Operador Nacional do Sistema Elétrico

Synchrophasor activities in Brazil

NASPI North American SynchroPhasor Initiative

September 6, 2007
Montreal – Canada

Rui Moraes & Héctor Voskis
Brazilian National Electrical System Operator

Introduction

Brazil

- **Territory: 8.5 million km²**
  - 20% of total America
  - 48% of total South America
- **2nd in the World in forest area**
  - 60% of Brazil territory
  - More than all Europe territory
- **Maximum dimensions:**
  - East - West: 4,328 km
  - North - South: 4,320 km
- **Capital: Brasília - DF**
- **Population: 186.4 million**
- **GDP (2006): 1,067.8 billion US$**
- **Energy reserves:**
  - Hydro (3º): 1,488 TWh/year
  - Crude oil: 12.22 billion barrels
  - Natural gas: 306 billion m^3
  - Uranium (6^0): 309,370 tons U_3O_8
  - Mineral coal(10^0): 23.95 billion ton

Brazil – Power System Data

North Subsystem

- An increasing exporter market (9 months/year)

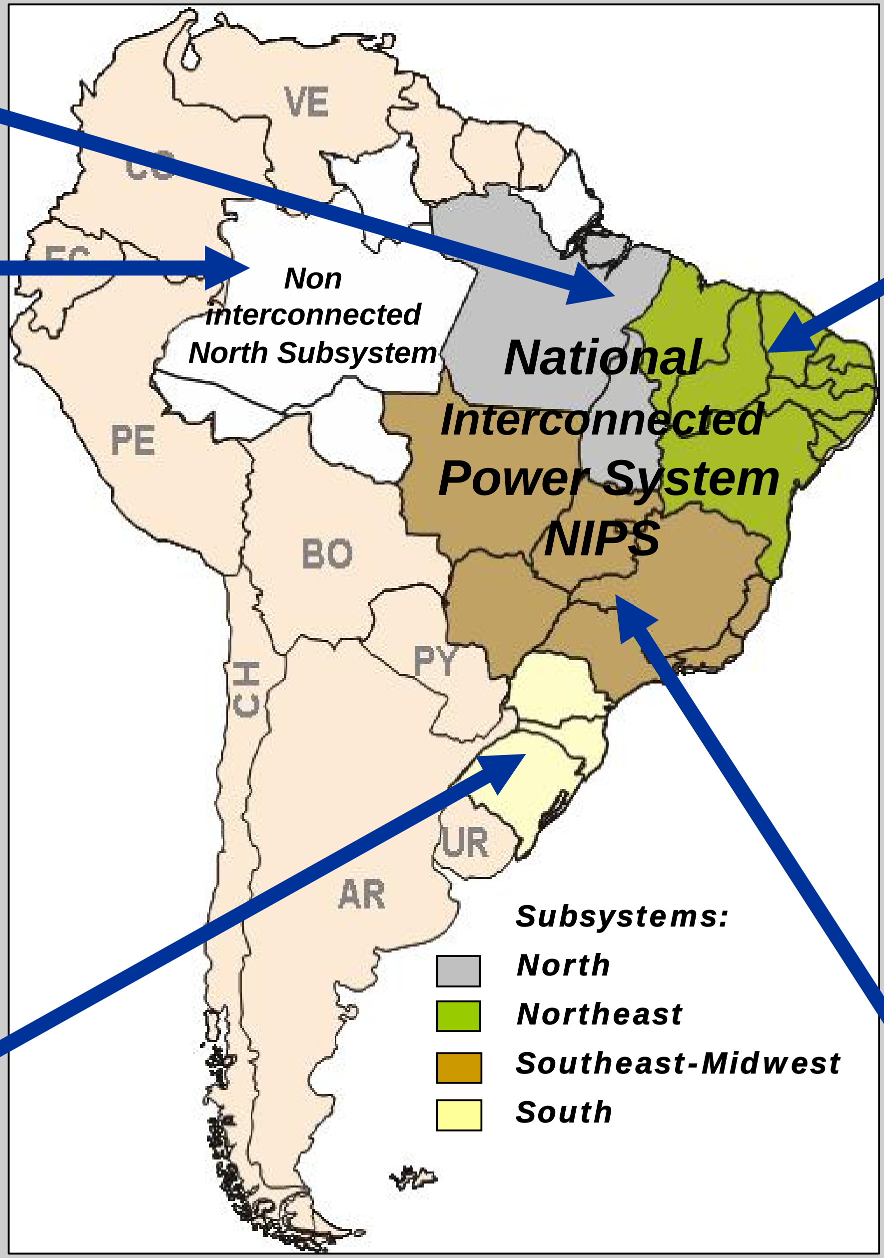
Non Interconnected

- Near 300 local systems (cities & small villages)

ENERGY PRODUCTION - 2006		
TYPE	GWhour	%
Hydro	382,232.88	91.8
Thermal	20,127.99	4.8
Nuclear	13,753.25	3.3
Wind	228.42	0.1
TOTAL	416,342.54	100.0

South Subsystem

- Hydro inflows with great variability



Northeast Subsystem

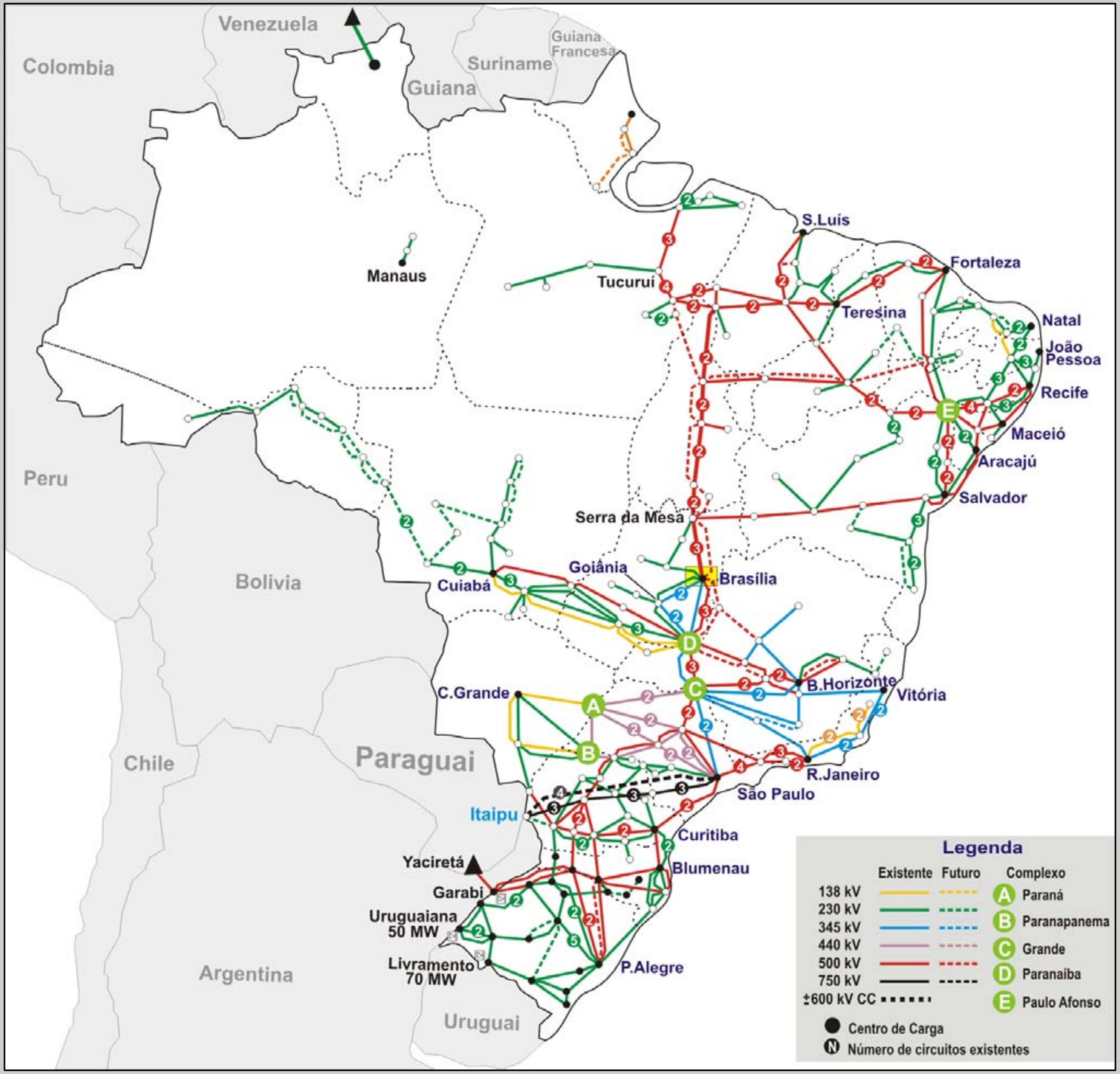
- An increasing market demand
- Most hydro resources already exploited

Power Generators (Dec 2006)			
TYPE	Power Plants	Capacity (MW)	%
Hydro	638	74,017	71
Gas	101	10,798	10
Oil	566	4,464	4
Biomass	269	3,713	4
Nuclear	2	2,007	2
Mineral Coal	7	1,415	1
Wind	15	237	0
TOTAL	1,598	96,651	100

Southeast/Midwest Subsystem

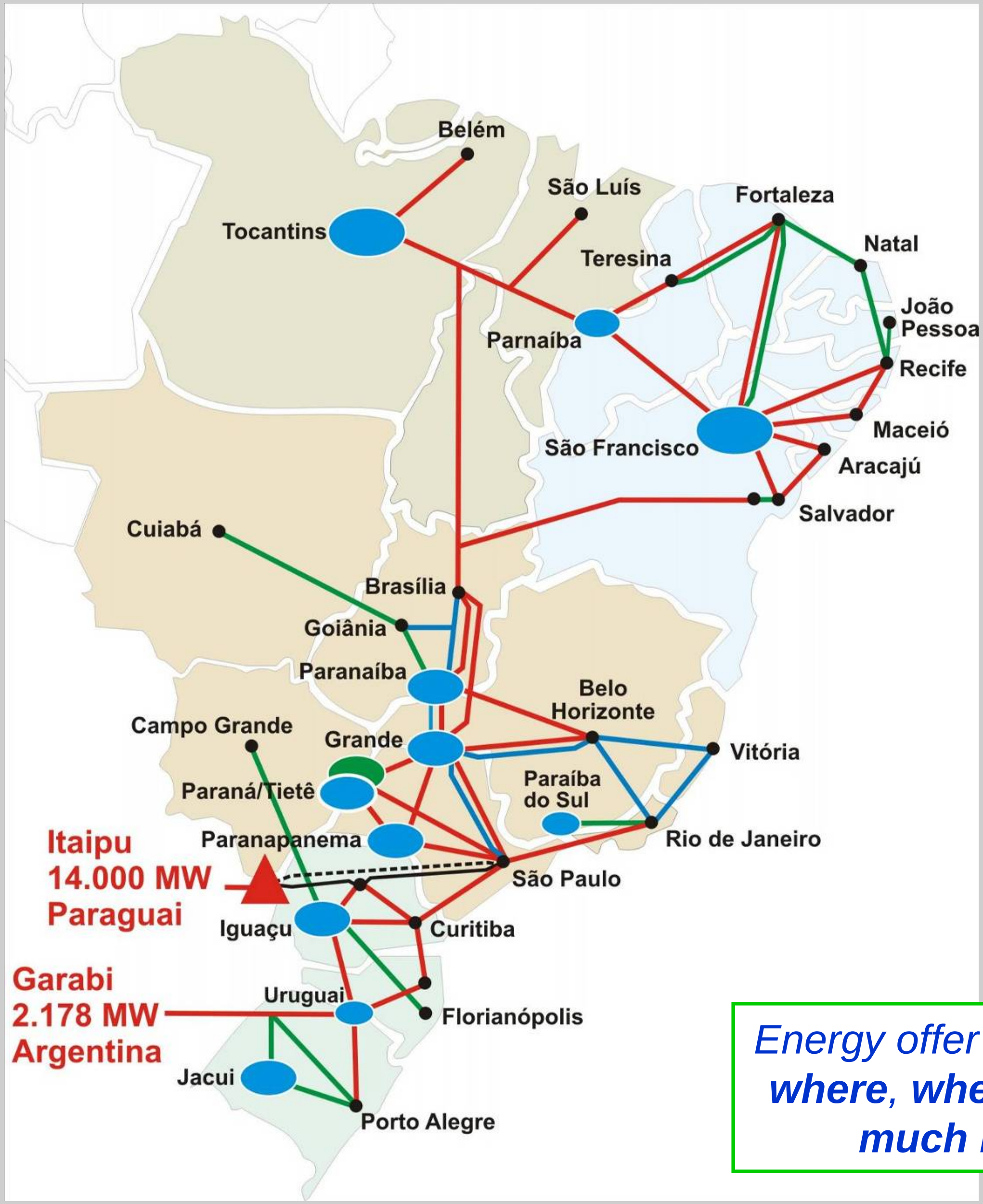
- Major market demand
- Higher hydro storage capacity

