ENVIRONMENTAL ASSESSMENT DUE TO HIG PENETRATION OF INVERTER-BASED GENERATION

THE BRAZILIAN CASE

Prof. Dr. Leandro Michels
Federal Universidade of Santa Maria (UFSM)
Institute for Smart Grids (INRI)

michels@gepoc.ufsm.br
www.facebook.com/leandromichels.sm/
www.linkedin.com/in/leandro-michels/
www.instagram.com/leandromichels/

Smart-grid Institute, Federal University of Santa Maria, Brazil

DG SPECIALIZED INSTITUTE

- Photovoltaics / Wind / Motor-generator Ethanol
- Smart grids / Distribution Transformers

RESEARCH & DEVELOPMENT

- Industry funding
- Public funding
- Graduate students

TESTING FACILITIES

- Photovoltaics Inverters
- Distribution Transformers
- Wind generators

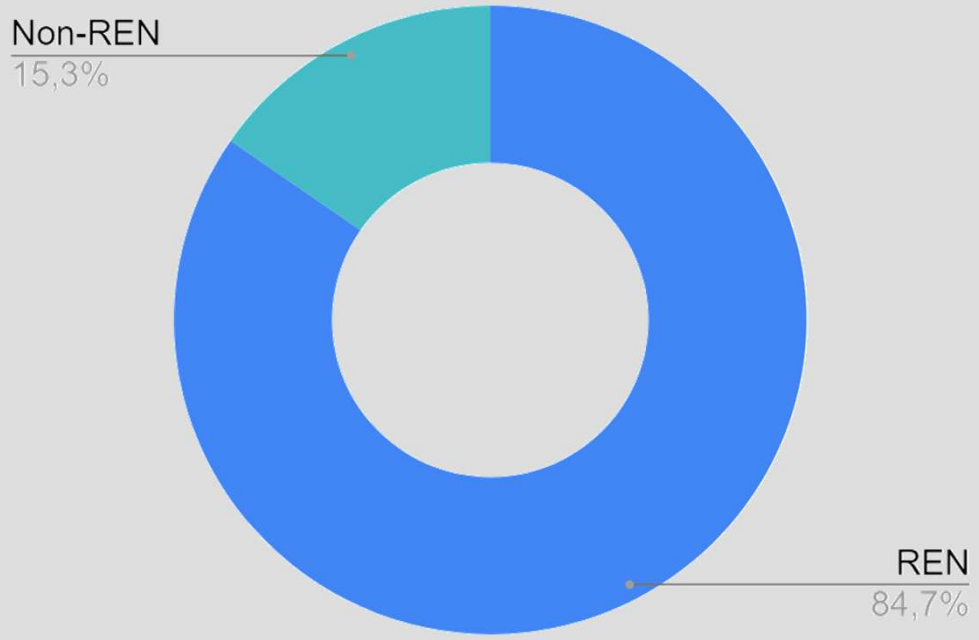
STATE OF RIO GRANDE DO SUL

1 Brazilian Power System

Contextualization

Brazilian Eletricity: Energy Balance 2022

TOTAL INSTALLED CAPACITY BY SOURCE



REN: 80.5% (2013) → 84.7% (2022)

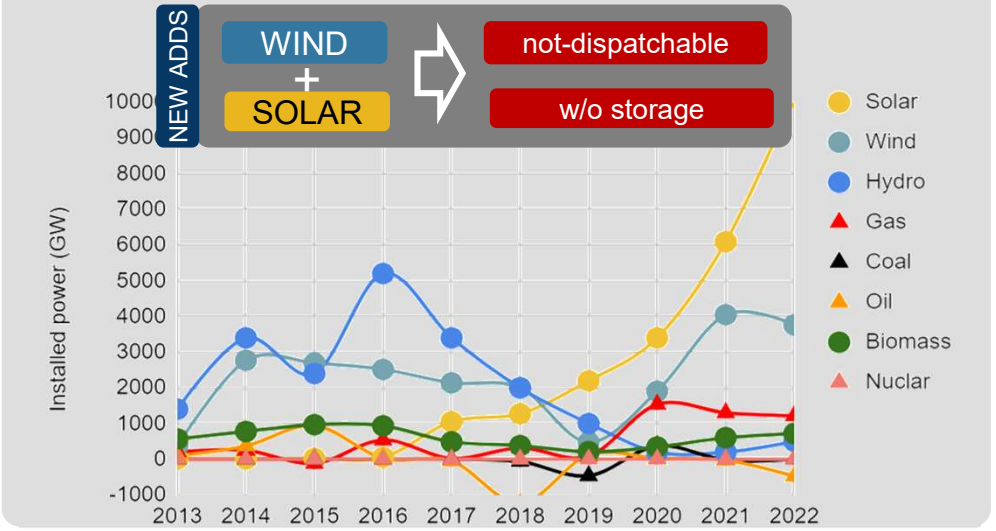
Source: Brazilian Energy Balance - EPE (2023)

TOTAL STORAGE CAPACITY (HYDRO POWER DAMS)

max STORAGE ~ 290 GW.month / avg LOAD ~ 75 GW = STORAGE RESERVE ~ 3.8 month

Source: National Operator of the Electric System (2023)

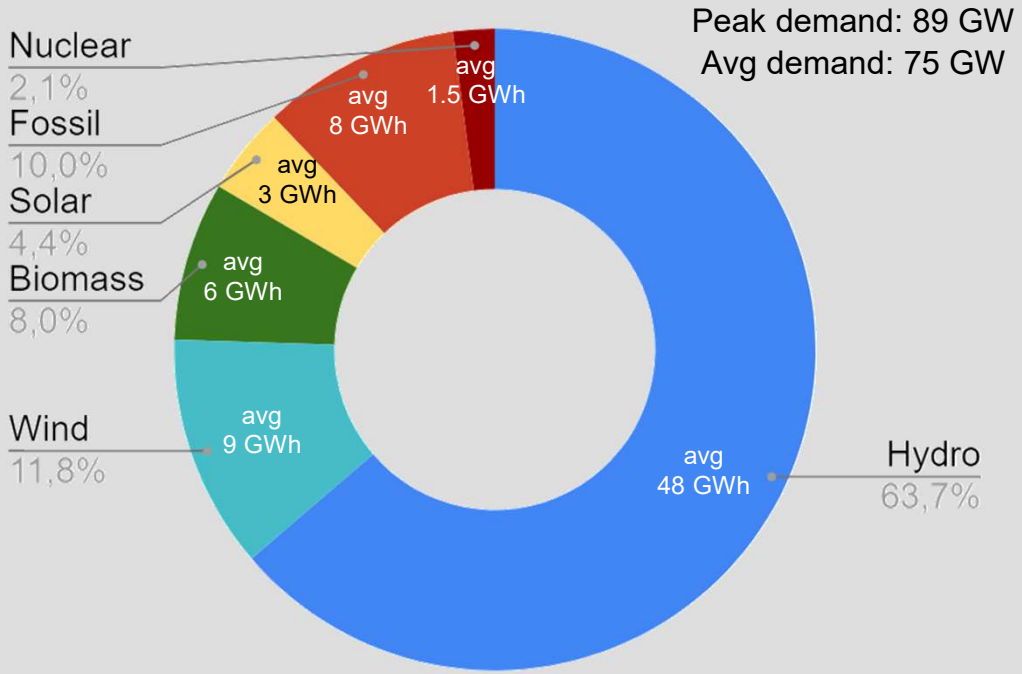
NEW ADDITIONS BY SOURCE



Source: Statistical Annuary of Electrical Energy - EPE (2023)

