 kV

Área Norte
Imperatriz 500 kV
Manaus 500 kV
P. Dutra 500 kV
Tucuruí 500 kV

Área Mato Grosso
Jauru 230 kV

Área Acre/Rondônia
Porto Velho 230 kV
Samuel 230 kV

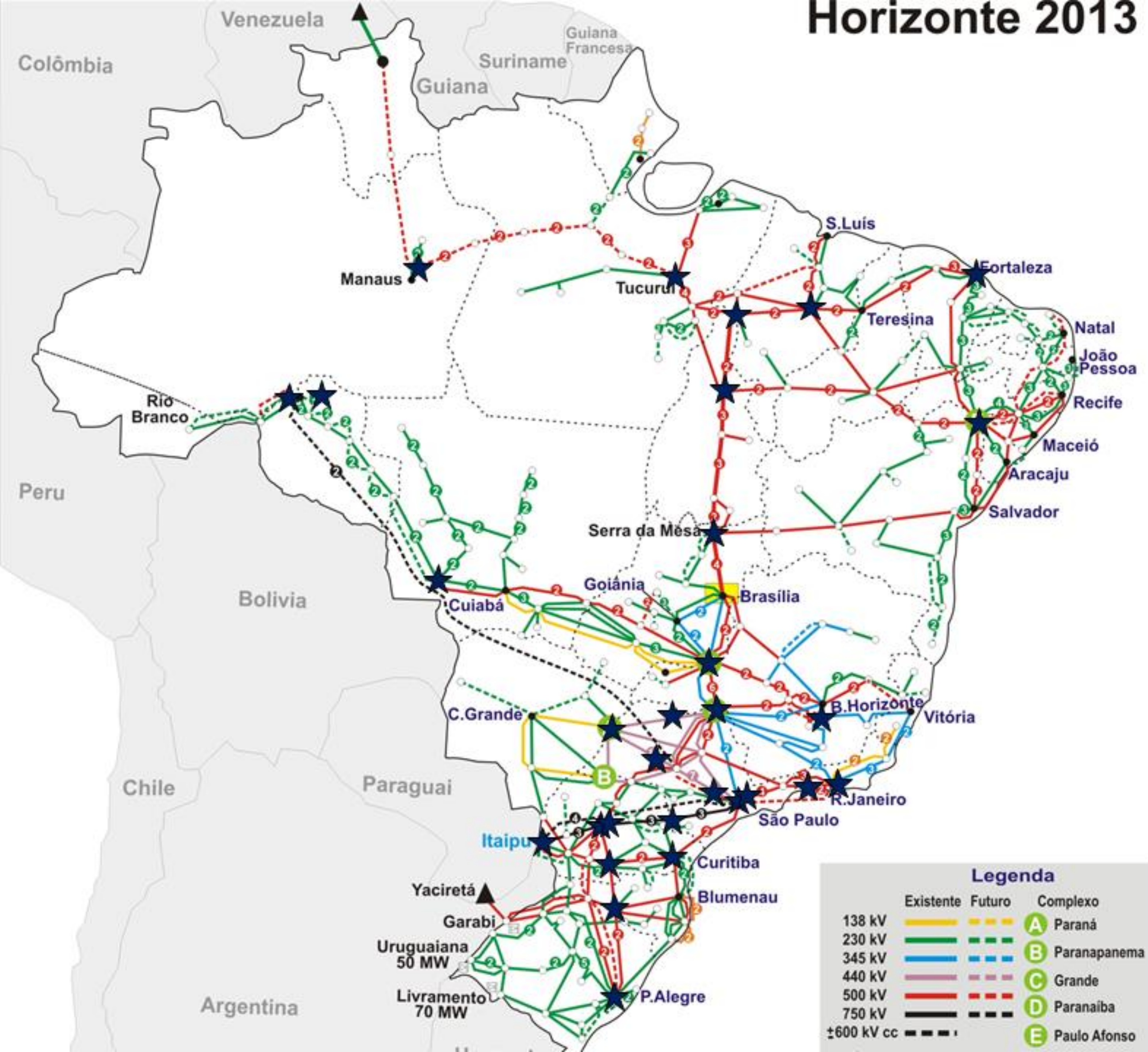
Área Nordeste
Fortaleza 500 kV
Paulo Afonso 500 kV

Sistema 765 kV / Link DC
Foz do Iguaçu 765 kV
Ibiúna 500 kV
Itaberá 765 kV
Ivaiporã 765 kV
Tijuco Preto 765 kV

Área SP
Água Vermelha 440 kV
Bauru 440 kV
Cabreúva 440 kV
Ilha Solteira 440 kV

Interligação Norte-Sudeste
Colinas 500 kV
Serra da Mesa 500 kV

Horizonte 2013



New Transmission Lines Requirements

ONS has been working towards a general requirement for PMUs for new transmissions lines

It has not been officially approved, but right now ONS thinks every new 500 kV Transmission Line will have to have PMUs at both ends.

ONS intends every new 500 kV Transmission Line auctioned in 2013 will have to have PMU measurements.

ONS will not buy any PMUs. Utilities will do. So we need a common and worldwide accepted standard to enforce. IEEE C37.118 is the answer?

IEEE C37.118 v2005

In 2008/2009 ONS conducted at NIST (USA) a certification process where the major 8 PMU manufacturers in the world were called to test their PMUs at ONS expenses. At that time, IEEE C37.118 only had steady state requirements. Additional dynamic tests were done to check PMUs dynamic behaviors.

No PMU was certified.

IEEE C37.118 v2011

ONS thought with this new version of the standard, the old problems would be corrected.

They were.

But new ones came up.

The new version brought issues with the Rate of Change of Frequency (ROCOF) during Dynamic Tests.

Where can I find a IEEE C37.118 v2011 PMU please?

So far, there are NO C37.118 v2011 PMUs on the market. They might never exist.

Why? IEEE C37.118 v2011 seems to be impossible to meet.

IEEE C37.118 working group is already aware of that. A revision to the standard might come along, but it will take another year or 2 to show up.

What to do?

ONS will work with manufacturers to establish a minimum and feasible set of requirements.

ONS will ask the manufacturers to disclose their PMU tests in order to check the accordance to the chosen requirements.

ONS will accept tests conducted at manufactures own lab facilities.

ONS will publish in its website which manufacturer has proved to meet the minimum requirements.

One manufacturer has already shared with ONS its results.