NIPS Main Grid

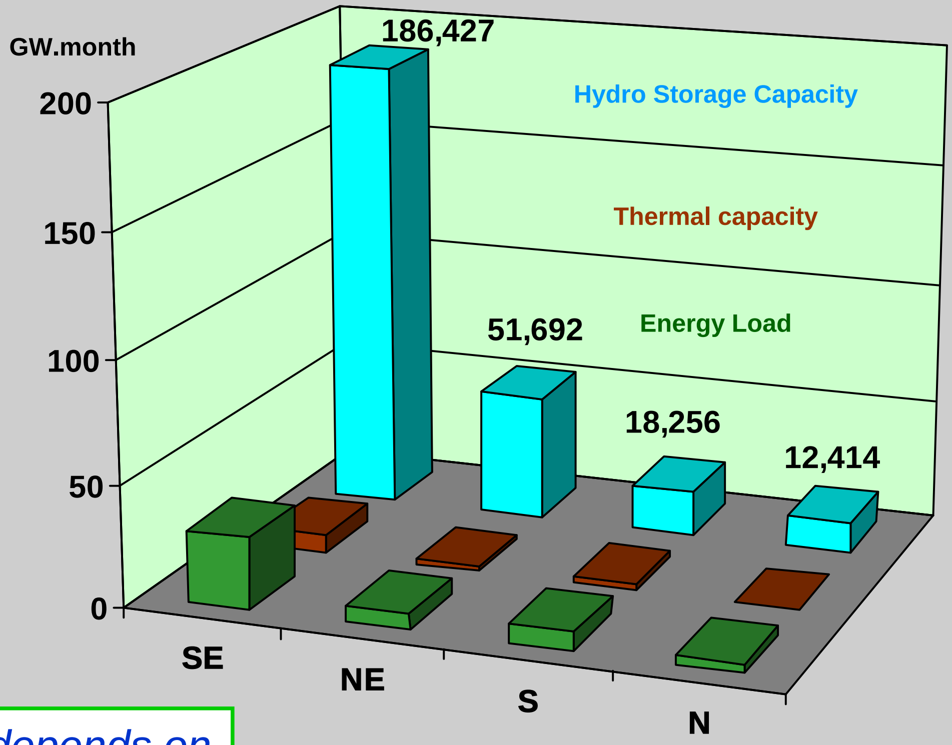


Generation	
Power Plants (> 30MW)	166
Generator Units	544
Utilities	78
Transmission	
Lines above 230kV (km)	83,049
# of circuits	693
Substations	353
Transformer capacity (GVA)	167
Utilities	52
Distribution + Free Consumers	
Utilities	106

NIPS Hydro Storage Capacity

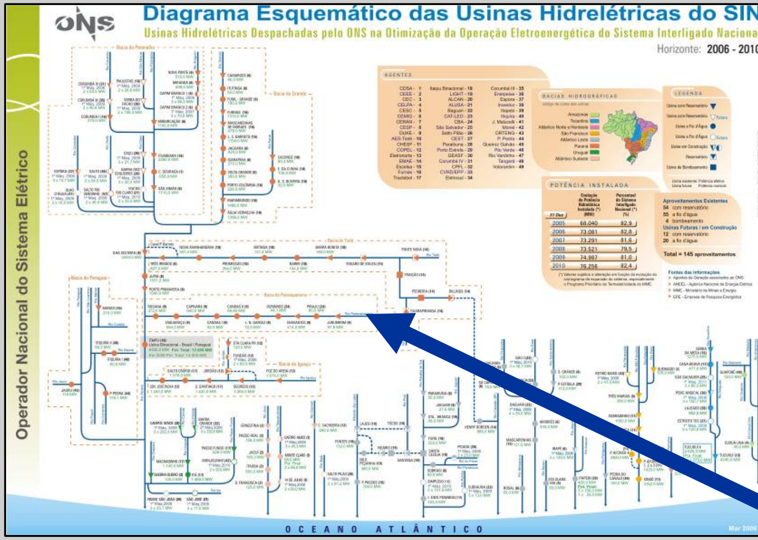


Total NIPS storage capacity
268,789 MW.month



Energy offer depends on ***where****,* ***when*** *and* ***how much*** *it rains*

Characteristics of Power Production

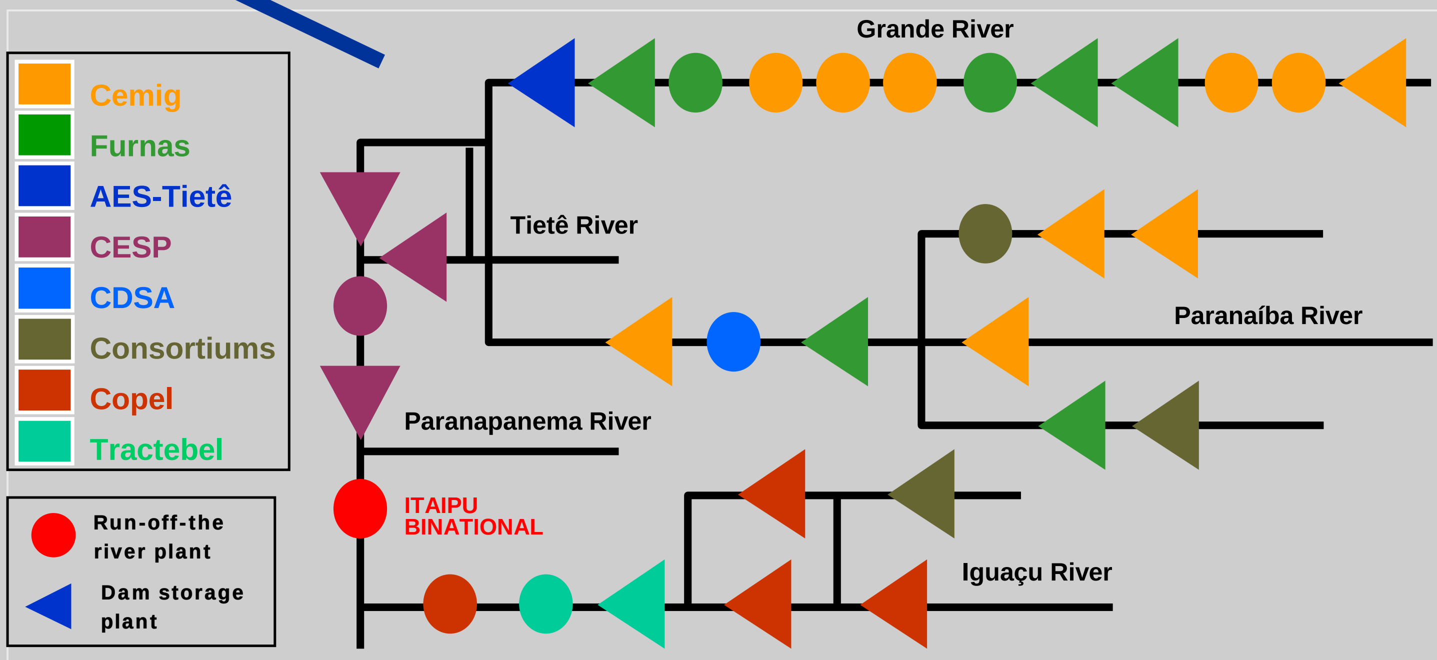


Hydro predominant: 91.8% of production was hydro in 2006

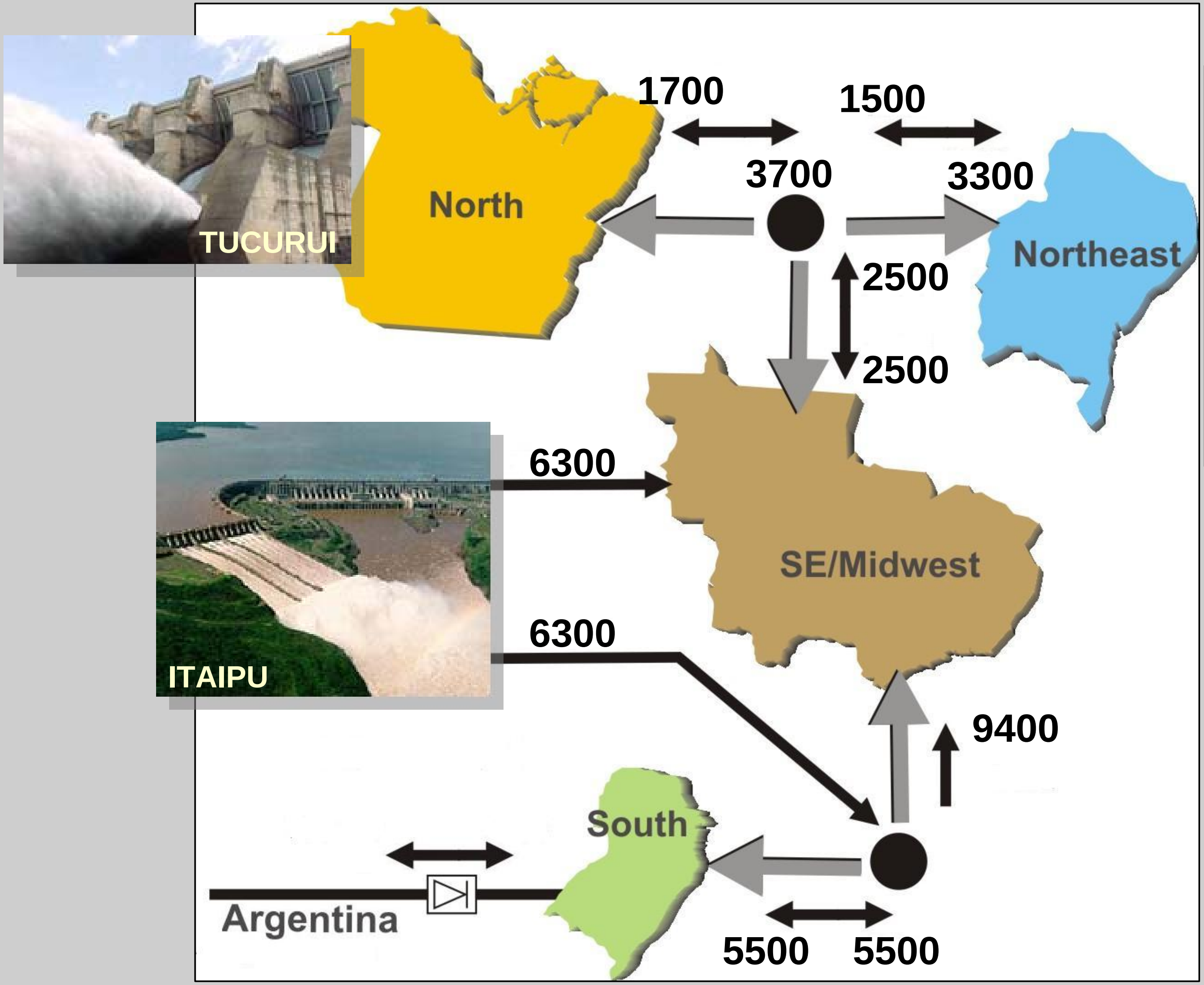
Multi-year regulation: Must comply with offer uncertainties and the long time for generation expansion. Present decisions on hydro storage versus thermal generation may impact energy cost and the future supply security

Multi-owned system: Public and private utilities own hydro plants in the same river in 12 large basins

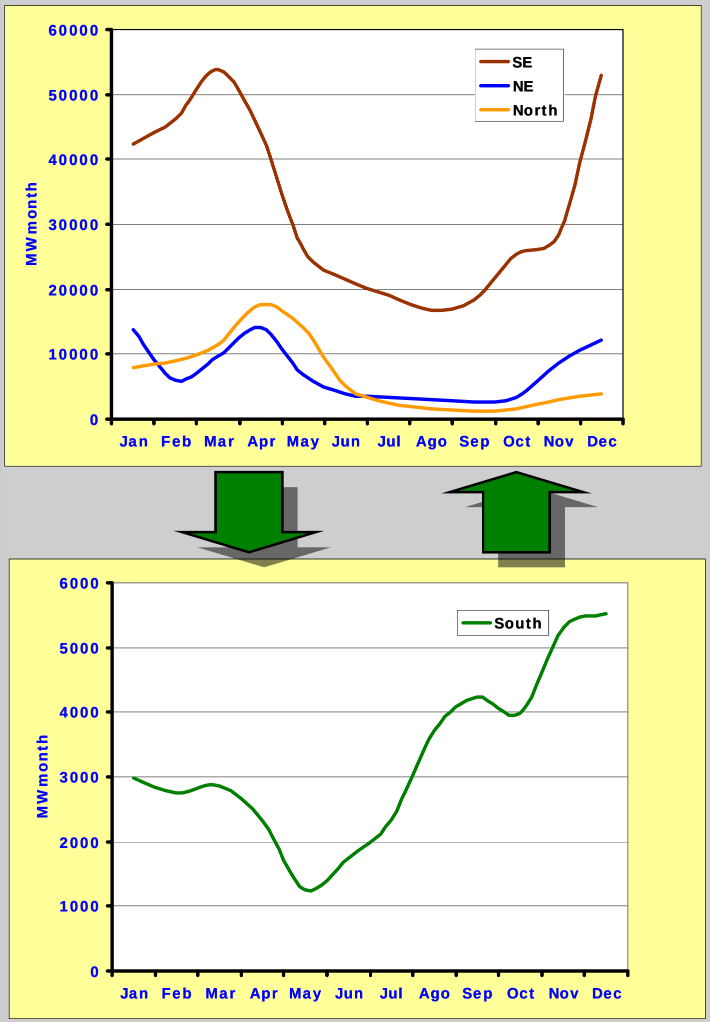
Interdependence in generation, environmental constraints, multi use of water, minimum outflows and flood control requires *centrally coordinated operation*



High Inter-regions Transfers



AVAIABLE INFLOW ENERGY



Source: ONS-ENA 2006

Complementary rain profiles & offer seasonality = High inter-regions transfers in both ways

