Installation of PMU for Improving the Supervision of Interconnected Brazilian Transmission System (SIN)

By
Prof. Robson Pires
robson.c.pires@gmail.com
Federal University of Itajubá – UNIFEI, MG – BRAZIL
CNPQ/PDE – 200703/2014-5

1. Motivation…

The main objective of the Brazilian Phasor Measurement System (PMS) is to:

- Allow the National Interconnected Power System (NIPS) dynamic behavior analysis determining the causes of electromechanical disturbances, acquiring data for re-adjustments of generation unit controllers, identifying new operational procedures, need for new Special Protection Systems (SPS) and validation of dynamic models;
- Provide synchrophasor data to ONS EMS/SCADA and allow real time apliccations. This data will be used to support the decision process in real-time operation.

2. 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	Partnership with Federal University of Santa Catarina (UFSC)
2012	MME/BIRD understandings for funding SPMS
2013	Telecommunication Technical Specification
2014	PDC Infrastructure / Applications Acquisition
2015	Beginning of Operation

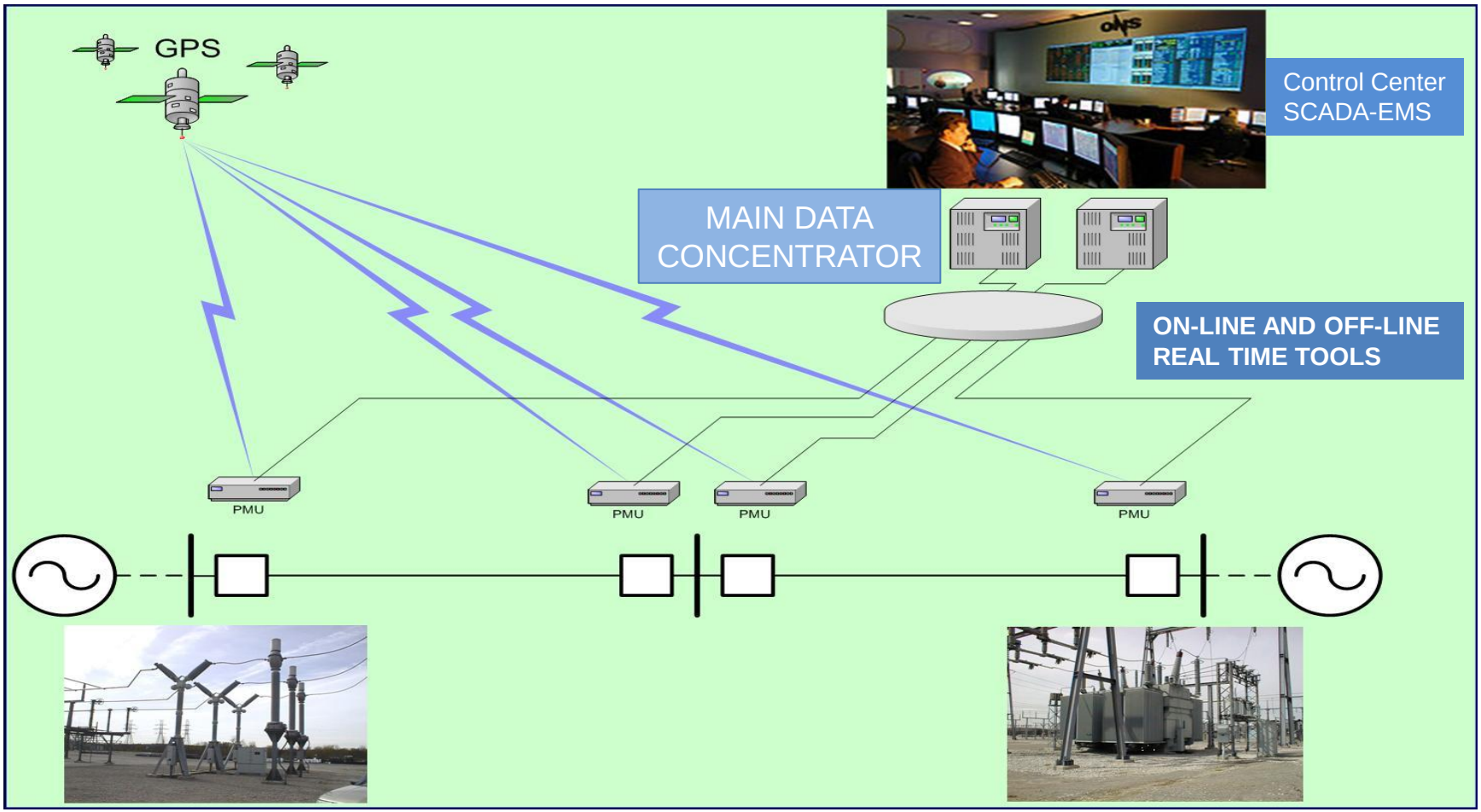
3. Regulatory Aspects

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

- Transmission Owners' duties
  - Transmission Owners (TOs) 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.

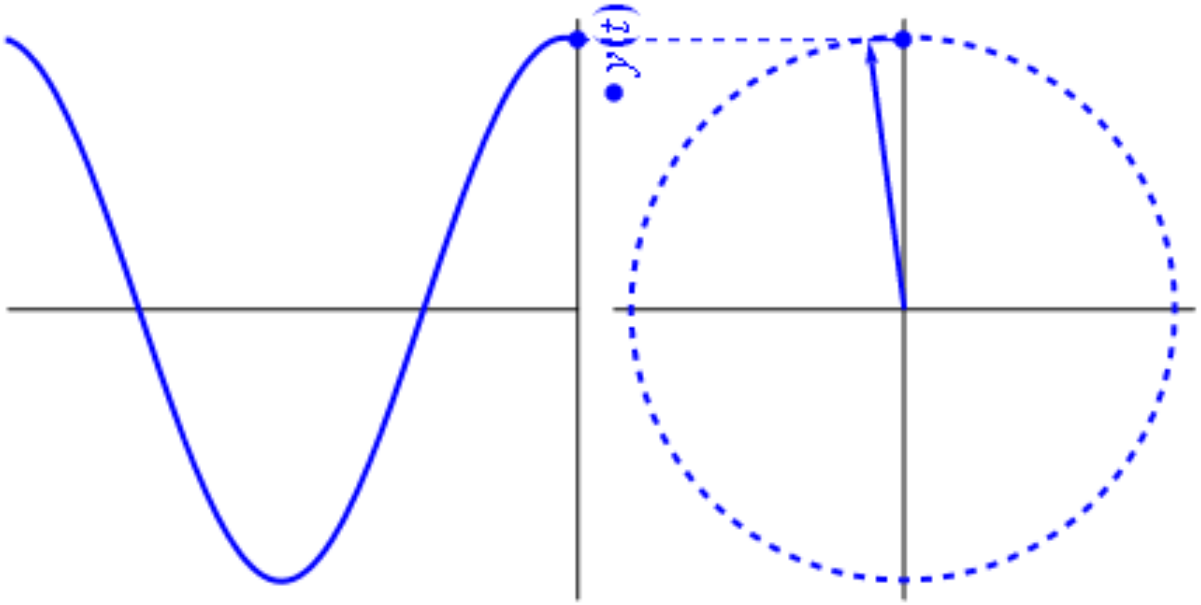
- ONS' duties
  - Define and specify the PMS architecture;
  - Specify, acquire and install the ONS' Phasor Concentrators;
  - Define PMU placement;
  - Define the schedule and coordinate the PMU installation by TOs.

