ONS EXPERIENCE ON THE INTEGRATION AND OPERATION OF A HIL FACILITY WITH 4 HVDC LINK MANUFACTURERS

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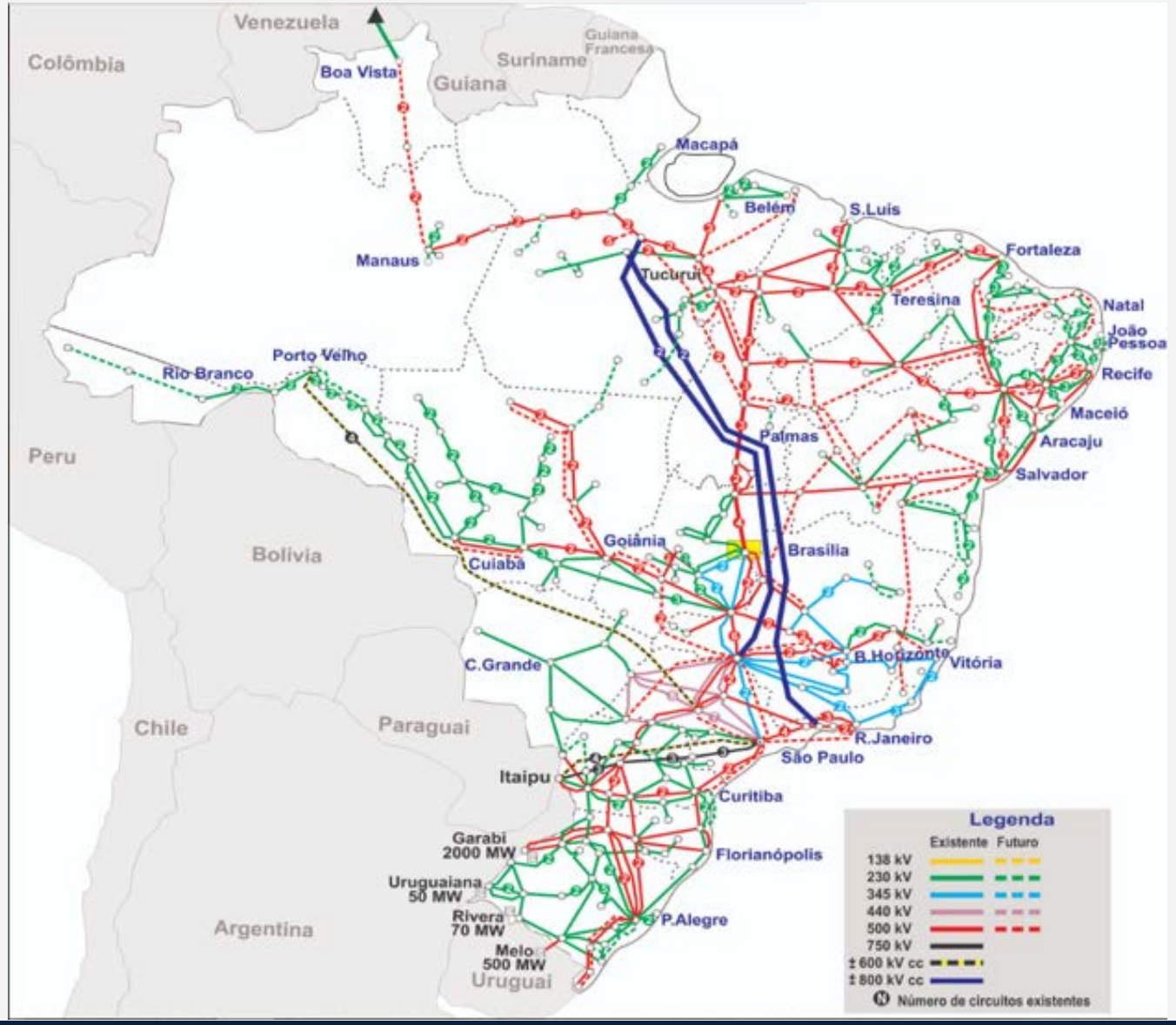
ONS – BRAZILIAN MAIN GRID SYSTEM OPERATOR

USER SPOTLIGHT SERIES BY RTDS Technologies

PRESENTATION TOPICS

- General data for the Brazilian Electric Power Transmission and Generation System
- ONS Duties in the Brazilian Interconnected Electric Power System
- ONS Real-Time Simulator Facility: Purpose, Infrastructure, Participants, Activities, etc
- Activities Involving Hardware in the Loop Studies
  - Madeira River HVDC Transmission System
  - Belo Monte HVDC Transmission System
  - HVDC Control Performance under multi-infeed configuration
  - Out of Step protection and PMU Studies
- Off-Line studies and support
- Development Activities
- Challenges
- Conclusions