NIPS Planned Expansion

Planned Generation Evolution 2006-2015

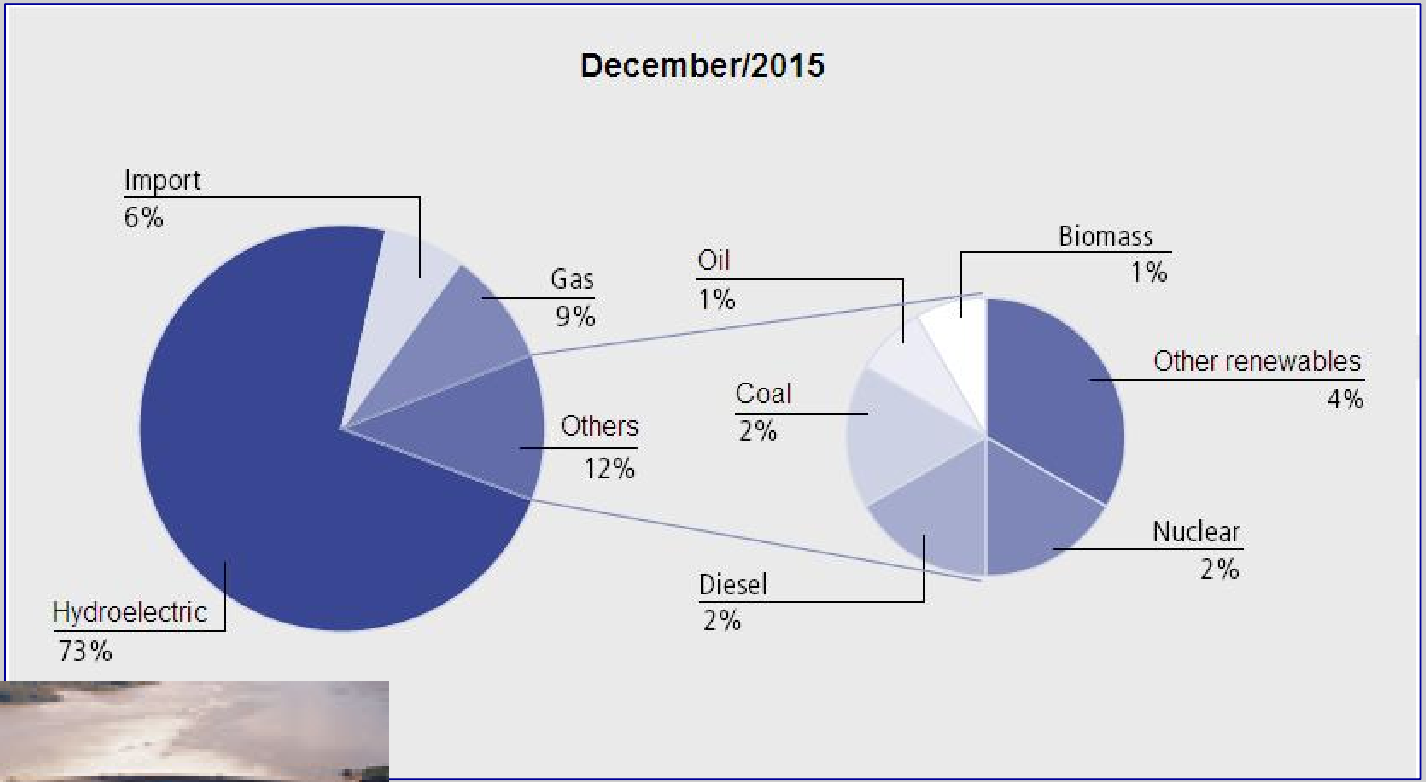


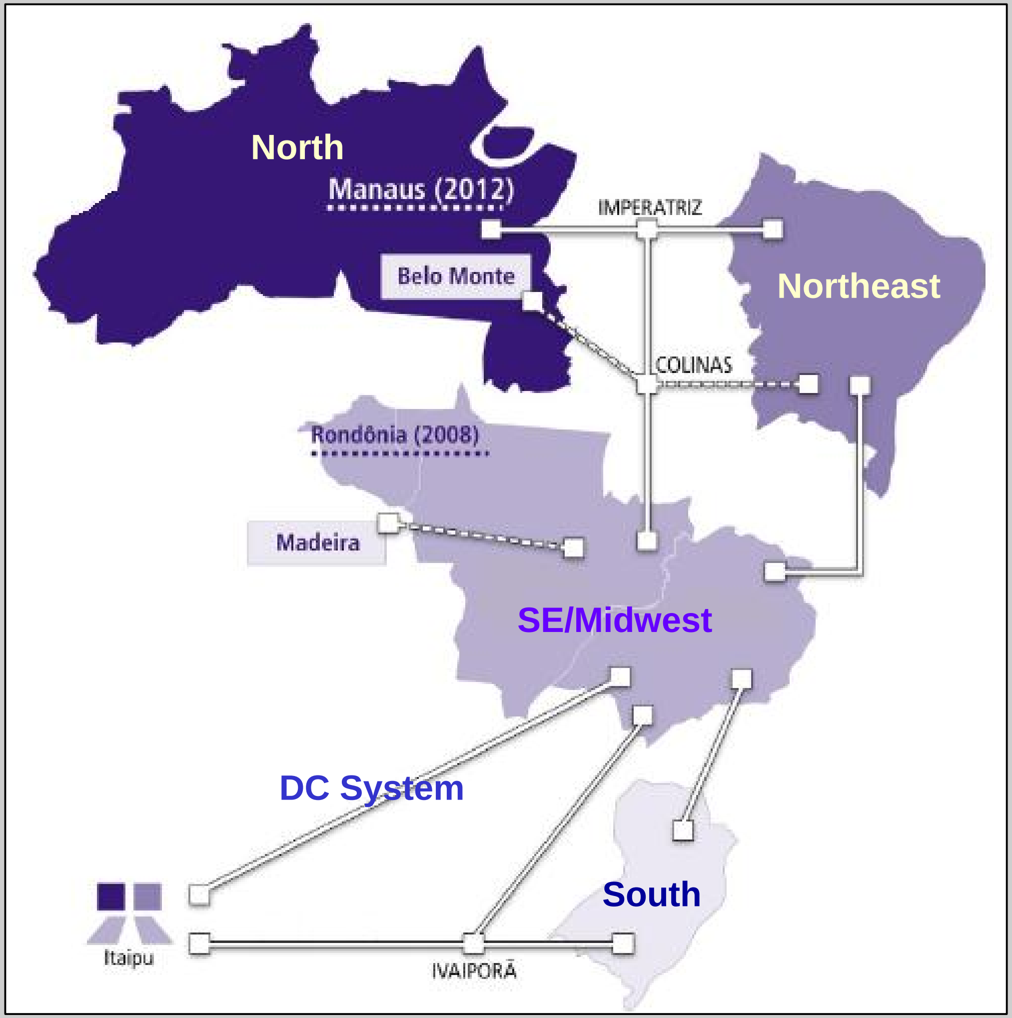
Photo: FURNAS

Jan/2006	Dec/2015	%
93,728 MW	**134,677 MW**	**43,7**

Source: EPE- PDEEE-2006/2015

Energy is predominantly hydroelectric and it will remain along the next decade

Planned Generation Evolution 2006-2015



Source: EPE- PDEEE-2006/2015

Main hydro power plants projects:

⇨ **Madeira river (2011)**

- ✓ Jirau – 3,300 MW
- ✓ Santo Antonio – 3,150 MW

⇨ **Xingu river (2013)**

- ✓ Belo Monte (1st stage) – 5,000 MW
- ✓ Belo Monte (Final) – 10,000 MW

Long transmission may impose challenge on secure system operation

Planned Transmission Evolution 2006-2015

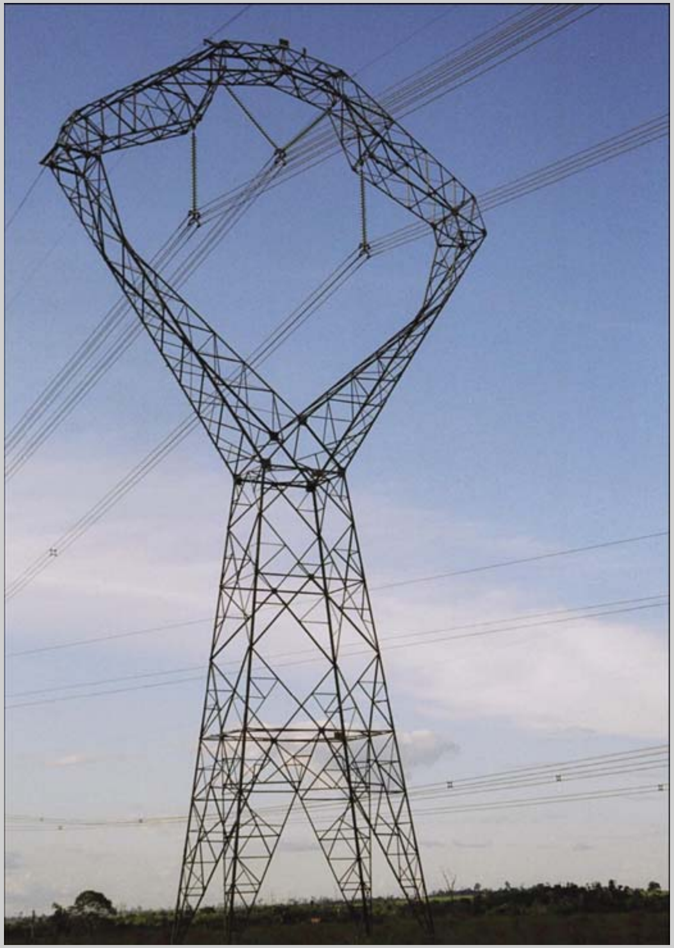


Photo: ELETRONORTE

Transmission Lines (km)			
Voltage (kV)	**2006**	**2015**	**%**
750	2,698	8,092	199.9
600-DC	1,612	6,512	304.0
500	27,023	46,806	73.2
440	6,785	6,793	0.1
345	8,834	9,673	9.5
230	35,140	45,343	29.0
Total	**82,092**	**123,219**	**50.1**

Transformer Capacity (MVA)			
Voltage (kV)	**2006**	**2015**	**%**
750	21,000	37,350	77.9
500	63,053	98,605	73.2
440	15,252	22,236	45.8
345	27,288	35,754	31.0
230	45,164	66,897	48.1
Total	**171,757**	**260,842**	**51.9**

Source: EPE- PDEEE-2006/2015

PMU Initiatives in Brazil

R&D Project

MedFasee Project

R&D project aiming to:

- Synchrophasor Measuring System prototype development
- Monitoring and Control tools development

Partners:

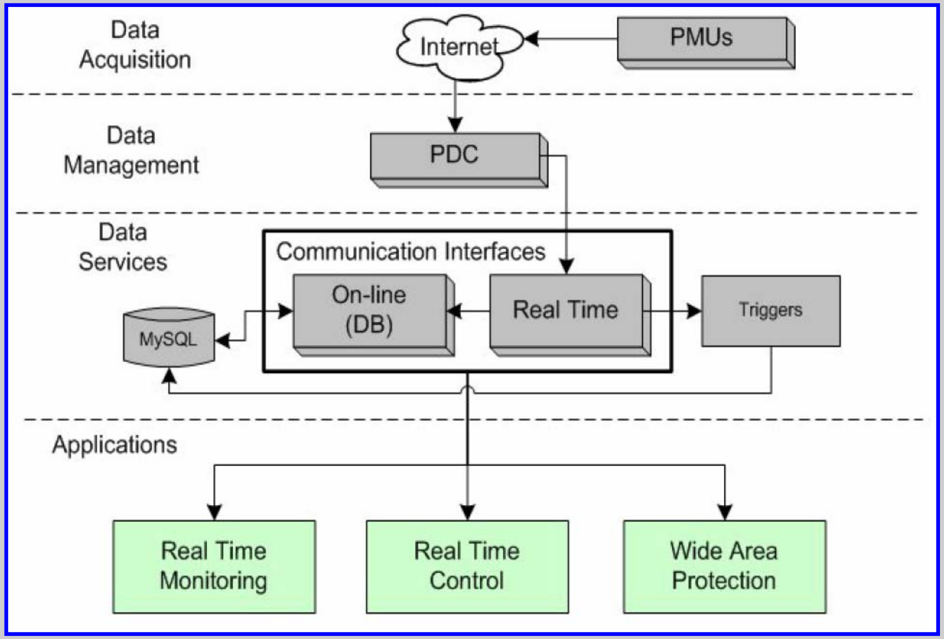
- ***REASON Tecnologia***
  - A Brazilian DFR manufacturer
- ***Santa Catarina Federal University***
- ***FINEP***
  - Government Research Financing Agency