4. PMUs – Working Principles



A. Shortcomings of Prior Work:

PMU's genesis…., 1893



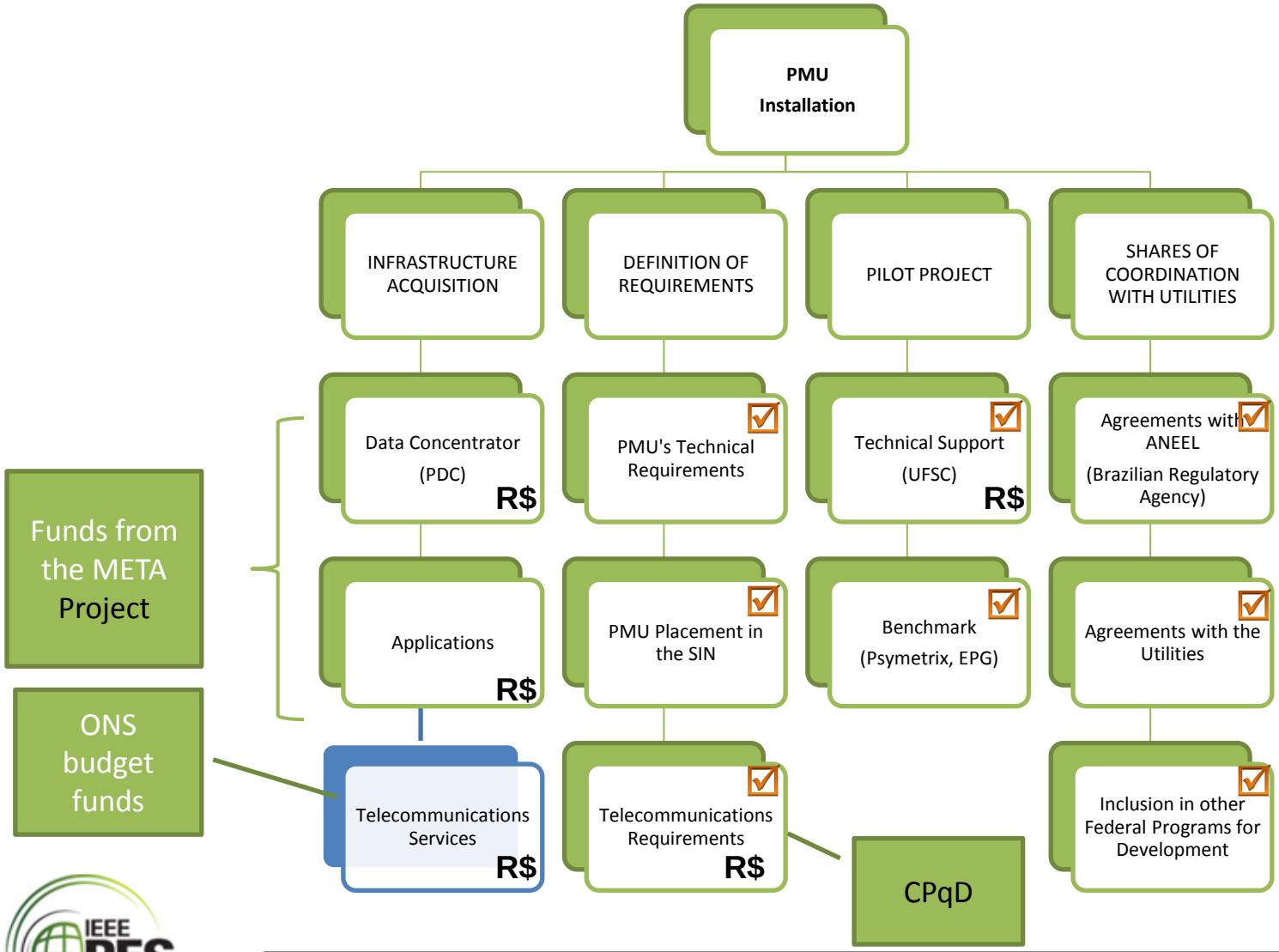
Charles Proteus Steinmetz (1865-1923)

Complex Quantities and their use in Electrical Engineering;

Proceedings of the International Electrical Congress, Chicago, IL; AIEE Proceedings, 1893; pp.33-74.