THE BRAZILIAN INTERCONNECTED POWER SYSTEM

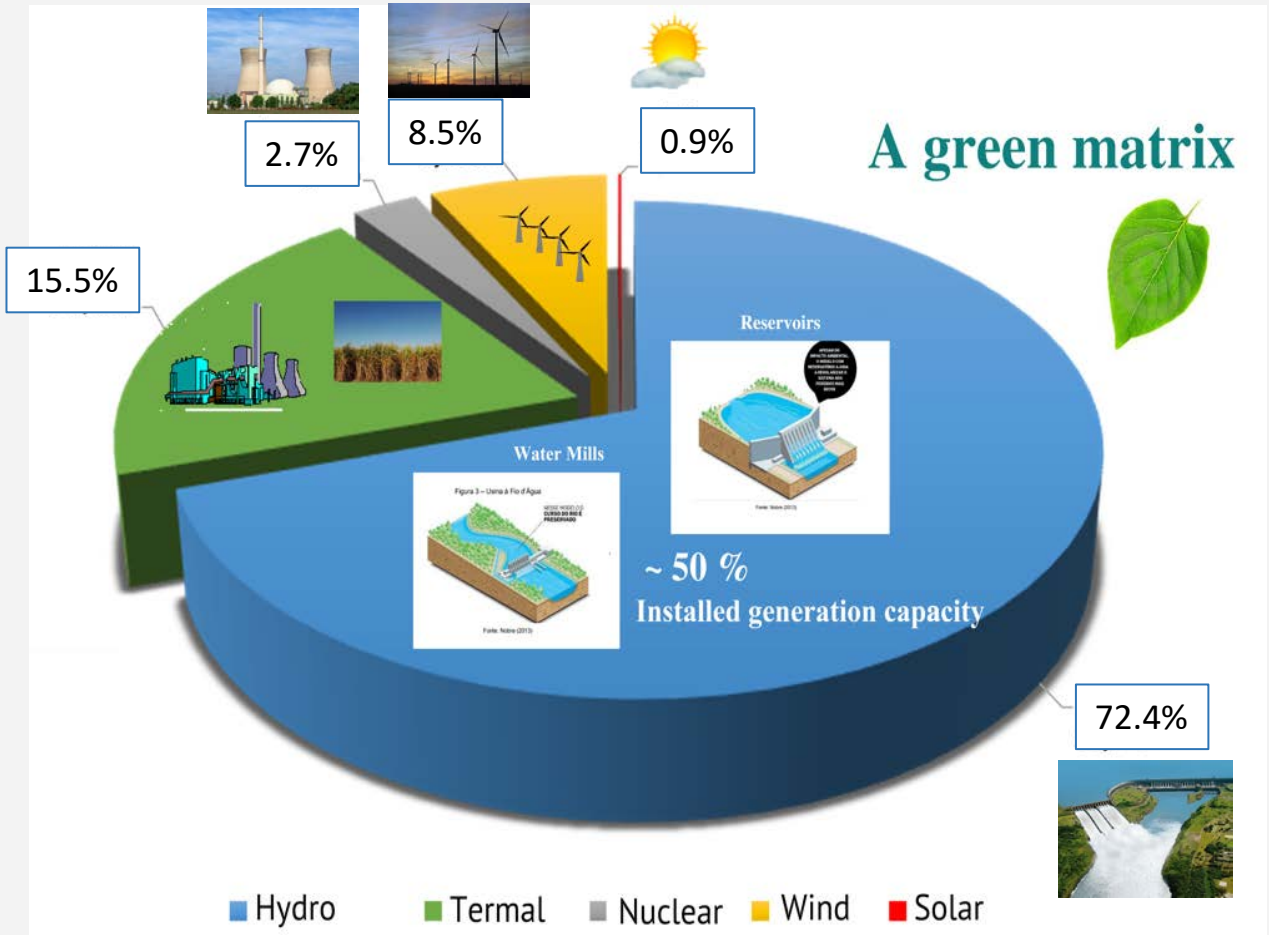


Multi-owned Transmission System:

- 117 utilities companies own more than 181,000 Km of Transmission lines above 230 kV (2020)

THE BRAZILIAN INTERCONNECTED POWER SYSTEM

Last 12 months → Generated Power (%)



SOURCE	Power (GW)		Increase
	2020	2024	%
Hydro	108.4	109.2	0.7
Biomass	13.7	14.5	5.8
Wind	15.3	19.9	30.0
Photovoltaic	3.0	4.3	43.3
Nuclear	2.0	2.0	0.0
Fossil	21.6	25.9	19.9
Total	164.0	175.8	7.2
Renewable	140.4	147.9	5.3

- It has a green matrix: About 85.6% of all generated Power is renewable.
- 63.6% of all planned expansions for electric power generation is based upon renewable sources.

THE BRAZILIAN INTERCONNECTED POWER SYSTEM

MME
Ministry of Mines and Energy

Brazilian government ministry - Implements sectorial policies (electricity, oil, gas, mining)

EPE
Energy Planning Company

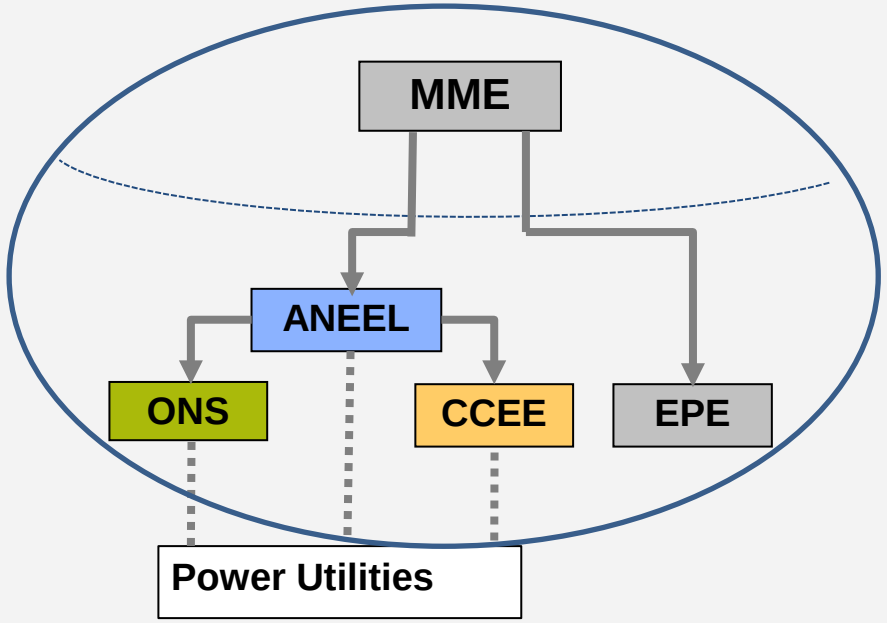
Public company – Electric system expansion planning

ANEEL
Electric Energy National Agency

Government agency - Regulation, mediating and control

CCEE
Electric Power Trading Chamber

Non-profit civil association - Energy Trading Accounting



ONS
Electric System National Operator

Non-profit private organization
Main Grid system operation

Generation, Transmission and Distribution Companies,
Energy Traders, Free Consumers,
Energy Importers and Exporters