Phasor Measurements at ONS

Santa Catarina Federal University (UFSC) Partnership

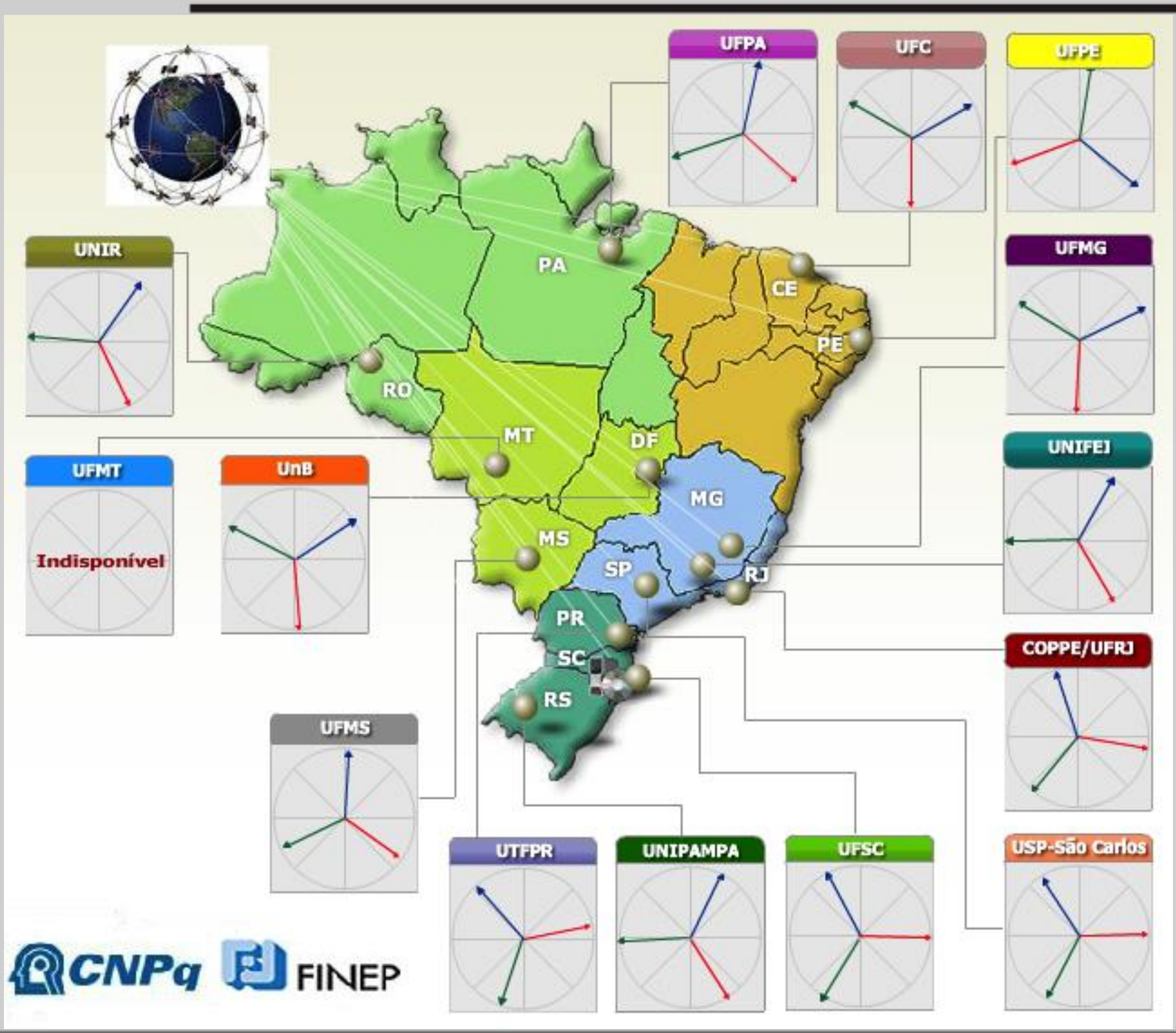
ONS started a partnership with UFSC in 2011:

- Dynamic performance and control systems analysis and investigation.
- UFSC's PMU System: MedFasee
- Started in 2003
- 14 PMUs installed on different Brazilian Universities
- All 5 Brazilian geographic regions are covered
- All PMUs are installed on low voltage side (outlets). Only synchrophasor frequencies are considered.
- 60 frames per second. Internet for synchrophasor transmission.

Benefits:

- Dynamic and offline visualization of NIPS synchrophasors
- Offline dynamic oscillations analysis
- Time savings and disturbance analysis quality improvements

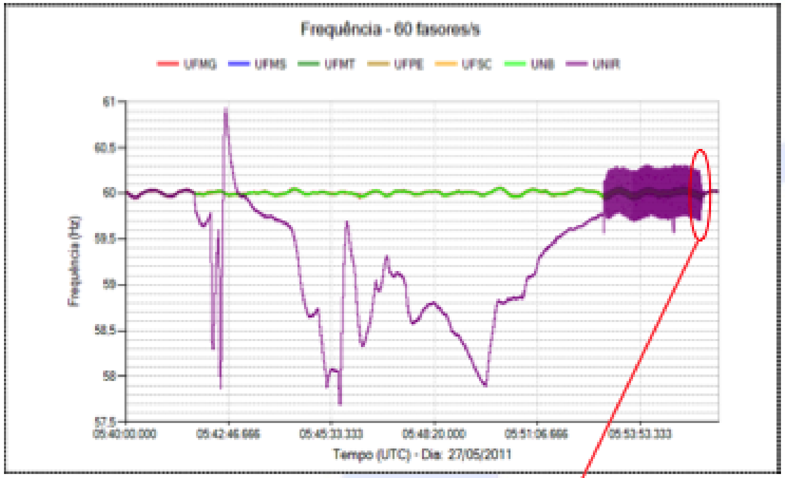
Santa Catarina Federal University (UFSC) Partnership

