International Conference on Power Systems Transients

June 07 - 10, 2021 - Belo Horizonte, Brazil

IPST 2021

Keynote Speech:

Brazilian Interconnected Power System - An Overview of a Continental Synchronous Grid

Antonio Ricardo de Mattos Tenório, MSc, MBA

Operador Nacional do Sistema Elétrico
ONS

Brazil

Outlook

1. ONS and the Regulatory Framework in Brazil
2. BIPS (Brazilian Interconnected Power System) Characteristics
3. International Asynchronous Interconnections
4. Reactive Power Management
5. Brazilian Generation Installed Capacity
6. Two largest Generation Plants – Itaipu and Belo Monte HPPs
7. Solar PV & Wind Power Generations
8. HVDC Transmission Bipoles – Itaipu, Madeira and Belo Monte Projects
9. Damping of the North-South Oscillation Mode (TCSC, HVDC POD)

About ONS

Operador Nacional do Sistema Elétrico (Brazilian System Operator)

A non-profit private organization, under regulation and inspection of the regulatory agency ANEEL.

ONS does not own assets for generation, transmission and distribution of electricity.

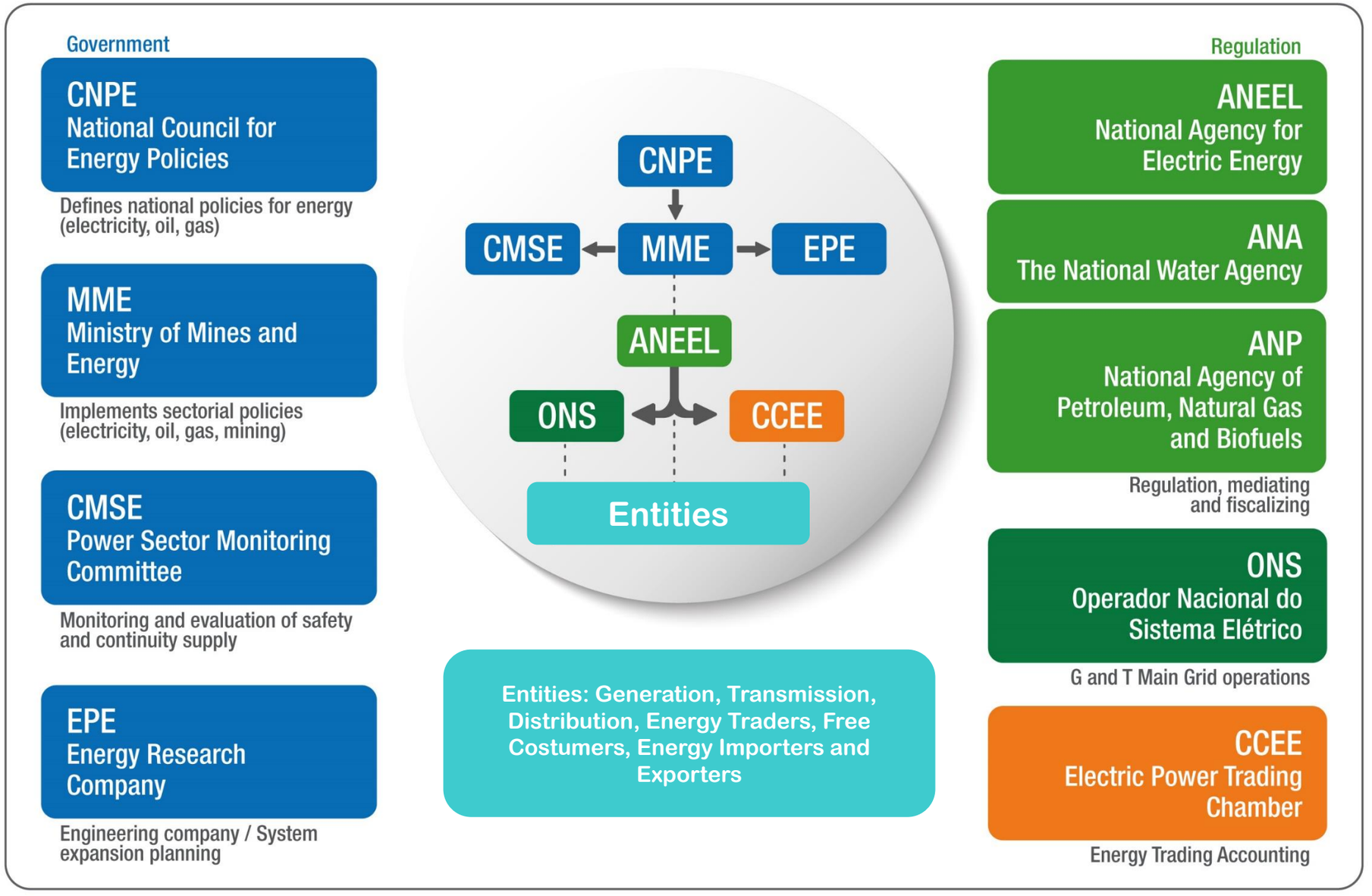
The centralized coordinated operation of BIPS guarantees the safety of supply, at minimum cost.

Mission

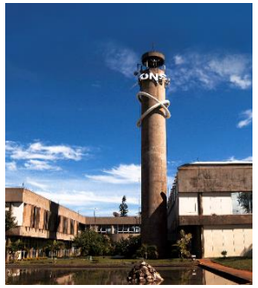
To guarantee the supply of electricity in the country, with quality and balance between safety and global cost of operation.

Legal Basis: Article 16 of Law 9648/98 (as reviewed by Law 10848/04), regulated by Decree nº 5081/04.

The Brazilian Electricity Sector



ONS's Resources and Installations



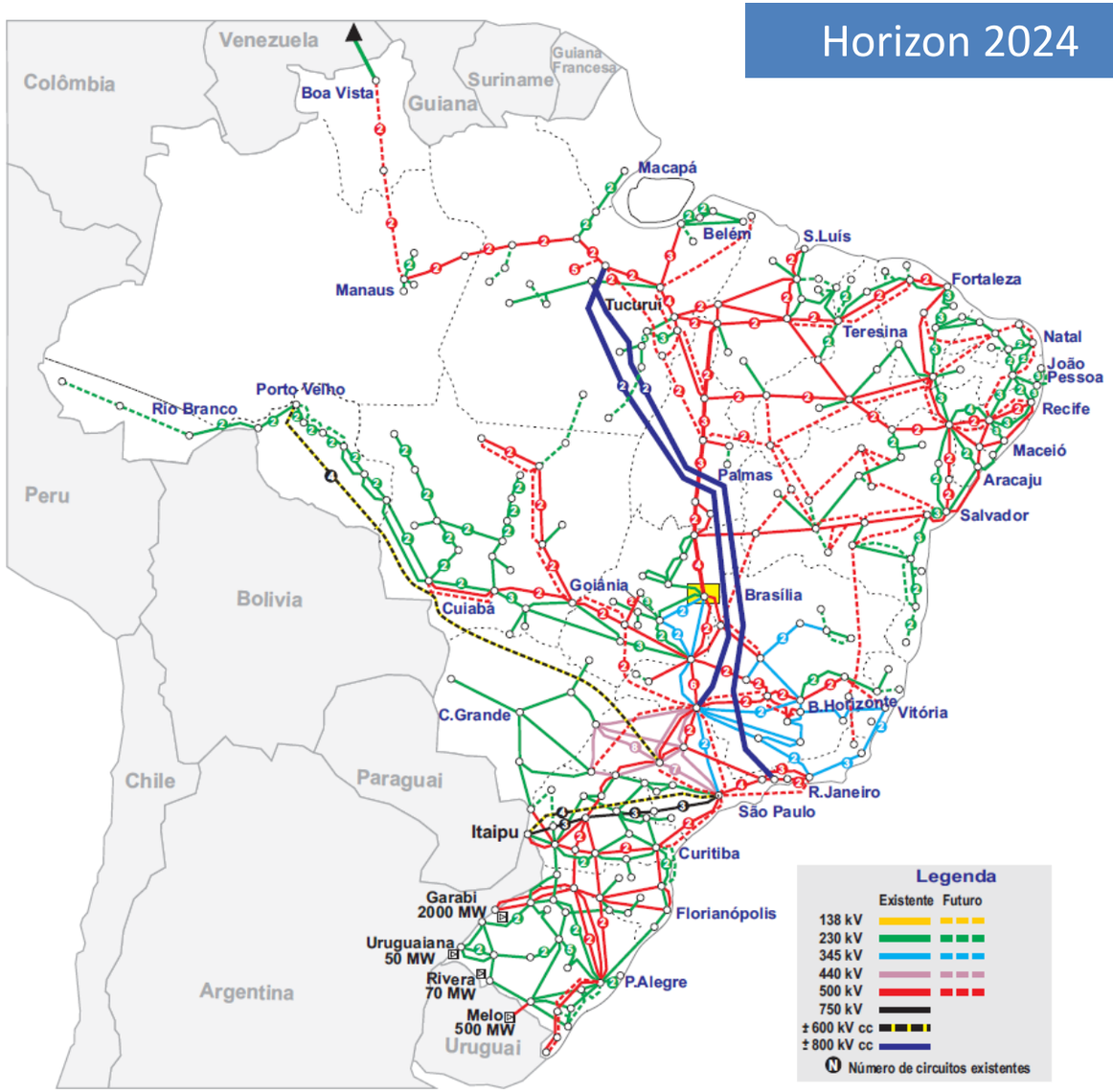
Brasília
National Control Center
N+MW Regional Control Center