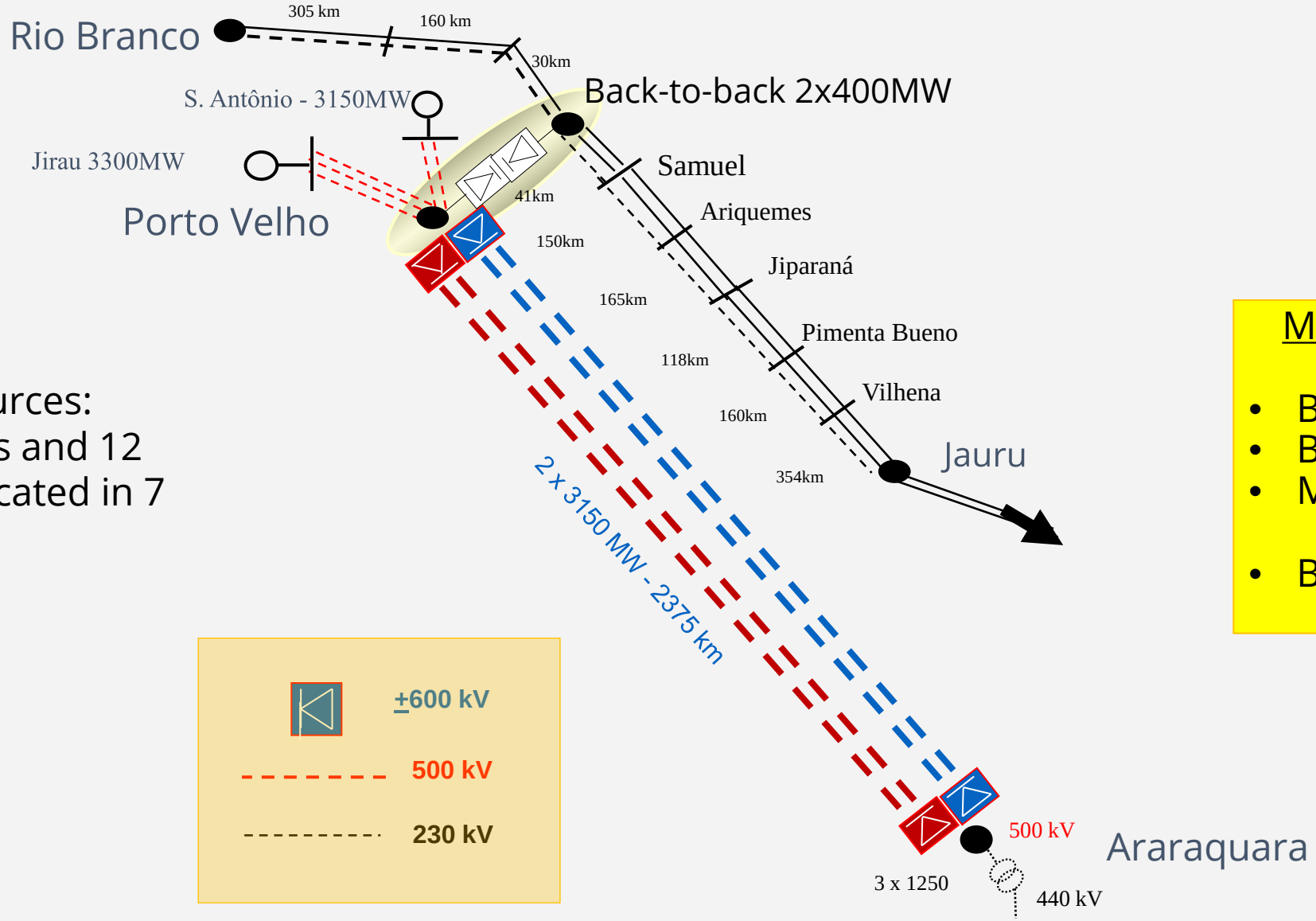
THE BRAZILIAN INTERCONNECTED POWER SYSTEM

Planning studies identify capacity to generate 17,508 MW in three hydrographic basins in the North region (Tapajós, Tocatins and Juruena rivers).

HVDC System	Voltage (KV)	Power (MW)	Line Length (Km)	Initial Operation
Itaipu	±600	2 x 3150	800	1984, 1987
Rio Madeira	±600	2 x 3150	2375	2013, 2014
Belo Monte	±800	2 x 4000	2092, 2439	2017, 2019
New Bipole	±800	4000	1460	To be auctioned

New Bipole will be used as network expansion for power transmission from renewable sources (wind and solar) in the Northeast and Central West.

OVERVIEW – RIO MADEIRA HVDC TRANSMISSION



Used Resources:
25 GPC boards and 12 PB5 boards alocated in 7 Racks

Manufacturers

- BP1 – ABB
- BtB – ABB
- Master – ABB

- BP2 – GE

OVERVIEW – RIO MADEIRA HVDC TRANSMISSION

Bipole 1/Master & BtB Replicas

Commissioning tests of
Bipole 1 & BtB (ABB)
October 2012

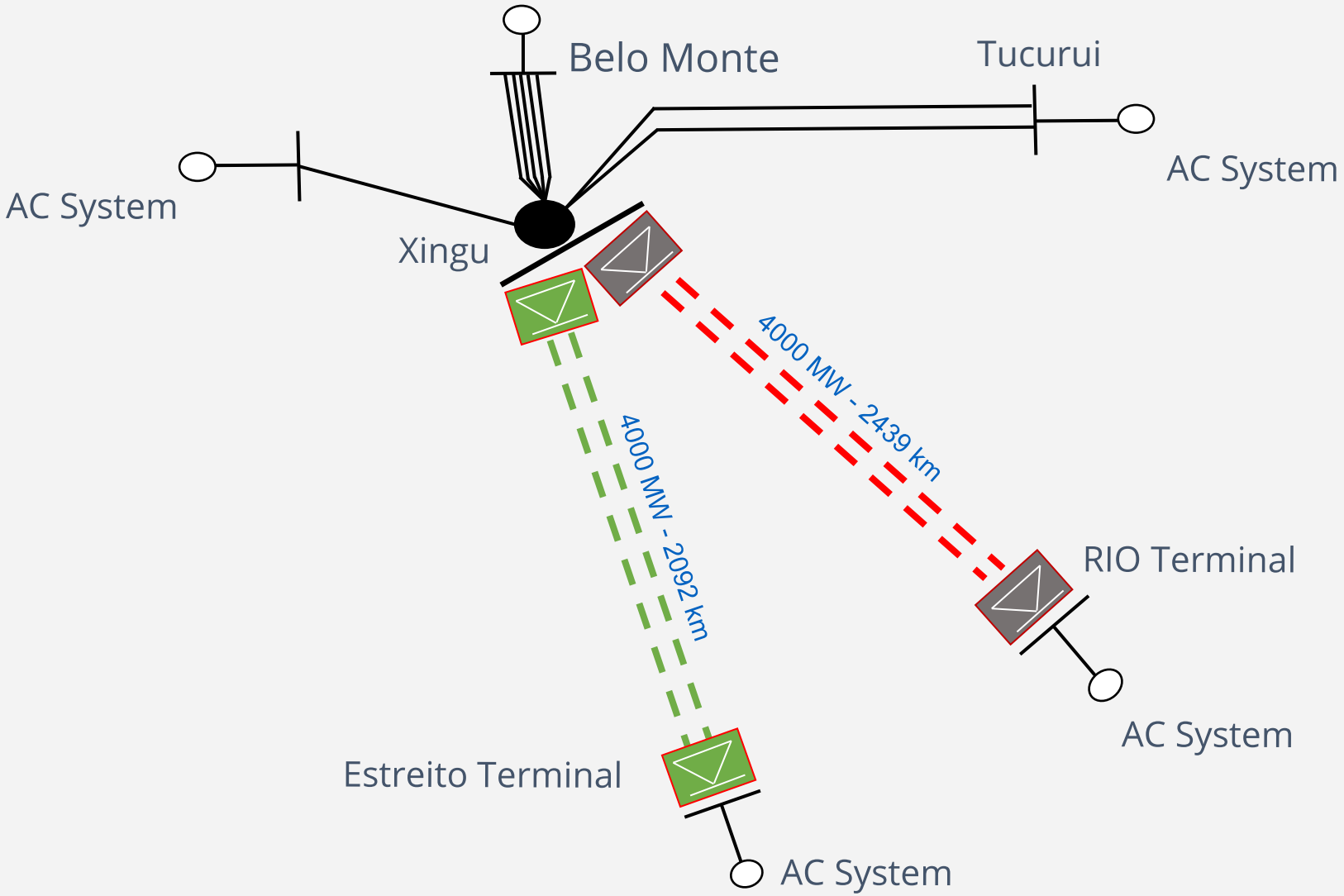
RTDS – AC System

Bipole 2

Commissioning tests
of Bipole 2 (GE)
July 2014

Join Operation - November 2014 - july 2017
Parallel Operation - February 2018 - June 2019

OVERVIEW – BELO MONTE HVDC TRANSMISSION



Manufacturers

- BP1 – Siemens
- BP2 – Nari
- Master – Nari

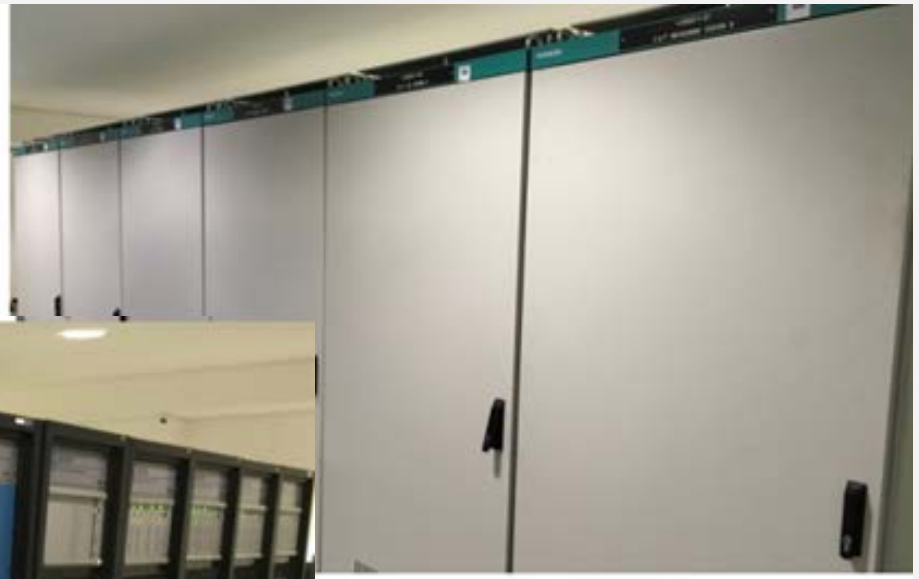
OVERVIEW – BELO MONTE HVDC TRANSMISSION

Bipole 2 - Nari

Commissioning Tests
October 2018

RTDS – Resources Expansion

Integration tests November 2018 - july 2019



Bipole 1 - Siemens

Commissioning Tests
October 2017

SIMULATOR ROOM RESOURCES

Note - Itaipu HVDC bipoles are fully modeled in RTDS. Its C&P logic is based on a model developed for PSCAD-EMTDC