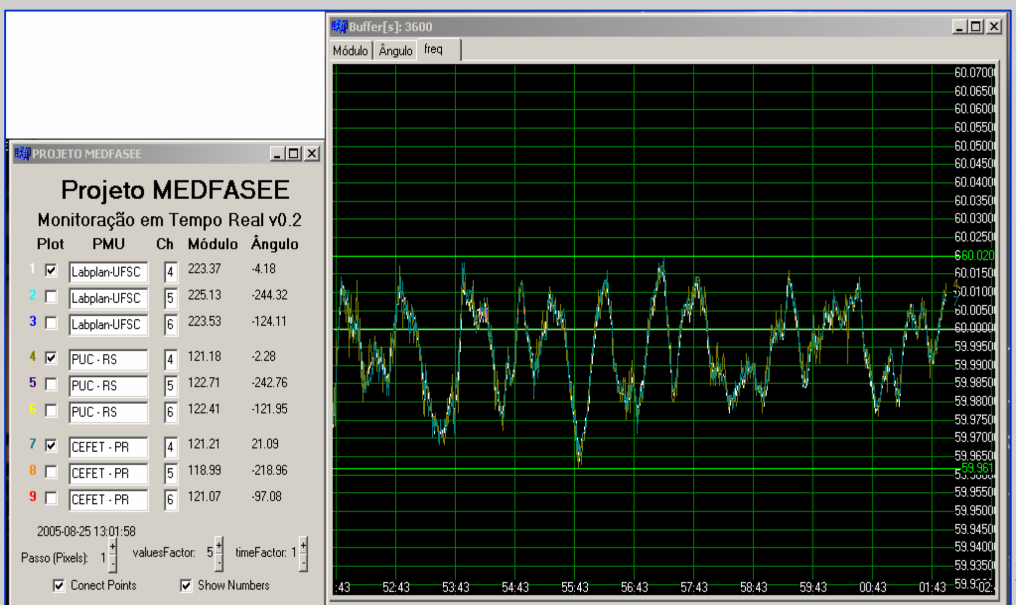
Source: LabPlan - UFSC

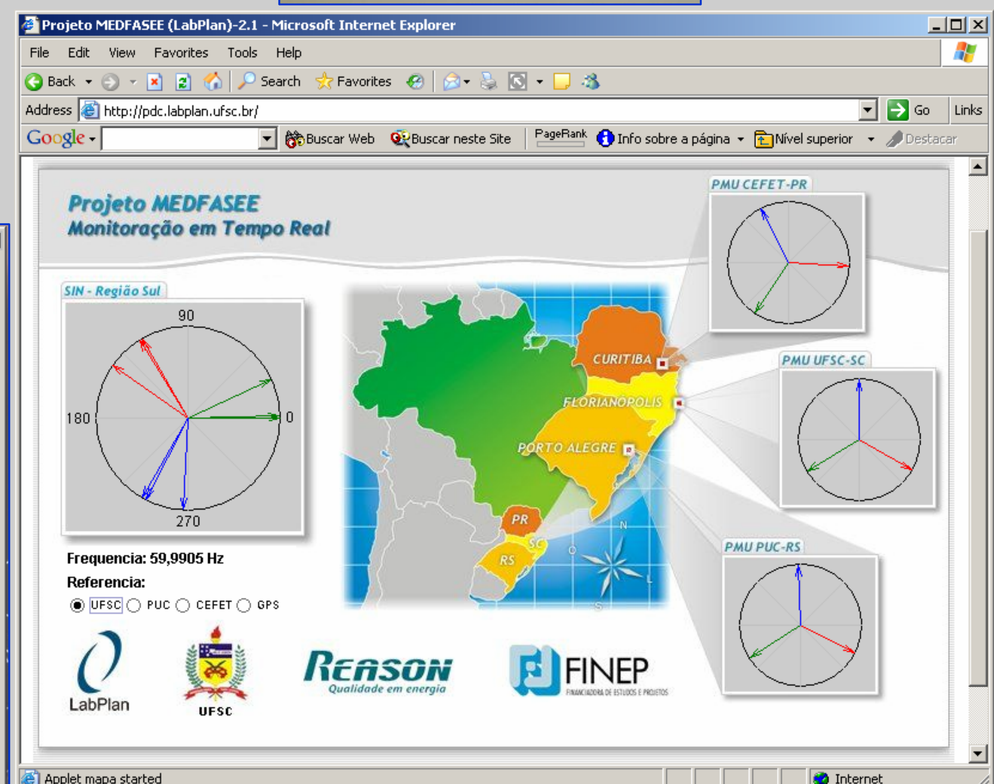
Achievements:

- Pilot System in the South of Brazil with a PDC and 3 PMU installed (Porto Alegre, Florianópolis e Curitiba)

MedFasee Project







Source: LabPlan – UFSC - REASON

ONS' Initiatives

The spark off event (as usual...)

- Studies for PMU application in Brazil was started by the Group for the Coordination of Interconnected Operation (GCOI), in the beginning of the nineties
- Difficulties faced by Brazilian economy during that decade and the restructuring of the electric energy sector delayed the project until 1999
- In August 1998, ONS was created and started to operate NIPS in *January 1999*
- A <u>huge blackout</u> occurred in *March 1999*, and revived the interest in PMU application, mainly for dynamic performance analysis during disturbances

First ONS Initiative

In 2000 ONS prepared a PMU system specification and started the bidding process, intending to deploy a PMU system for dynamic disturbance recording

This bidding process **was discontinued** due to:

- ✓ PMU technology was not mature at that time
- ✓ ONS received only two proposals
- ✓ Expected difficulties for PMU installation in Utilities' substations by ONS
    - Engineering project
    - Installation & commissioning
    - Maintenance
    - Telecommunication issues
- ✓ Later on ANEEL decided ONS could **not own** transmission assets

Need to reformulate the project strategy, from a centralized approach to a decentralized one

PREMISE →

Guarantee the adequate PMU system performance while allowing PMU integration from different suppliers

NIPS’
Synchronized Phasor Measuring System – SPMS

Project Strategy

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

- **The ANEEL's Resolution 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
    - Coordinate certification tests on PMU models to guarantee the system's integration and global performance
    - Define the schedule and coordinate the PMU installation by utilities

NIPS – SPMS

- **Motivation**

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

- **Two projects are in course (ONS' Action Plan 2007-2009)**

- **Deployment of a Phasor Recording System (Project 6.2)**

  The main goal is to 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

- **Studies for Phasor Measurement Technology Application to Support Real Time Operators Decision (Project 11.11)**

  The main goal is to extend the application of the initial SPMS for real-time applications

NIPS PMU System Architecture Design

Application Requirements

APPLICATION	PMU Location	PMU Data Rate (phasors/s)	PMU Data Latency	PMU Data Reliability
Wide-area dynamic disturbance recording	Inter-tie substations and power plants	10 – 60	Not critical	Critical (Local storage)
Wide-area real time monitoring	All major buses	1 – 10	1 – 5 s	Not critical
Synchronized state estimation	For full observability	1 – 10	1 – 5 s	Not critical
Phase angle Monitoring	Selected buses	1 – 10	1 – 5 s	Not critical
Real-Time System Oscillations Monitoring	Inter-tie Substations	10 – 60	1 – 5 s	Not critical
Wide-area protection and control system	Selected bus and lines	30 – 120	Few cycles (<150ms)	Critical (Redundant channels)

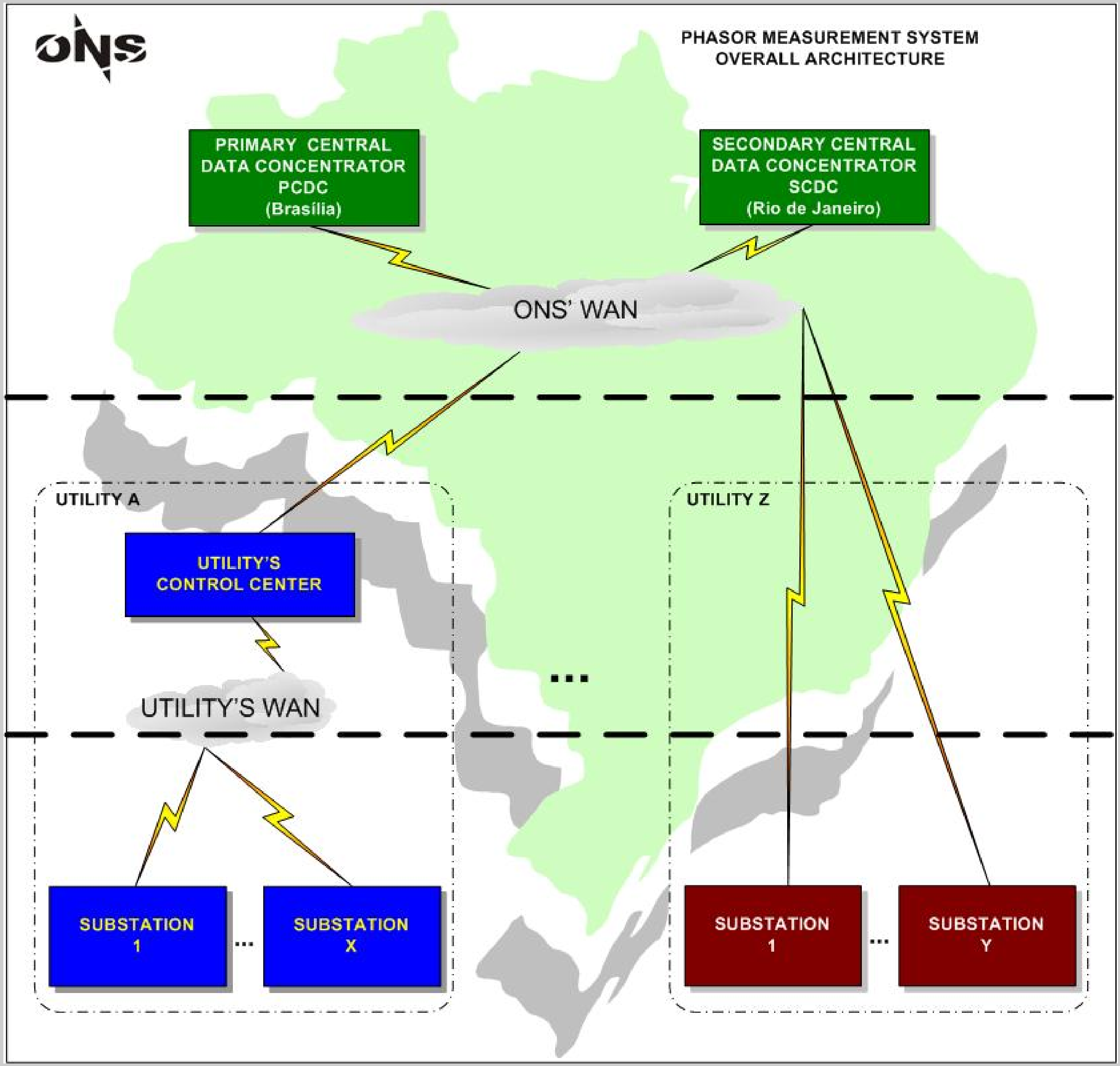
SPMS Main Requirements

- **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 10 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

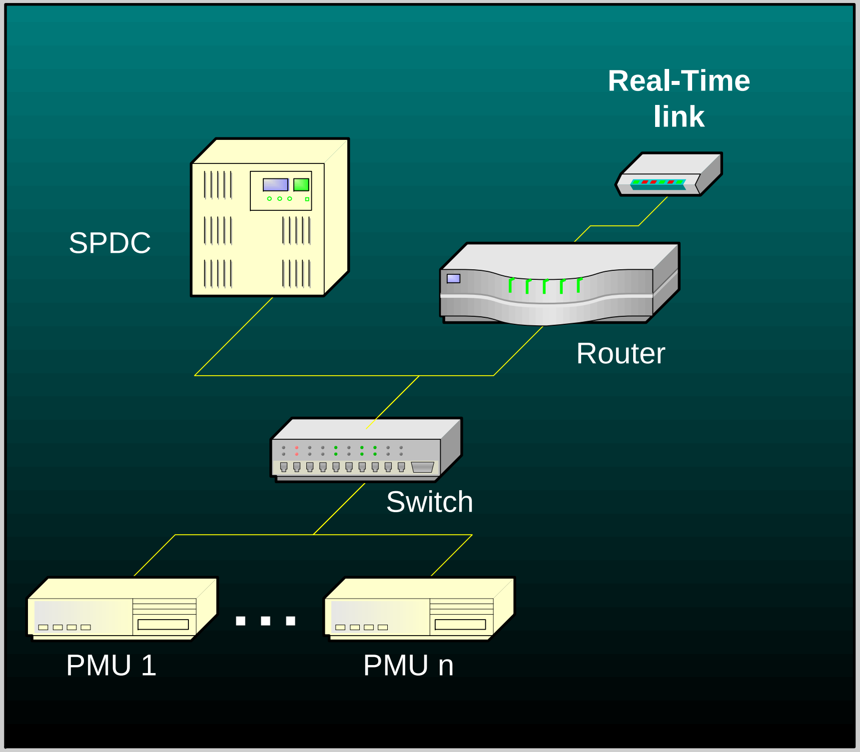
SPMS Overall Architecture



- 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 Level

Substation Architecture

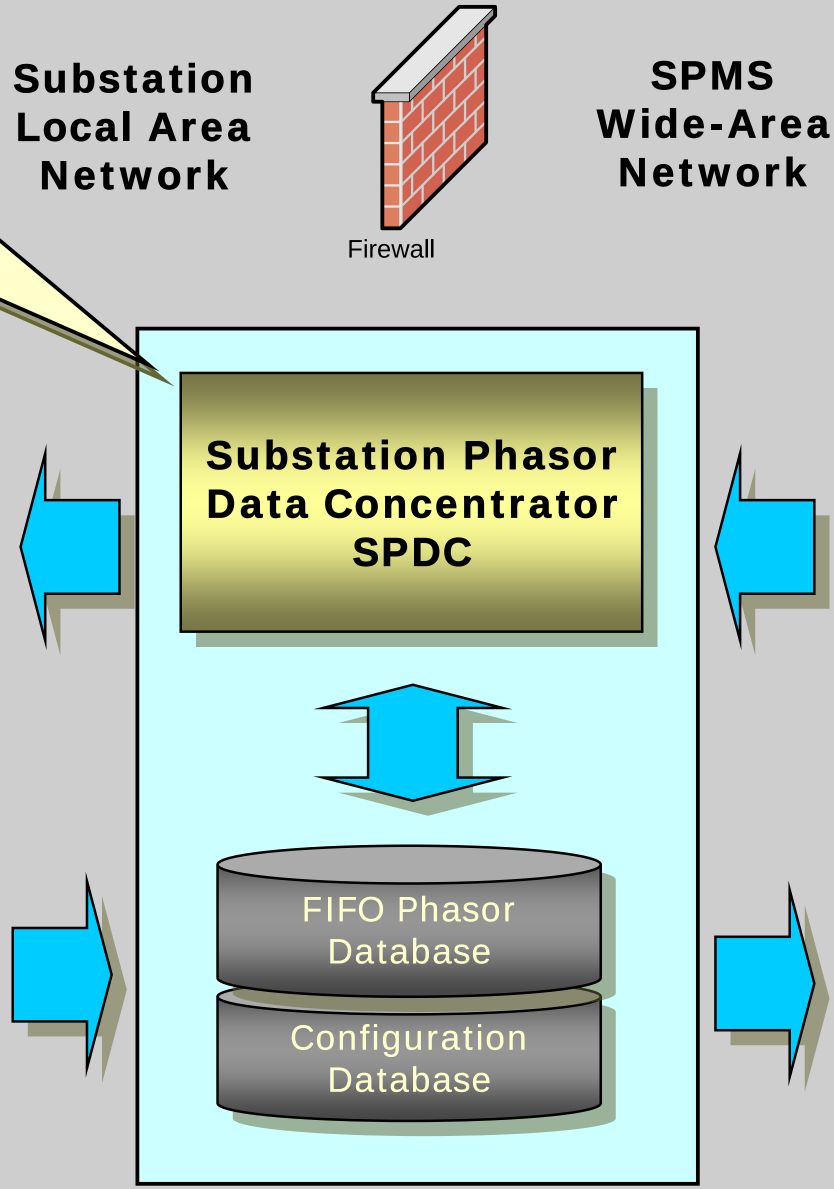


- **PMU send real-time data in C37.118 format using UDP/IP *multicast* addressing**
  - ✓ **PMU data will be routed to the SPDC to be aligned and stored**
  - ✓ **If desired, the Utility may use a phasor reporting rate higher than that used by ONS (10 pps)**
- **The total bandwidth should consider:**
  - ✓ **The real-time phasor data to ONS' PCDC/SCDC (10pps)**
  - ✓ **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 PCDC/SCDC commands to restore offline data when communication failures occurs**
  - ✓ **Provide indirect access to critical devices with PMU functionality**

Substation PDC

Time align PMU data
Data processing
Data storing
Data resending
Firewalling
Protocol converter



PMU commands:

- Configuration files request
- Start/Stop phasor streams

C37.118 Phasor Streams:

- From PMU, Relays, DFR, etc.