Source: Mark Adamiak - GE

5. Overview of the project



6. META Project – BIRD

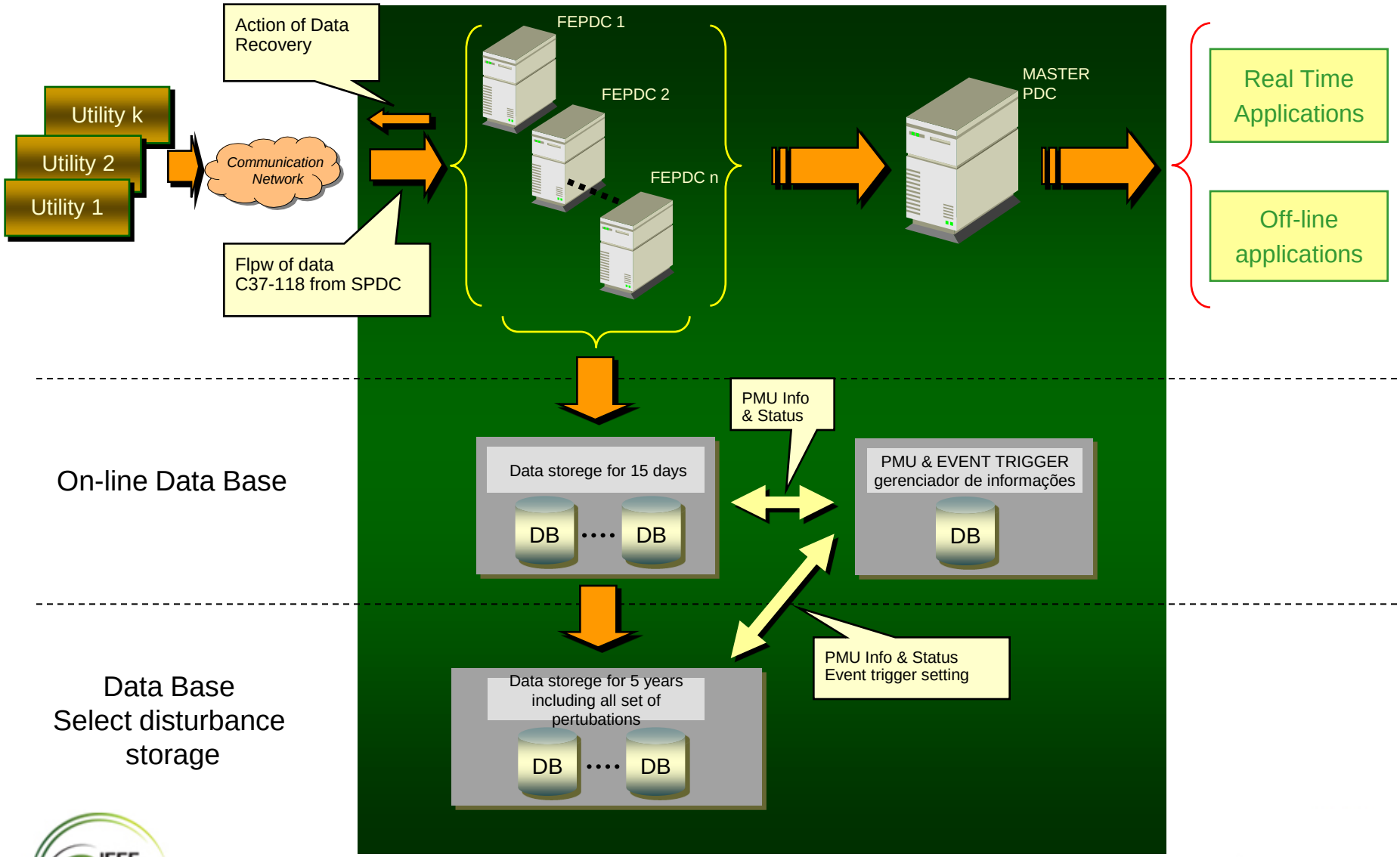
- Technical Assistance Project of Energy and Mineral Sectors
- Ministry of Mines and Energy / ONS RE 3/118/2010 ⟹ Funding for PDCs , operating systems and applicatives

Step 1 of the META project: $ 50 million

Part intended for ONS : US $ 4.7 million ☞ (resource -repayable)

Conversely ONS : Own Task Force

7. Framework for the installation of PMU in the SIN



8. Power System Network Real-Time Applications

Frequency Monitoring

- Display in real-time the minimum and maximum frequency detected among all PMUs across the PSN;
- Display in real-time the deviation from nominal frequency for any selected PMU;
- Display in real-time the frequency of any selected PMU.

Voltage Monitoring

- Display in real-time the voltage profile of all PMUs across the PSN;
- Display in real-time the deviation from nominal voltage for any selected PMU;
- Display in real-time the voltage of any selected PMU.

Angle Monitoring

- Display in real-time the angle deviation profile of all PMUs across the PSN;
- Display in real-time the deviation from the Angle Reference for each PMU. The Angle Reference shall be configured by the user;
- Display in real-time the angle of any selected PMU;
- Display in real-time the angle difference of any pair of selected PMU.

Power Monitoring

- Display in real-time the Power Flow (active and reactive) of any selected PMU across the PSN.

...

Oscillatory Stability Monitoring

- Calculate all observable modes of oscillation based on the measured signals;
- Calculate all vectors representing the amplitude and phase (mode shape) of the oscillations for each mode;
- Display all the calculated data (mode damping, mode amplitude and mode phase) for each mode based on the synchrophasor measurements for a configurable length of time;
- Display the group of measurements which are oscillating in phase or out of phase based on the mode shape analysis. Pinpoint which measurement/s is/are contributing more to a specific mode of oscillation;
- Display an historic overview of the spectrum of modes for a selected time period;
- Provide alerts and alarms based on preset values of oscillations poorly damped or with large amplitudes modes.

Restoration Support Application

- Identify in Real-Time an islanding condition of the PSN;
- Identify the different islands creating groups of measurements pertaining to the same island;
- Provide visualization of frequency deviation between areas;
- Provide alarms and visual indication of an islanding condition;
- Display the angle and the frequency of all measurements across the PSN;
- Display the frequency deviation of all measurements to the nominal frequency;
- Display the voltage and frequency delta between any 2 selected measurements.

...

Disturbance Detection and Location

- Detect and display in real time a disturbance occurrence;
- Suggest the type of disturbance (generation trip, load shedding, transmission line tripping);
- Based on all available signals, pinpoint the most likely geographical disturbance location.

Additional Features

- Alarm Application;
- PMU Status Overview;
- Playback System;

Support Functions

- Decimate any selected measurement to a chosen value, e.g. 1 sample/second;
- Send any decimated measurements or results calculated by the previous applications to other ONS EMS applications using ICCP-TASE.2, IEC 61850 and XML facilities.

Common Applications

PMU Topology Management

- Include, adjust and exclude analog and digital measurements;
- Calculate sequence values (positive, negative and zero) from phase values;
- Create new measurements from the existent analog or digital values;
- Select which measurements will be stored in the real-time database;
- Import and export CIM-XML database description;
- All measurements configured in this subsystem will have to be correlated to a power system asset (transmission line, transformer, breaker, etc.). All power system information will be obtained using the CIM-XML model of the system.

Graphical User Interface (GUI)

- Layers
  - » The GUI will present all information based on a layer control system. It will be composed by 3 layers: GIS, Network Topology and Substation Display. The user will be able to present all layers or to filter out any selected layer.
- GIS
  - » The GUI shall have the capability of presenting a geo-spatial information layer from a Geographic Information System – GIS.
- Network Topology
  - » The Network Topology layer must be able to import the Power System Network topology information from ONS Database. This topology information contains all necessary geographical information to draw the Power System on the top of the previous layer. The topological information uses the CIM-XML standard.
- Substation Display
  - » The Substation Display layer must be able to import a figure representing the substation schematic. All configured measurements using the PMU Topology Management will be graphically represented in this layer. All measurements symbols shall be freely located over the substation schematic.