ONS REAL-TIME SIMULATOR FACILITY (SSCC)

ONS Real-Time Simulator Facility – Power System Simulator				
Platform	Processor & Clock	Single phase node limit	Number of racks/chassis	Number of cards/cores
GPC card	02 CPUs 1,0 GHz per card	72	2	8
PB5 card	02 CPUs 1,7 GHz per card	2x90	10	60
Chassis NovaCor	01 CPU with 10 cores 3,5 GHz	2x300	03	21
Chassis OP5700	02 CPUs with 08 cores 3,2 GHz	16x90	01	1

Hardware Resources:

- 2 racks with 8 GPC cards
- 10 racks with 60 PB5 cards
- 3 Novacor chassis with 21 cores
- 1 OP5700 chassis with 1 core

ONS REAL-TIME SIMULATOR FACILITY (SSCC)

ONS Real-Time Simulator Facility – HVDC C&P replicas					
Supplier	Generation	Cubicle set *	Cubicle Quantity	Supervisory System	Graphical Engineering Tool
ABB	MACH2	Bipole and Back-to-Back C&P logic, Master Control	10	MACH HMI	Hidraw Visual Studio
GE/ALSTOM	SERIES V (VME chassis)	Bipole C&P logic	06	SAGE	Hand code
SIEMENS	SIMATIC TDC (VME chassis)	Bipole C&P logic	06	SIMATIC-WinCC	CFC – Continuous Function Chart
NR EC	PCS-9550	Bipole C&P logic, Master Control	05	PCS-9550 HMI	Accel Visual suite

Replica Resources:

Rio Madeira Project

- 2 Bipoles C&P from ABB
- 2 Master Controls from ABB
- 2 Back to Back from ABB
- 2 Bipoles from GE/Alstom

Belo Monte Project

- 2 Bipoles from Siemens
- 2 Bipoles from NARI
- 2 Master Controls from NARI

ONS REAL-TIME SIMULATOR FACILITY (SSCC)

Current applications of the ONS DC system real-time simulator (SSCC) :

- Commissioning/tuning of HVDC Control and Protection (C&P) under joint operation;
- Support for HVDC transmission systems operation based on LCC technology (04 bipoles);
- Diagnosis of real plant misoperation under abnormal or switching events;
- Interaction Analysis among electrically close HVDC substations – Under AC network configurations with Multiple Infeed;
- Evaluation of Protective Relays;
- Evaluation of supplementary wide-area protection systems supported by phasor measurement units (PMU);

SIMULATOR ACTIVITIES

Real-Time Simulator Activities:

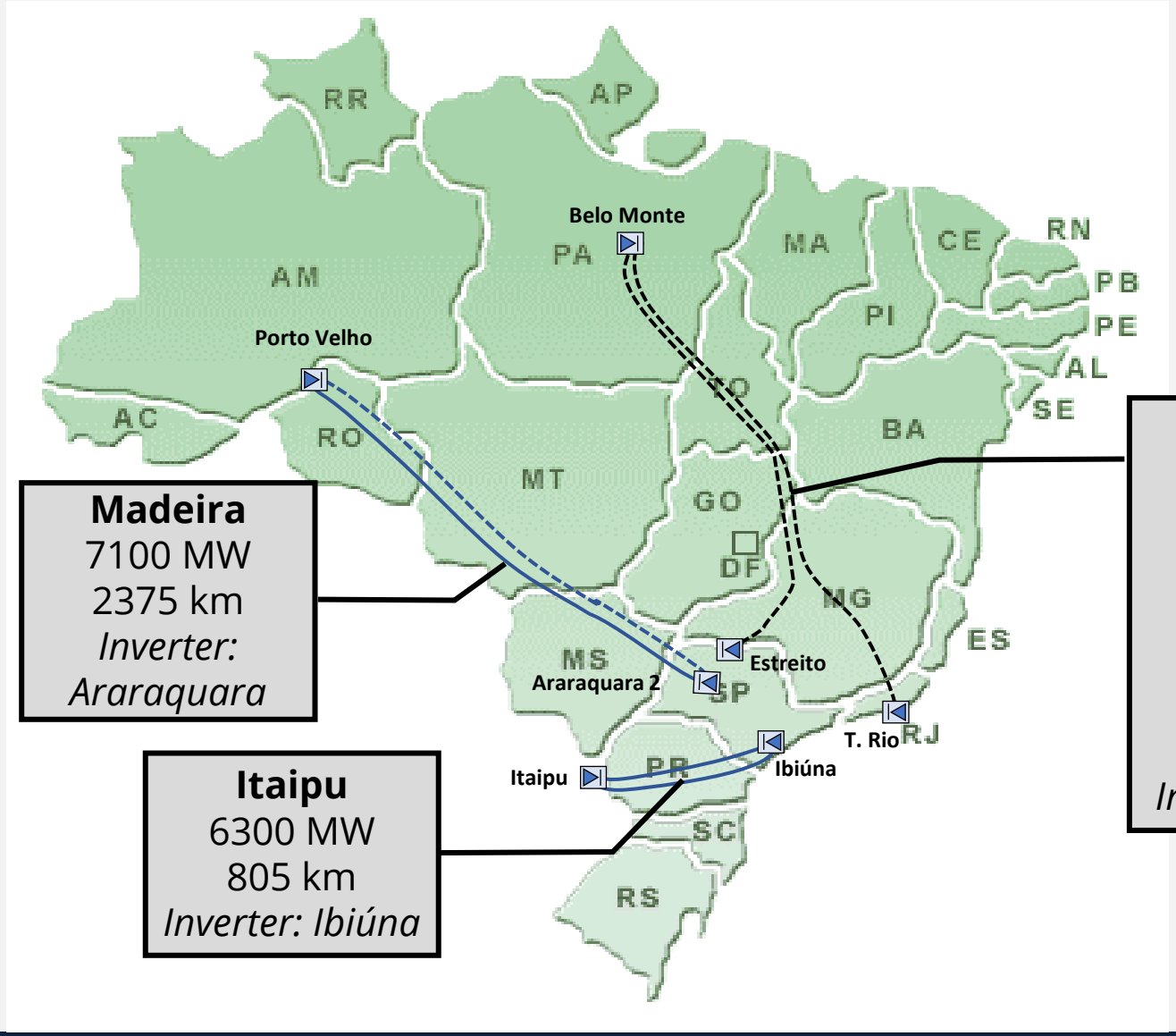
- RTS Platform Management → RTDS day to day operations, first level maintenance and scenarios set-up;
- Simulator up-date to keep it ready for demands from utilities as well as other areas inside ONS;
- Replicas operations → Start-up, shutdown, error diagnosis routines, etc;
- Utilities support → Support utilities on signal monitoring and connection to RTDS;
- Analysis and validation of C&P models in PSCAD - EMTDC programs;
- Network equivalent preparation for RTDS (load flow, short-circuit and stability analysis);
- PSCAD - EMTDC multi-infeed studies aiming HIL tests on RTDS;
- RTDS Dynamic performance evaluation of HVDC links (coverage of the criteria defined in the concession contract).

