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Vulnerable Operation of Brazilian Northeastern System Under Hydric Crisis and Large Amount of Renewables

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Presentation summary

I. Introduction
II. Impact of the new energy matrix on the behavior of the northeast system
III. Inertia and grid frequency stability
IV. Alternatives to compensate for inertia losses
V. Ancillary services
VI. Brazilian Ancillary services under review
VII. Conclusions

Introduction

- Since the 1950s, hydroelectric energy generated in the falls of the São Francisco River has reached Brazil’s Northeast big cities.
- The load in this region is 17% of Brazilian load and was supplied by hydro plants in recent decades.
- In recent years, the increase in drought has forced regulatory organizations to drastically reduce the use of water, often limiting plants to operate with less than 20% of their capacity.

Hydroelectric power plant

Figure 1. Brazilian map.

Introduction

- Brazilian electrical grid is almost totally interconnected, this is a great advantage when we talk about hydric crisis.
- The need for more energy has increased the use of thermoelectric plants and renewable sources, especially wind and more recently, solar.

Hydroelectric power plant

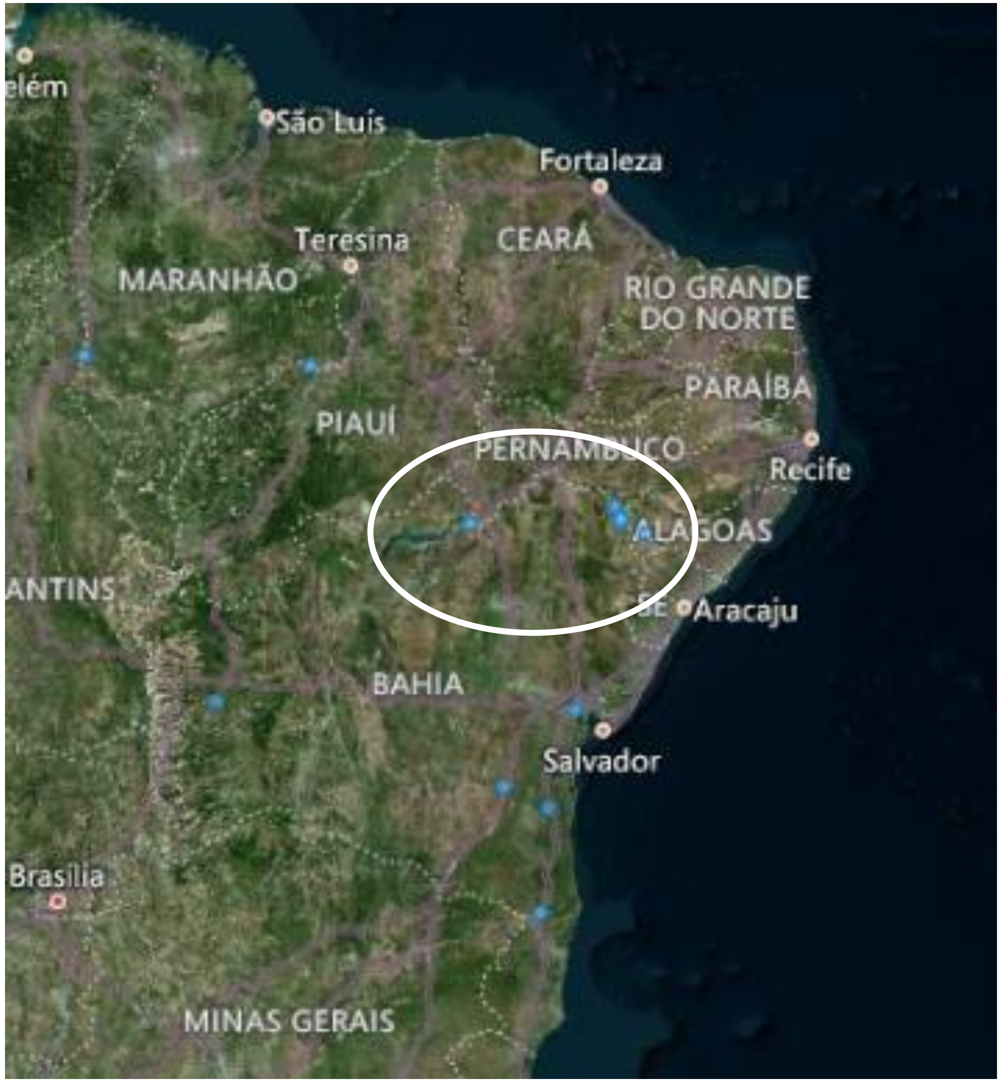
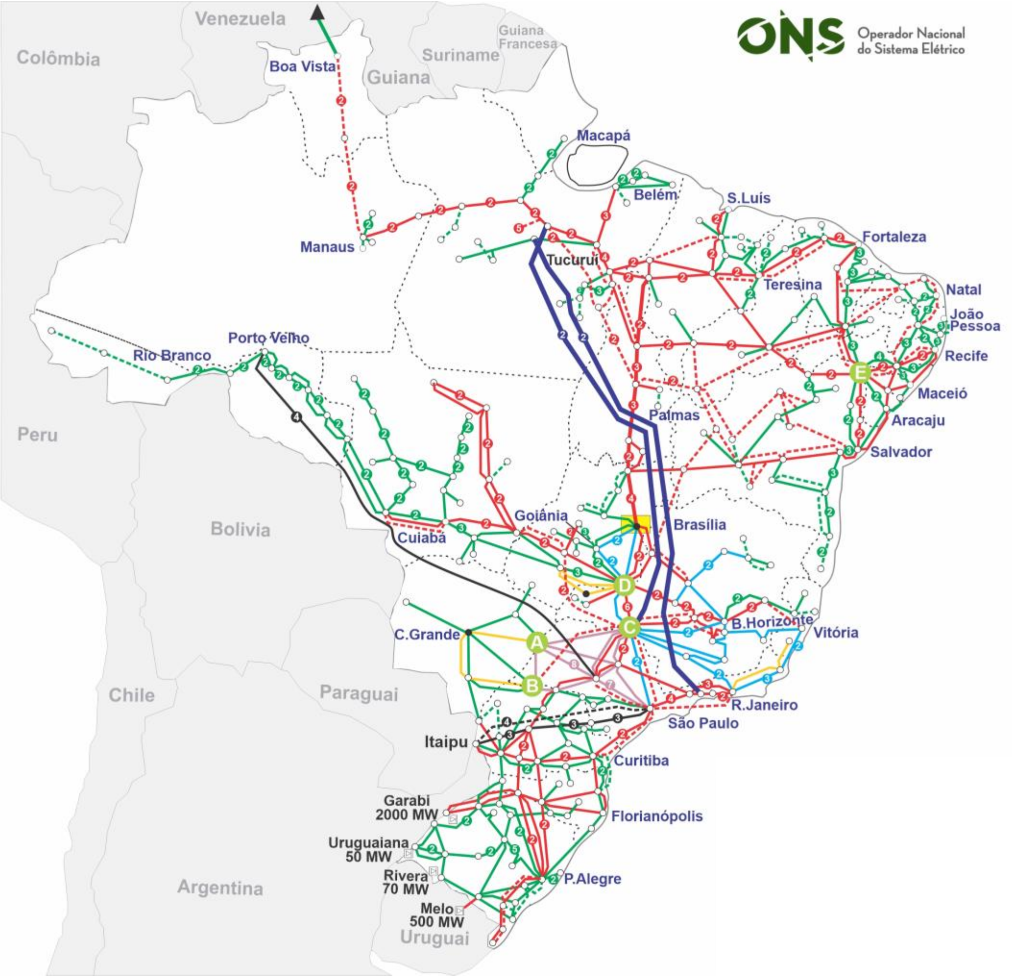


Figure 2. Northeastern map.