SPDC commands:

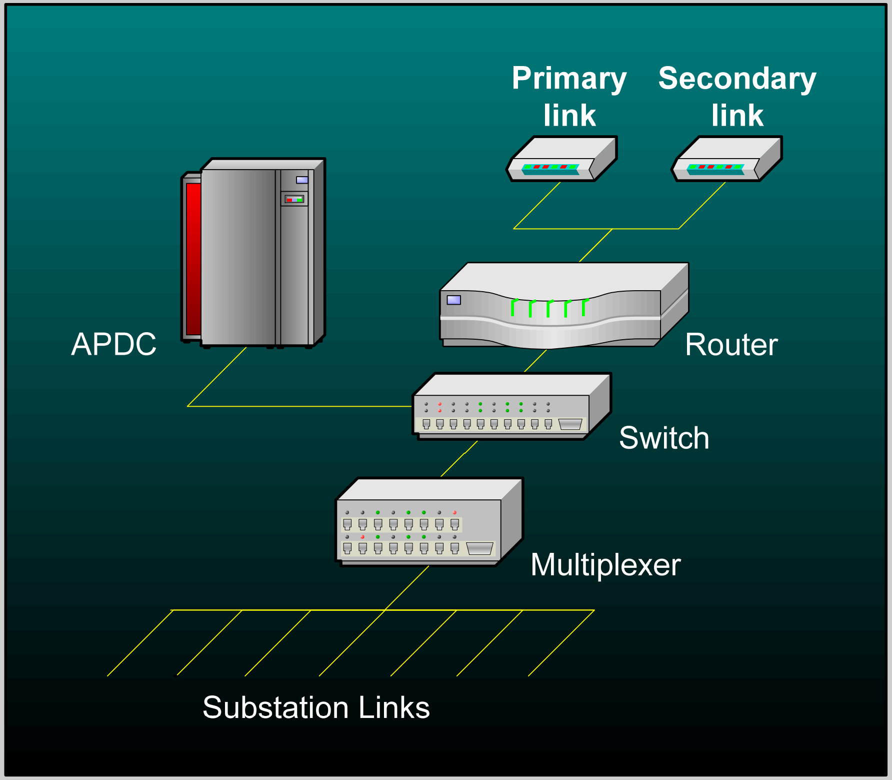
- Configuration files request
- Start/Stop phasor streams
- Missing data requests

C37.118 Phasor Streams:

- To ONS (10pps)
- To the utility (eg: 30pps)

Utilities’ Control Center Level

Utilities' Control Center Architecture



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

Main characteristics:

- When a PMU data stream reaches the Utility's Control Center network, it will be routed directly to ONS' PCDC/SCDC
  - ✓ *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*

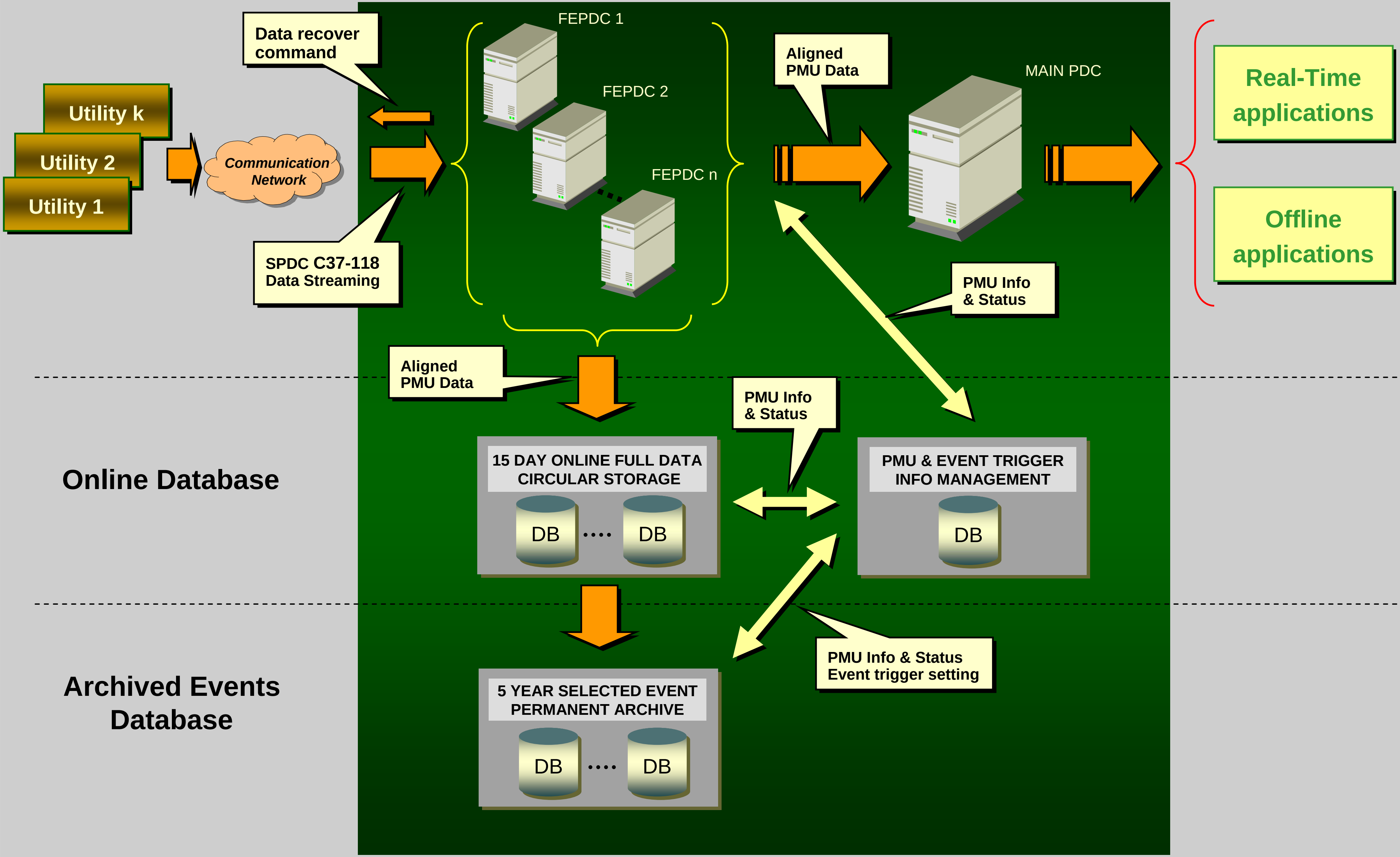
ONS’ Control Centers Level

PCDC/SCDC Architecture

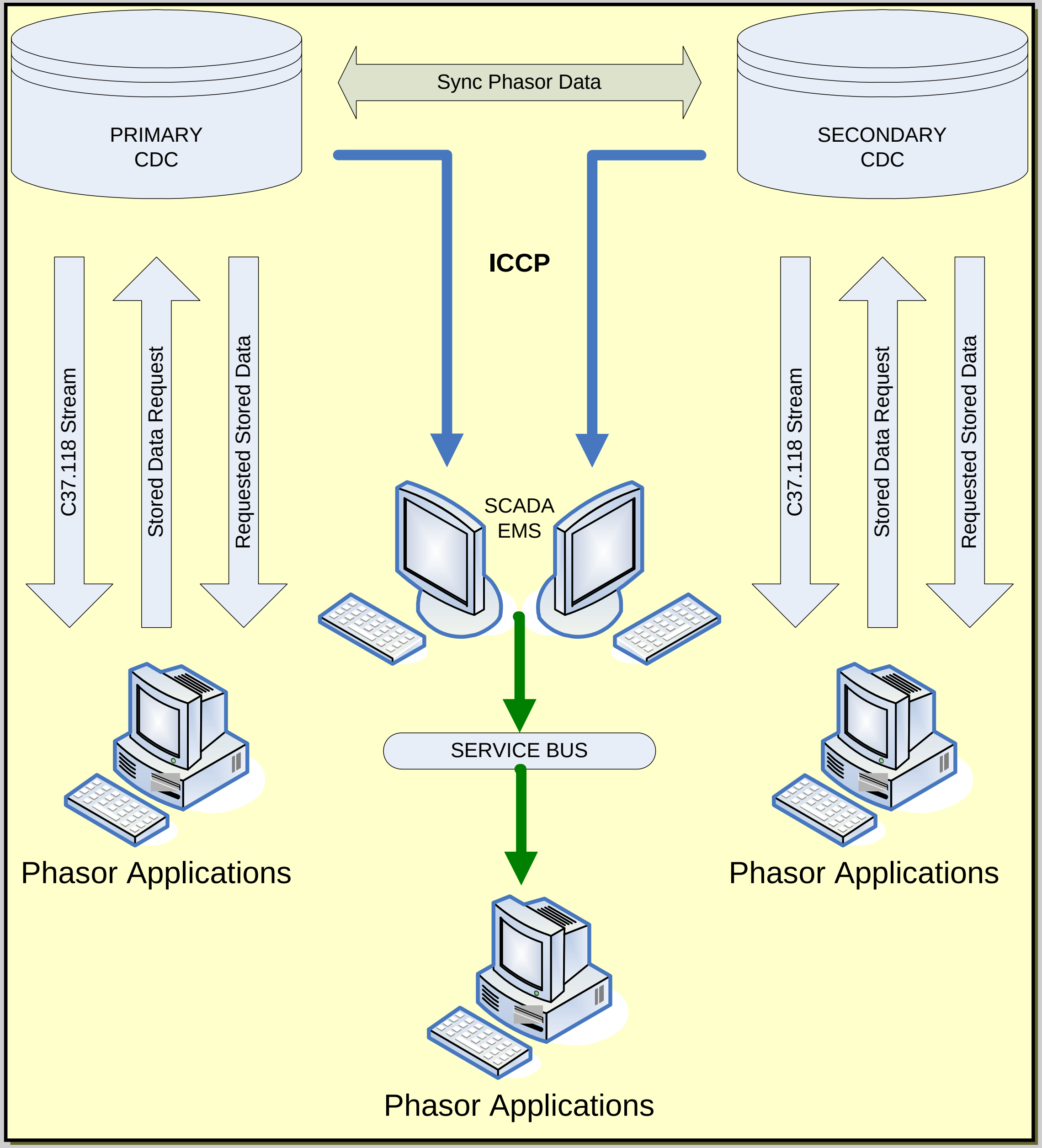
Two level CDC structure (Front-end and a Master PDC)

- **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

PCDC & SCDC Block Diagram



PCDC & SCDC Data Transfer



Main Advantages of Proposed Architecture

- **Flexibility**
  - ✓ Allow the use of different phasor report rates for Utility's application
  - ✓ Two connection alternatives for sending the data to ONS
  - ✓ Optional use of Utility's Phasor Data Concentrator (APDC)
  - ✓ PMU data can be sent directly to other substation or other Utility's Control Center, without needing to be aligned by SPDC (allow real-time control applications)

- **Reliability**
  - ✓ Hardware & software failures
  - ✓ Data storage, backup and restore
  - ✓ Substation Phasor Data Concentrator allow comply with telecommunication failures

- **Scalability**
  - ✓ Expansible structure allowing increasing the PMU number to attend NIPS evolution (multiple FEPDCs)

- **Low latency**
  - ✓ Use of multicast technology saves bandwidth and minimizes system latency

IEEE C37.118
Extension Needs

SPDC Command Data

IEEE C37.118-2005 Standard extension:

COMMAND WORD BITS	DEFINITION
Bits 15–4	Reserved for future use.
Bits 3–2–1–0:	
0001	Turn off transmission of SPDC data frames.
0010	Turn on transmission of SPDC data frames.
0011	Send SPDC HDR file.
0100	Send SPDC CFG-1 file.
0101	Send SPDC CFG-2 file.
1000	Extended frame.
1001	**Send SPDC buffer data defined by 16 bytes in extended frame**

N	FIELD	SIZE	DEFINITION
1	**SOC_S**	**4**	**Buffer start SOC time stamp**
2	**FRACSEC_S**	**4**	**Buffer start Fraction of Second and Time Quality**
3	**SOC_E**	**4**	**Buffer end SOC time stamp**
4	**FRACSEC_E**	**4**	**Buffer end Fraction of Second and Time Quality**

SOC Second-of-Century count starting at midnight 01-Jan-1970 (UNIX time base)

FRACSEC Fraction of second and time quality

Present Project Status

Main Milestones

- SPMS technical specifications were concluded, and the following documents were issued:
  - ✓ NIPS PMU System Architecture Design
  - ✓ NIPS PMU System Technical Specifications – Phasor Measurement Unit
  - ✓ NIPS PMU System Technical Specifications – ONS’ Central Data Concentrator
  - ✓ NIPS PMU System Technical Specifications – Substation Phasor Data Concentrator and Backup Storage
  - ✓ NIPS PMU System Technical Specifications – Communication Requirement
  - ✓ NIPS Test Methods Specifications – Phasor Measurement Unit
- Studies for PMU placement for dynamic performance recording was concluded
- The ONS’ Board *non-obstat*

ONS

Next Steps

- ⇨ Conclude the expression of interest and pre-qualifying process of companies to perform PMU certification tests
  - ✓ Pre-qualification submission will be accepted until **September, 17th**