Brazilian Eletricity: Energy Balance 2022

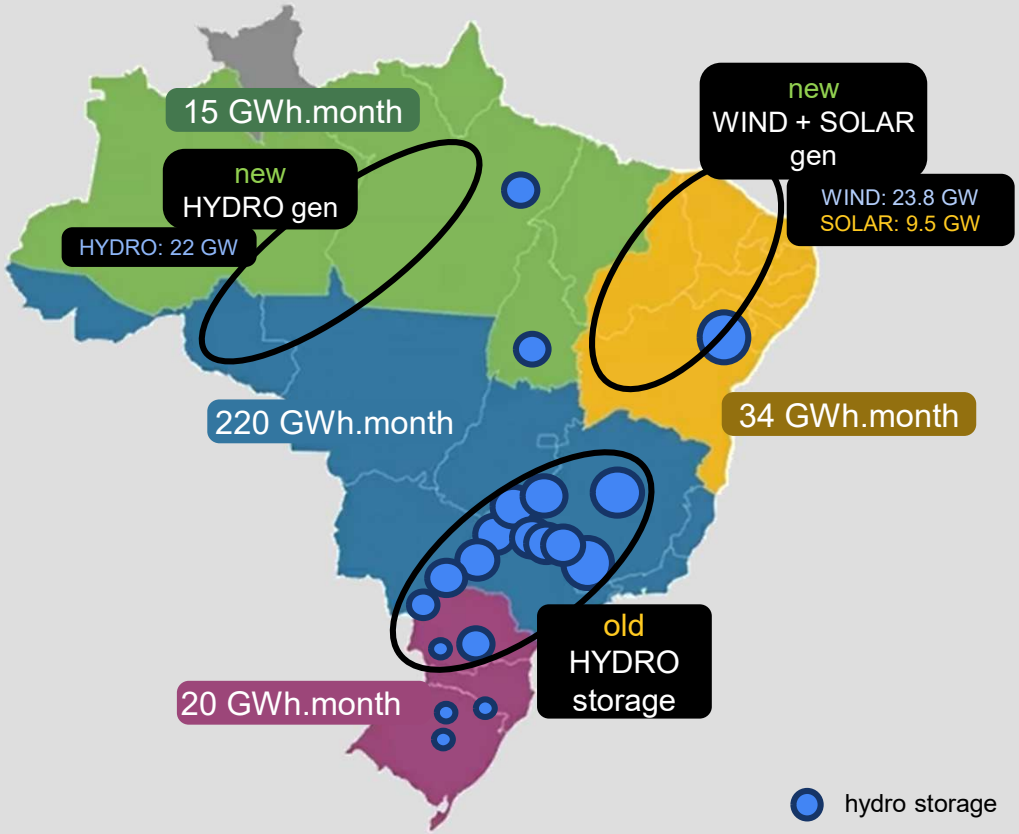
TOTAL ELECTRICITY SUPPLY BY SOURCE



RENEWABLES: 88 % → REN GEN offer → 100% demand; REN GEN use → 90% demand

Source: Brazilian Energy Balance - EPE (2023)

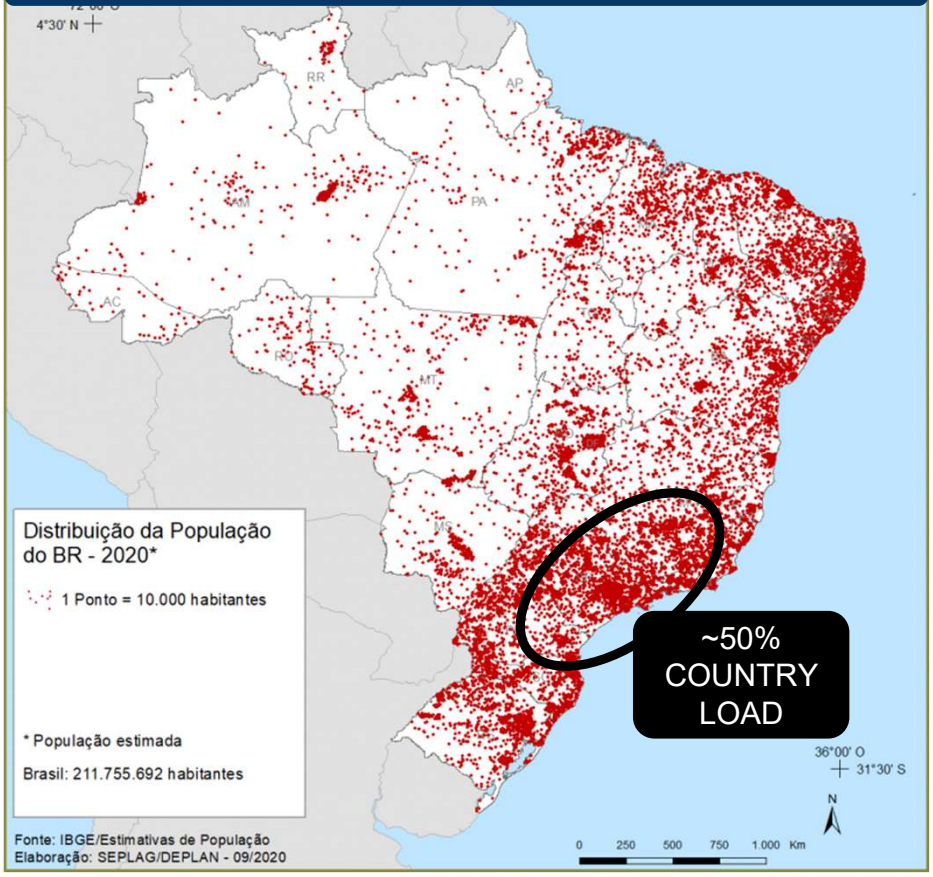
HYDRO STORAGE CAPACITY



Source: Brazilian Energy Balance - EPE (2023)

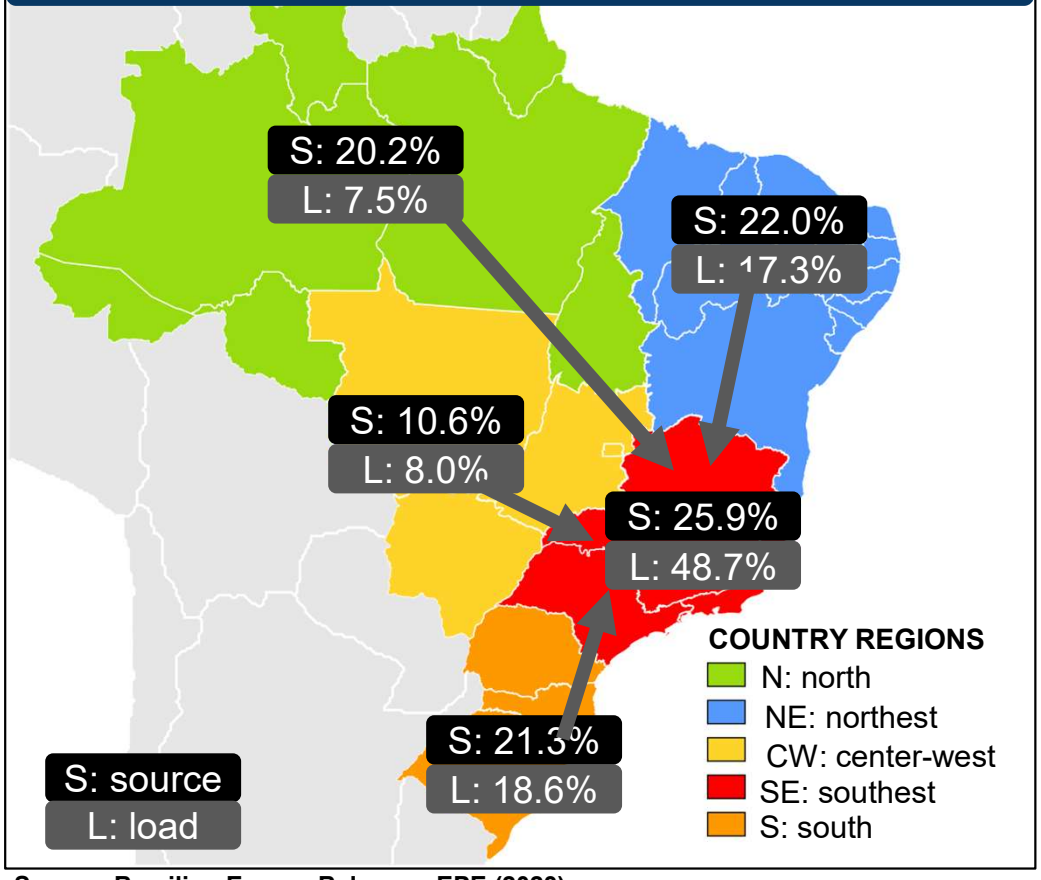
Brazilian Source/Load Distribution

POPULATIONAL DENSITY



Source: Brazilian Institute of Geography and Statistics - IBGE (2020)