UPDATE AND DEVELOPMENT

Customization and Development Activities:

- Evaluation of complementary tools to enhance RTS infrastructure (other real-time tools);
- Auxiliary tools for Model/database conversion and validation;
- Real-time Co-simulation (Integrating RTDS with others EMT real-time simulators) [1];
- Improved FDNE models based on efficient computation;
- Remote Interconnection with other simulation centers;
- User defined components on FPGA hardware for better use of RTS resources.

HVDC INTERACTIONS ON MULTI-INFEED STUDY



Madeira
7100 MW
2375 km
Inverter: Araraquara

Itaipu
6300 MW
805 km
Inverter: Ibiúna

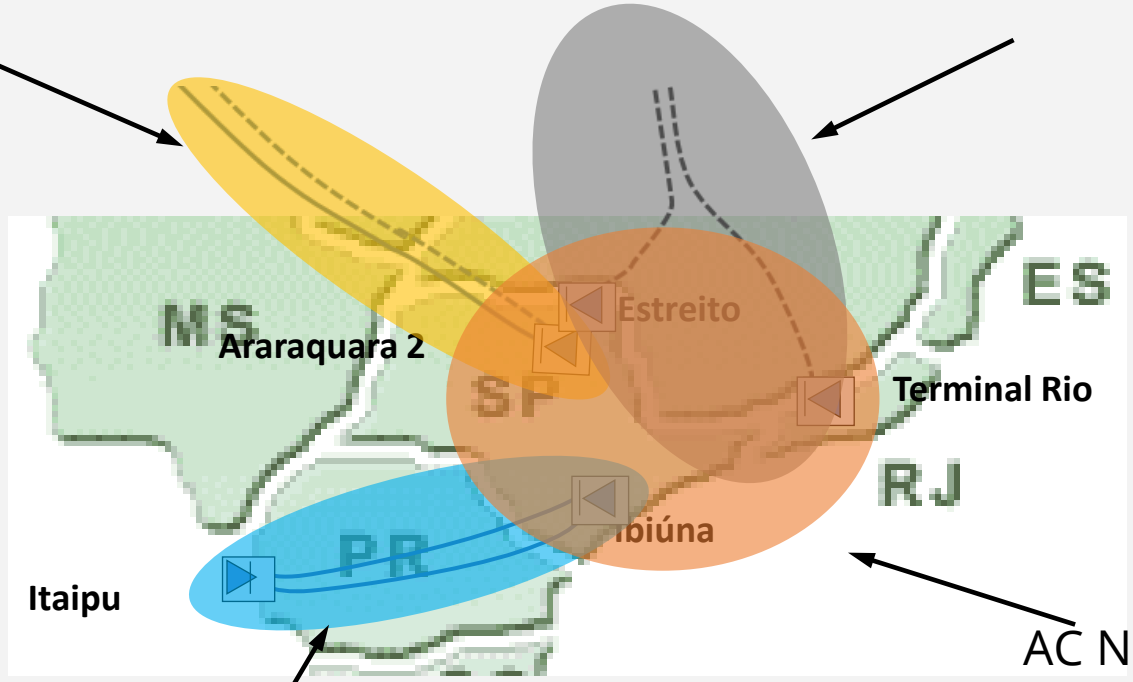
Belo Monte 1
4000 MW
2140 km
Inverter: Estreito

Belo Monte 2
4000 MW
2518 km
Inverter: Terminal Rio

HVDC INTERACTIONS ON MULTI-INFEED STUDY

C&P Replicas + RTDS

C&P Replicas + RTDS



AC Network where Multi-Infeed phenomena are to be studied

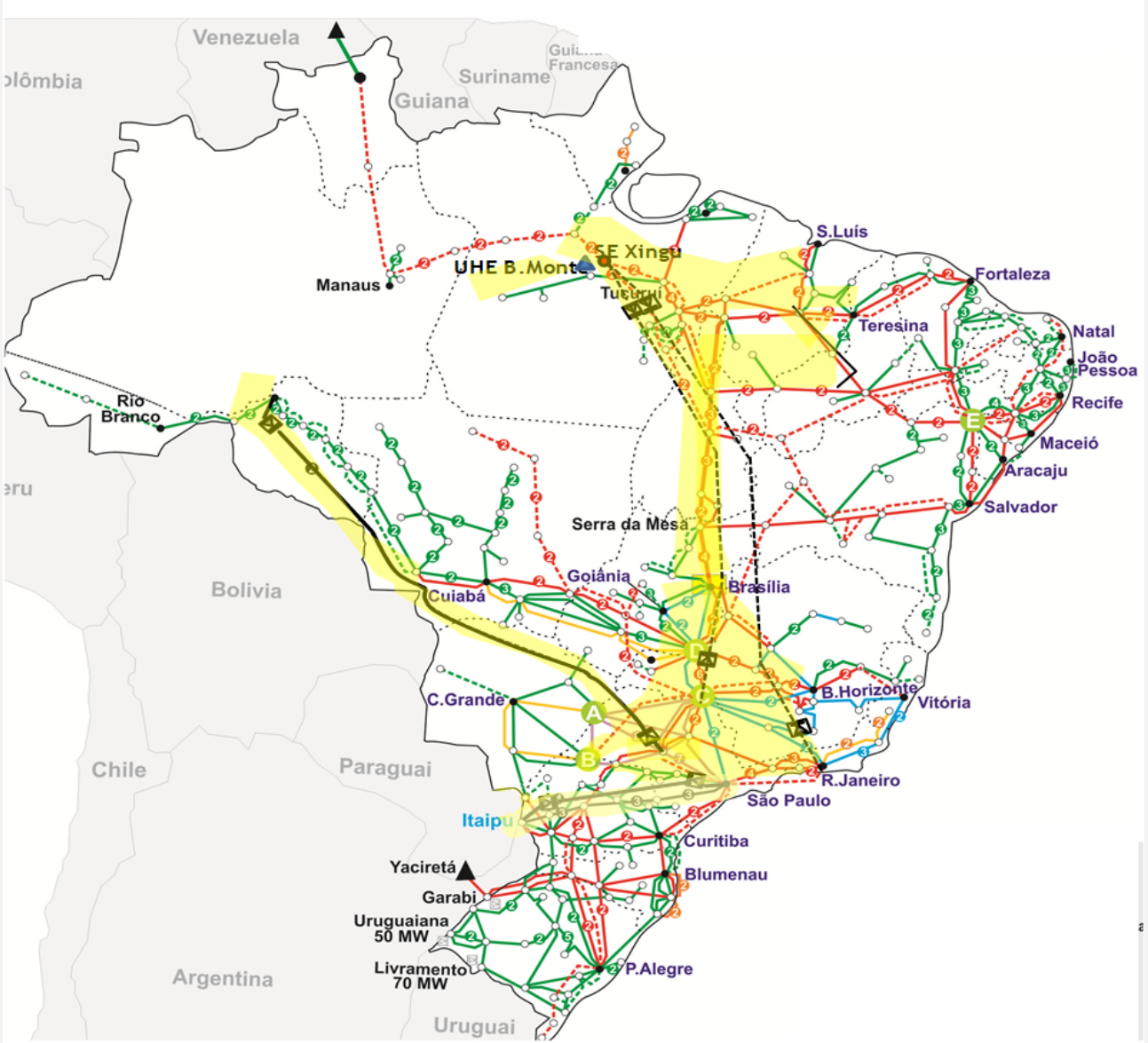
C&P Modeled in RTDS

HVDC INTERACTIONS ON MULTI-INFEED STUDY

- **Multi-infeed**
  - Evaluation of control and protection interaction effects (transient and dynamic ranges) among converter stations electrically nearby
  - Replicas allow better precision in the studies when compared with models developed for off-line programs.