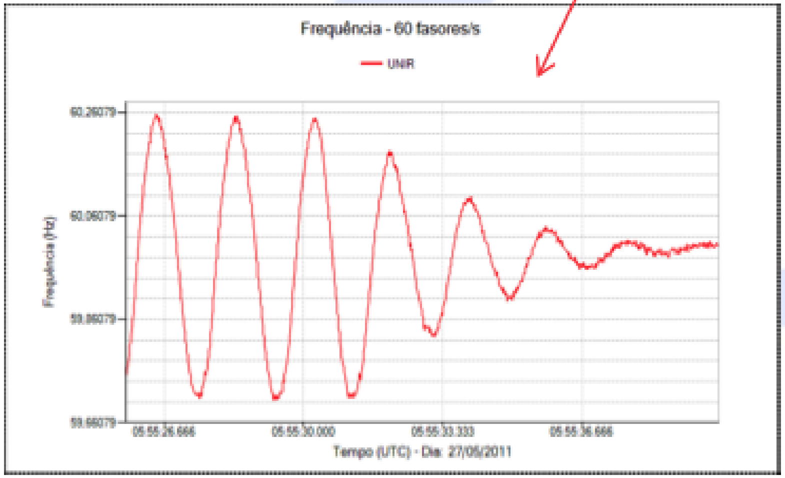


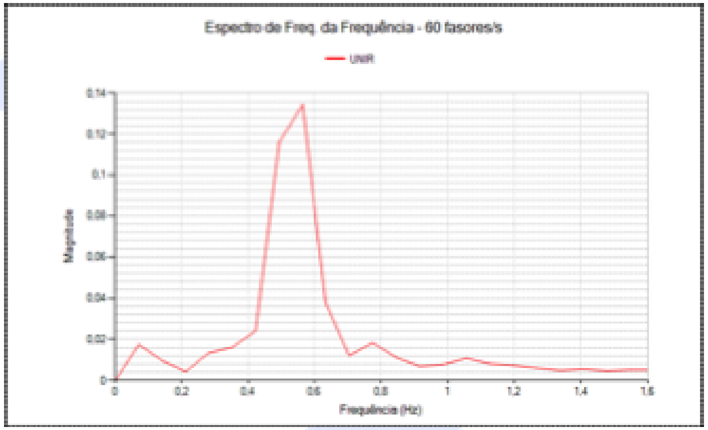
ONS

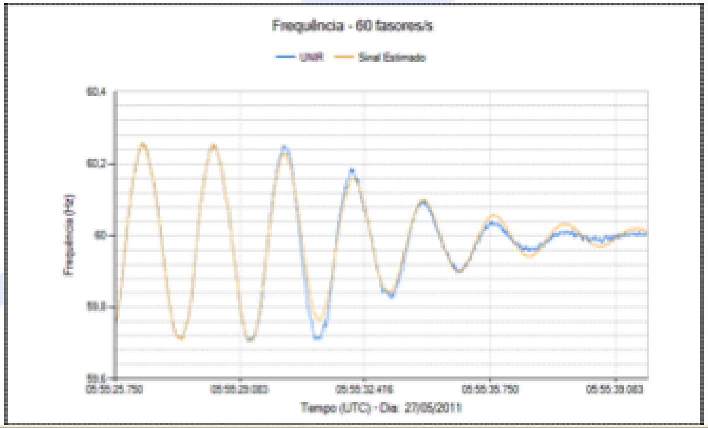
Santa Catarina Federal University (UFSC) Partnership

◆ Ex. de análise: abertura AC-RO/SIN









Energia	Frequência (Hz)	Amortecimento (%)	Amplitude	Fase (rad)	Real	Imaginário
573,494	0,519	8,674	0,431	-1,667	-0,284	3,264
367,521	0,567	10,424	0,397	1,459	-0,373	3,563
10,605	0,788	19,992	0,104	1,963	-1,01	4,95
4,878	1,564	30,753	0,119	2,644	-3,176	9,826
1,713	1,055	9,496	0,034	2,685	-0,632	6,629
0,38	1,963	13,751	0,026	-1,672	-1,596	12,336

ONS

Santa Catarina Federal University (UFSC) Partnership

Caso I - Oscilações Sustentadas do Centro-Oeste

UHE Cachoeira Dourada

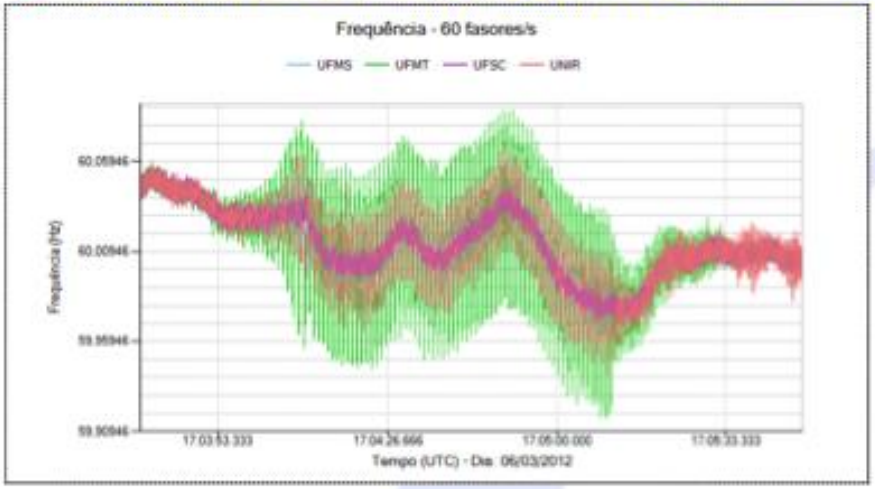
- Data: 06/03/2012

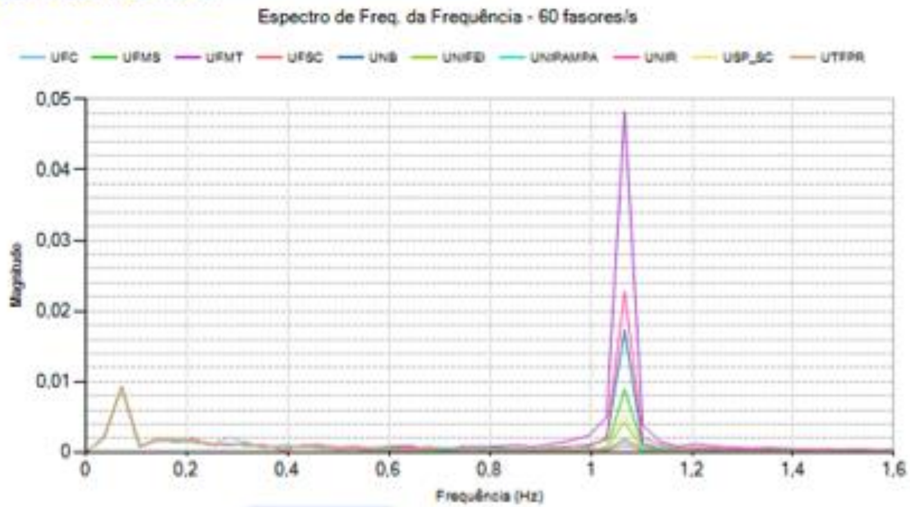
- Período
  - 1: 17h03min53s a 17h05min30s
  - 2: 17h27min50s a 17h36min56s
  - 3: 17h44min46s a 17h44min56s