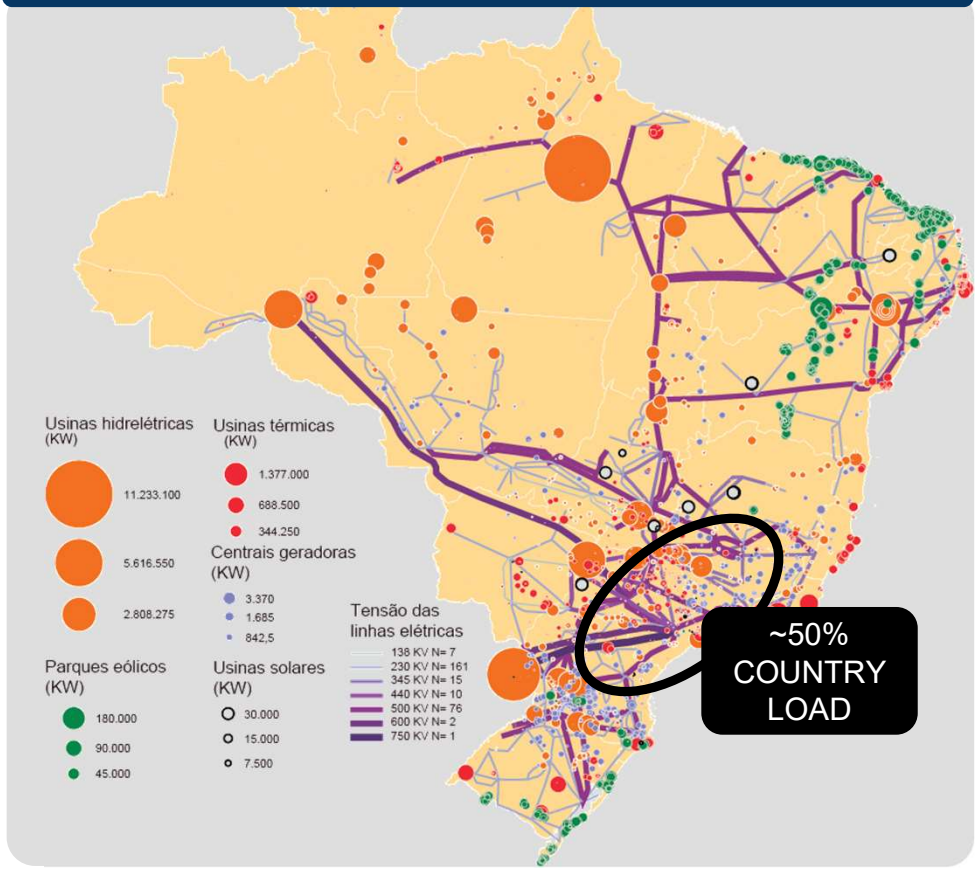
ANNUAL ENERGY FLOW



Source: Brazilian Energy Balance - EPE (2023)

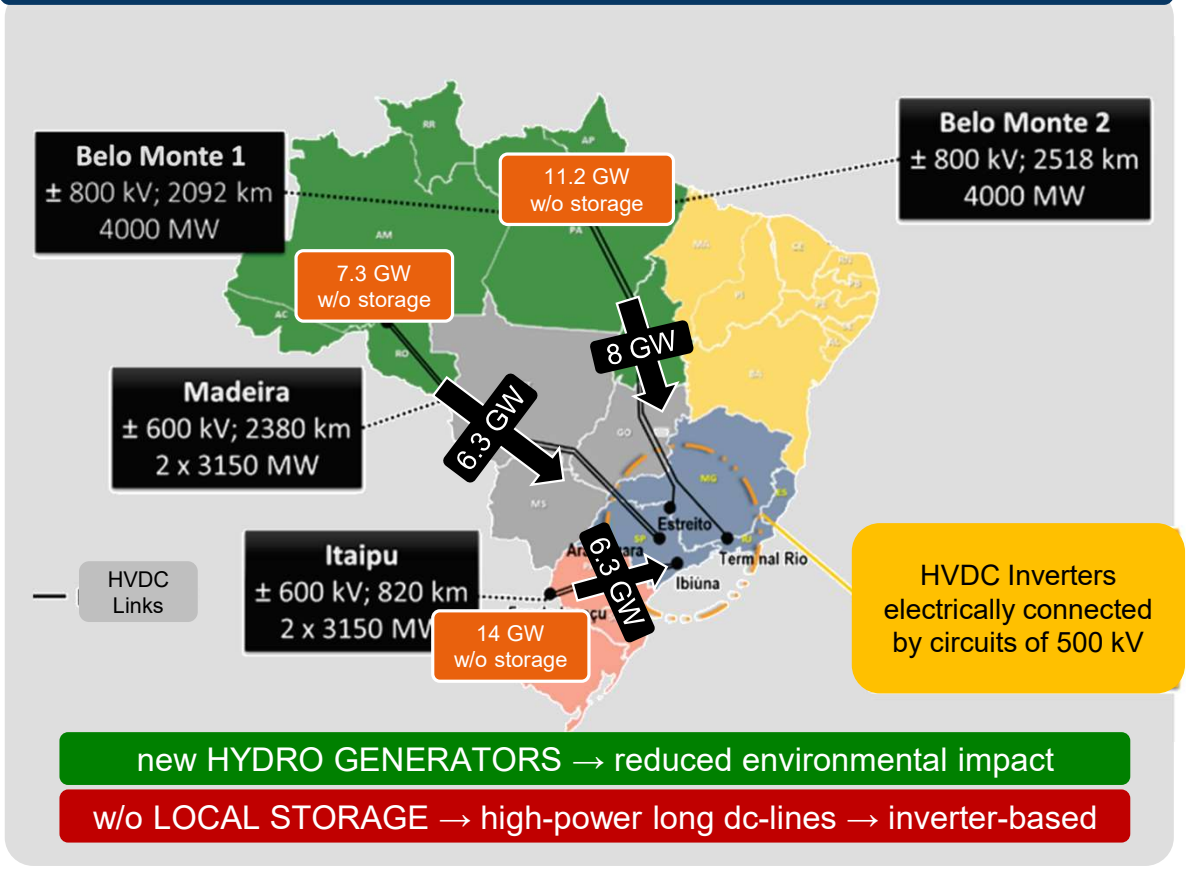
Brazilian Interconnected Power System

INTERCONNECTED POWER SYSTEMS



Source: https://gisepeprd2.epe.gov.br/WebMapEPE/ (2023)

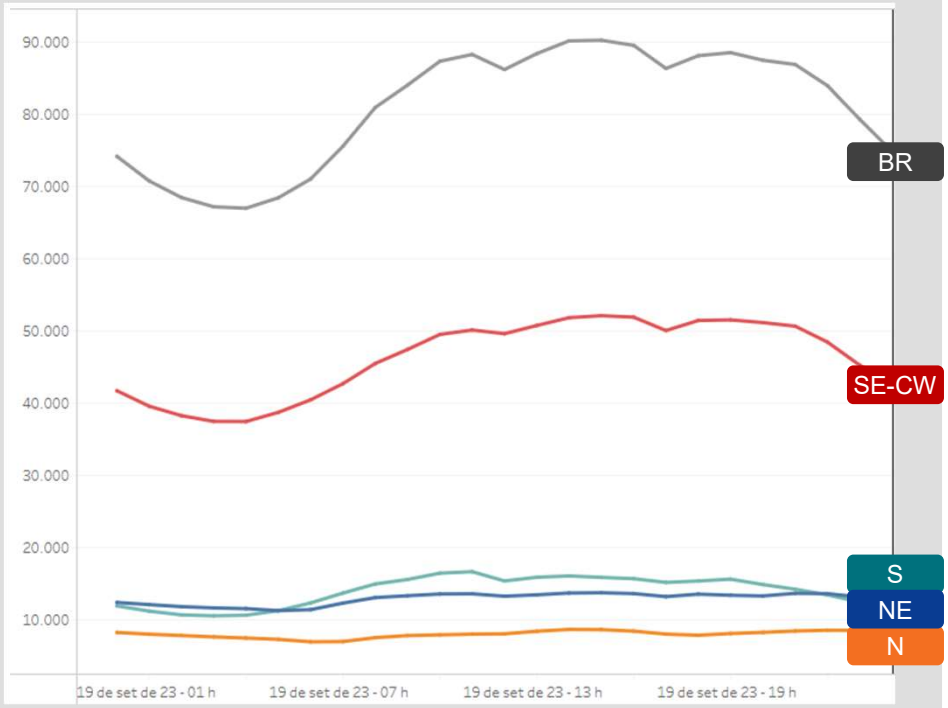
HVDC LINKS FOR LONG-LINES HIGH-POWER HYDRO



Source: https://gisepeprd2.epe.gov.br/WebMapEPE/ (2023)