Recife
N/NE Branch and NE Regional Control Center

Rio de Janeiro
Central Office and SE Regional Control Center

Florianópolis
Southern Branch and
S Regional Control
Center

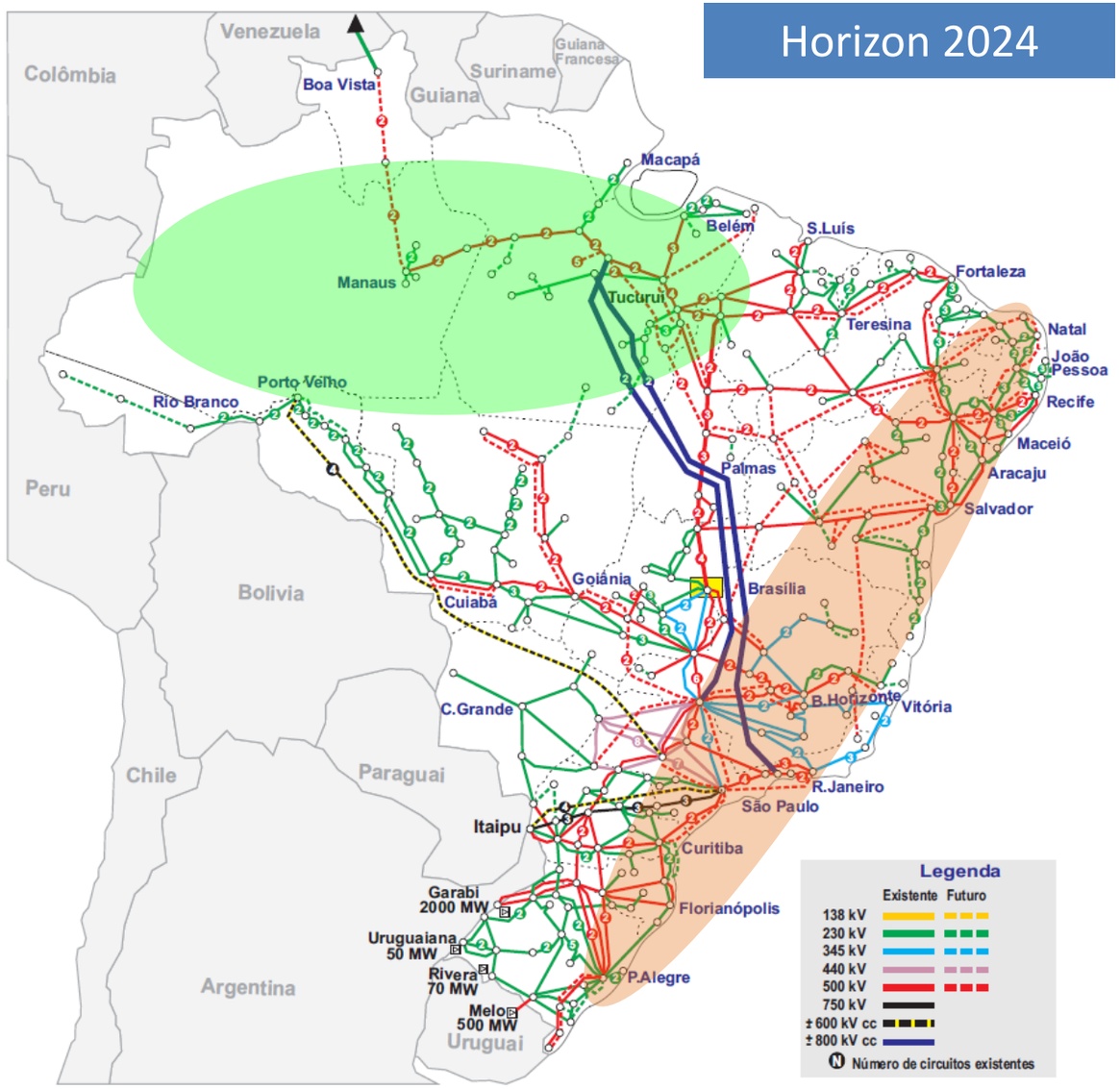
The Brazilian Interconnected Power System (BIPS)



- Brazil – 26 federation states + FD
- BIPS is one of the world's largest synchronous networks
- Complex Hydro-Thermal-Renewable generation grid
- BIPS expands at voltages of 500 kVac and 800 kVdc
- One ISO only → ONS

8.5 million km²

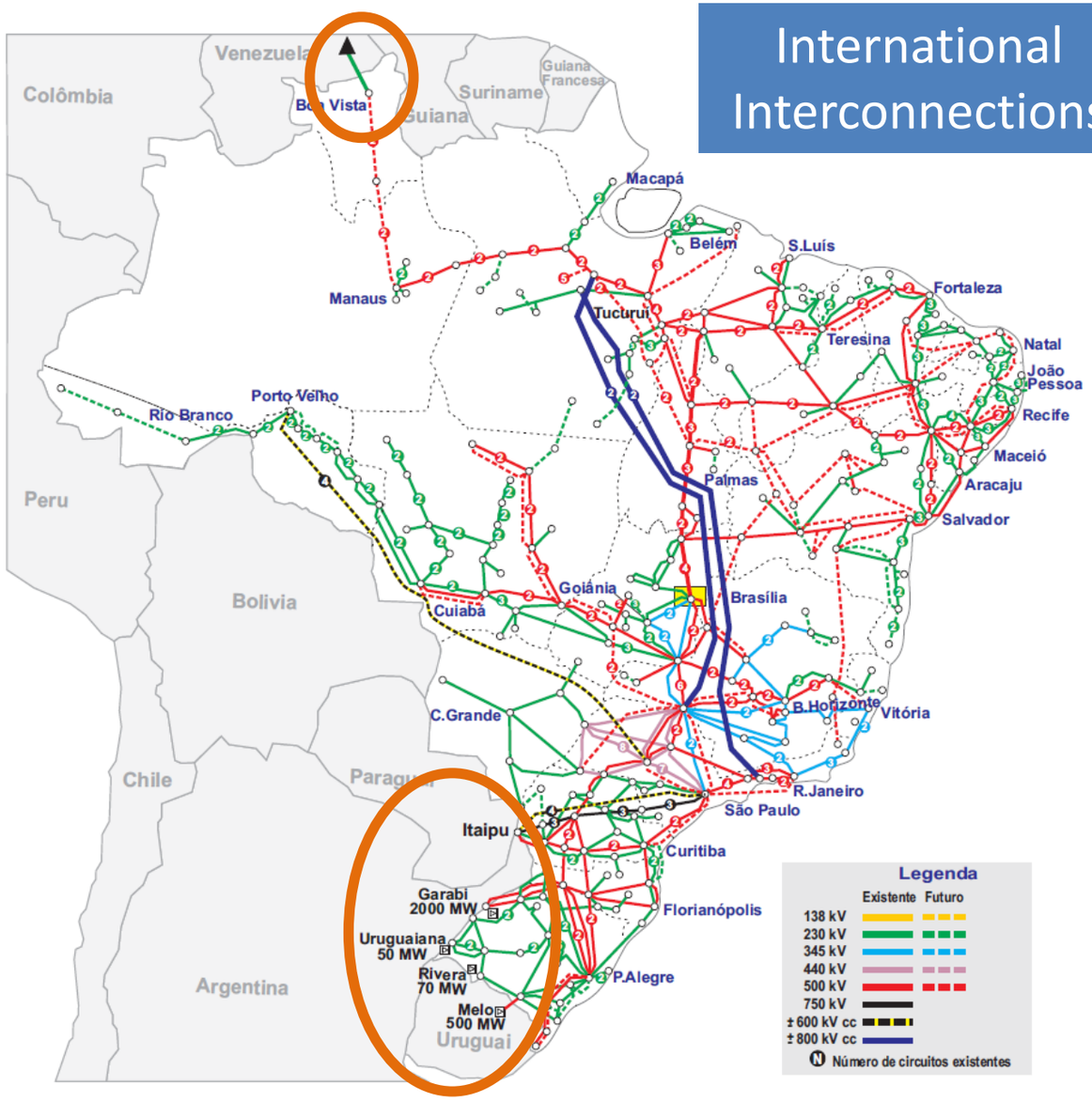
The Brazilian Interconnected Power System (BIPS) - Continued



BIPS encompasses:

- ~172.2 GW – generation installed capacity
- Multi-owned transmission system: > 133 T entities dealing with 145,600 km of lines at 230 kV and above (18,748 km of DC lines)
- Hydro power is predominant - 63.9%
- **Main load centers are on the coast**
- **New hydropower plants are far from load centers i.e., located in Northern Region**
- Operating at 60 Hz, while several southern neighboring countries at 50 Hz
- Suitable for HVDC projects & FACTS controllers
- Synchrophasor Measurement System deployed with capacity for 1000 PMUs/6000 phasors at 60 fps. It's currently running with 300 PMUs.

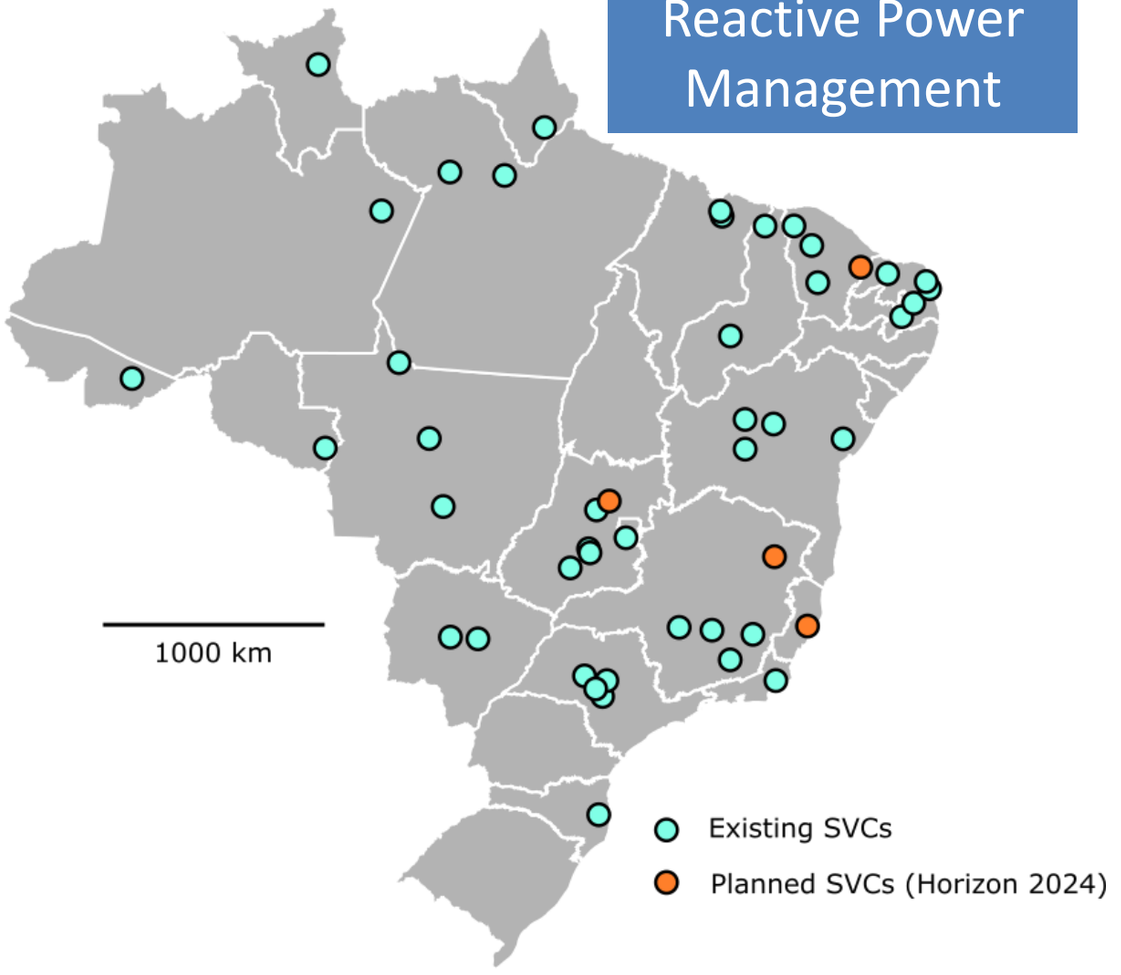
The Brazilian Interconnected Power System (BIPS)