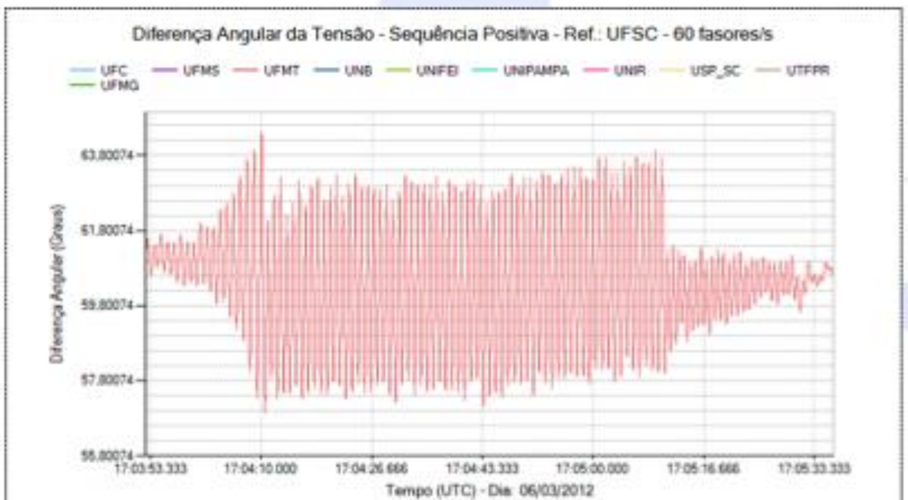
- Oscilações registradas
  - UFMT, UNIR, UnB, USP-SC, UFMG e UFMS

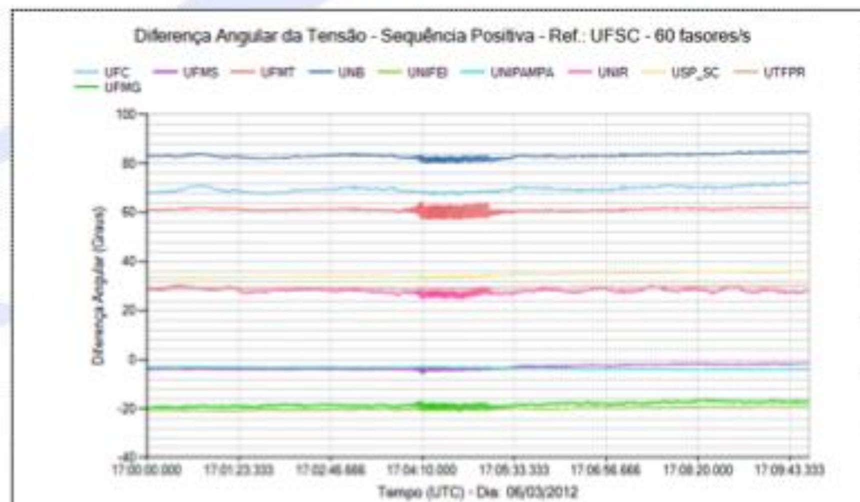
Santa Catarina Federal University (UFSC) Partnership

- Período 1: 17h03min53s a 17h05min30s





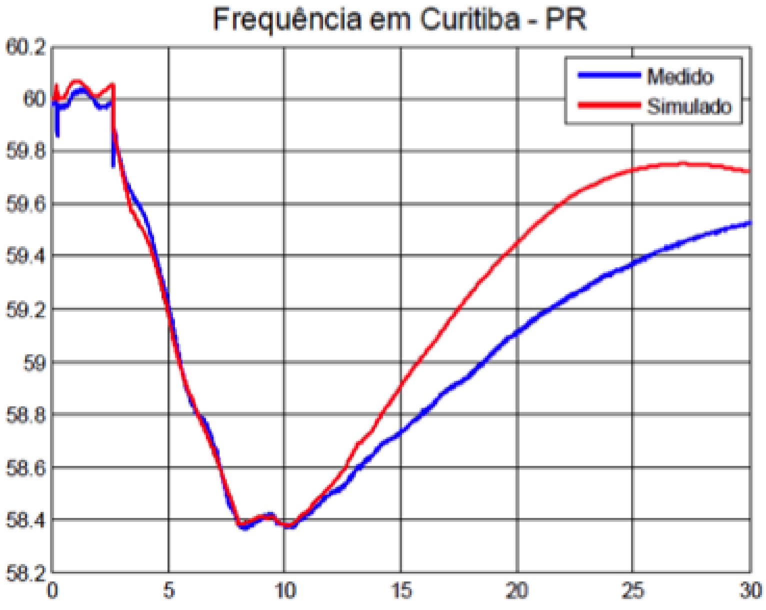


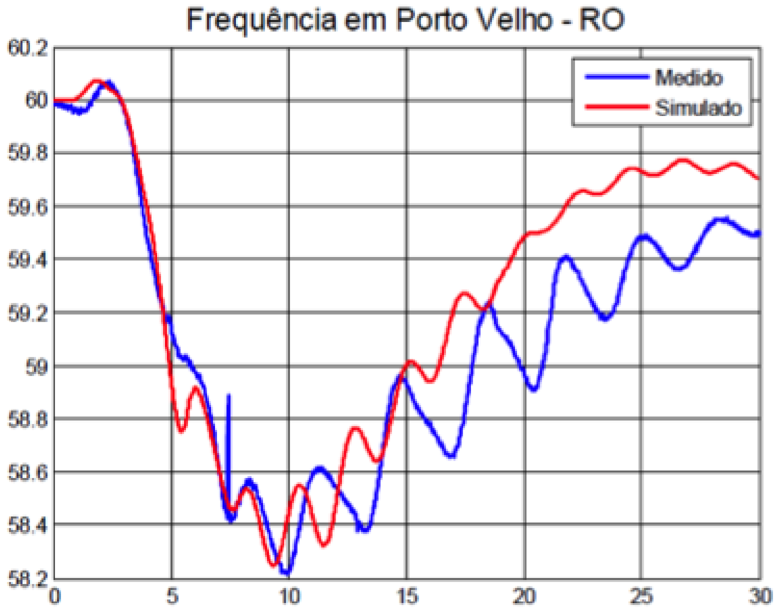


Validação de modelos de simulação

Aplicação: 02/09/2011 – Perda da UHE de Itaipu 60 Hz

- Avaliação qualitativa
  - Frequência: Curitiba-PR e Porto Velho-RO.