Load vs. Generation

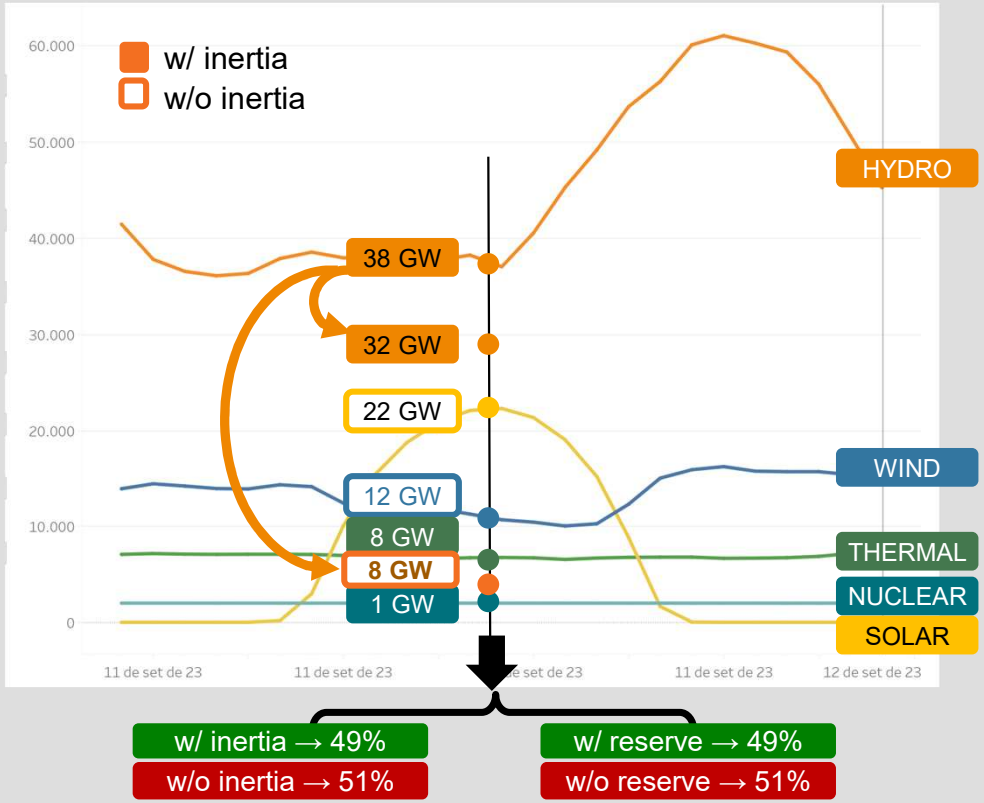
TYPICAL DAILY LOAD VS. TIME – SUBSYSTEM



LOAD → > 50% SE REGION

Source: National Operator of the Electric System (2023)

TYPICAL DAILY GENERATION VS. TIME



Source: National Operator of the Electric System (2023)

2 High Penetration of Inverter-based Generation (IBR)

Stability Challenges

Contextualization: Stability of Electric Power Systems

POWER SYSTEM OPERATOR

GENERATION = LOAD + LOSSES

GENERATION
LOSS TRANSMISSION
LOSS GENERATION

LOAD-GENERATION UNBALANCE

Extra Energy
Reactive support

INSTANTANEOUS SUPPORT
- INERTIA OF GENERATORS
- SYNCRONOUS-CONDENSER
- FAST-RESPONSE ESS
- INVERTERS w/ EXTRA POWER

+

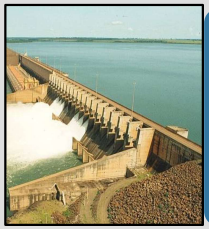
LONG-TIME SUPPORT
- EXTRA ENERGY DISPATCH
- SYNCRONOUS-CONDENSER
- HIGH-CAPACITY ESS
- INVERTERS w/ EXTRA ENERGY

BRAZILIAN POWER SYSTEM

INERTIA → HIGH: >230GW.s
ENERGY RESERVE → HIGH: hydro + thermal

HIGH INERTIA (instantaneous extra power)

+



LOCAL STORAGE (modulation of power)

NORTHEST BRAZILIAN POWER SUBSYSTEM

LOCAL INERTIA → LOW: ~80% inverter-based generation
LOCAL ENERGY RESERVE → LOW: depends on other regions

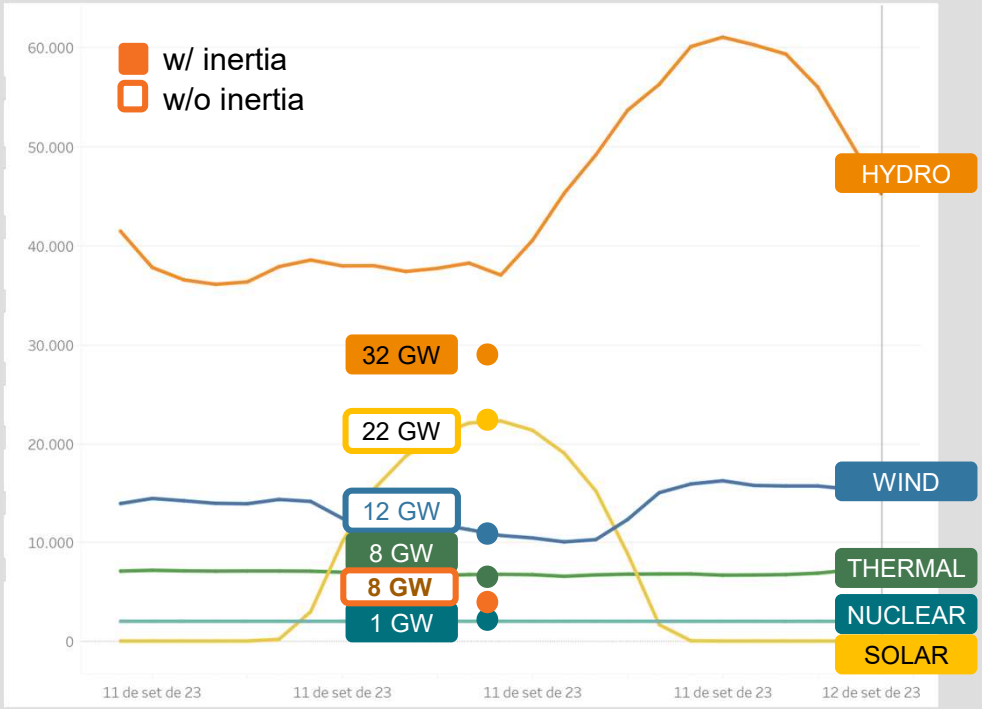
LOW INERTIA (low reactive support)

+

LOWER LOCAL STORAGE (maximum power)

Brazilian System Operation: Typical Day

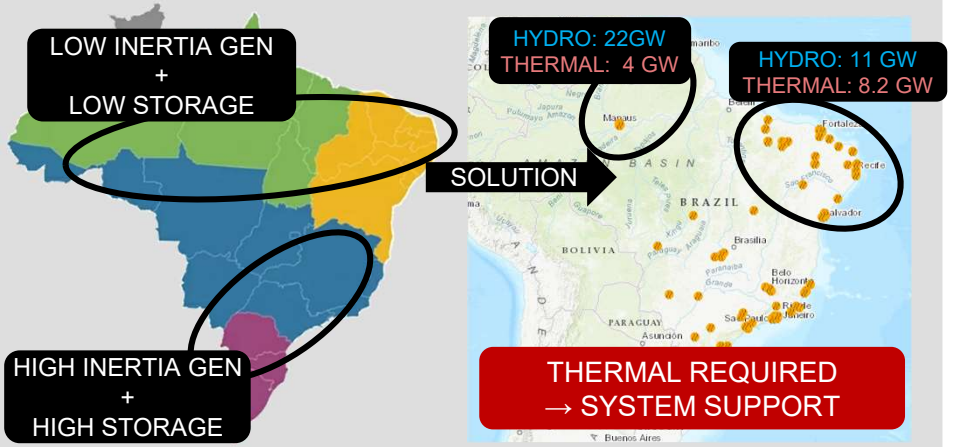
TYPICAL DAILY GENERATION VS. TIME



STABILITY SUPPORT

32 GW	8 GW + 1 GW	8 GW + 12 GW + 22 GW
HIGH INERTIA	MEDIUM INERTIA	SMALL INERTIA
ENERGY STORAGE W/ FAST RESPONSE	ENERGY STORAGE W/ SLOW RESPONSE	W/O LOCAL ENERGY STORAGE