...

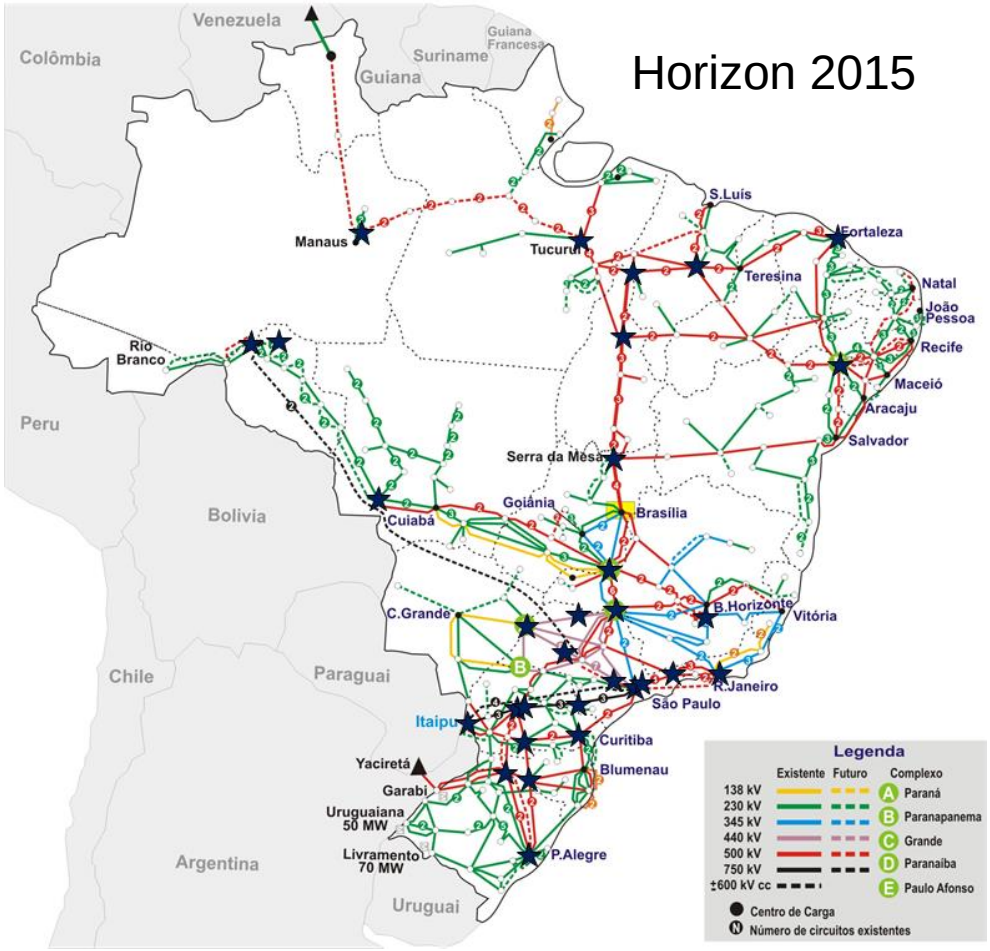
PMU Measurements Historical Overview

User Control

- This application will be responsible for configuring all users who interact with the SMS. The SMS will encompass at least 3 kinds of users: Administrators, Configurators, Power System Applications Users (Real-Time and Analysis).

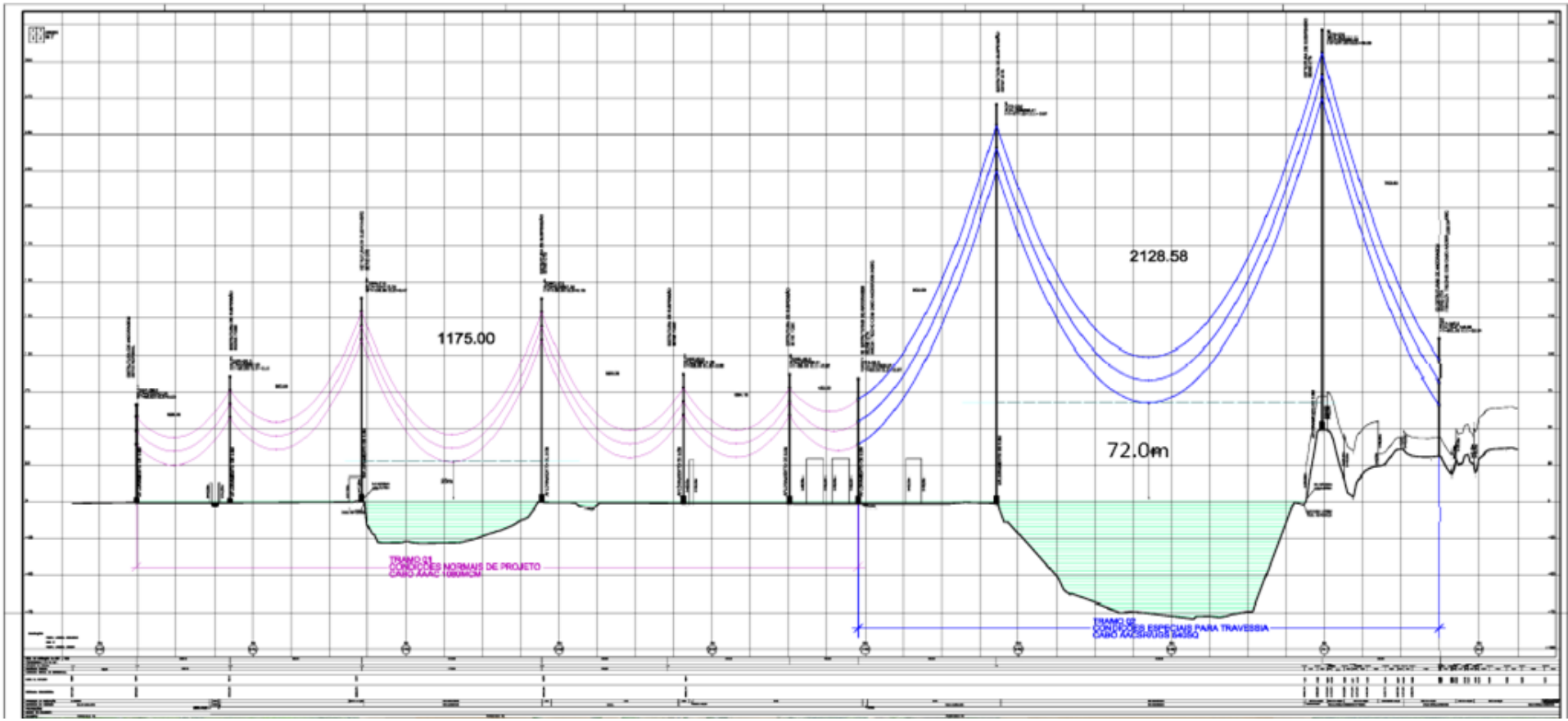
Log System

9. Monitored Substations of the SIN



31 Substations
181 Line Terminals

…Amazon River Crossing



PMU Installation in the SIN – 31 Substations

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

South Region
Areia 525 kV
Bateias 525 kV
Campos Novos 525 kV
Itá 525 kV
Ivaiporã ESU 525 kV
Nova Santa Rita 525kV