- **Main phenomena**
  - Commutation failures on different converters
  - Power and Voltage Stability
  - Control demands due to coordinated recovering
  - High level control coordination by means of power and voltage modulation between different HVDC links
  - Frequency stability
  - Over-Voltage
  - Harmonic instability

HVDC INTERACTIONS ON MULTI-INFEED STUDY



	Detailed Circuit	External Circuit
BUS	74	34
Trasmission Lines	114	250
Synchronous Machine	25	-
Dynamic Loads	5	150
Source Equivalents	32	-
3 Winding Transformes	5	10
2 Winding Transformes	30	155

The external circuits (not marked with yellow in the map) will be modeled as equivalent circuits (as shown in the table).

CUSTOMIZATION AND DEVELOPMENT ACTIVITIES

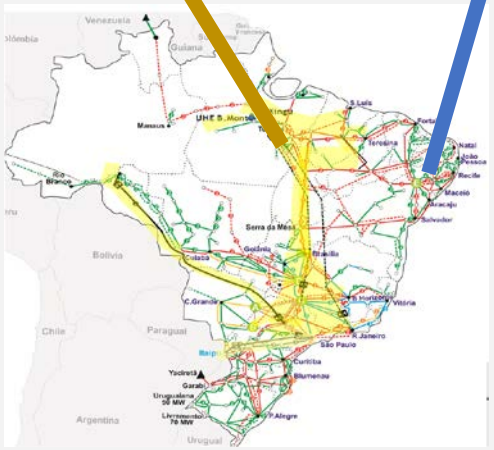
FPGA(FDNE)

Remote Interconnection (remote sites)

RTS-1

RTS-2

Real-Time Co-Simulation (same site)



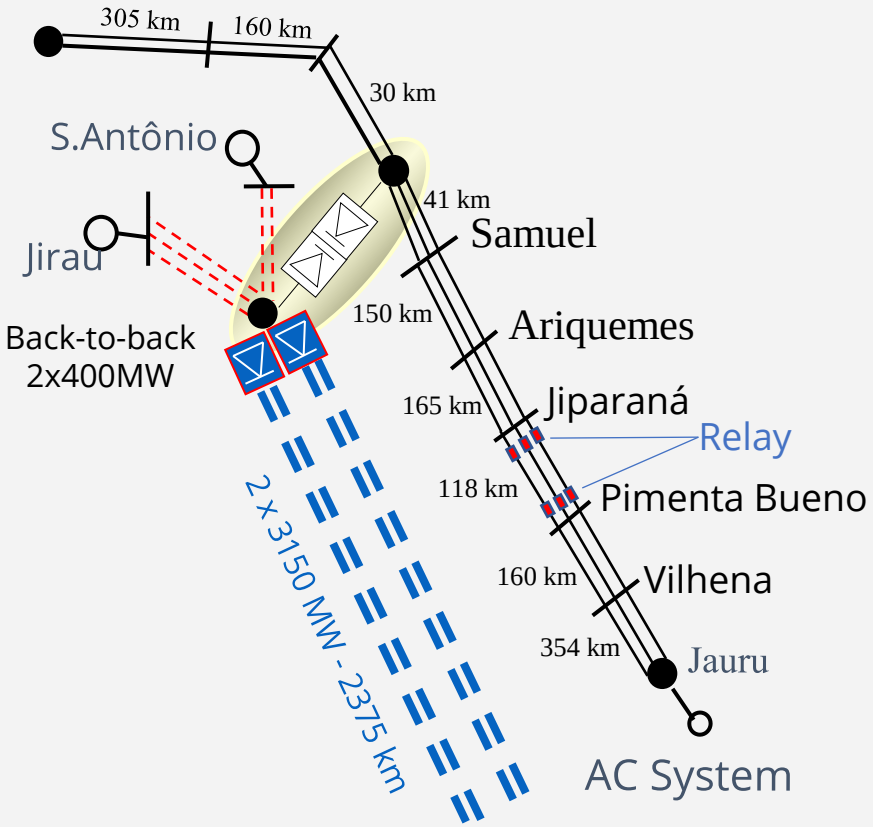
- Improved FDNE model using efficient computations and/or FPGA
- Real-Time co-simulation;
- Remote Interconnection with other simulation centers

PROTECTION RELAYS STUDIES

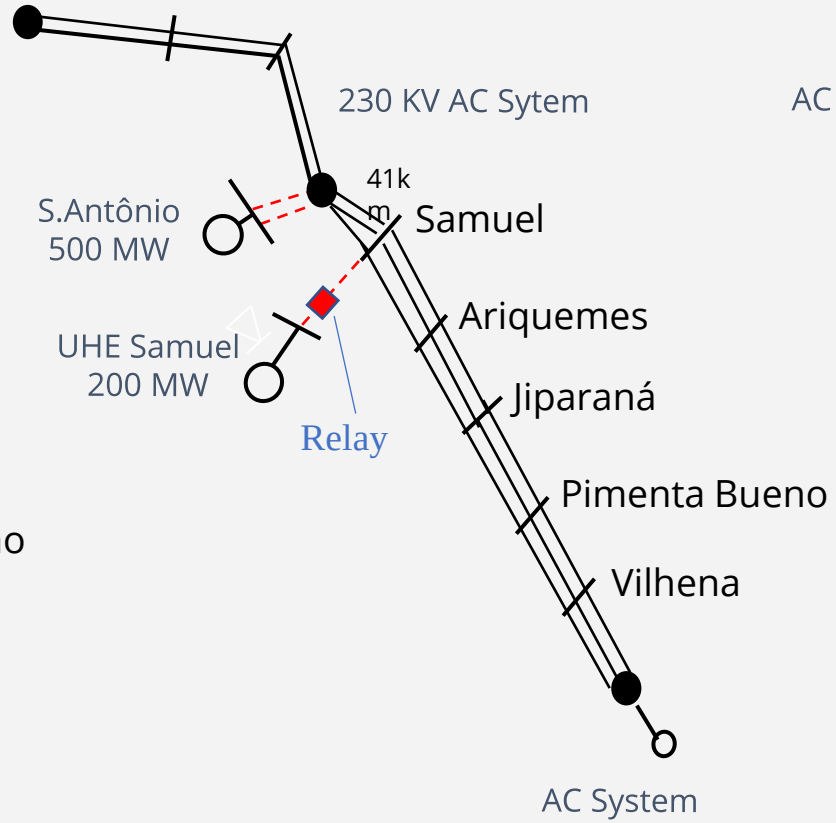
- **Partnership with Schweitzer (SEL)**
  - SEL-411L Advanced Line Differential Protection
  - SEL-700G Generator Protection Relay
  - SEL-T400L Time-Domain Line Protection (Travelling Wave algorithm)