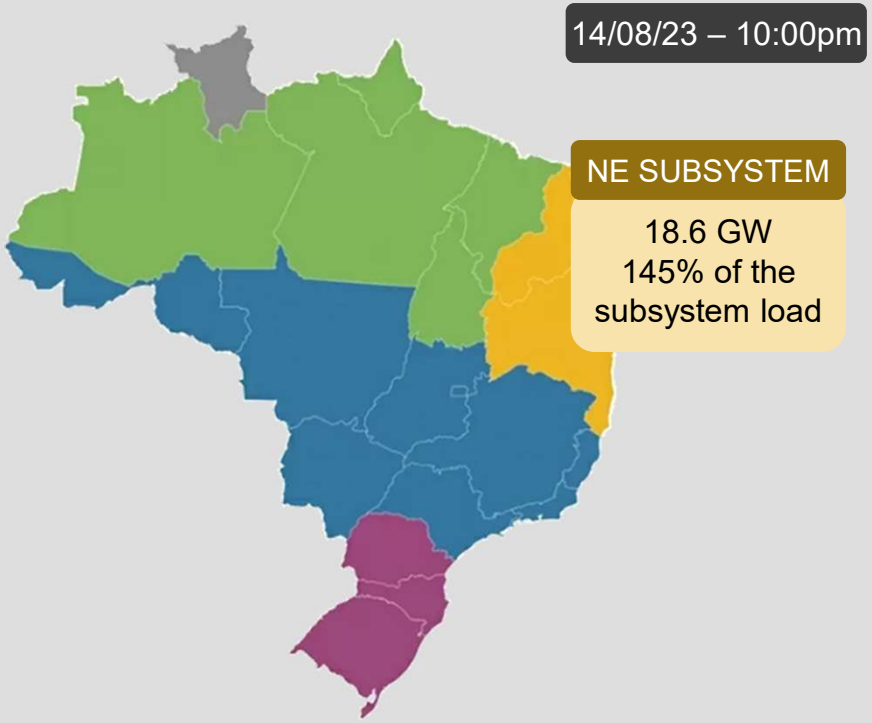
THERMAL GENERATION: STABILITY SUPPORT



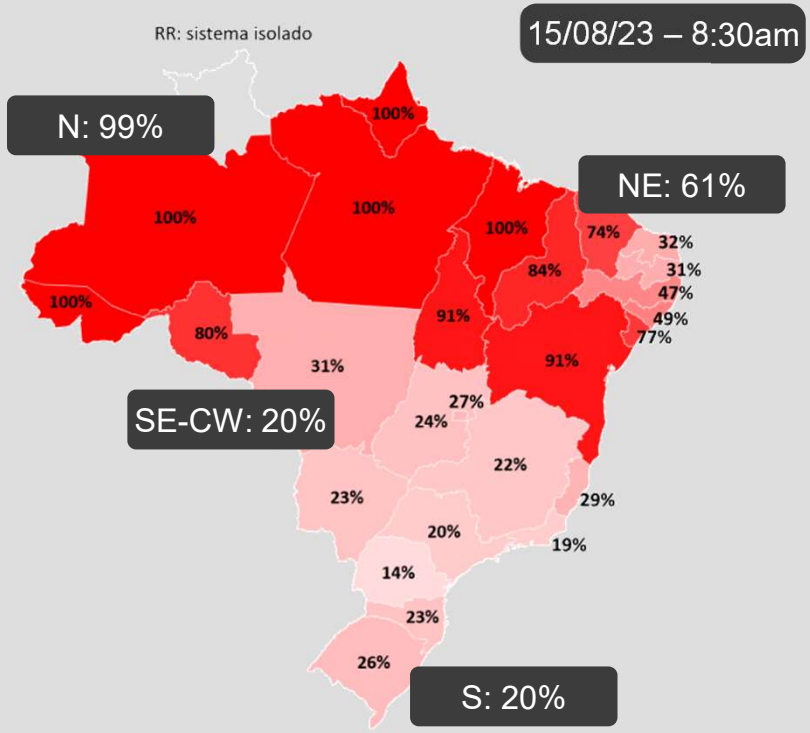
Source: National Operator of the Electric System (2023)

2023 Brazil Blackout: Whats happened?

RECORD WIND GENERATION – NE SUBSYSTEM



NATIONWIDE OUTAGE – LOAD CUTTING



Source: National Operator of the Electric System (2023) – Blackout preliminar report

2023 Brazil Blackout: What happened?

Norte		
Geração	Verificada	Programada
Hidráulica	2.493	2.514
Térmica	1.399	1.389
Eólica	210	304
Solar	3	0
Total	4.104	4.207

Carga	Verificada	Programada
Total	6.588	6.561

Nordeste		
Geração	Verificada	Programada
Hidráulica	2.539	2.459
Térmica	287	449
Eólica	16.317	16.745
Solar	3.211	3.681
Total		23.334

Carga	Verificada	Programada
Total	10.151	10.242

WIND + SOLAR

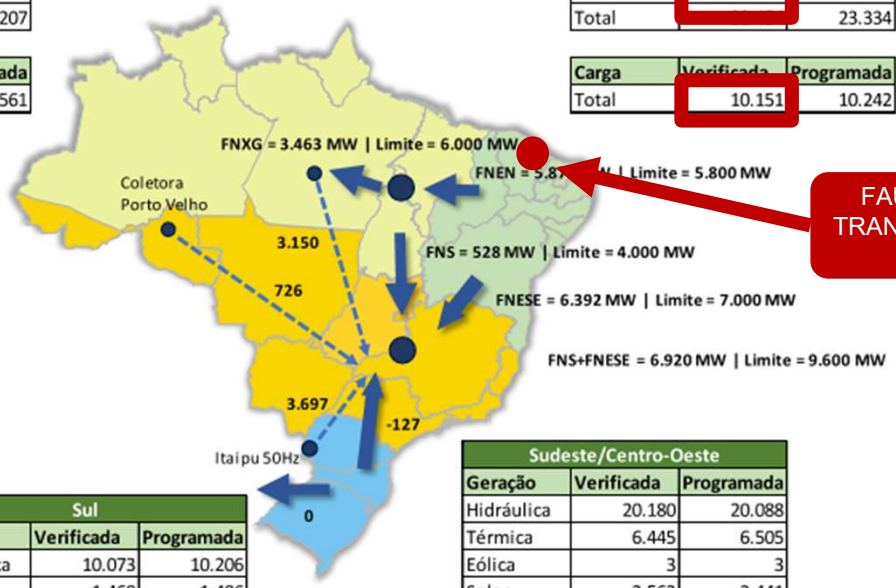
19,5 GW

LOCAL LOAD

10,1 GW

SIN		
Geração	Verificada	Programada
Hidráulica	35.284	35.267
Térmica	9.698	9.829
Eólica	16.748	17.256
Solar	5.777	6.124
Total	67.508	68.476

Carga	Verificada	Programada
Total	67.507	68.200



Sudeste/Centro-Oeste		
Geração	Verificada	Programada
Hidráulica	20.180	20.088
Térmica	6.445	6.505
Eólica	3	3
Solar	2.562	2.441
Total	29.189	29.037

Carga	Verificada	Programada
Total	38.882	39.165

Sul		
Geração	Verificada	Programada
Hidráulica	10.073	10.206
Térmica	1.468	1.486
Eólica	218	204
Solar	2	2
Total	11.761	11.898