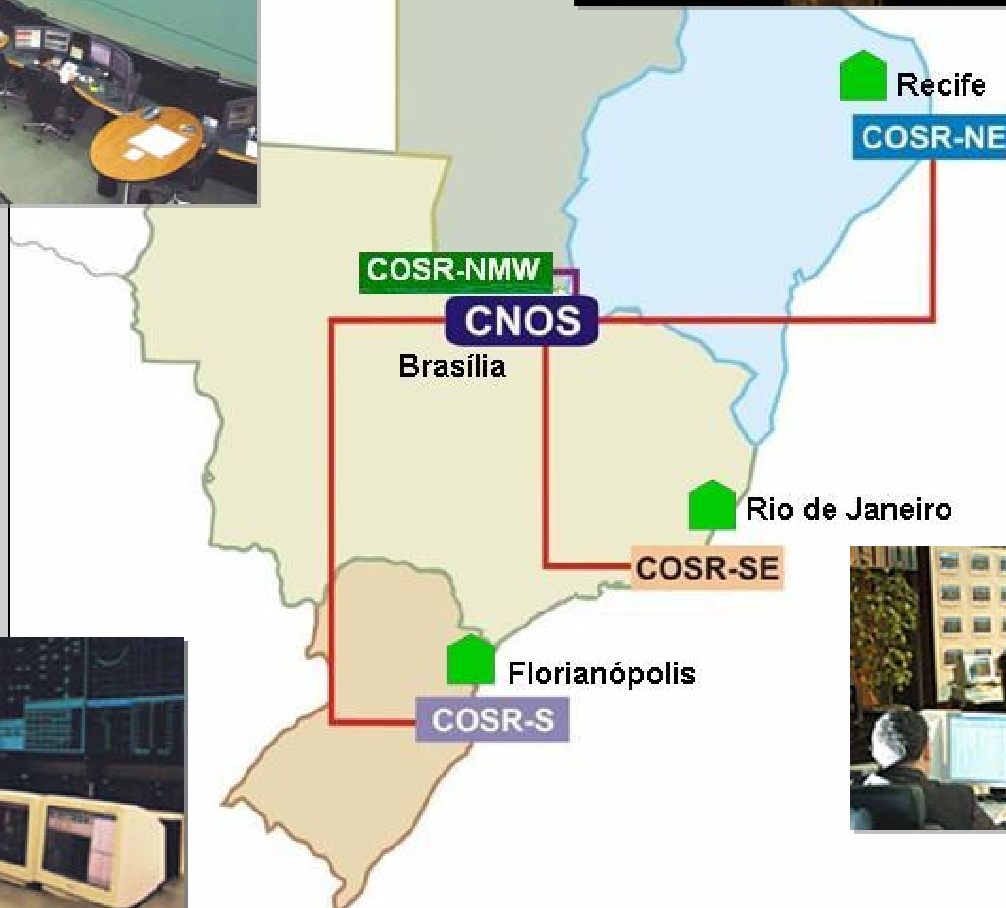
If you are interested in provide this service, please follow the instructions on http://www.ons.org.br/concorrencias

- ⇨ Contract PMU certification tests before the end of the year

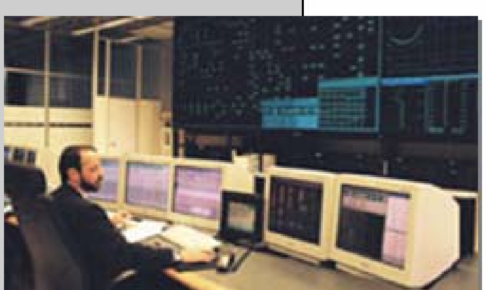
- ⇨ Start the ONS Central Data Concentrator procurement process

ONS' Operational Infrastructure

ONS' Control Centers & Offices



ONS Central Office



Present Control Center Applications

National Control Center - CNOS

Moving operation from corrective to preventive actions

Production Control

- Generation deviation (Planned x Executed)

Transmission Lines Control

- Automatic interconnection limits setting (based on load levels & period of the day)

Security Assessment

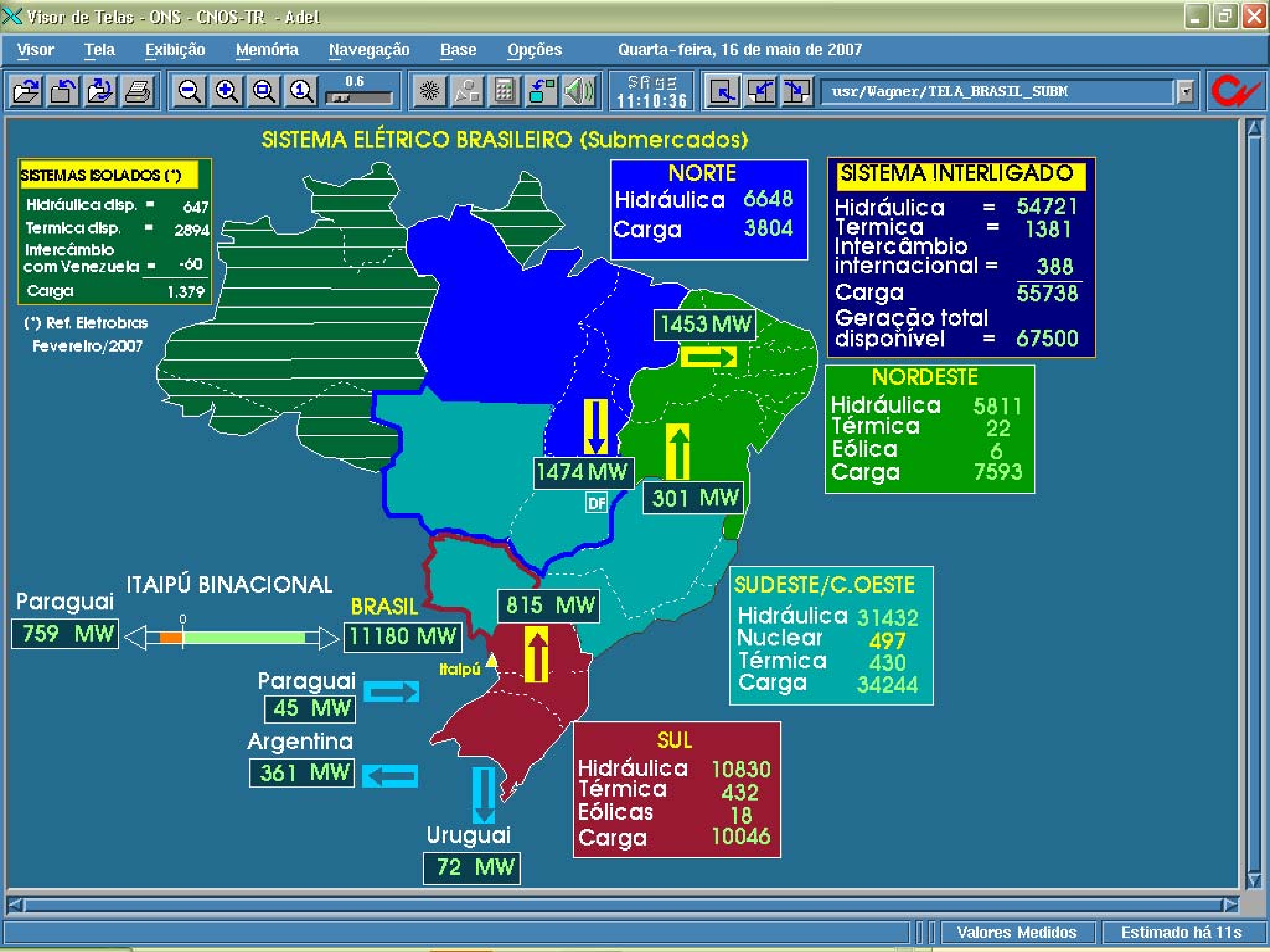
- Real Time Dynamic Security Analysis and Assessment

Detection and Forecast

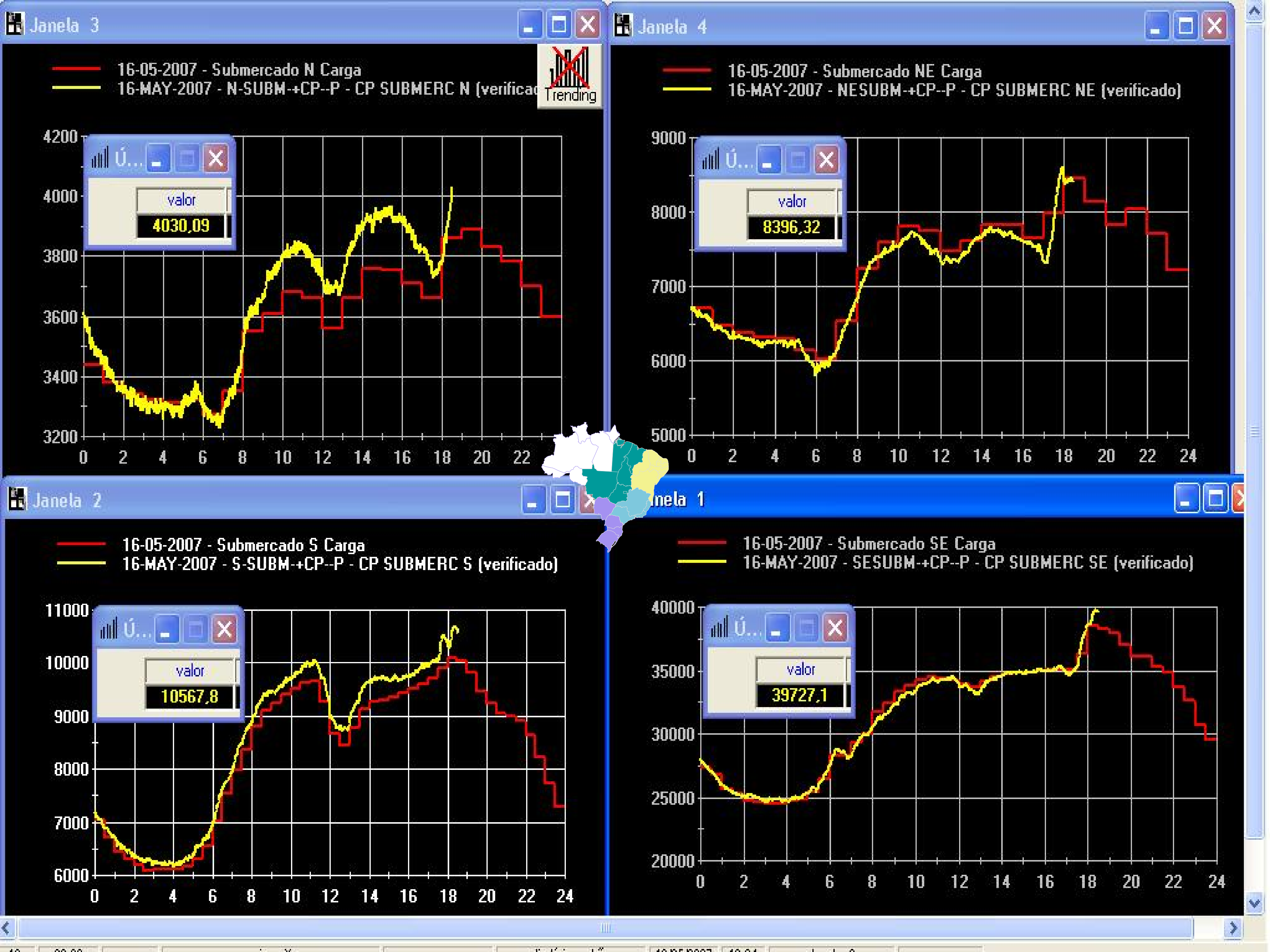
- Short-Term Load Forecast
- Lighting detection
- Forest & bush fire

Event Historian

- Event recording and playback



Visor de Telas - ONS - CNOS-TR - Adel
Visor
Tela
Exibição
Memória
Navegação
Base
Opções
Quarta-feira, 16 de maio de 2007
0.6
SAGE
11:10:36
usr/Wagner/TELA_BRASIL_SUBM
SISTEMA ELÉTRICO BRASILEIRO (Submercados)
SISTEMAS ISOLADOS (*)
Hidráulica disp. = 647
Termica disp. = 2894
Intercâmbio com Venezuela = -60
Carga 1.379
(*) Ref. Eletrobras Fevereiro/2007
NORTE
Hidráulica 6648
Carga 3804
SISTEMA INTERLIGADO
Hidráulica = 54721
Termica = 1381
Intercâmbio internacional = 388
Carga 55738
Geração total disponível = 67500
1453 MW
1474 MW
301 MW
DF
NORDESTE
Hidráulica 5811
Térmica 22
Eólica 6
Carga 7593
ITAIPÚ BINACIONAL
Paraguai
759 MW
0
BRASIL
11180 MW
815 MW
Itaipú
SUDESTE/C.OESTE
Hidráulica 31432
Nuclear 497
Térmica 430
Carga 34244
Paraguai
45 MW
Argentina
361 MW
Uruguai
72 MW
SUL
Hidráulica 10830
Térmica 432
Eólicas 18
Carga 10046
Valores Medidos
Estimado há 11s


Janela 3
16-05-2007 - Submercado N Carga
16-MAY-2007 - N-SUBM-+CP--P - CP SUBMERC N (verificac
Trending
valor
4030,09
Janela 4
16-05-2007 - Submercado NE Carga
16-MAY-2007 - NESUBM-+CP--P - CP SUBMERC NE (verificado)
valor
8396,32
Janela 2
16-05-2007 - Submercado S Carga
16-MAY-2007 - S-SUBM-+CP--P - CP SUBMERC S (verificado)
valor
10567,8
Janela 1
16-05-2007 - Submercado SE Carga
16-MAY-2007 - SESUBM-+CP--P - CP SUBMERC SE (verificado)
valor
39727,1


FREQUENCIA
FNE
RNE
FNS
ELO
SENE
FSE
Sul Recebe
Rec S
RSE
500
440

Intended PMU Applications

PMU Prospective Applications Results

Possible Economic Gains Identification:

The analysis for the transmission limits between the North and Northeast regions for March 2006 shows realistic congestion situations

If the PMU-based limits were 10 to 20% higher than current limits then the economic gain for that month could have been between 1 to 2 million US$

Potential Applications Analyzed:

Voltages Phase Angle Monitoring (VPAM)
System Oscillations Monitoring (SOM)
Line Loading Limit Monitoring (LLLM)
Wide-Area Harmonics Monitoring (WAHM)
Enhanced Voltage Stability Assessment (EVSA)
On-Line Contingency Analysis (OLCA)
Wide-Area System Protections (WASP)
Wide-Area System Controls (WASC)

Selected Applications:

Voltages Phase Angle Monitoring
System Oscillations Monitoring

Selected PMU Applications

VPAM – Voltage Phase Angle Monitoring

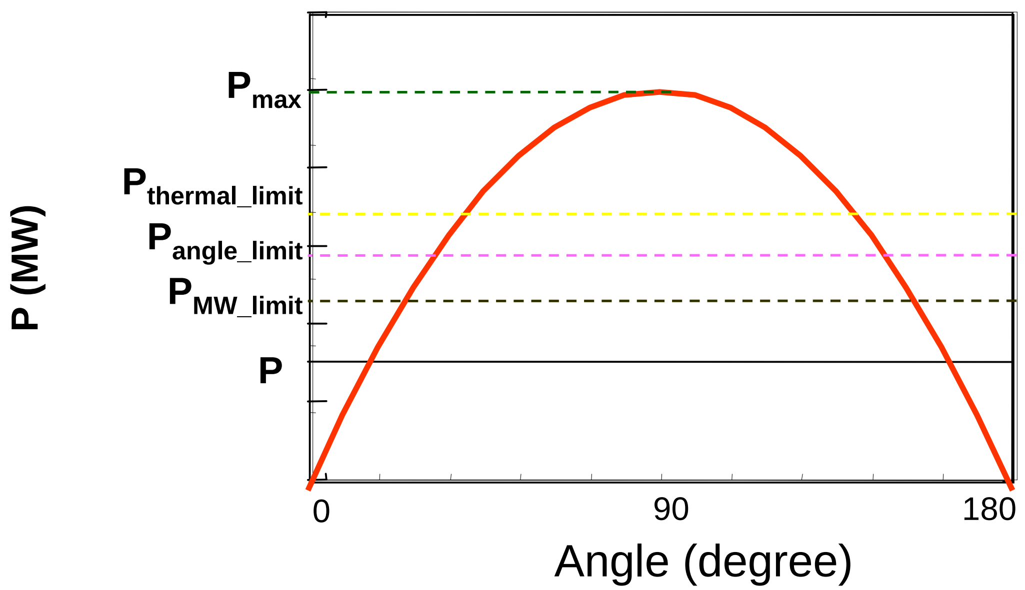
- **StressMon** – System Stress Monitoring
- **SynchAssist** – Closing a connection between two electrical islands
- **LoopAssist** – Closing a breaker in a loop in the transmission network