State of Minas Gerais
Itumbiara 500 kV
Jaguara 500 kV
Ouro Preto 345 kV

North Region
Imperatriz 500 kV
Manaus 500 kV
P. Dutra 500 kV
Tucuruí 500 kV

State of Mato Grosso
Jauru 230 kV

States of Acre/Rondônia
Porto Velho 230 kV
Samuel 230 kV

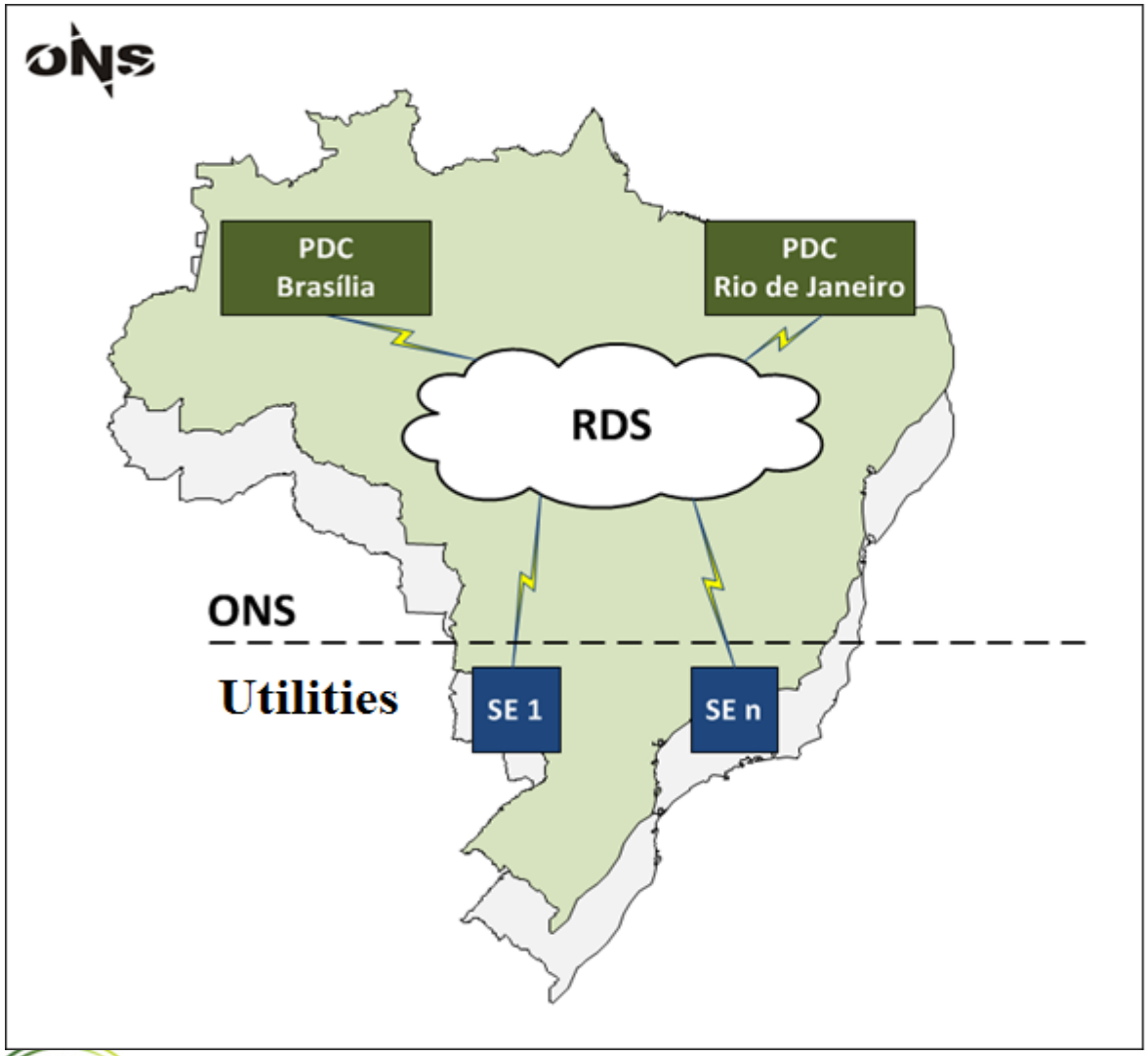
Northeast Region
Fortaleza 500 kV
Paulo Afonso 500 kV

Transm. System of 765 kV / Link DC
Foz do Iguaçu 765 kV
Ibiúna 500 kV
Itaberá 765 kV
Ivaiporã FUR 765 kV
Tijuco Preto 765 kV