- BIPS interconnects asynchronously via HVDC systems to:
  - Paraguay – Itaipu @ 50 Hz
  - Argentina: 2 BtB-CCC – 2@1100 MW; Uruguaiana BtB @ 50 MW,
  - Uruguay - Rivera BtB @70 MW, Melo* BtB @ 500 MW
- BIPS (Boa Vista isolated system) has an AC tie with Venezuela via an asynchronous line - currently out of operation.
- Planning 800 kV from Graça Aranha to Silvania (close to Brasilia) - 2027

The Brazilian Interconnected Power System (BIPS)

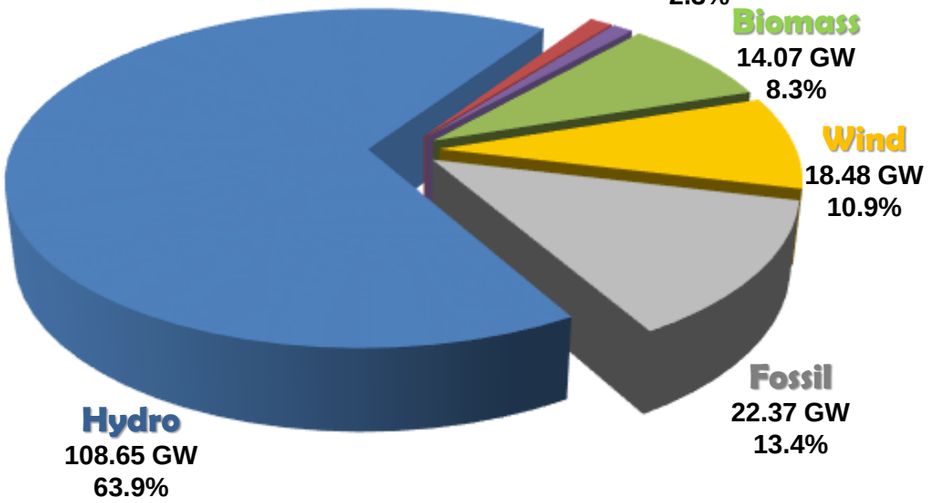
SVCs in Brazil – Reactive Power Management



- SVCs installed on 230, 345, 440 and 500 kV networks
- A fleet of SVCs > 40 units
- 454 hydropower plants -> 1200 generators (> 30 MW)
- Many Switchable/fixed Shunt Reactors/Capacitors are in operation
- Many AC lines are series compensated by FSCs

Brazilian Generation Installed Capacity

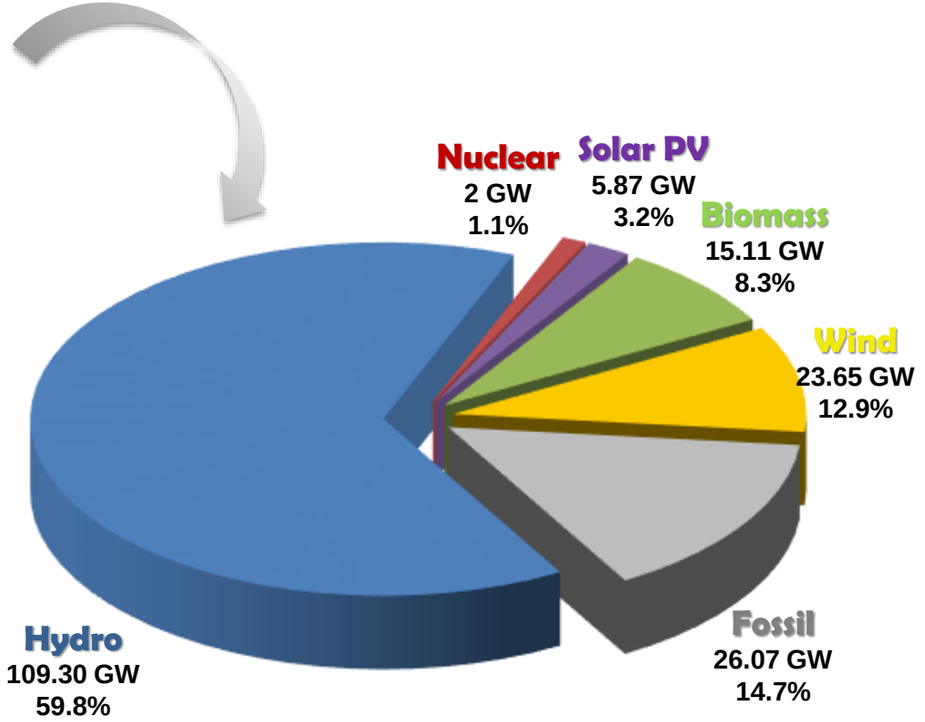
2021



≈ 87% renewable

Total 170.2 GW

2025

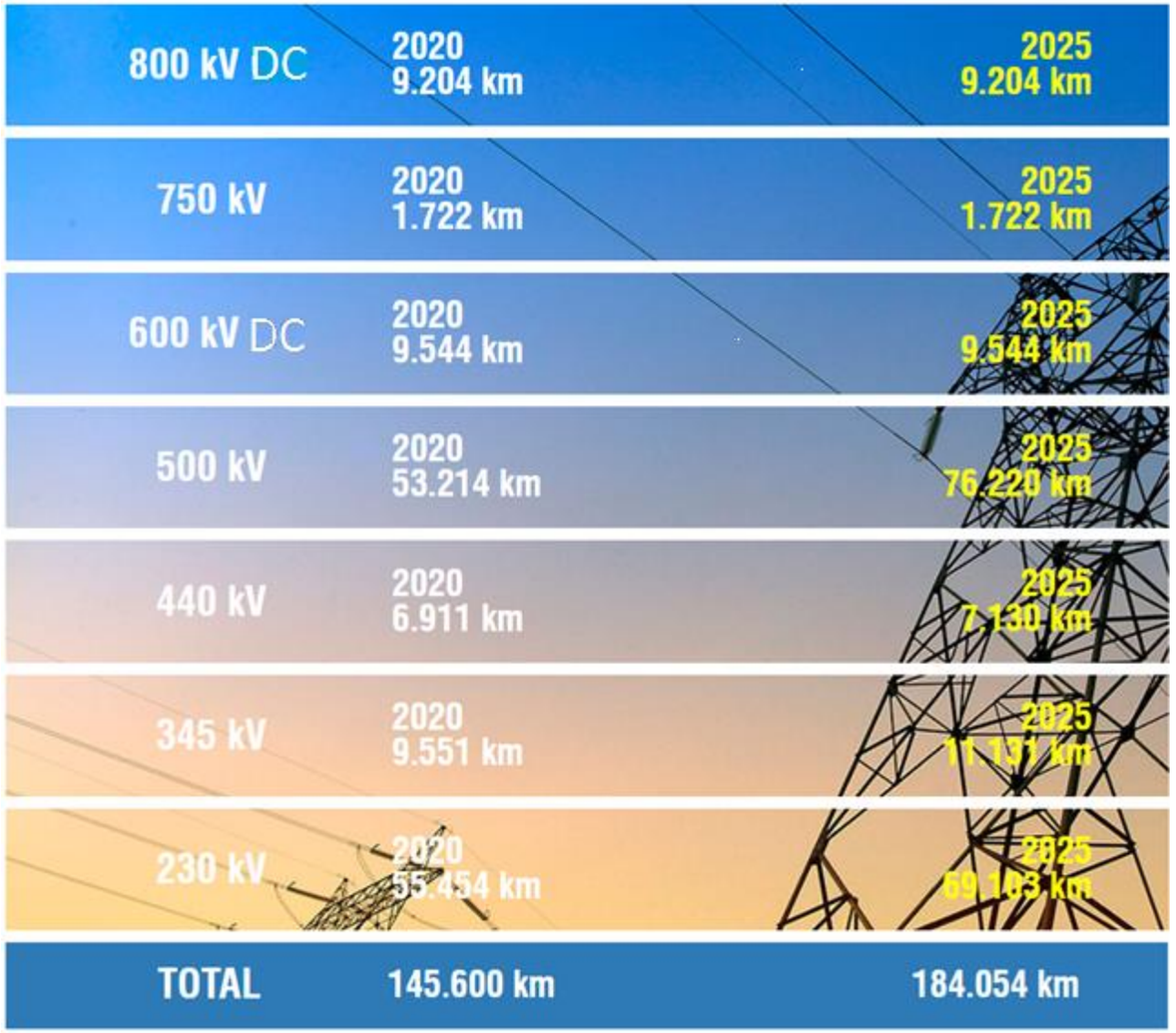


≈ 85% renewable

Total 182.7 GW

Source: ONS

BIPS – Transmission Lines



Itaipu Hydro Power Plant – Binational Generation Company (Brazil & Paraguay)

Itaipu HPP (Itaipu Binacional) is the world's second-largest operational hydroelectric **power plant** in terms of installed **power (14 GW – 10 Gen. @60Hz + 10 Gen. @50Hz generators).**

It was put in operation in 1984

It cost US$ 17.6 billion (2016)

1984 – 1992 → 2 to 18 generators @ 700 MW
2006-2007 → 19 to 20 generators @ 700 MW

It supplies approx. 11% of energy consumed in Brazil and 89% in Paraguay.