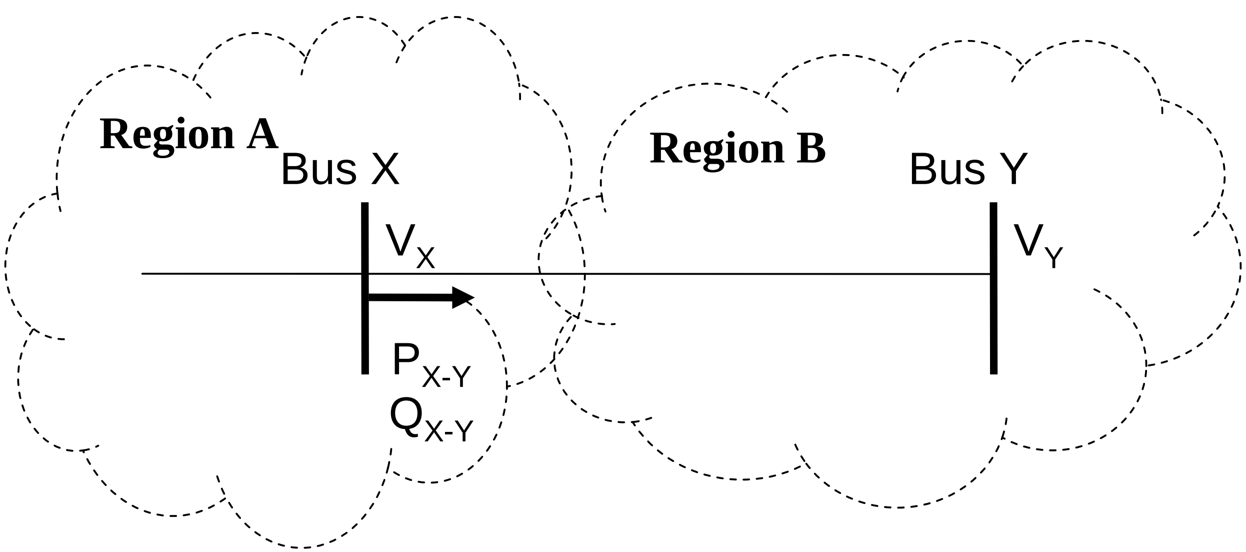
SOM – System Oscillations Monitoring

- **DampAlarm** – System Damping Alarming

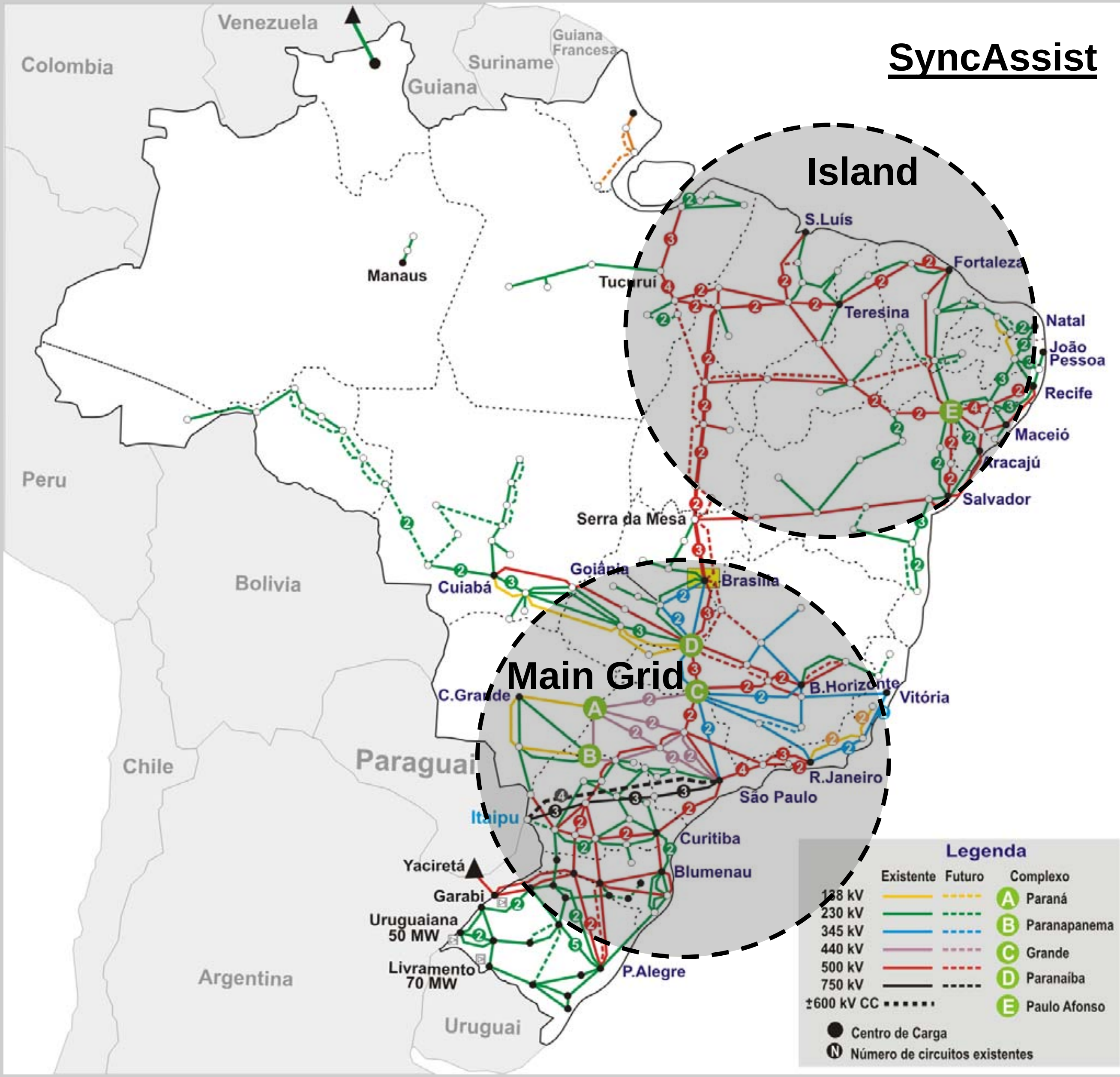
VPAM – Voltage Phase Angle Monitoring

StressMon

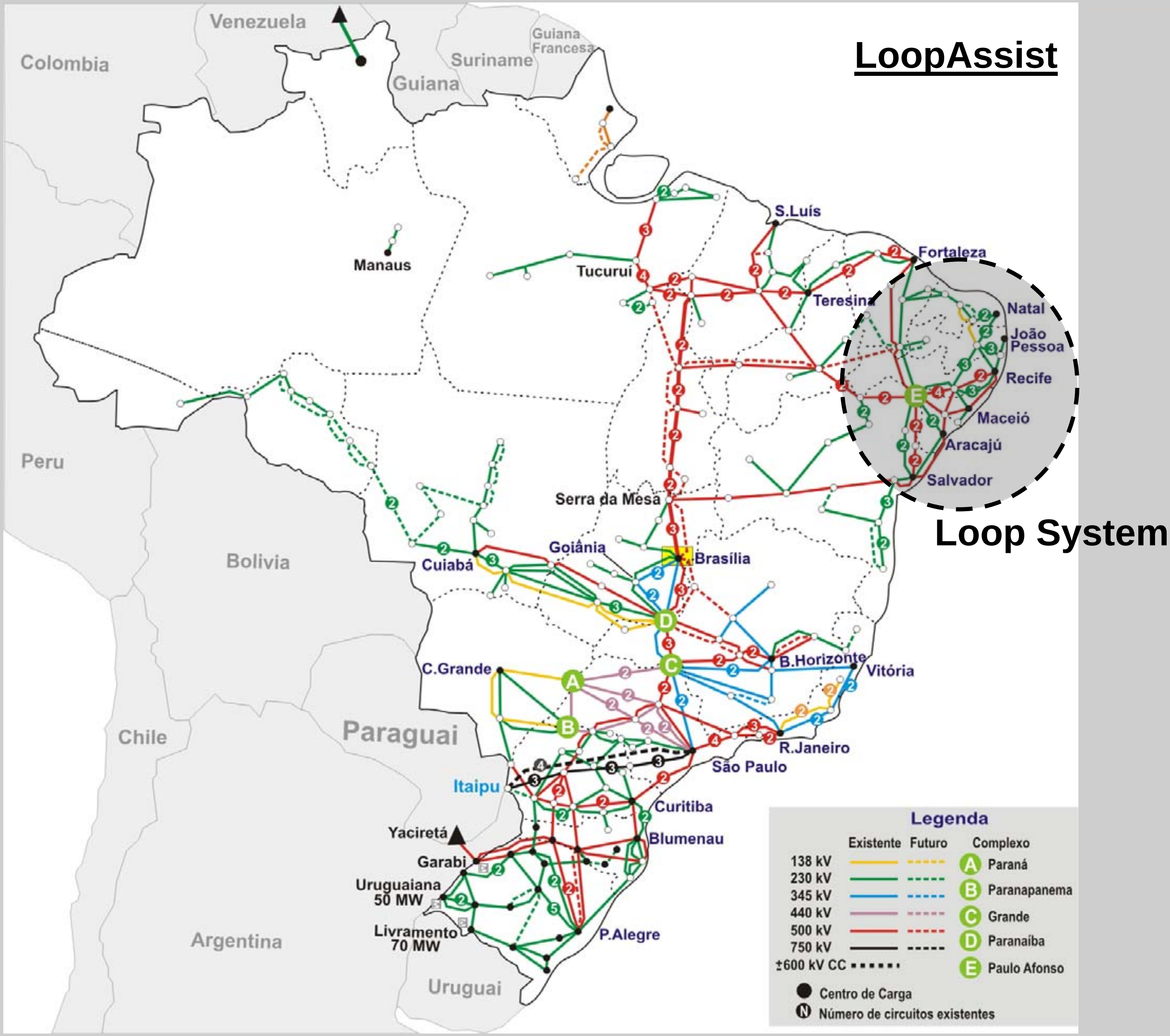




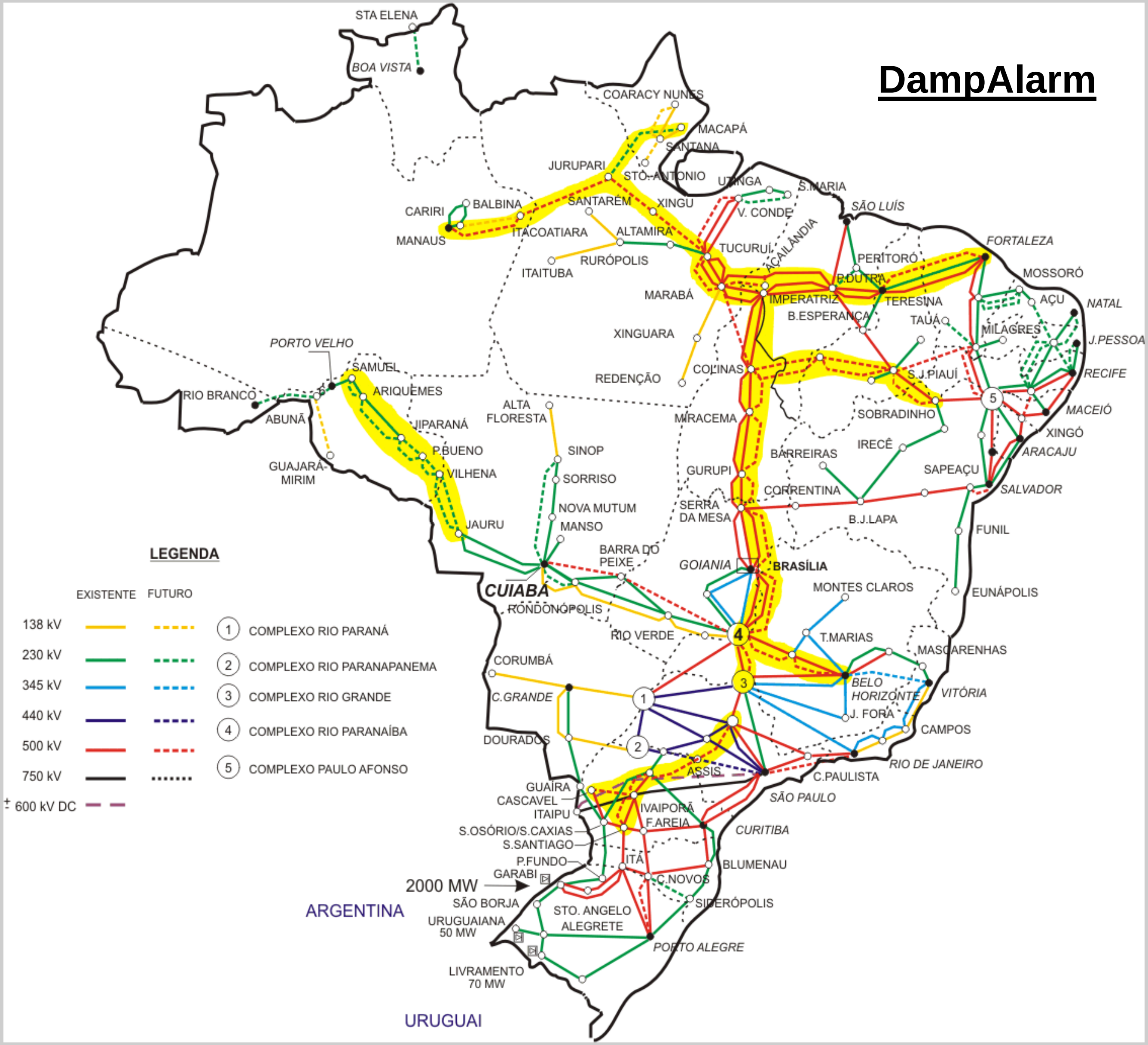
VPAM – Voltage Phase Angle Monitoring



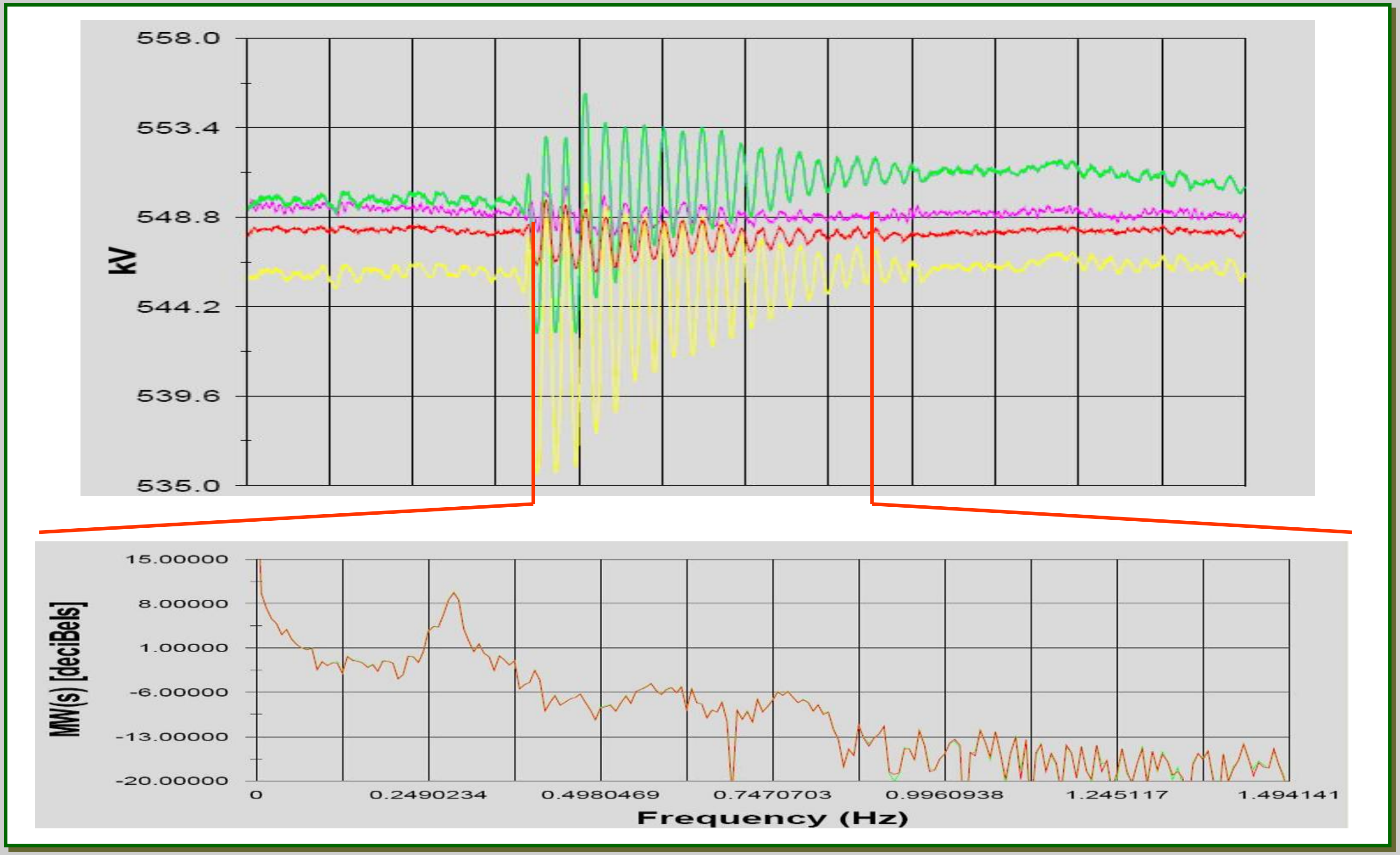
VPAM – Voltage Phase Angle Monitoring



SOM – System Oscillations Monitoring



SOM – System Oscillations Monitoring



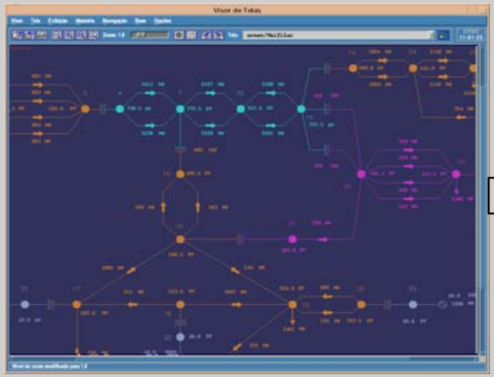
Dominant mode	1	2	3	4
Freq. (Hz)				
Damping (%)				
Time constant				

ONS

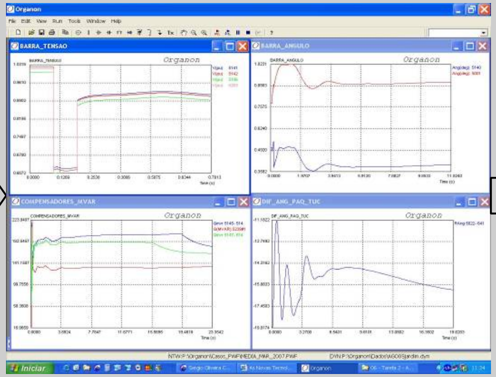
Application Validation and Testing

PMU Applications Validation

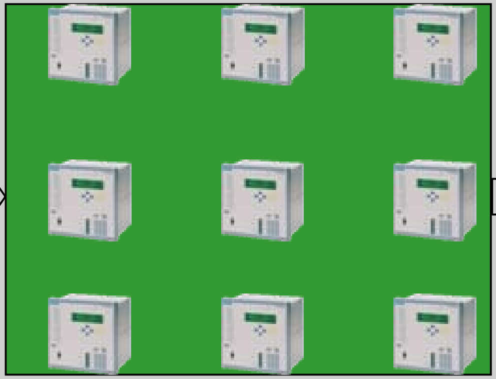
State Estimator



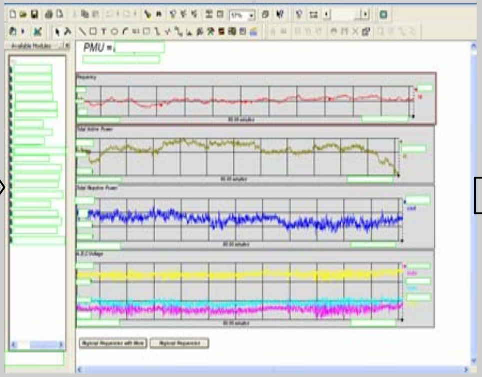
Dynamic Simulator



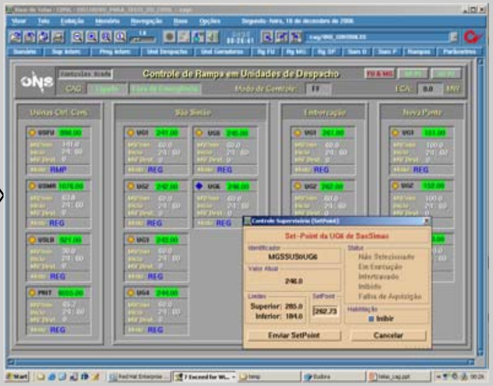
Phasor Output



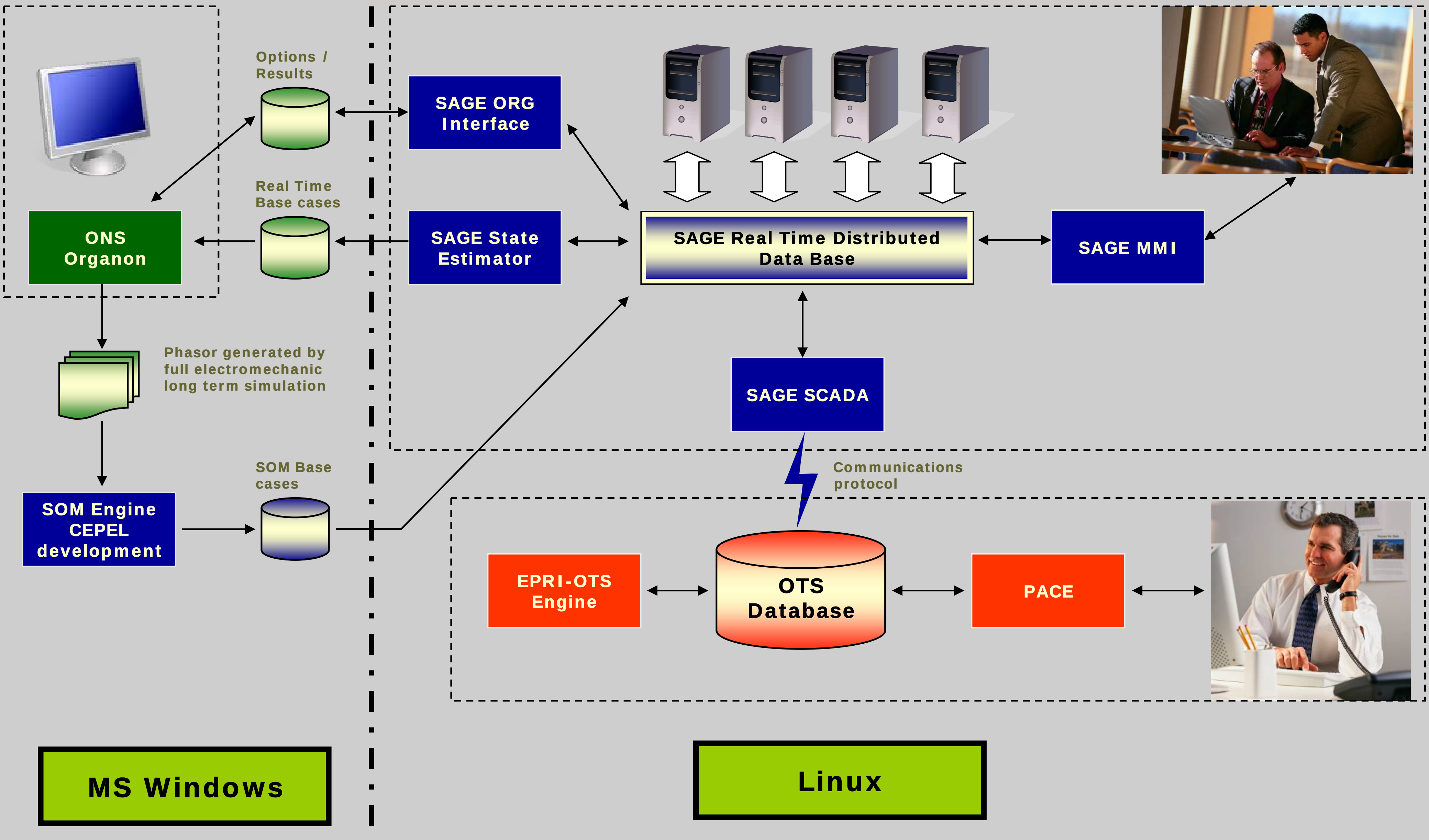
Phasor Applications



OTS



PMU Applications Validation



Brazilian Electric System
National Operator

Thank you!