PROTECTION RELAY STUDIES

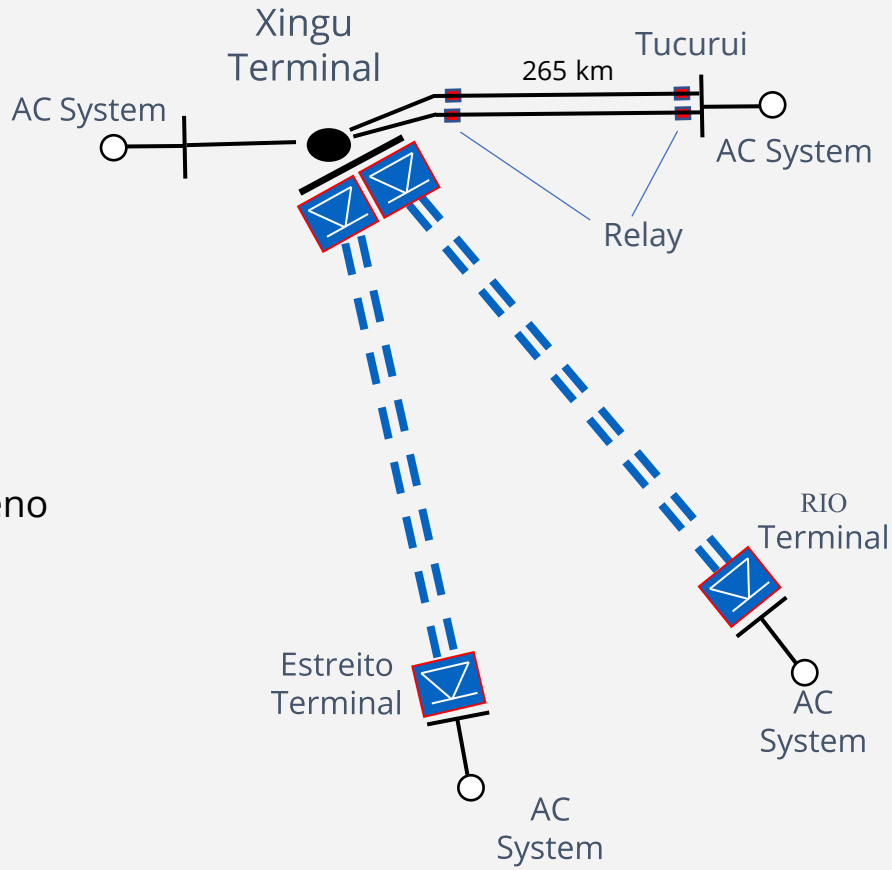
SEL-411L



SEL-700G



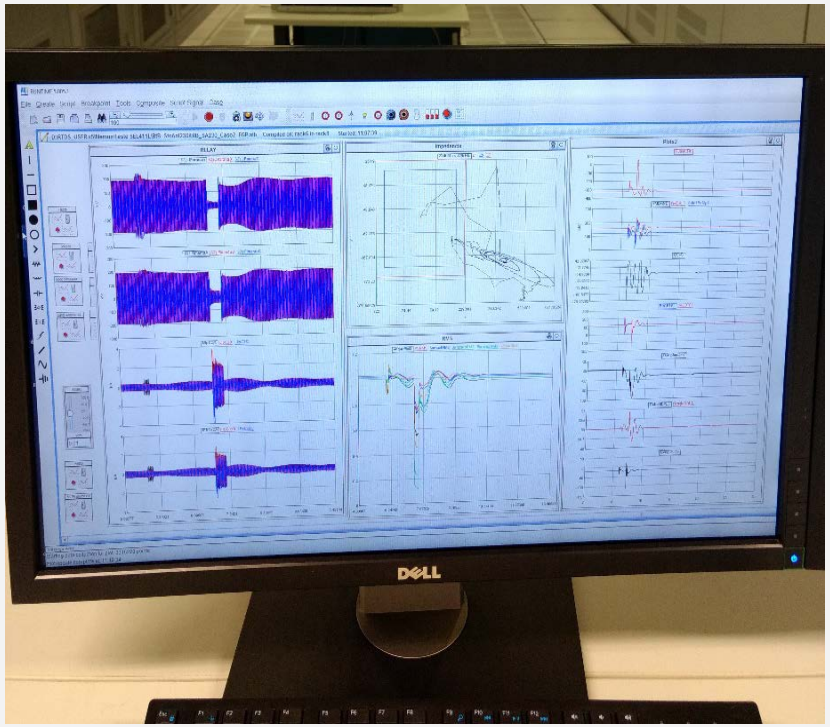
SEL-T400L



SEL-411L

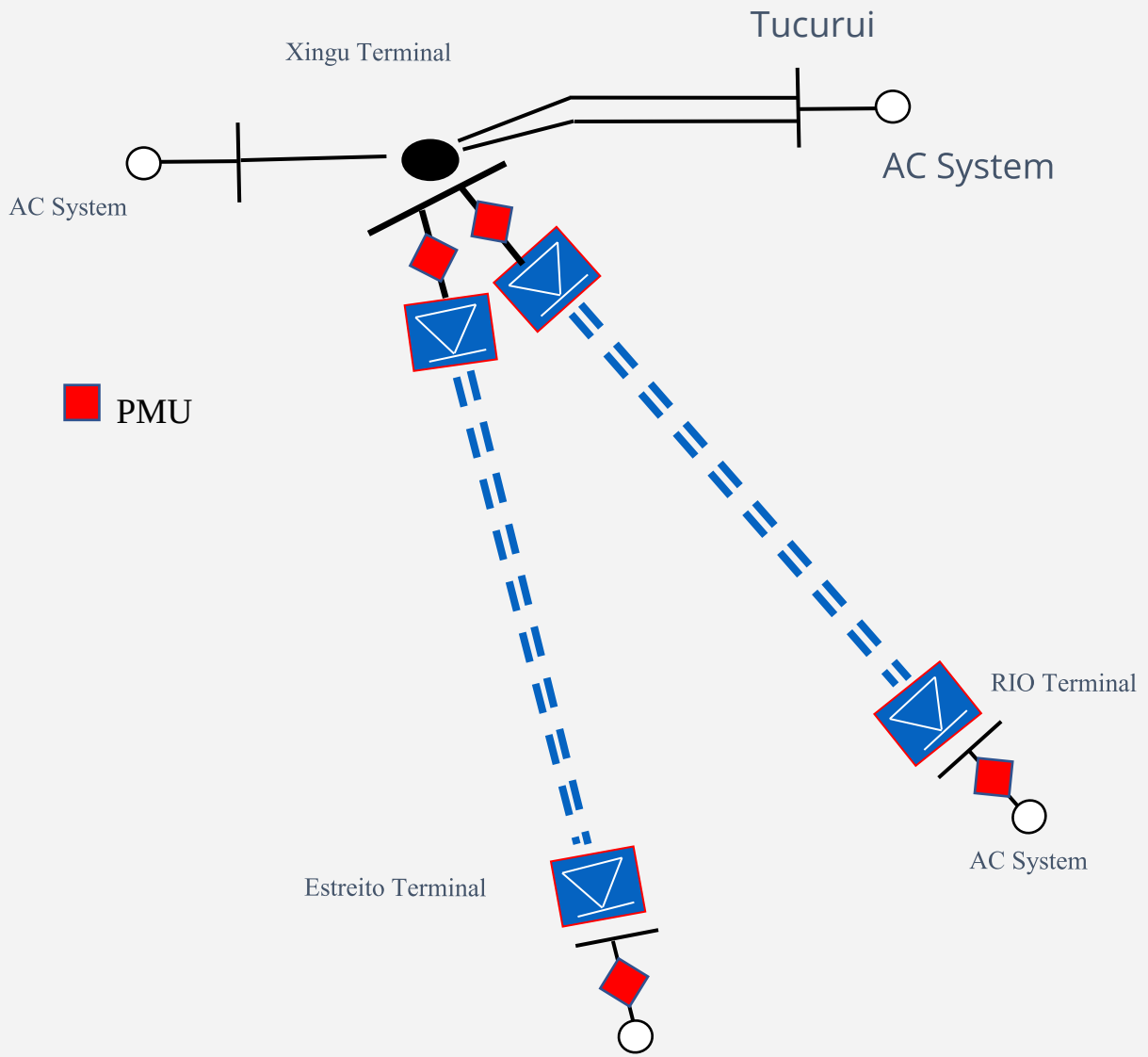
HVDC Replica

Protection Relay

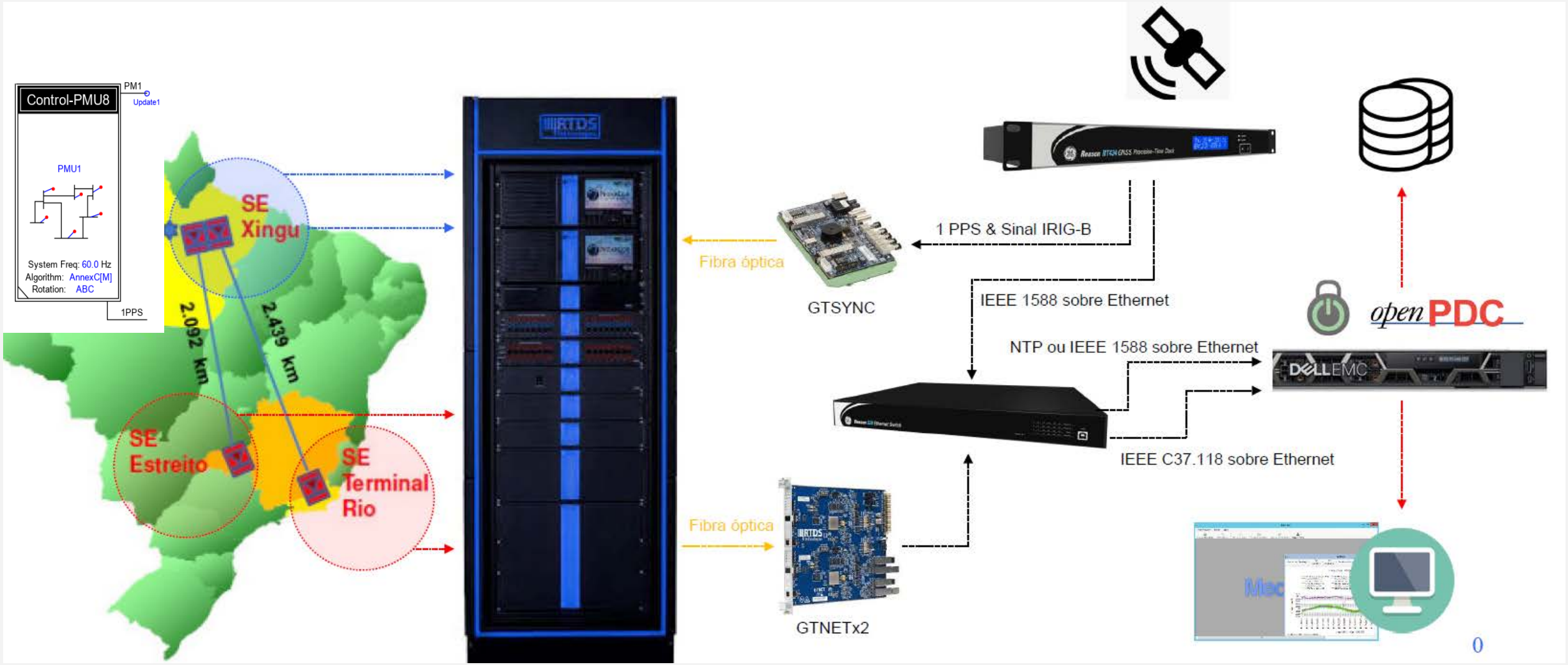


RSCAD

PMU STUDIES


Tucurui
Xingu Terminal
AC System
AC System
PMU
RIO Terminal
AC System
Estreito Terminal

PMU STUDIES


Control-PMU8
PM1
Update1
PMU1
System Freq: 60.0 Hz
Algorithm: AnnexC[M]
Rotation: ABC
1PPS
SE Xingu
SE Estreito
SE Terminal Rio
2.092 km
2.439 km
RTDS
Fibra óptica
GTSYNC
1 PPS & Sinal IRIG-B
IEEE 1588 sobre Ethernet
NTP ou IEEE 1588 sobre Ethernet
IEEE C37.118 sobre Ethernet
Fibra óptica
GTNETx2
openPDC
DELL EMC

CHALLENGES

- The Operation of the Simulator imposes some challenges:
  - Keeping up reliability and availability of C&P replicas along with real plant operating time: corrective maintenance and support contracts with the manufactures;
  - Familiarize the SSCC crew with different hardware and software platforms for effect of: fault diagnosis, predictive maintenance, monitoring internal C&P logic signals and operation;
  - Expansion Planning, Updating real-time simulation equipment, and developing new tools to improve quality and fidelity of the simulations.
  - To adopt user defined components of proper computational as well as complimentary hardware (FPGA) for rationalizing of the RTS resources use.