By Jonas de Carvalho - Flickr, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=76038827

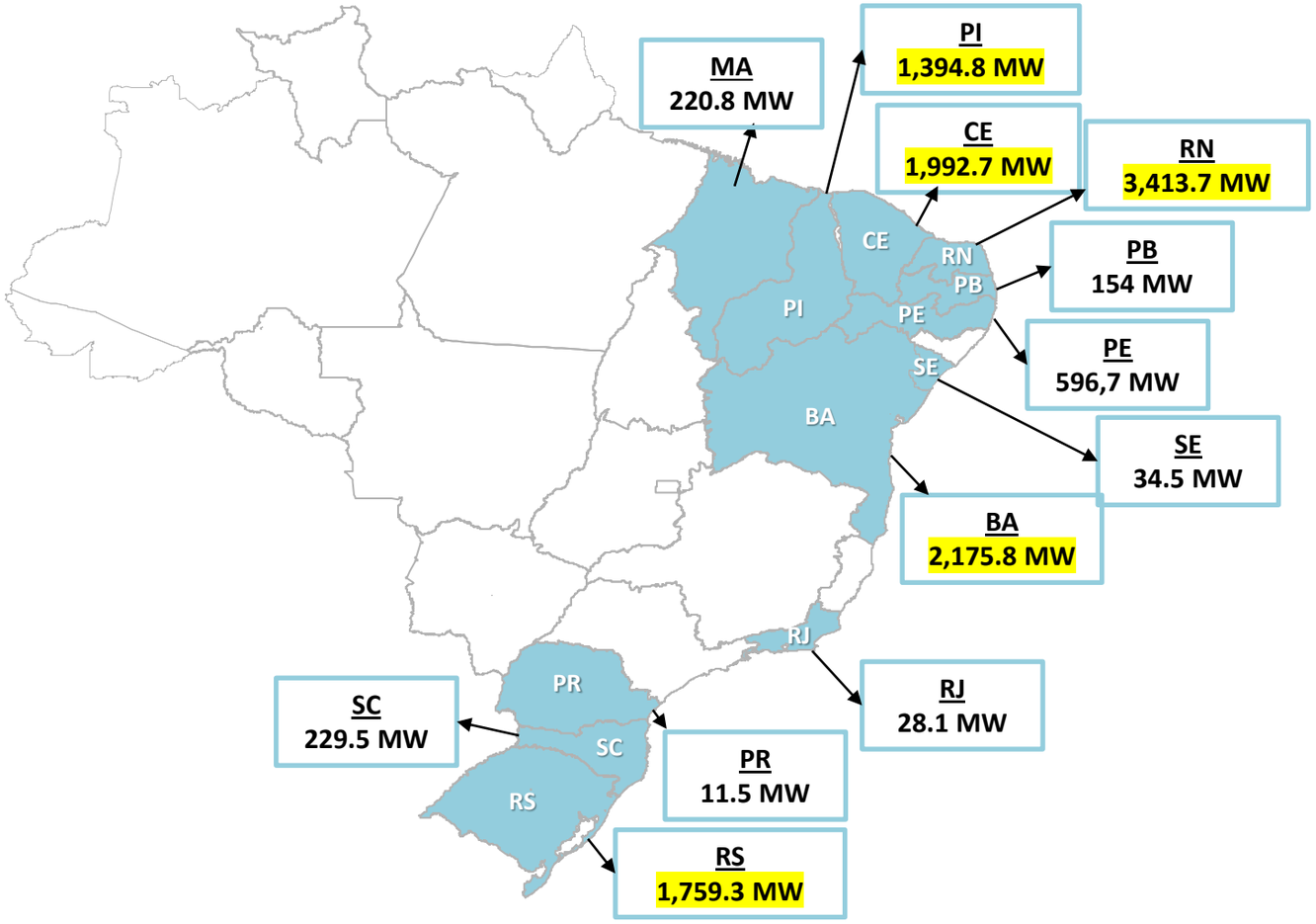
Belo Monte Hydro Power Plant – main features

- The second largest HPP (1st totally located) in Brazil and the fourth largest in the world by installed capacity
- Installed capacity – 18 generators @ 611 MW = 11,000 MW
- Auctioned in 2010, started in 2016, and accomplished in 2019 (18th generator)
- It pushes power through the 800 kV HVDC Bipoles toward Southeastern Brazil
- It cost about US$ 18.5 billion (estimate)

Evolution of Wind Power Capacity in Brazil – 2018 to 2023

Installed Capacity at the end of 2018
14 GW

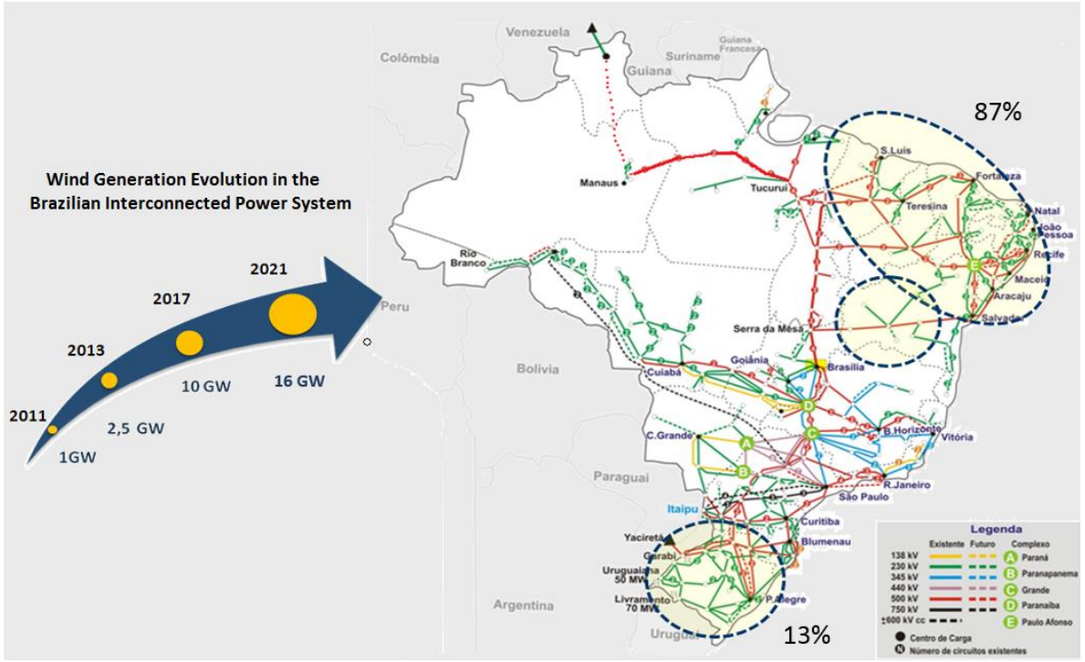
Installed Capacity at the end of 2023
17 GW



Source: CCEE May/19

Evolution of Wind Power Capacity in Brazil – 2018 to 2023

Brazil has been experiencing a fast growth of wind generation, mainly concentrated in its Northeastern and Southern regions, that has led the country to the 9th place in the world´s ranking of Wind generation installed capacity



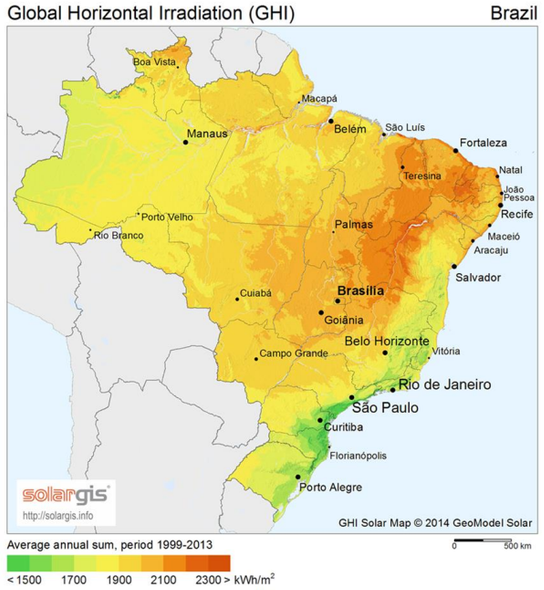
Country	MW	% Share
PR China*	168,690	34.7
USA	82,184	16.9
Germany	50,018	10.3
India	28,700	5.9
Spain	23,074	4.7
United Kingdom	14,543	3.0
France	12,066	2.5
Canada	11,900	2.4
Brazil**	10,740	2.2
Italy	9,257	1.9
Rest of the world	75,577	15.5
Total TOP 10	**411,172**	**84**
World Total	**486,749**	**100**

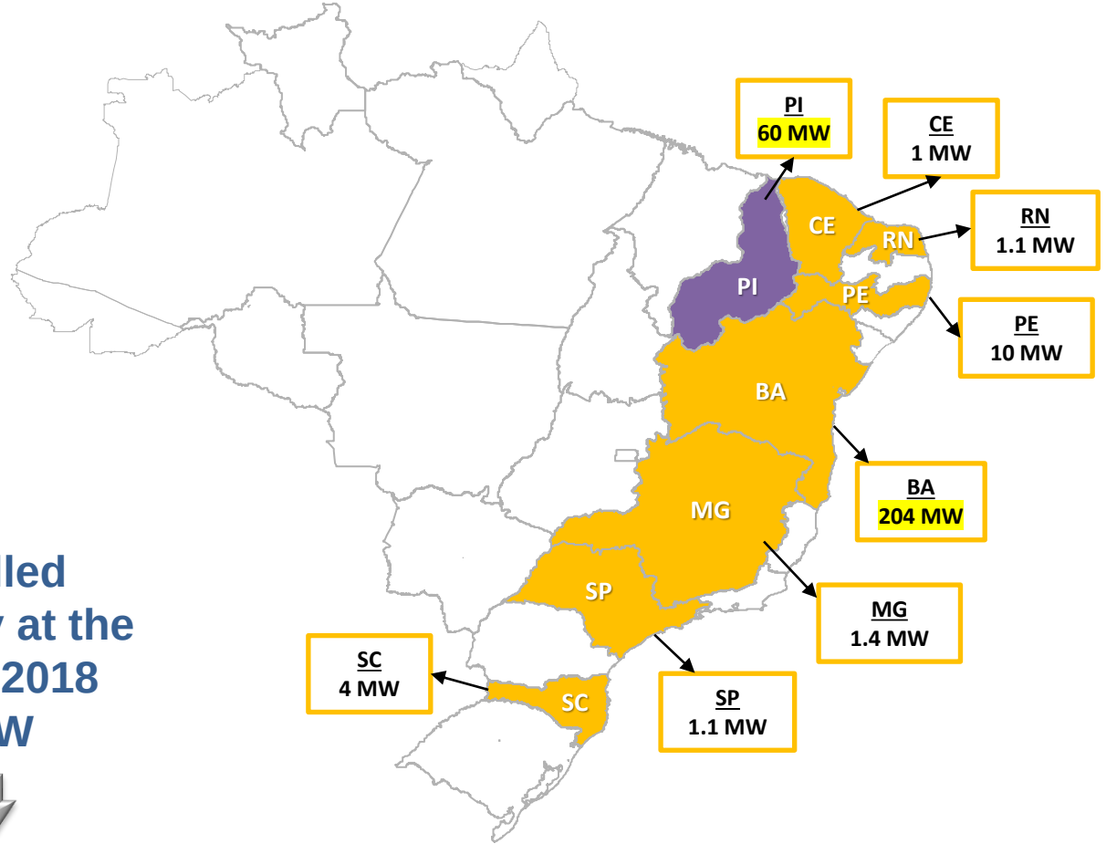
Source: GWEC

(2018)