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

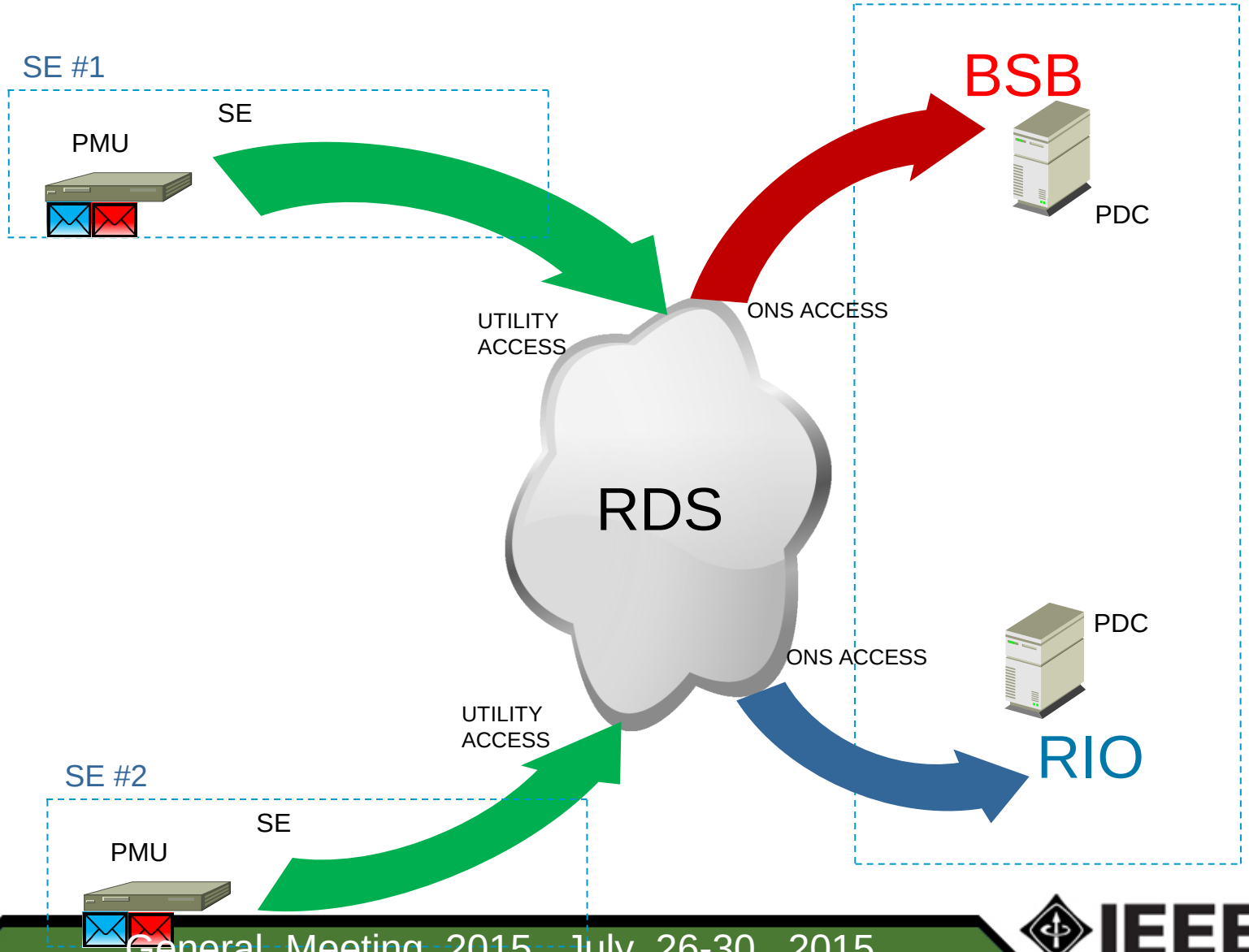
Interconnection North-Southeast
Colinas 500 kV
Serra da Mesa 500 kV

10. PMU data communication network (RDS)

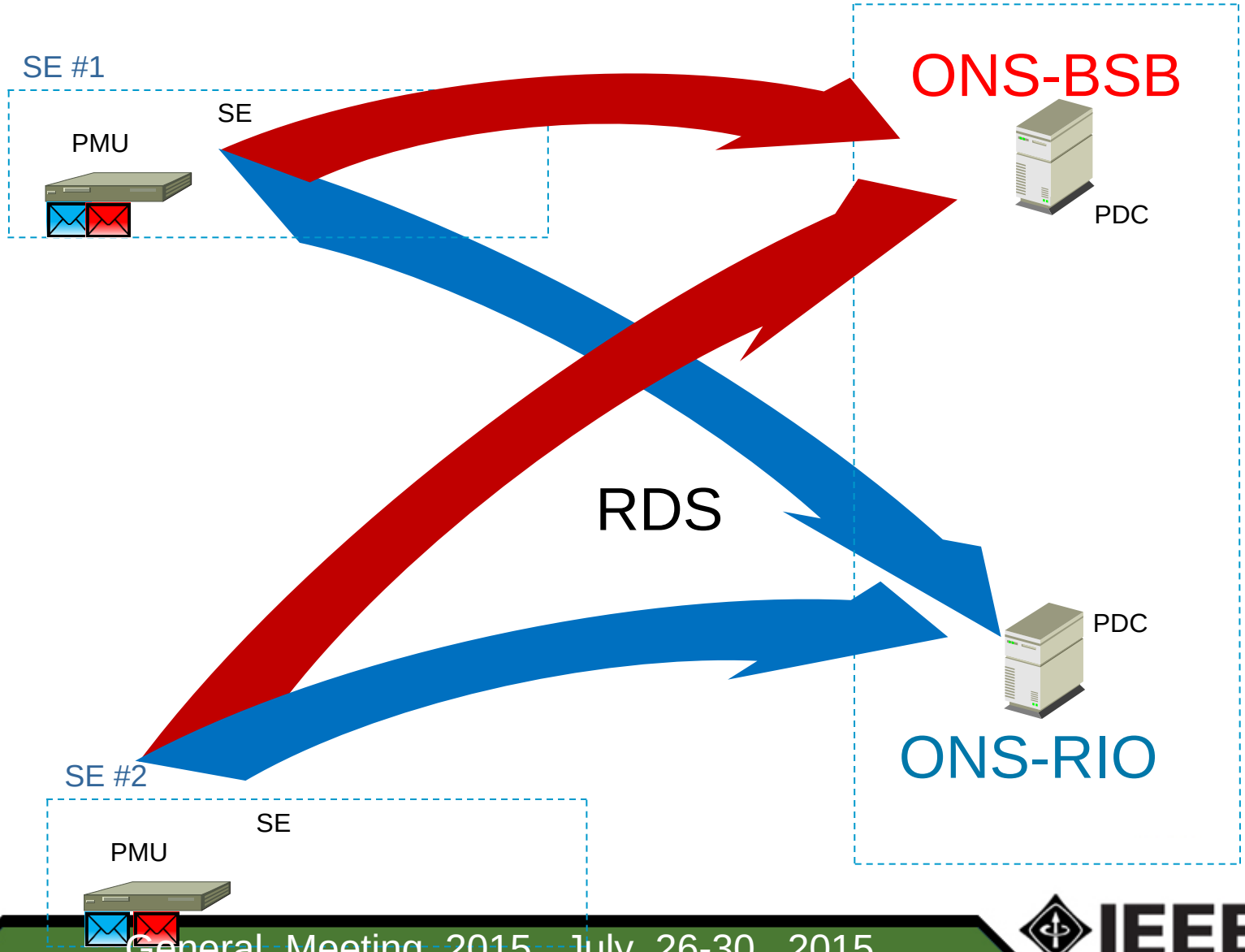


- Architecture on two levels
- Dedicated telecommunications channels for guaranteed bandwidth and the system security
- Phasor in real time using unicast addressing and C37.118 format
- SE connecting directly to the RDS