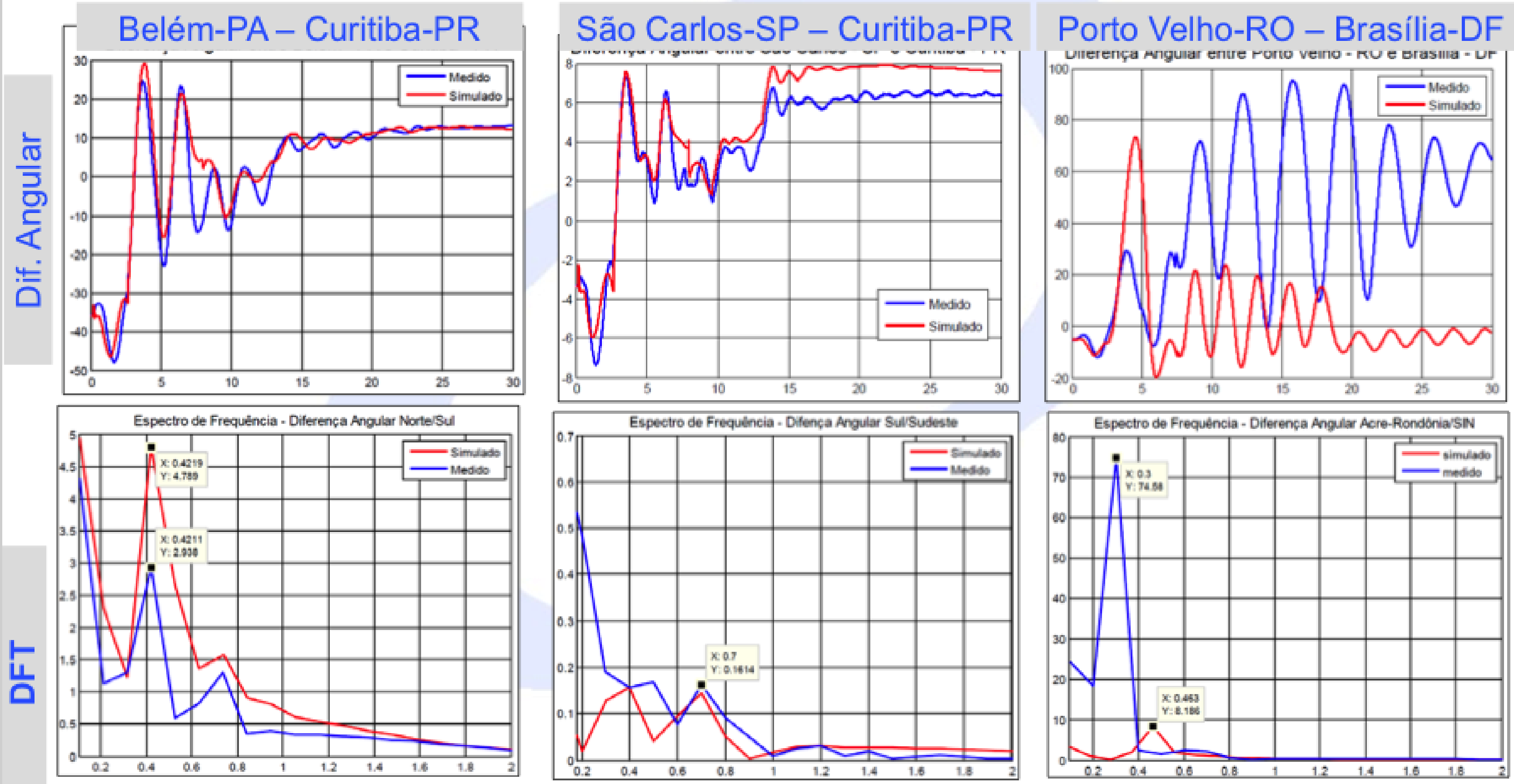




Validação de modelos de simulação

Aplicação: 02/09/2011 - Perda da UHE de Itaipu 60 Hz

- Avaliação qualitativa e quantitativa

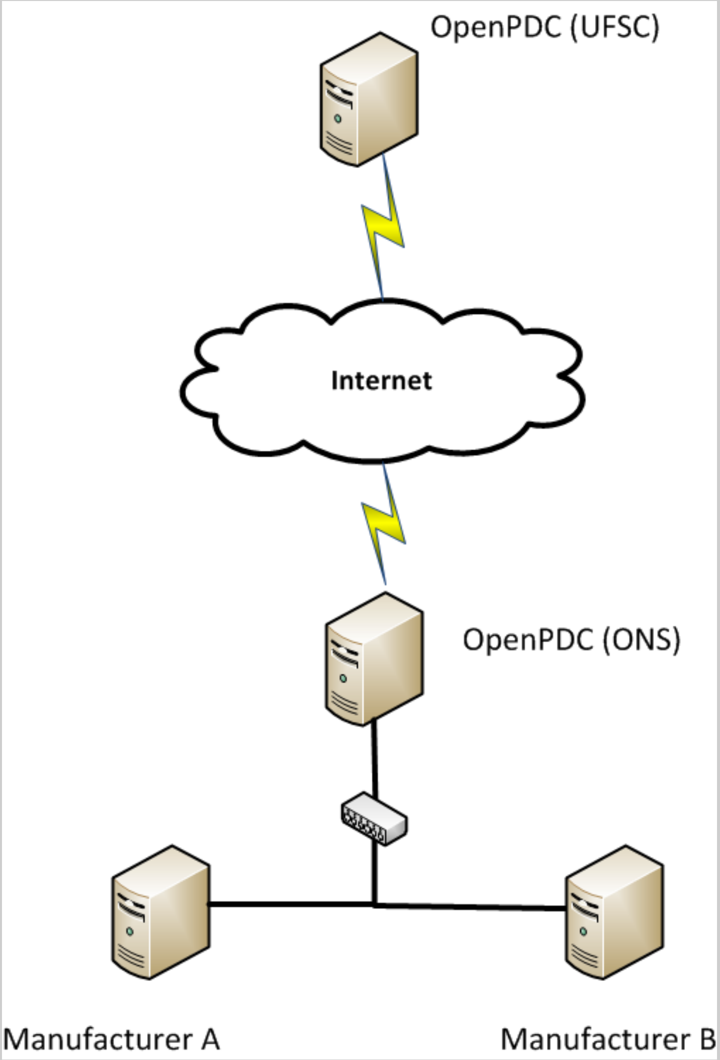


Santa Catarina Federal University (UFSC) Partnership

Mês	Ocorrência	Data	Descrição
Jan-12	1	08-01-2012	Abertura da interligação AC/RO-SIN
	2	18-01-2012	Abertura da interligação AC/RO-SIN
	3	22-01-2012	Abertura da interligação AC/RO-SIN
	4	24-01-2012	Perturbação na área Rio de Janeiro
Fev-12	1	13-02-2012	Abertura da interligação AC-RO/SIN
	2	20-02-2012	Perturbação no Paraná (Curitiba)
Mar-12	1	06-03-2012	Oscilações sustentadas referentes a UHE Cachoeira Dourada
	2	18-03-2012	Ensaios de rejeição de máquinas de 50 e 60 Hz da UHE de Itaipu
	3	25-03-2012	Desligamento da UHE Dardanelos situado no estado do Mato Grosso
	4	30-03-2012	Abertura da interligação AC-RO/SIN
Abr-12	1	01-04-2012	Abertura da interligação AC/RO-SIN
	2	09-04-2012	Abertura da interligação AC/RO-SIN
	3	28-04-2012	Abertura da interligação AC/RO-SIN
	4	29-04-2012	Abertura da interligação AC/RO-SIN
Mai-12	1	03-05-2012	Registros das repercussões no SIN dos testes de energização da unidade geradora 02 da UHE Santo Antônio
	2	09-05-2012	Testes para a conexão da UG3, de 50 MW, da UTH Santa Luzia I.
	3	13-05-2012	Desligamentos de LTs de 345 kV associados a SE Baixada Santista
Jun-12	1	15-06-2012	Oscilações sustentadas em Porto Velho (Termonorte II)
Jul-12	1	20-07-2012	Abertura da interligação AC-RO/SIN

Manufacturer's Benchmark

Benchmark


OpenPDC (UFSC)
Internet
OpenPDC (ONS)
Manufacturer A
Manufacturer B

What for?