Source: CCEE May/19

Evolution of Solar PV Capacity in Brazil – 2018 to 2023

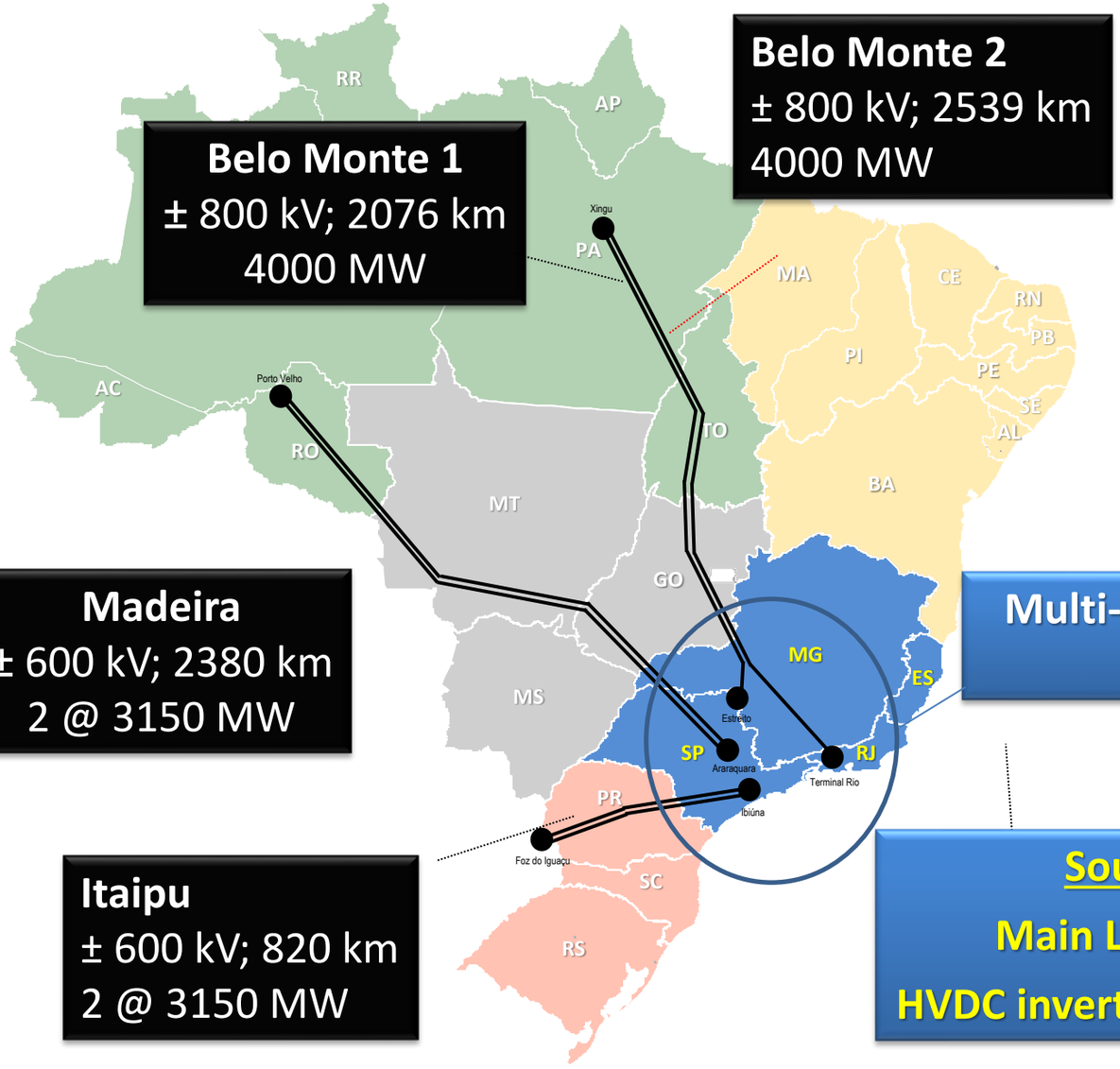




Installed Capacity at the end of 2018
2 GW

Installed Capacity at the end of 2023
4 GW

HVDC Transmission in Brazil



Belo Monte 1
± 800 kV; 2076 km
4000 MW

Belo Monte 2
± 800 kV; 2539 km
4000 MW

Madeira
± 600 kV; 2380 km
2 @ 3150 MW

Itaipu
± 600 kV; 820 km
2 @ 3150 MW

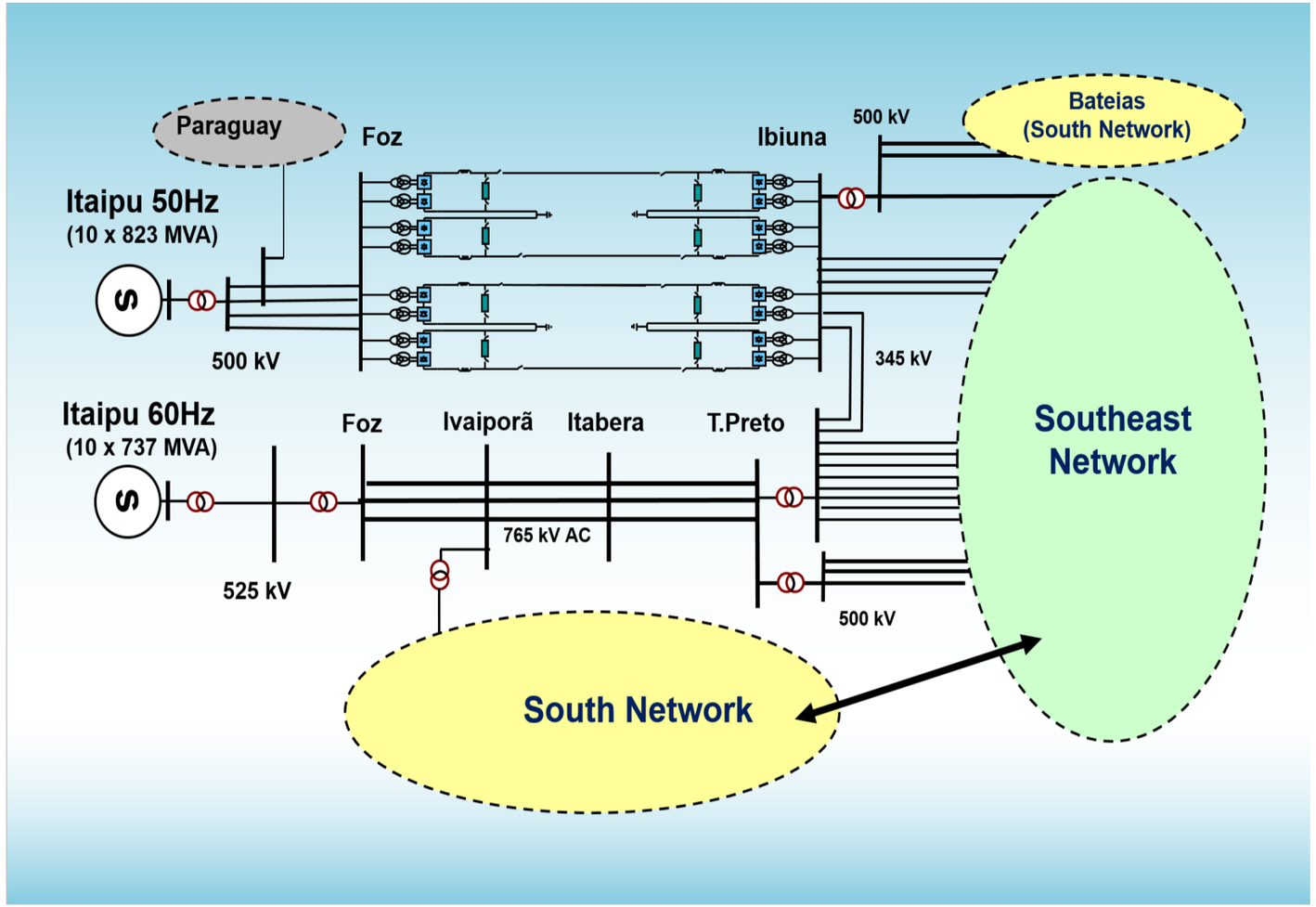
Multi-infeed in Southeastern Brazil

Southeastern Brazil

Main Load Center ~ 45 GW

HVDC inverters (6 bipoles) ~ 20.6 GW

Itaipu Project – Challenges to the first Brazilian HVDC Link



- Binational Generation Project (Brazil & Paraguay)
- The largest hydropower plant at that time (1980s)
- The largest DC voltage level at that time (±600 kV)
- Two Bipoles rated at 3,150 MW each
- 750 kV AC system in parallel, which was uncommon at that time
- Refurbishment to be accomplished soon

Source: Workshop on performance & design requirements of HVDC links, CE-B4 Cigre-Brasil, 2011 (Furnas' presentation)

Itaipu Project – 765 kV AC Lines vs. Two ±600 kV HVDC Bipole Lines - Furnas

Three AC 765 kV Lines - 6300 MW

Foz do Iguaçu Substation

Two DC ± 600 kV Bipoles - 6300 MW

Foz do Iguaçu Substation

Itaipu Project – Challenges to the first Brazilian HVDC Link

Foz do Iguaçu Converter Station

Ibiúna Converter Station

Source: Workshop on performance & design requirements of HVDC links, CE-B4 Cigre-Brasil, 2011 (Furnas' presentation)

Madeira River HVDC Project

Generation Auction:

Santo Antonio Hydropower plant

→ 50@82.25MVA = 4141 MVA

Jirau Hydropower plant

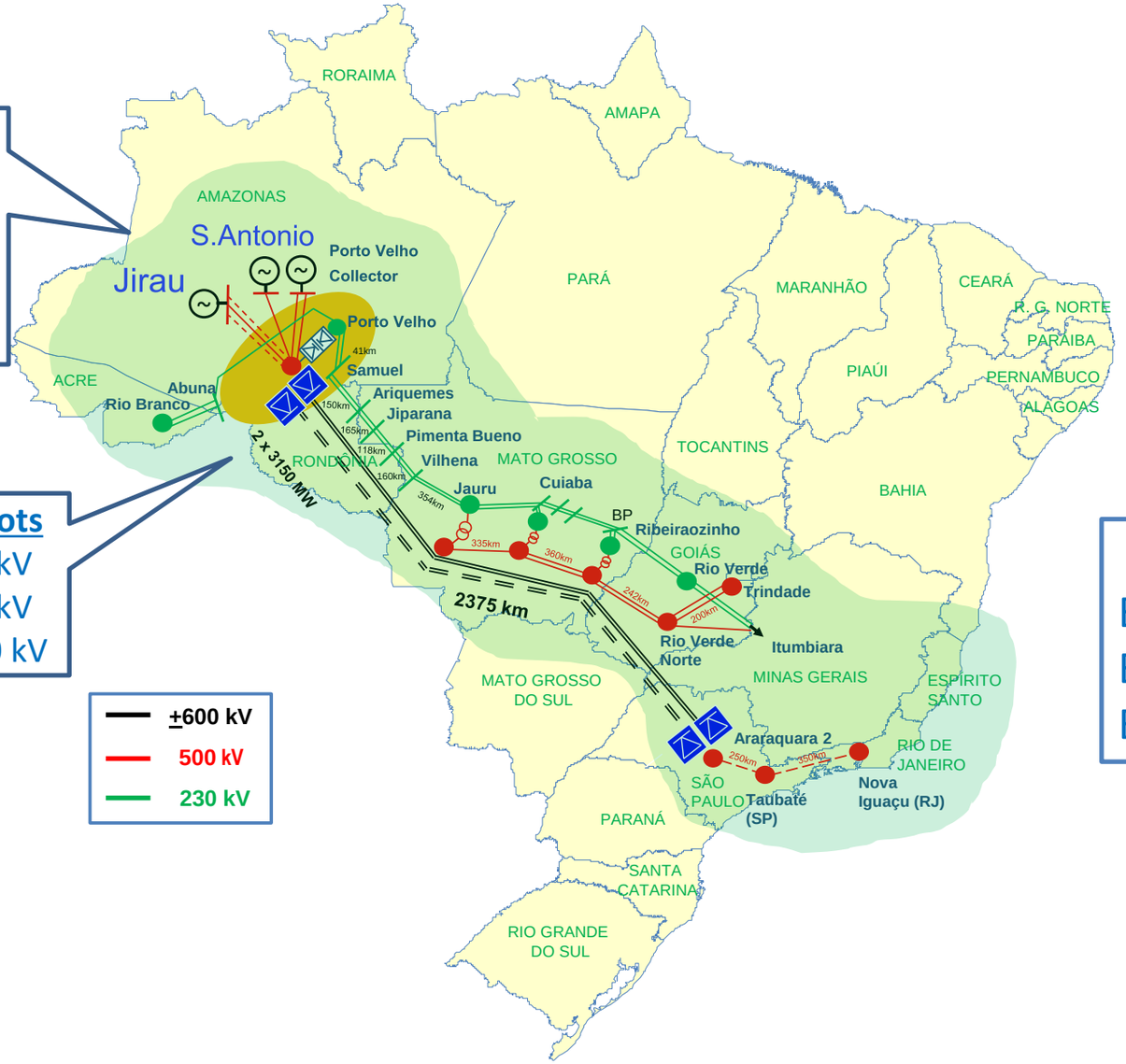
→ 50@83.33MVA = 4166 MVA

Transmission auction – 7 lots

Bipole 1: 3150 MW, ±600 kV

Bipole 2: 3150 MW, ±600 kV

BtB : 2@400 MW, 500/230 kV



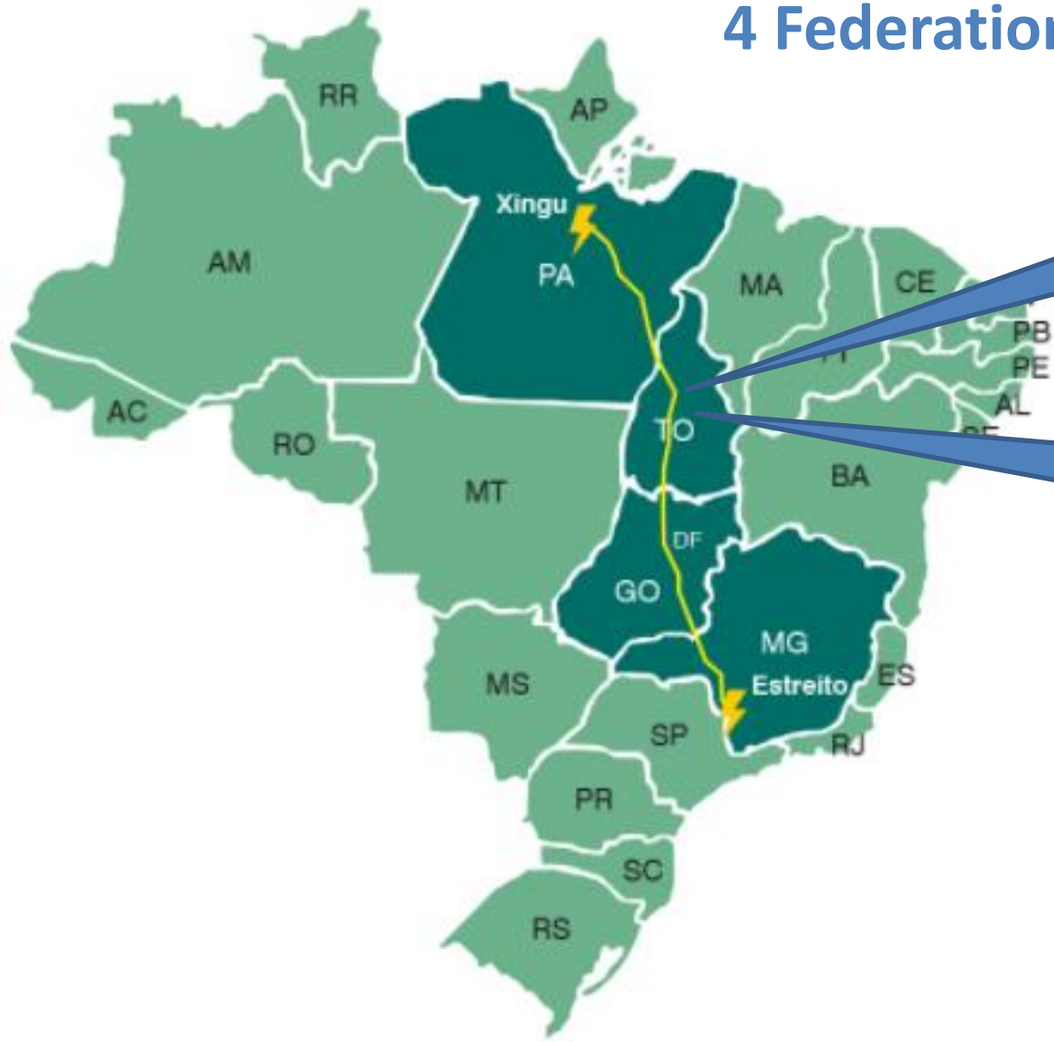
Operation

BtB – 2012

Bipole #1 – 2013

Bipole #2 – 2015

The First Brazilian, ± 800 kV HVDC Link - DC Line passing through 4 Federation States – Dec 2017