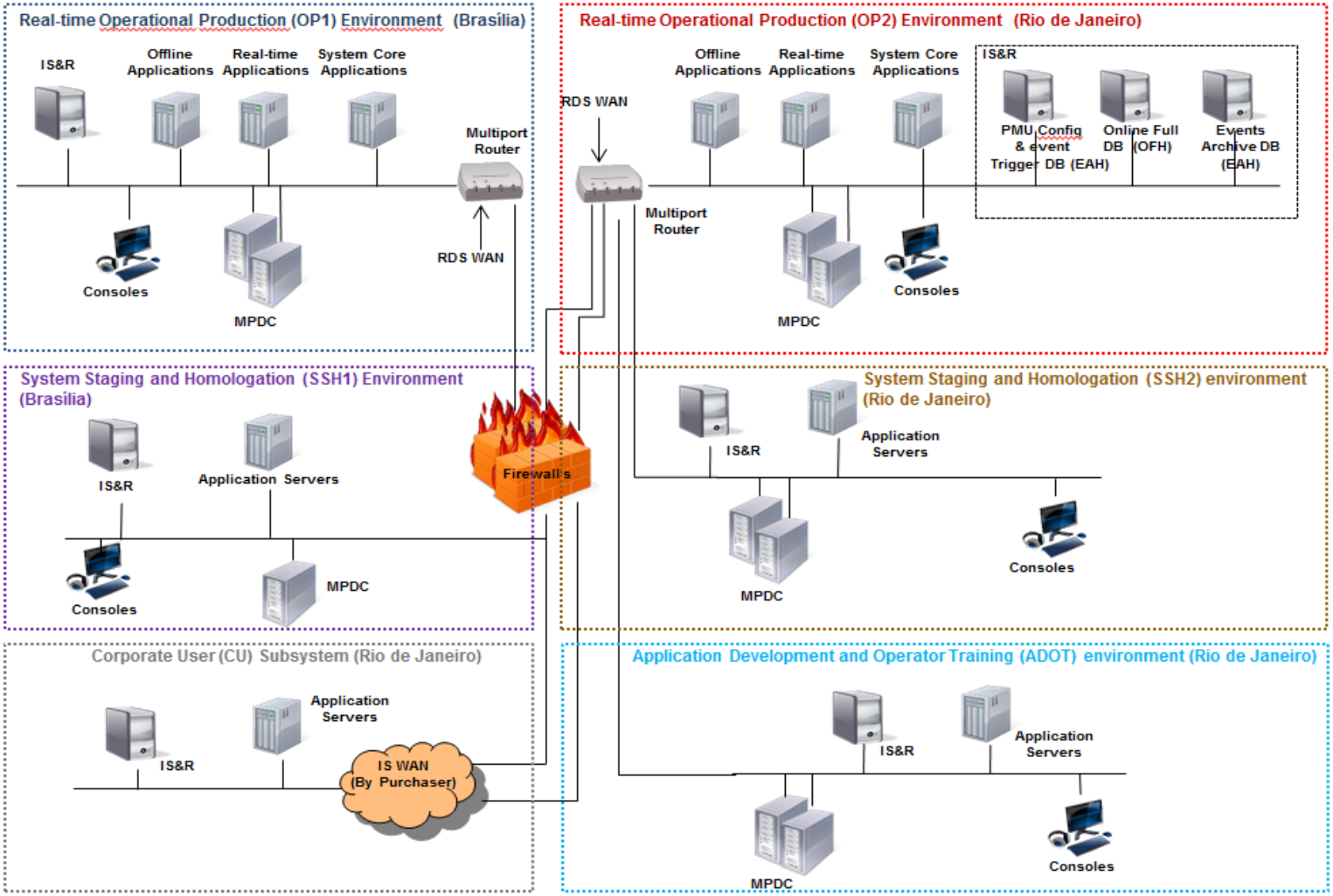
Alternative 1 – The RDS is hired by ONS



Alternative 2 – The RDS is hired by the Utilities



ONS Phasor Data Concentrators

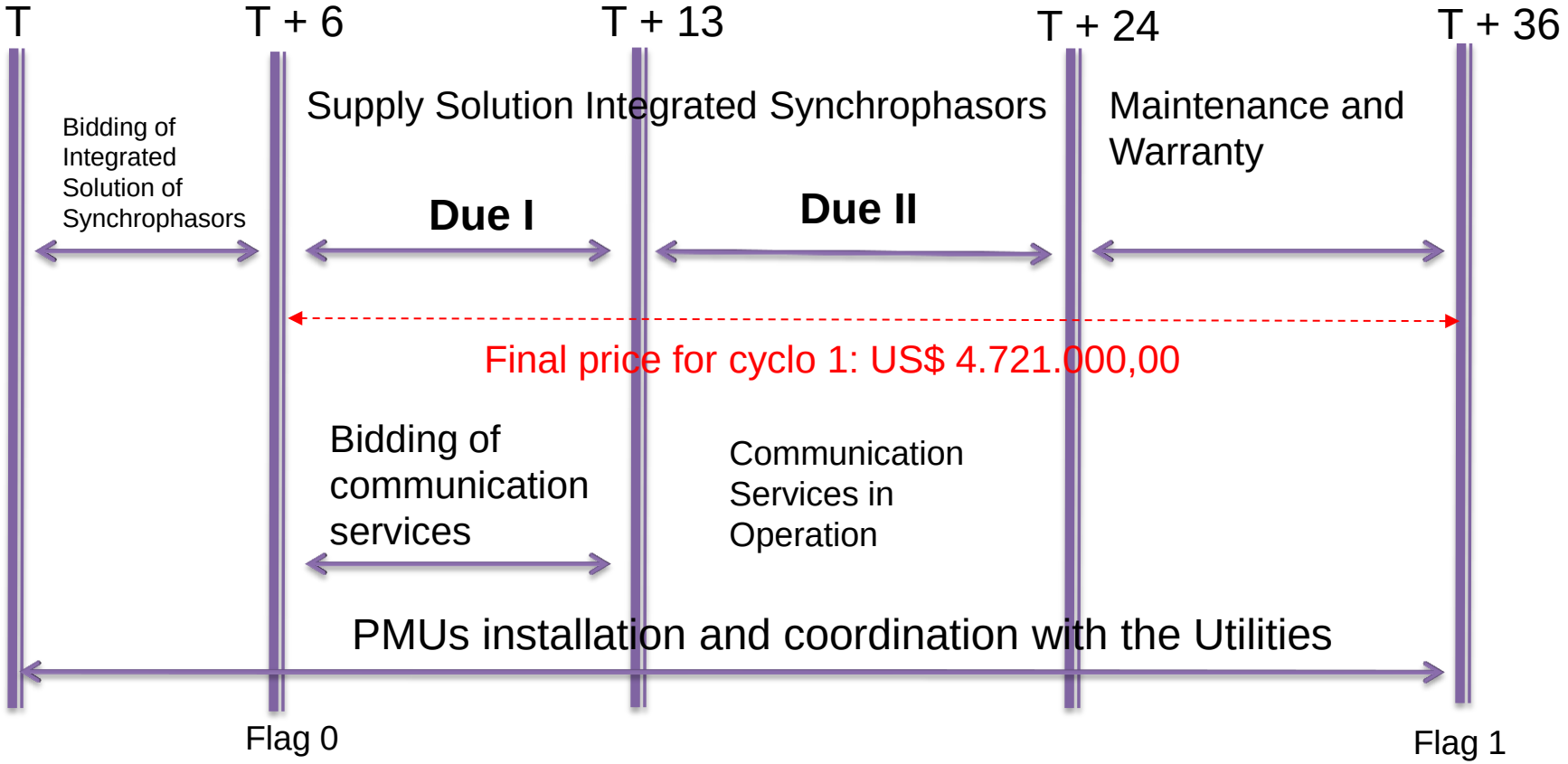


Approximate Costs

Communication Services	
Alternative # 1:	**U$ 1.3M/year (31) e U$ 3.4M in 2018 (102).**
Alternative # 2:	**U$ 1.6M/year (31) e U$ 4.3M in 2018 (102).**

Note:
Regardless the choice, there will need to allocate staff telecommunication reinforcement (2 to 4 people depending on the alternative to be chosen)

11. Time Schedule

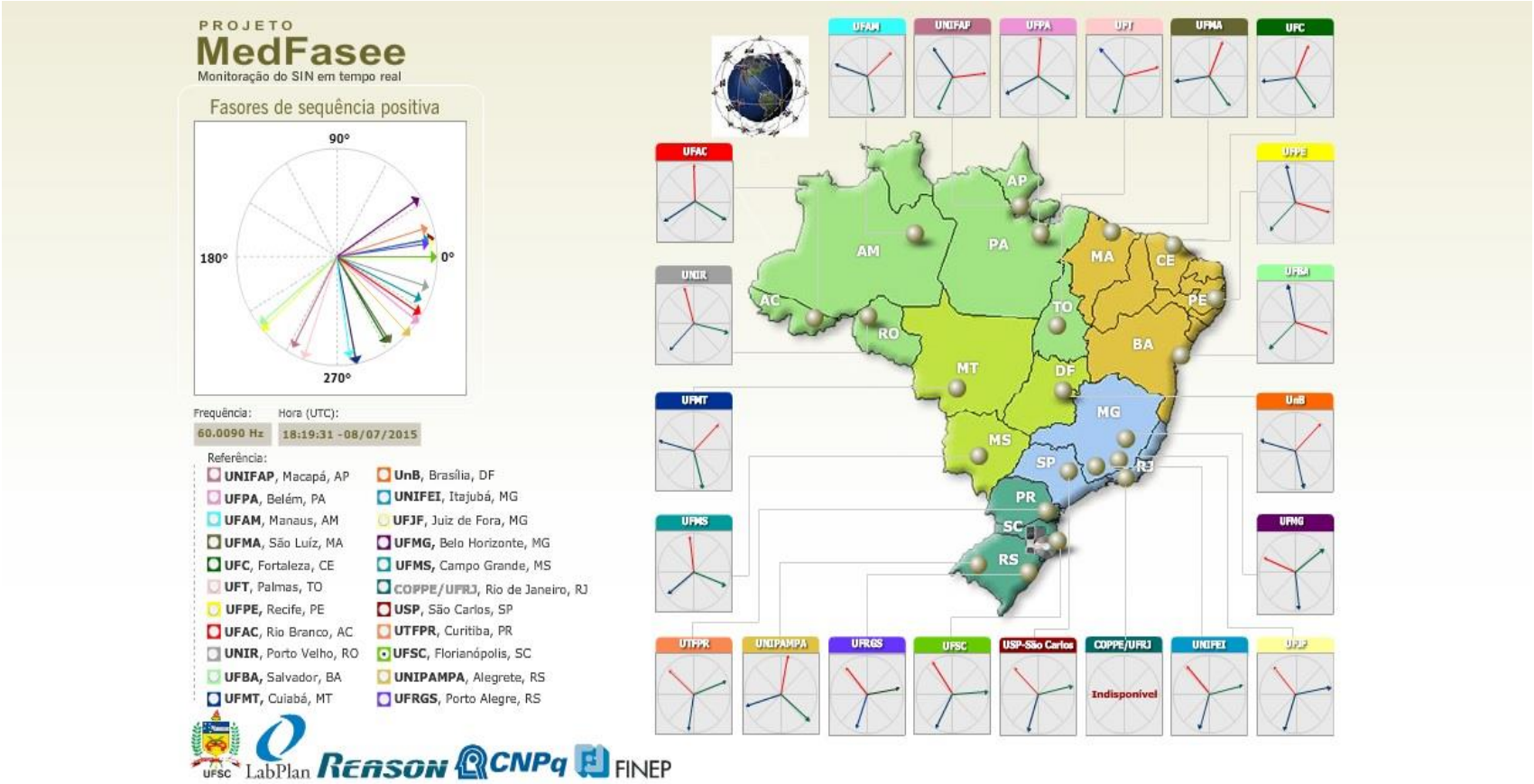


- **Cyclo 1** (30 months from Flag 0 – PMU system installation) – Financial Support provided by META Project.

  Due I: Product shelf version of the vendor, i.e., customization task specified by the ONS is not included
  Due II: Final product with the whole technical requirements stated by ONS staff included.

- **Cyclo 2** (30 months from Flag 1 – evolution / new developments / customizing – Not funded yet!...

12. The current use of PMU data, among others…



13. Our "two cents" for incorporating PMUs in PSSE

Research (CNPQ/PDE – 200703/2014-5**)**

Title: "Complex-Valued Model Solution Aiming Power Flow & Power System State Estimation Problems",

which results will be presented in the forthcoming papers submitted to IEEE-PES Transactions on Power Systems.

THANK YOU !...