ONS is very interest on Phasor Data Concetrator solution. But this is not enough.

ONS main focus is on APPLICATIONS.

ONS main question is: How can synchrophasors make real-time operation more secure?

During Jan/Jun 2013 ONS will conduct extensive analysis of all market solutions available for synchrophasor applications. Two manufacturers have already agreed on install pilot systems in ONS.

Any other manufacturer wants to join?

NIPS PMU System Architecture Design

SPMS Main Requirements

For offline applications:

- ✓ The maximum expected local and inter-area oscillations are around 2 Hz
- ✓ Data acquisition and archiving must be reliable to support communication failures

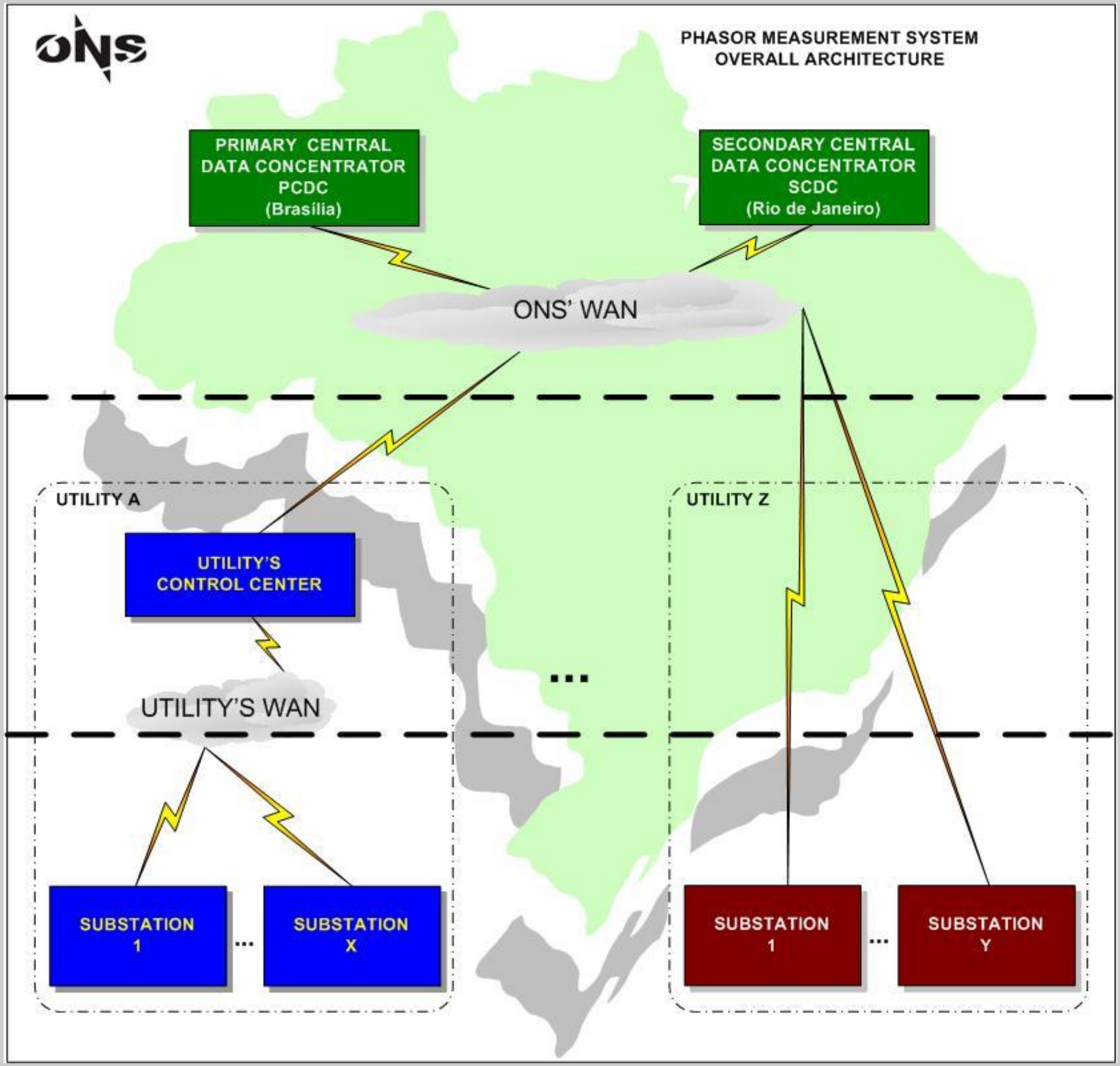
For real-time applications:

- ✓ It shall meet the maximum overall latency time of 2 seconds
- ✓ A report rate of 60 phasor per second is sufficient to expected applications

For overall system:

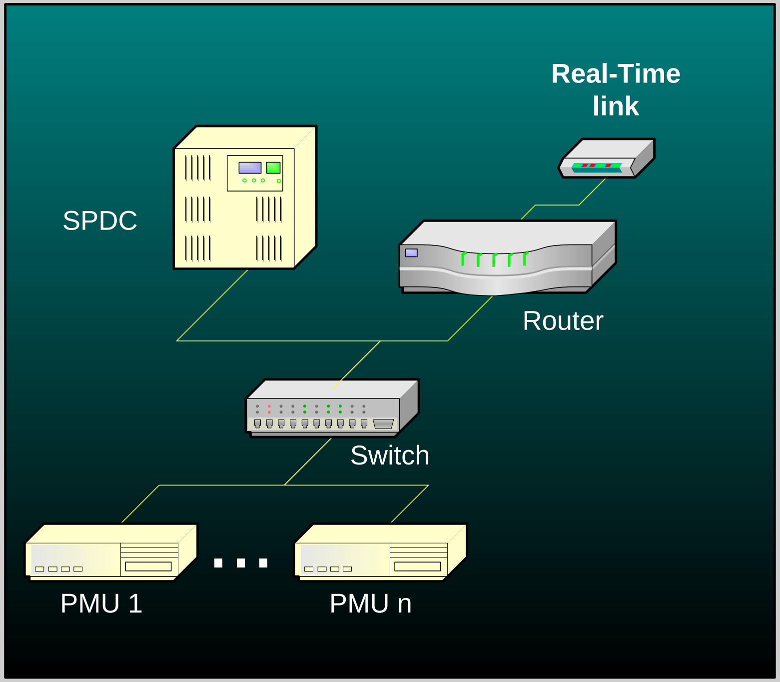
- ✓ It must attend ONS' and Utilities' needs
- ✓ It must be scalable
- ✓ Cyber security must be considered