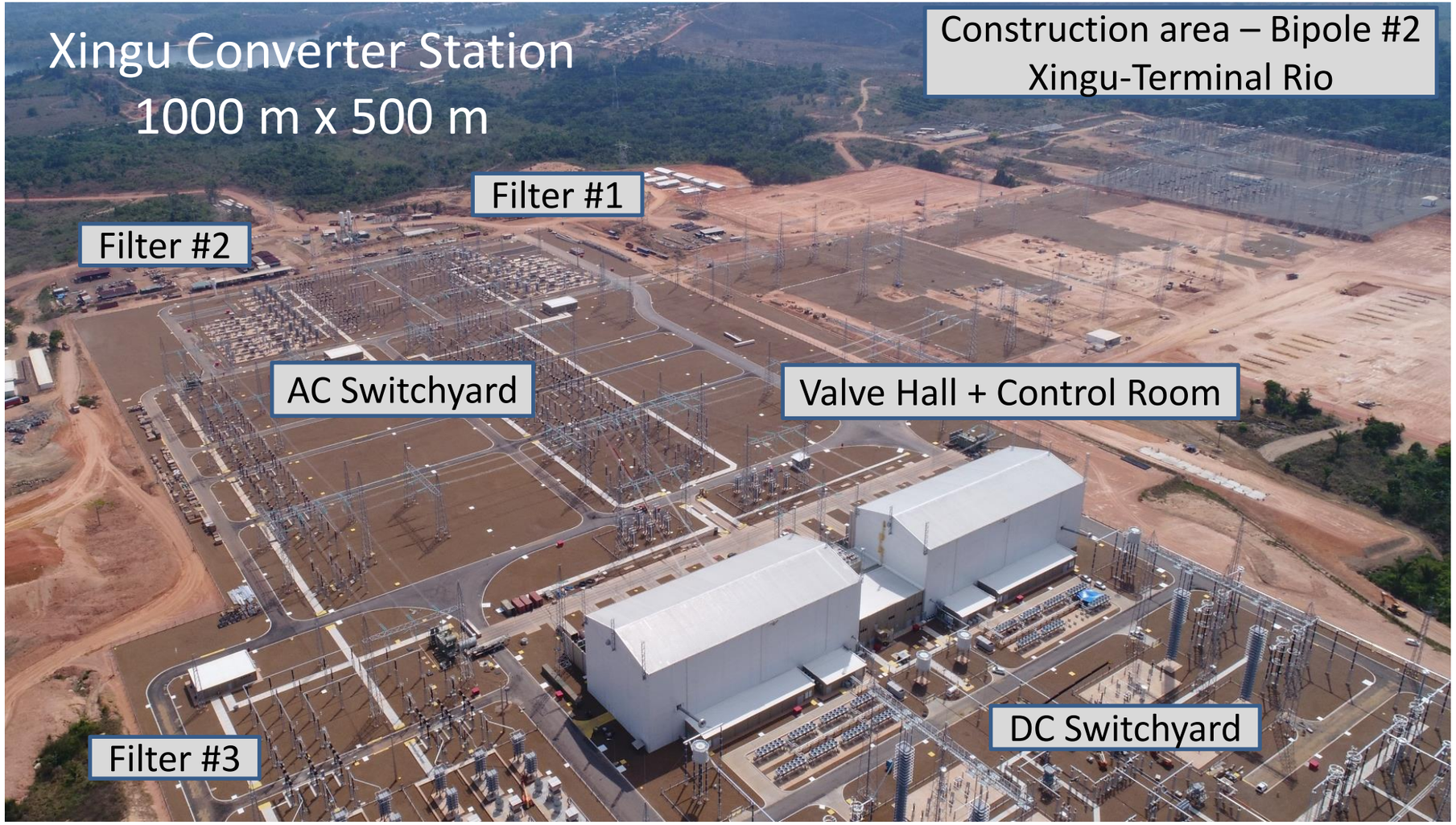


±800kV,4000 MW, 2,076 km, HVDC LCC

The first 800 kV HVDC Bipole in the West

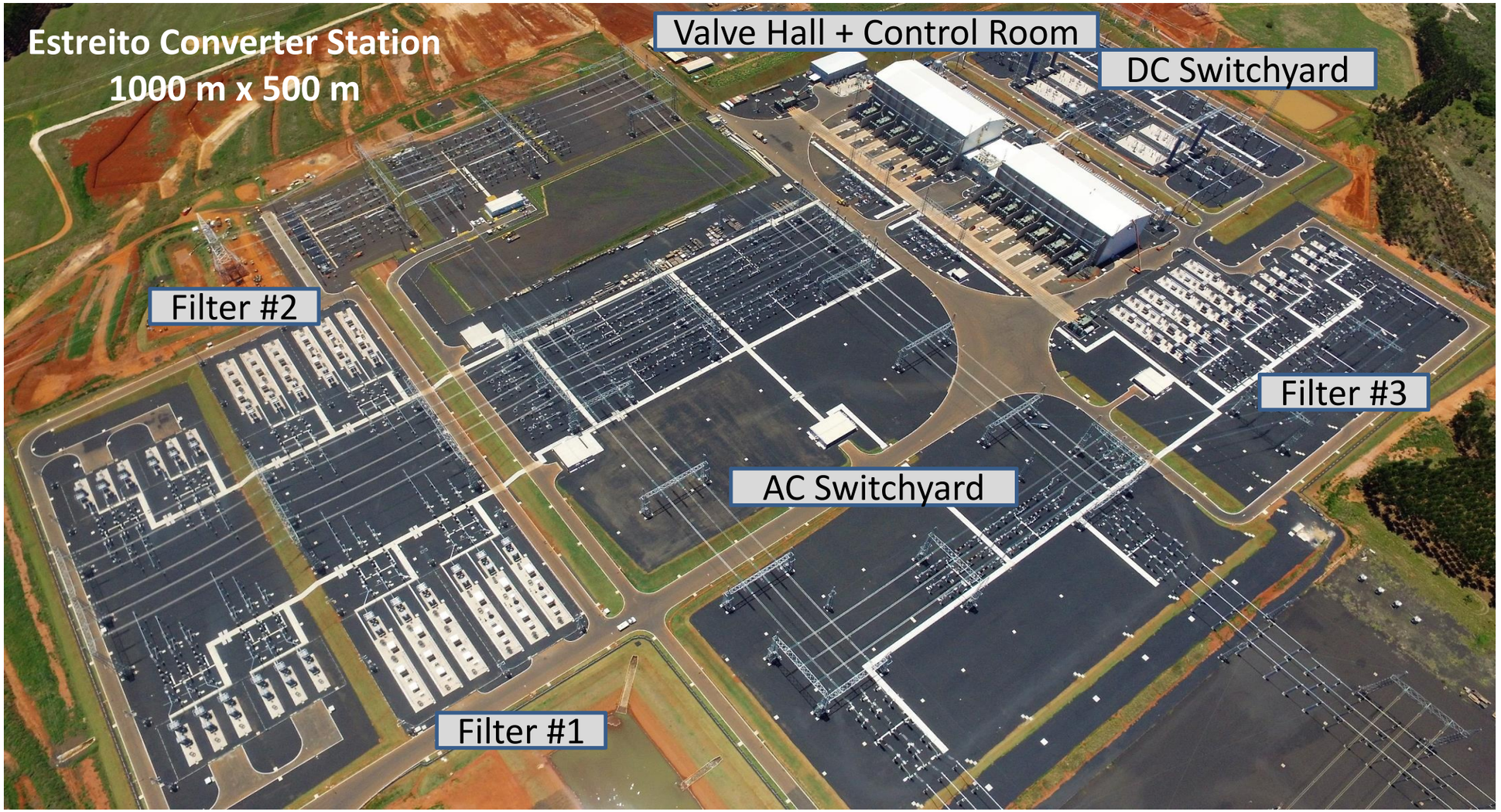
Source: BMTE

±800 kV, 4000 MW Xingu-Estreito Bipole – Xingu C/S



Source: BMTE

±800 kV, 4000 MW Xingu-Estreito Bipole – Estreito C/S



Source: BMTE

±800 kV, 4000 MW Xingu-Estreito Bipole

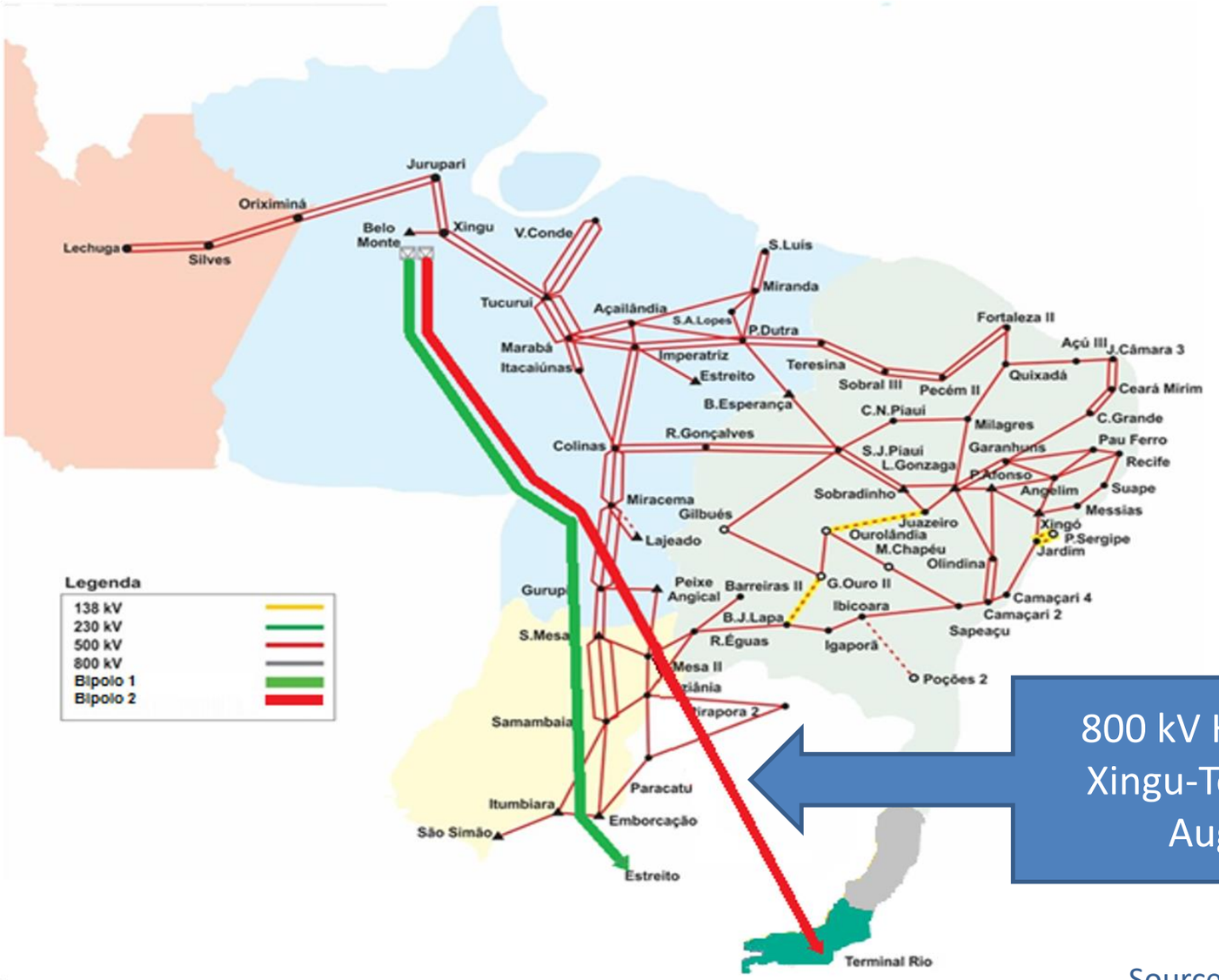
GROUND ELECTRODES

ESTREITO

XINGU

Source: BMTE

The Second Brazilian ±800 kV, 4000 MW Xingu-Terminal Rio Bipole



800 kV HVDC Bipole Xingu-Terminal Rio, Aug. 2019

Source: XRTE

±800 kV, 4000 MW Xingu-Terminal Rio Bipole

Source: XRTE

±800 kV, 4000 MW Xingu-Terminal Rio Bipole

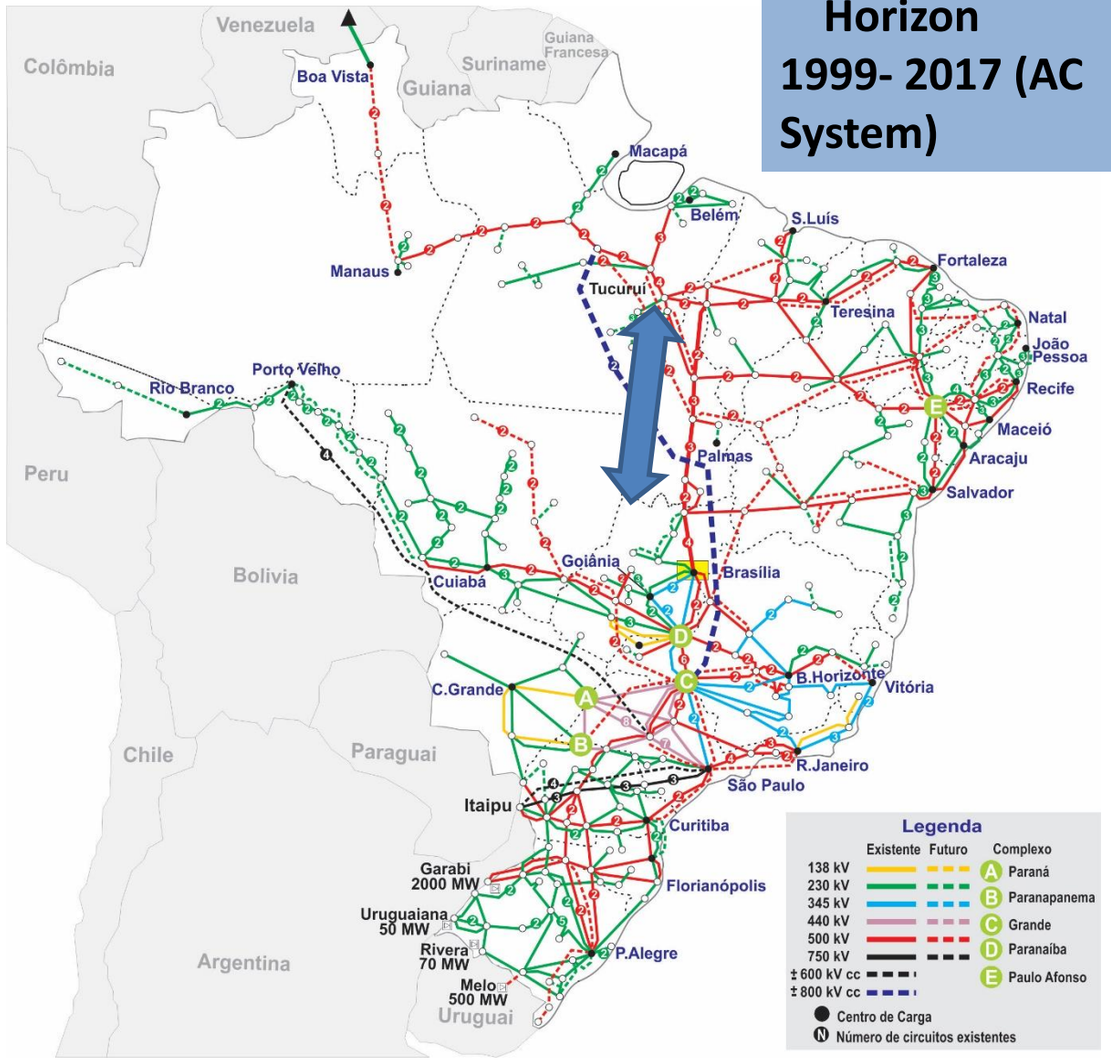
Xingu C/S – Aerial Overview

Source: XRTE

±800 kV, 4000 MW Xingu-Terminal Rio Bipole

Source: XRTE

Interarea oscillation mode - BRAZILIAN NORTH-SOUTH INTERCONNECTION (BNSI) – 500kV, 1020 km

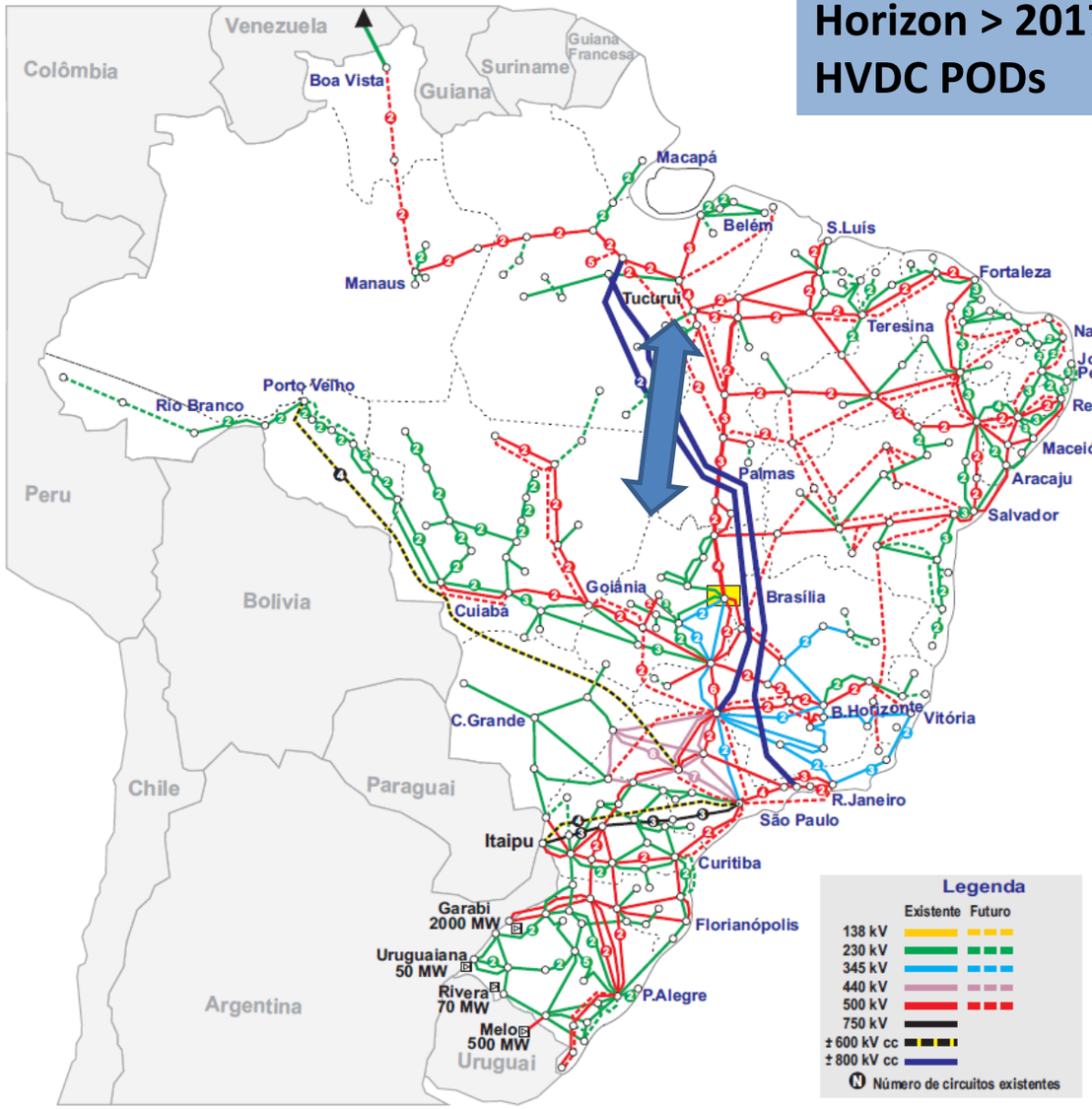


- **Equipped with 2-4 TCSCs → damp interarea mode**
  1020 km long, 1-3 ckts , 500 kV
- **Series compensated lines**

1999	f_{IA} = 0.17-0.22 Hz (1CKT)