Carga	Verificada	Programada
Total	11.887	12.232

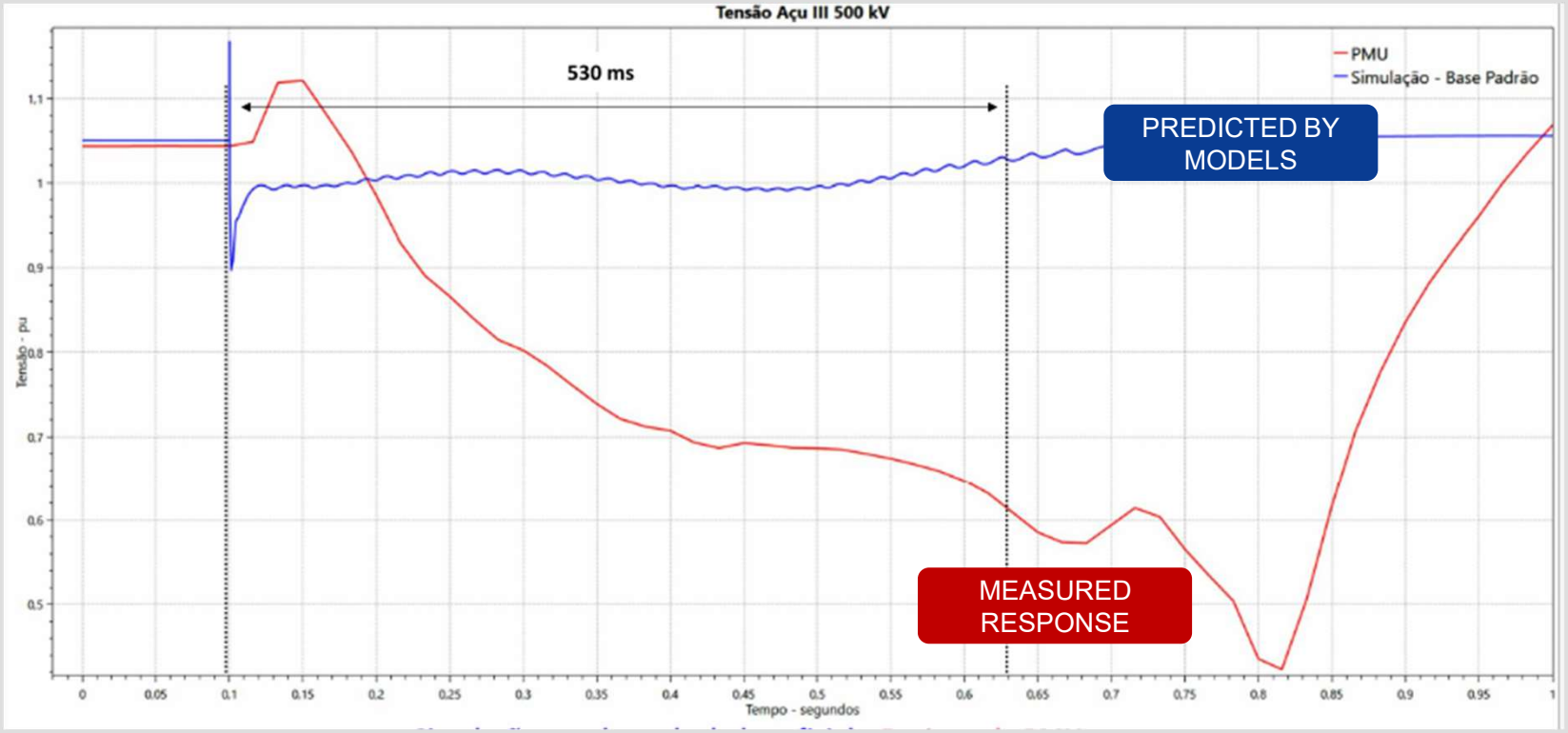
Fluxo AC

Fluxo DC

Source: National Operator of the Electric System (2023) – Blackout preliminar report

2023 Brazil Blackout: Why did it happen?

ANALYSIS FROM NATIONAL SYSTEM OPERATOR



SYSTEM SELF RECOVERY NO BLACKOUT

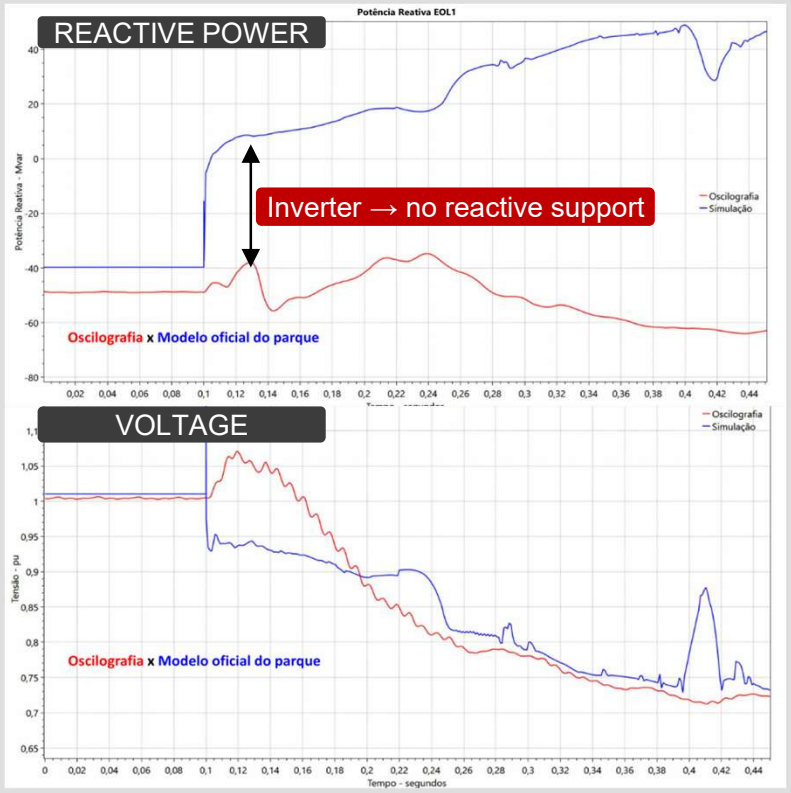
WHY THIS DIFFERENCE ?

SYSTEM COLPAPSE BLACKOUT

Source: National Operator of the Electric System (2023) – Blackout preliminar report

2023 Brazil Blackout: IBR Response

WIND GENERATOR 1



MEASURED RESPONSE

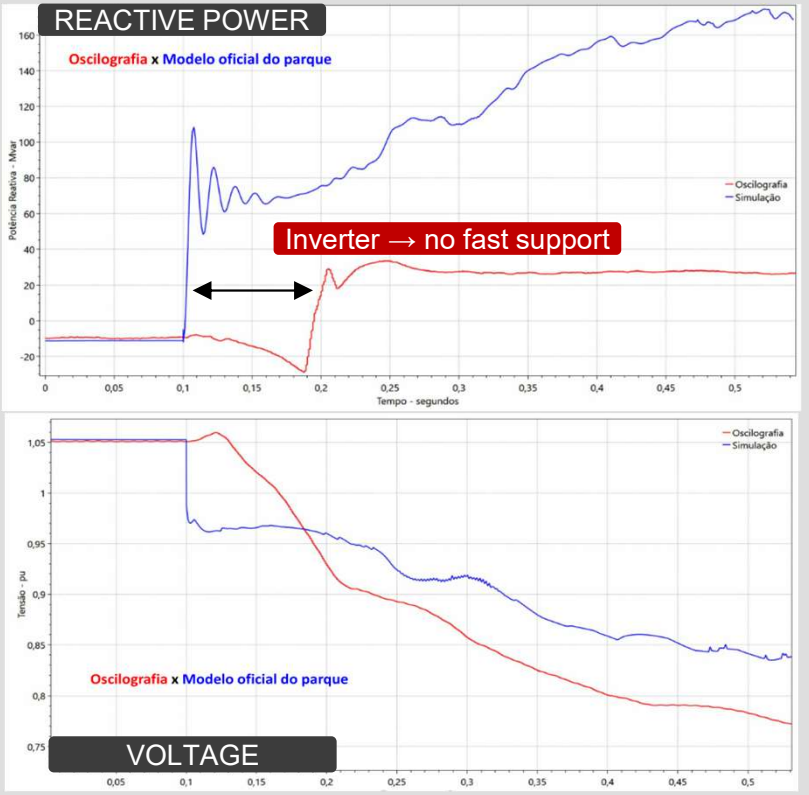
≠

PREDICTED BY MODELS

MOST WIND + SOLAR → COMPLETELY DIFFERENT FROM MODELS CONSIDERED FOR PROJECT APPROVALS

HIGH RISK !!!