SPMS Overall Architecture



- Three level architecture with two connection options from the substation level to the ONS' Central Data Concentrators
- Redundant Phasor Data Concentrator (Primary & Secondary) for data safety
- A Phasor Data Concentrator in each substation (SPDC) for local storage, aggregation, processing and repacking
- Private TCP-IP network using dedicated telecommunication channels for bandwidth guarantee and system security
- Use of IEEE C37.118 Standard for data transfer and UDP/IP data format with multicast IP addressing for Real-Time phasors

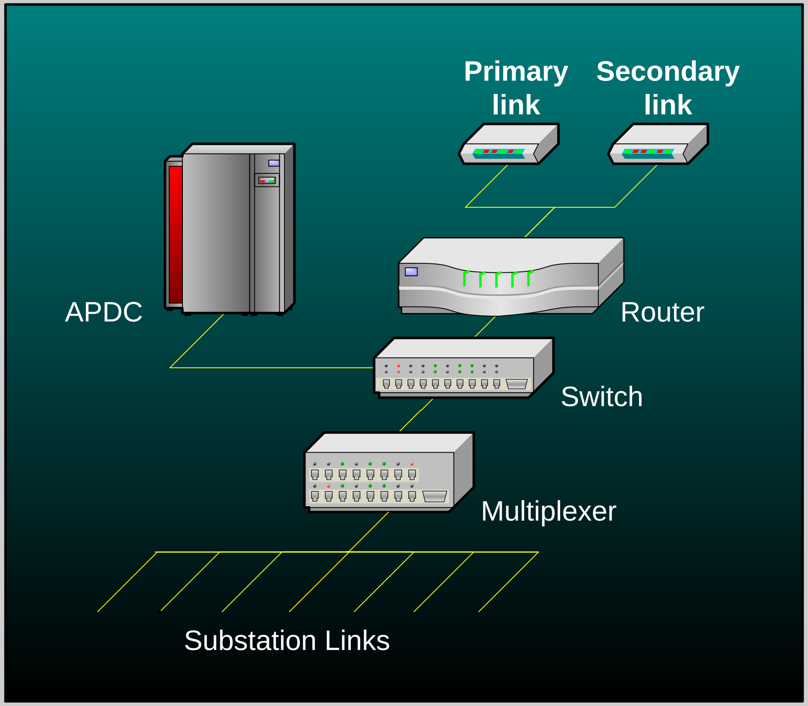
Substation Architecture



- **PMU send real-time data in C37.118 format using UDP/IP *multicast* addressing**
  - ✓ PMU data will be routed to the SPDC to be aligned and stored
  - ✓ If desired, the Utility may use a phasor reporting rate higher than that used by ONS (60 fps)
- **The total bandwidth should consider:**
  - ✓ The real-time phasor data to ONS' PDC (60 fps)
  - ✓ The real-time phasor data to Utility's PDC (Reporting rate select by the agent)
  - ✓ Some additional bandwidth to missing data resending

- **A Substation Phasor Data Concentrator – SPDC will always be used to:**
  - ✓ Allow the use of different phasor selections and report rates to ONS or Utility applications
  - ✓ Store phasor data and answer PDC commands to restore offline data when communication failures occurs
  - ✓ Provide indirect access to critical devices with PMU functionality

Utilities' Control Center Architecture



Main characteristics:

- When a PMU data stream reaches the Utility's Control Center network, it will be routed directly to ONS' PDC
  - ✓ *No processing time*
- If Utility decided to use his own APDC, the multicast data stream will also be routed to it
  - ✓ *No bandwidth impact on substation channels*

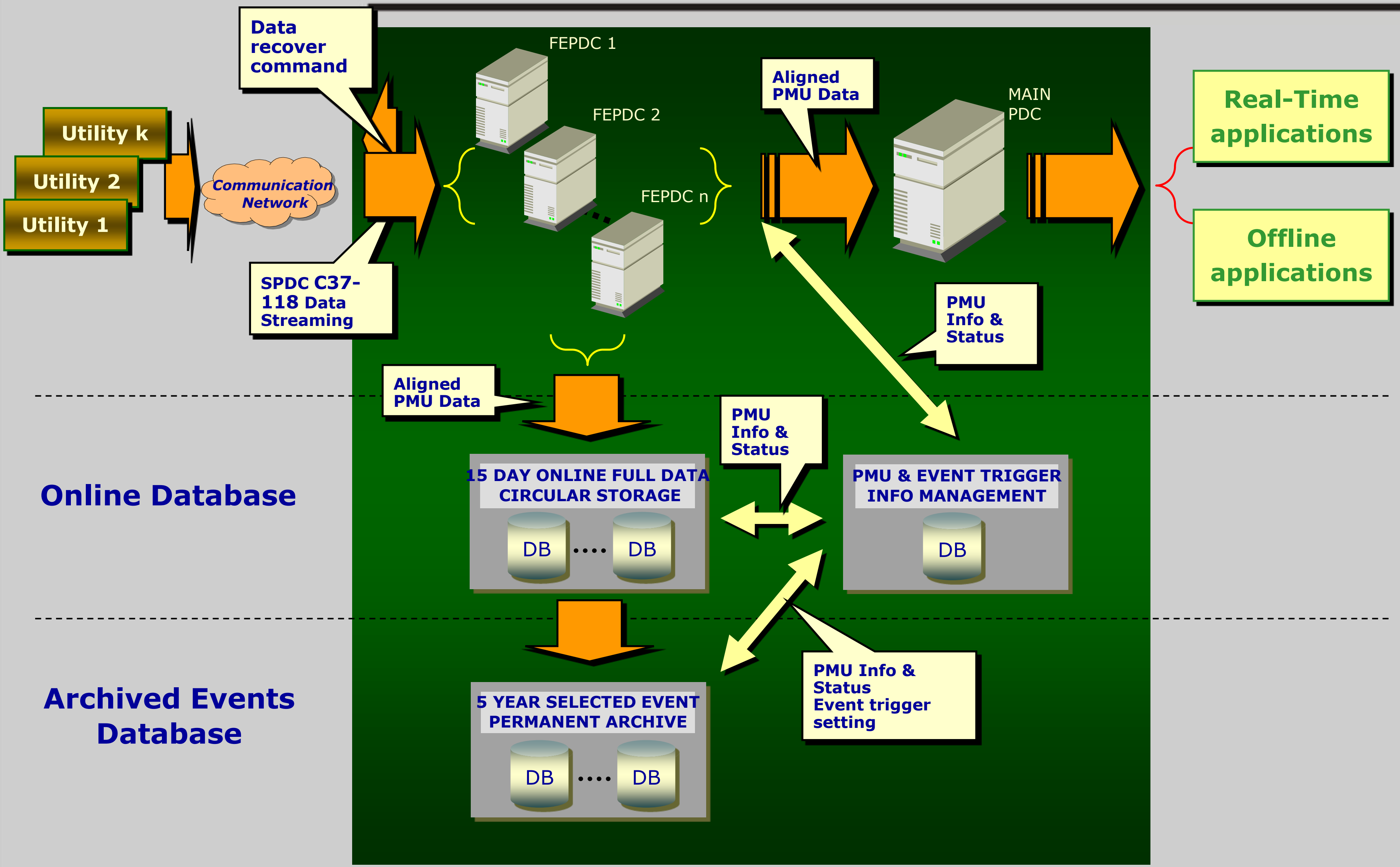
Utility Phasor Data Concentrator (APDC):