CONCLUSIONS

- This simulator provides an environment where Utilities, other sectors inside ONS and Agents in the electric sector can find more precise, reliable and detailed representation of the HVDC links, when compared with off-line tools.
- The strategy of having four replicas in the same simulator, showed to be right since the multi-infeed studies planed for the Brazilian Interconnected Power System will produce more reliable results due to the more precise representation of the HVDC Links when compared to models programed in off-line programs.
- The Bipole for which there is no replica in the simulator, will be modeled inside RTDS based on its implementation for the PSCAD program.

REFERENCES

- **[1] - XIV SEPOPE** - REAL-TIME COOPERATIVE SIMULATION BETWEEN RTDS AND HYPERSIM, TEST RESULTS FOR THE IEEE 39 BUS SYSTEM
- **[2] - XXIV – STPC** - AVALIAÇÃO DO DESEMPENHO DE DIFERENTES METODOLOGIAS DE APLICAÇÃO DAS FUNÇÕES DE BLOQUEIO E DISPARO POR OSCILAÇÃO DE POTÊNCIA E PERDA DE SINCRONISMO UTILIZANDO UM SIMULADOR DIGITAL EM TEMPO REAL (RTDS).
- **[3] - XXV SNPTE** - AVALIAÇÃO DAS FUNÇÕES DE PROTEÇÃO DE UNIDADES GERADORAS FRENTE AO FENÔMENO DE OSCILAÇÃO DE POTÊNCIA ATRAVÉS DE TESTE NO SIMULADOR DIGITAL EM TEMPO REAL - RTDS

THANK YOU FOR YOUR ATTENTION

Questions?