SOLAR GENERATOR 1



Source: National Operator of the Electric System (2023) – Blackout preliminar report

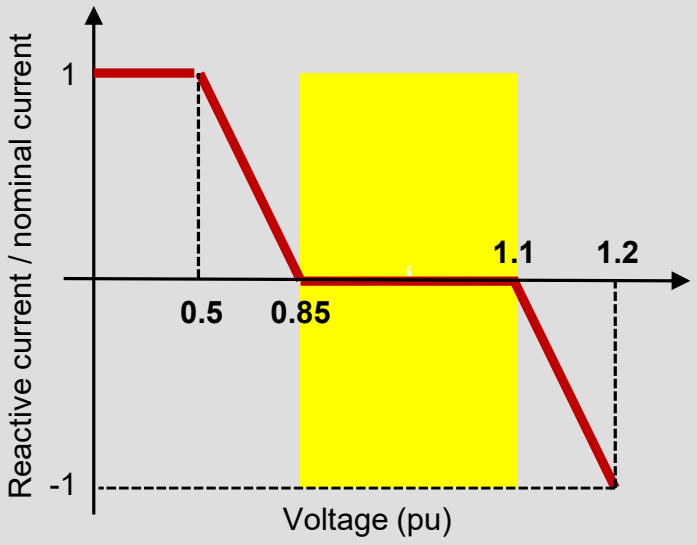
3

High Penetration of Inverter-based Generation (IBR)

How to avoid the problem?

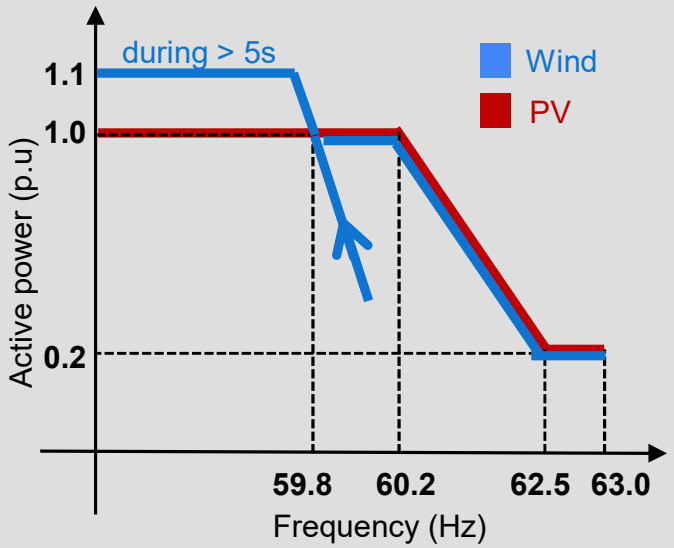
Immunity to grid frequency/voltage disturbances

REACTIVE INJECTION UNDER FAULTS



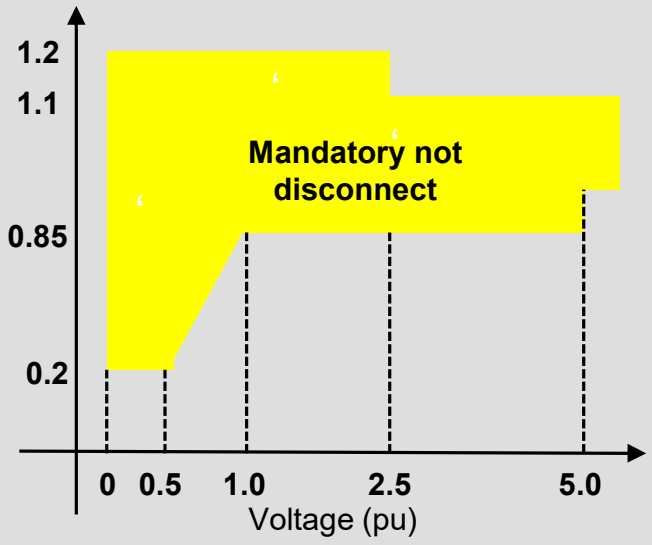
RESPONSE SHOULD BE INSTANTANEOUS

ACTIVE INJECTION UNDER FAULTS



RESPONSE SHOULD BE INSTANTANEOUS

VOLTAGE RIDE-TROUGHT

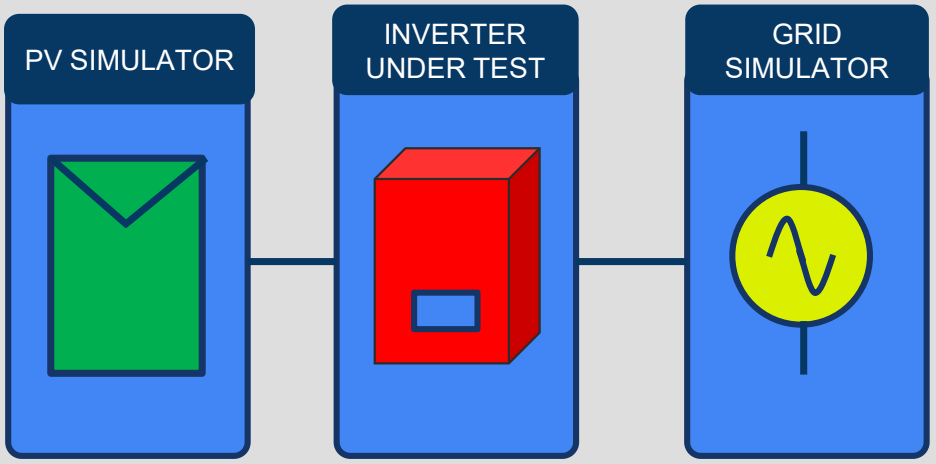


RESPONSE SHOULD BE INSTANTANEOUS

Source: National Operator of the Electric System (2023) – Grid Code for High-Power Plants

Inverters may be tested in many conditions

TEST: IDEAL GRID CONDITION (CERTIFICATION)

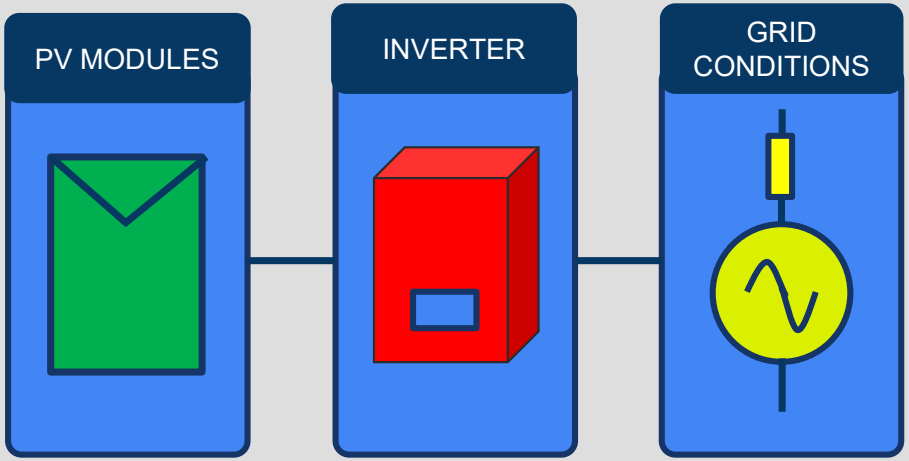


Grid conditons: ideal (no harmonics, zero impedance)

Test of immunity for critical cases: pré-defined sequence, each test done after inverter is turned on

Test for a single inverter

REAL: NON-IDEAL GRID CONDITION



Grid conditions: distorced grid, variable impedance

Critical cases: not same of pré-defined sequence, normally several times

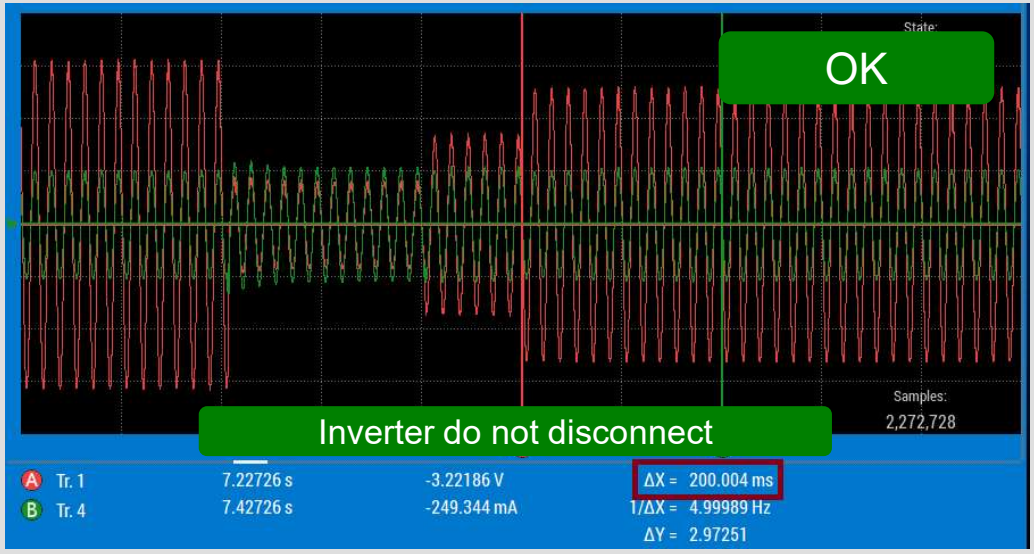
Power plant: multiple inverters operating togheter