- Use of APDC is optional, allowing PMU data to be used by Utility
- The APDC gets data from the multicast PMU or SPDC data streams
- APDC may send phasor data to Utility's own SCADA or EMS servers

Two level PDC structure (Front-end and a Master PDC)

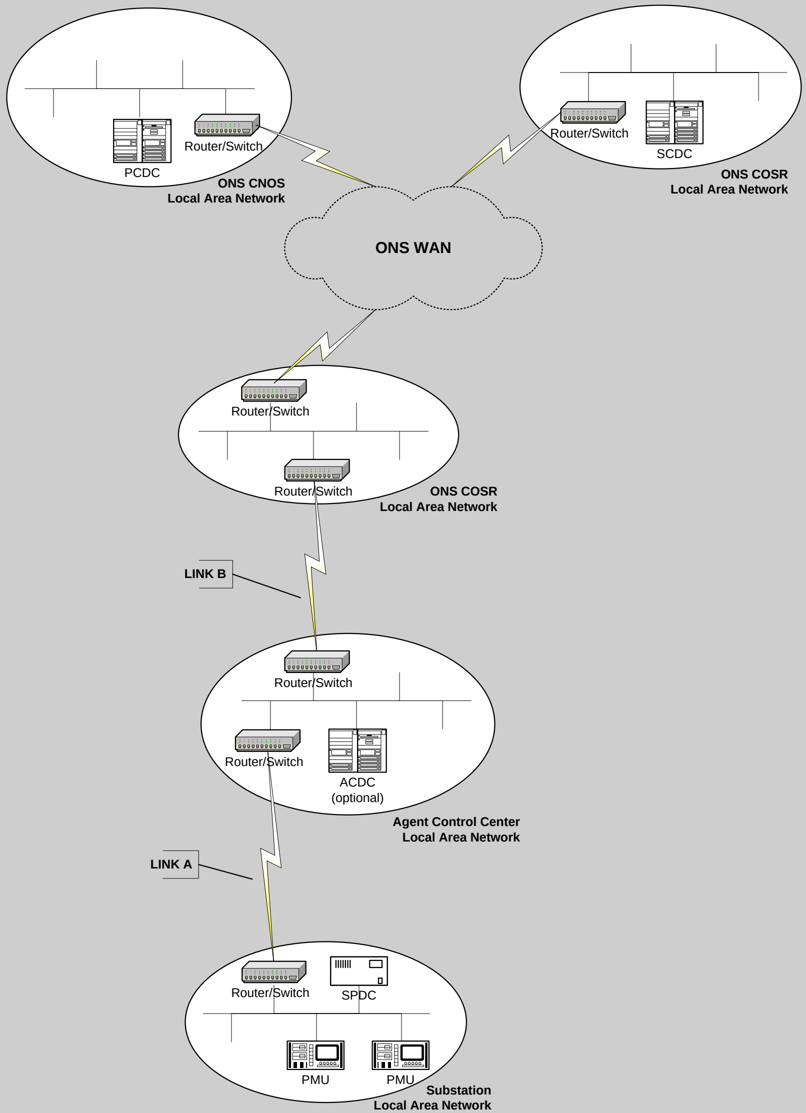
- **Front-end Phasor Data Concentrators (FEPDC):**
  - ✓ Align received PMU data streams according to the time tag information and perform data scaling and other processing
  - ✓ Store the received PMU data for a specified period of time
  - ✓ Initiate the process to recover lost PMU data when main communication link fails, sending a request to the corresponding SPDC
  - ✓ Data received from SPDC shall be aligned with other PMU data
- **Master Phasor Data Concentrator (MPDC):**
  - ✓ Align PMU data stream from all FEPDC and send the aligned data to real-time applications server (SCADA-EMS)
- **Databases:**
  - ✓ PMU data online database
  - ✓ PMU Information and event trigger setting management database

PDC Block Diagram



Telecommunication Network

Network Traffic



Private IP network with 3 traffic types:

- **Real-Time Traffic – RT**
  - ✓ 2 second maximum latency
  - ✓ Data are transmitted 24 hours a day, 7 days a week
  - ✓ Defines the channel bandwidth
- **Offline Traffic – OL**
  - ✓ No latency requirement
  - ✓ Data are transmitted only when requested by PDC
  - ✓ Needs to be 100% reliable
- **Control Traffic – CT**
  - ✓ Low bandwidth 2 way traffic

Overall Time Requirement

PMU processing time	30 ms
Substation LAN delay	30 ms
SPDC processing time	650 ms
Substation – Utility's Control Center channel latency	200 ms
Utility's Control Center LAN delay	30 ms
Utility's Control Center – ONS COSR channel latency	100 ms
ONS COSR LAN delay	30 ms
COSR – CNOS channel latency	100 ms
CNOS LAN delay	30 ms
PDC processing	800 ms
TOTAL	**2.000 ms**

OBS: Channel latency correspond to the one-way delay

Challenges

Challenges

- **The system will start minimal but it must be expansible to final configuration**
  - ✓ What methodology could be used to test and guarantee system expansibility?
- **Development of SPDC is a concern as there are some non-standard needs**
- **Availability and cost of communication links**
- **Huge volume of data to store and manage**

ONS Control Centers	Bandwidth (bps)
COSR-NMW	2 Mbps
COSR-NE	1,5 Mbps
COSR-S	0,5 Mbps
COSR-SE	5 Mbps
TOTAL	9 Mbps

~ 1,25 T bytes for a 15 days FIFO data buffer

Operador Nacional do Sistema Elétrico

Thank you!