2003	f_{IA} = 0.3-0.35 Hz (2 CKTs)
2009	f_{IA} = 0.40-0.45 Hz (3 CKTs)

Interarea mode - BRAZILIAN NORTH-SOUTH INTERCONNECTION (BNSI) – 500kV, 1020 km

Horizon > 2017- HVDC PODs



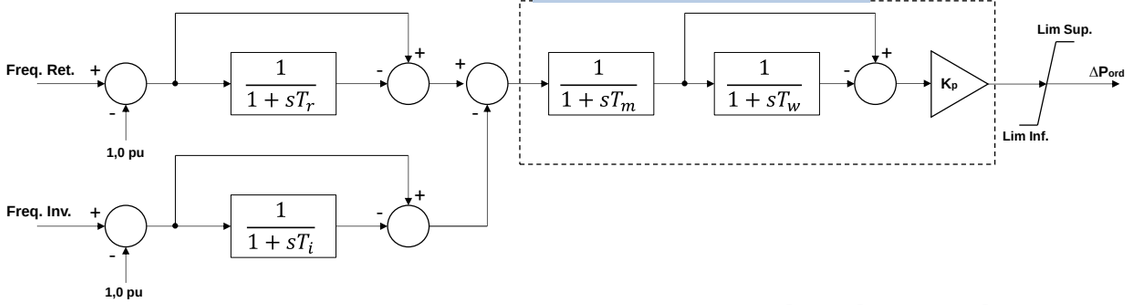
- POD on Bipole 1 (2017)
- POD on both Bipoles 1 and 2 (2019)

>2009 f_{IA} = 0.35-0.45 Hz (3 CKTs)

±800 kV, 4000 MW Xingu-Estreito /Xingu-Terminal Rio Bipoles

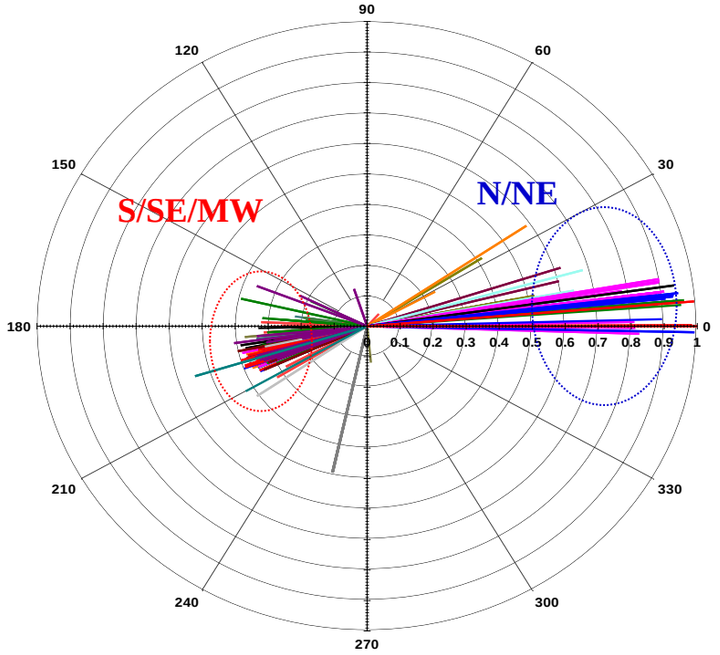
- **North-South:** electromechanical mode (0.4 Hz – 0.45 Hz), depending on configuration and inertia synchronized.
- **Damping:** to be ensured by PSS of generators in North and Northeast areas and TCSCs in North/South terminals. TCSCs are now retired.
- **Xingu–Estreito/Xingu-T. Rio HVDC Bipoles:** provide additional damping
- **Stabilizing Signal** utilizes the electrical frequencies measured at rectifier and inverter.

POD Transfer Function



In operation in both 800 kV Bipoles

POD – Power Oscillation Damping



Mode-shapes @ inter-area mode N/NE vs S/SE/MW

Thank you for your attention!

ricardo.tenorio@ons.org.br

ONS Operador Nacional do Sistema Elétrico