Case study: Ideal vs. Real grid condition

TEST: IDEAL GRID CONDITION (CERTIFICATION)

Grid conditons: ideal (no harmonics, zero impedance)

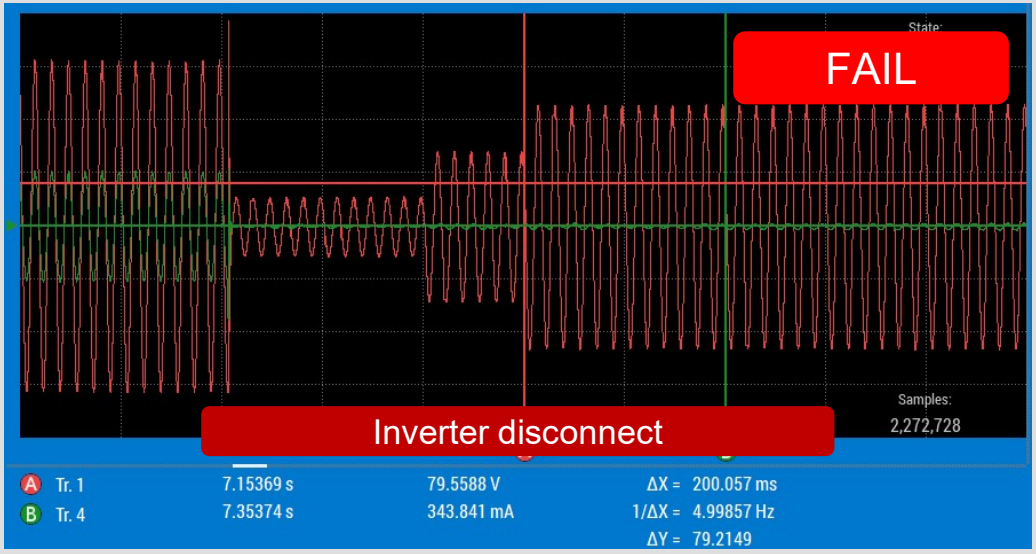
Test of immunity for critical cases: pré-defined sequence, each test done after inverter is turned on



TEST: REAL GRID CONDITION

Grid conditons: ideal (no harmonics, non-zero impedance)

Test of immunity for critical cases: pré-defined sequence, each test done after inverter is turned on



Source: Msc. Thesis Igor Bitencourt (UFSM, 2022) – inverter for DG

Software realibility: An important point!

Lion Air Flight 610 Crash: Oct 29th 2018

Ethiopian Flight 302 Crash: Mar 10th 2019

TRANSPO / AVIATION / TECH

Boeing finds another software problem on the 737 Max

/ It's at least the third flaw found since the plane was grounded last year

By Sean O'Kane

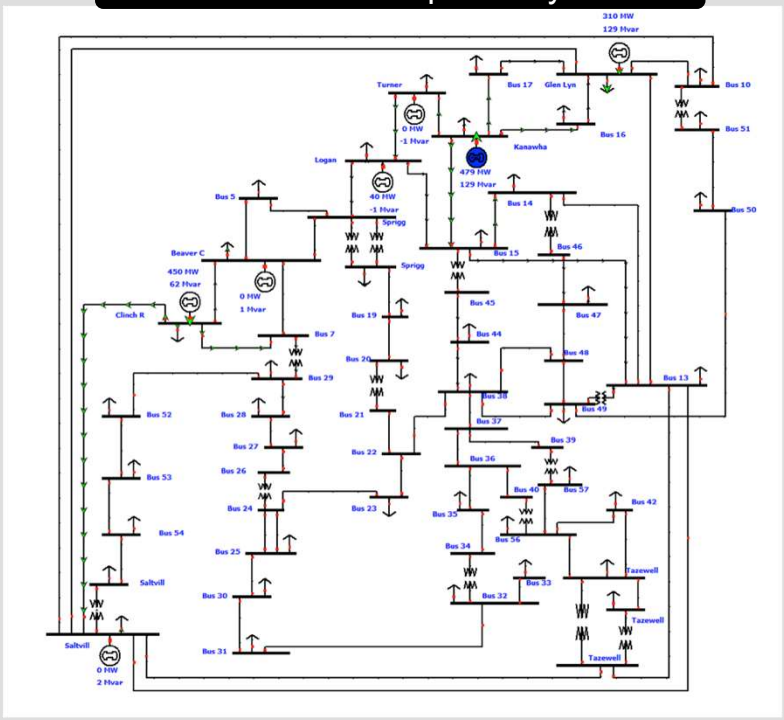
Feb 7, 2020, 2:42 AM GMT+9 | 0 Comments / 0 New

Inverter software realiability must be also tested

Software reliability: Long test campaign using HIL

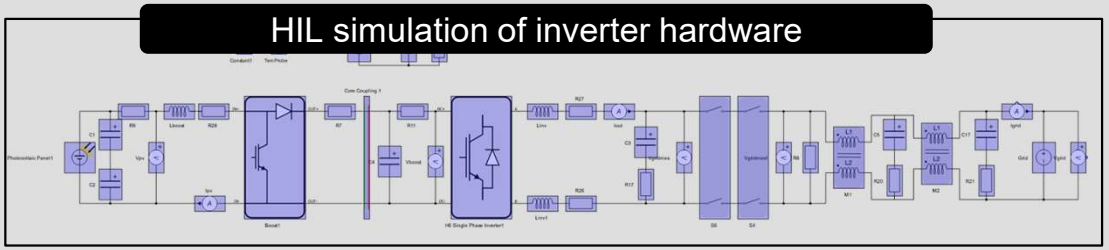
POWER SYSTEM

HIL simulation of power system

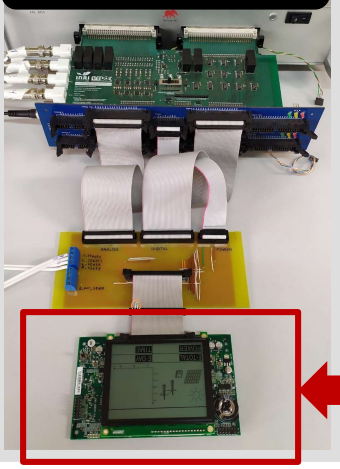


INVERTER ENVIRONMENT

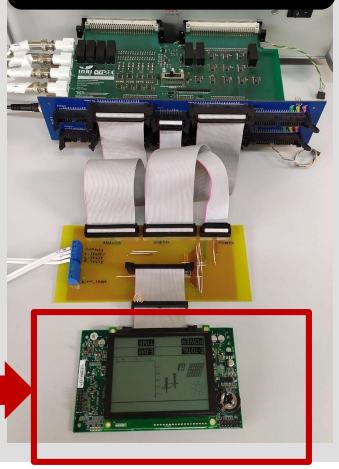
HIL simulation of inverter hardware



Real inverter control board



Real inverter control board



Inverter control board

Source: IEEE 57-bus system

4 Conclusions

Perspectives

Conclusions

FROM BRAZILIAN EXPERIENCE

High penetration of renewable generation on electric system → forward full energy transition

Some moments > 50% of energy from inverter-based resources

Power system → stability issues

New solutions must be developed to test inverter-based resources under fault conditions

Colaborative research

ENVIRONMENTAL ASSESSMENT DUE TO HIG PENETRATION OF INVERTER-BASED GENERATION

THE BRAZILIAN CASE

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michels@gepoc.ufsm.br
www.facebook.com/leandromichels.sm/
www.linkedin.com/in/leandro-michels/
www.instagram.com/leandromichels/