Introduction



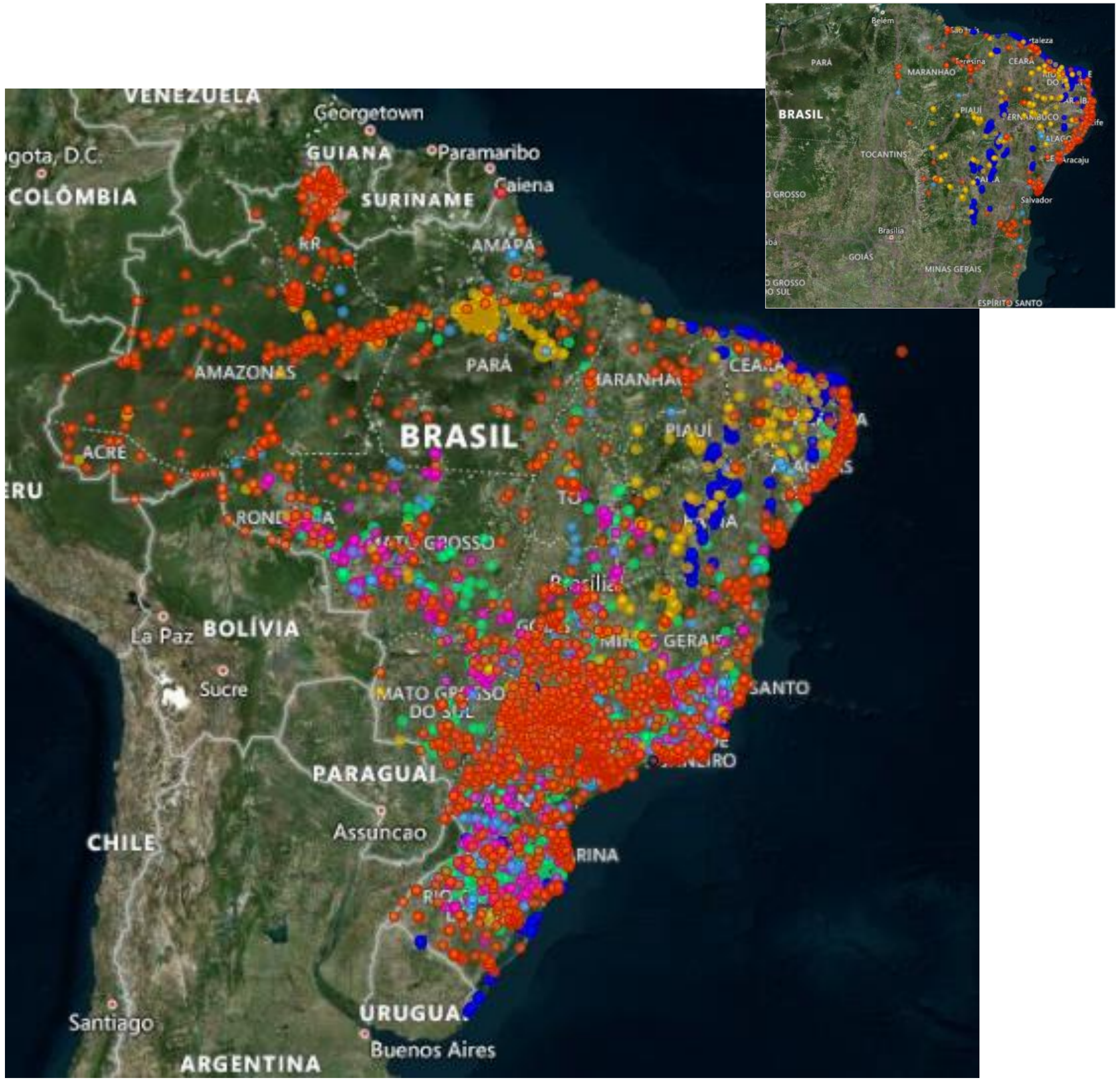
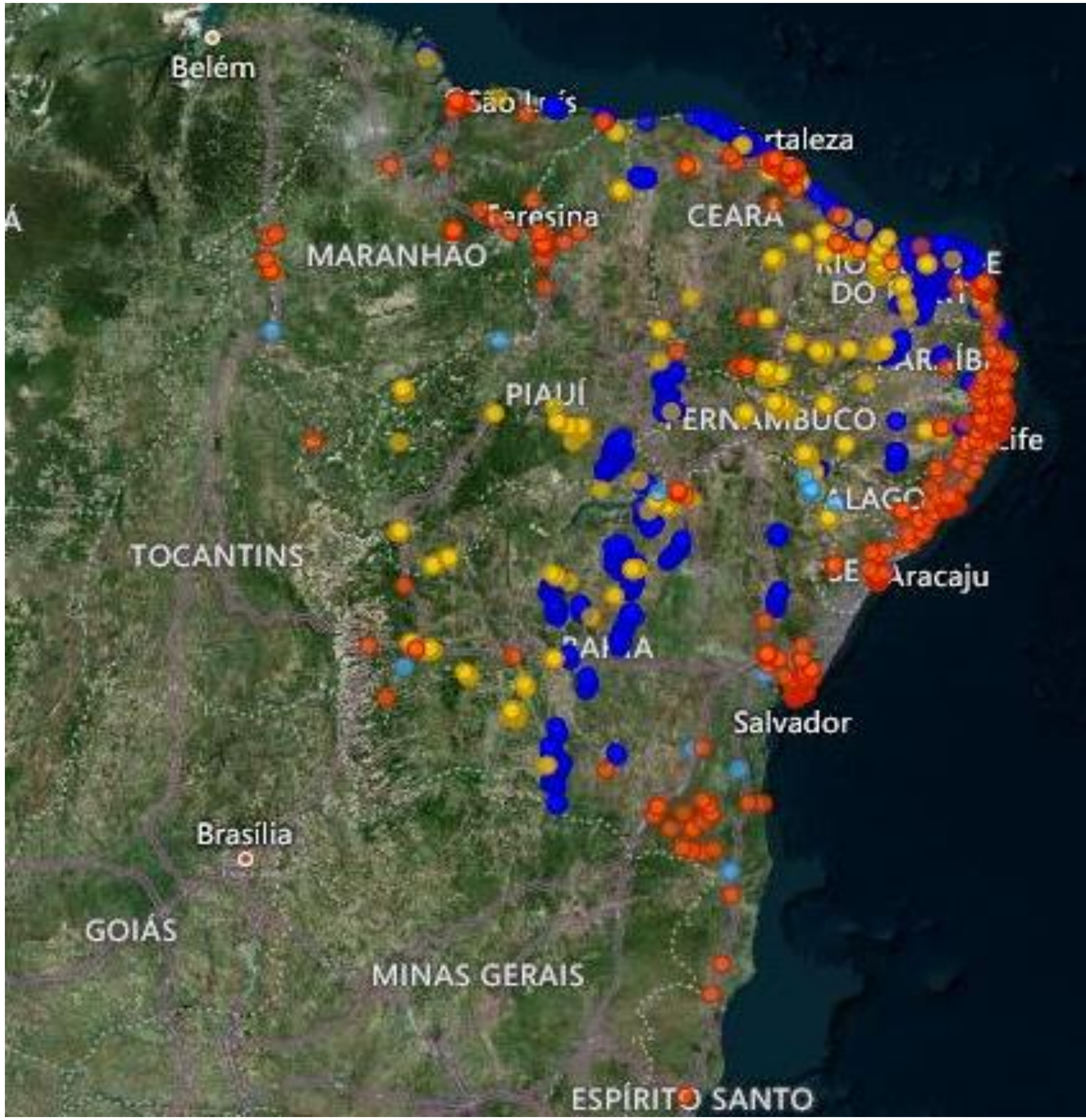


Figure 3. Brazilian electrical system maps.

Introduction

- What is the impact of the new energy matrix on the behavior of the electric system in Northeast region?
- What are the challenges faced by this new configuration in which hydroelectric plants operate with few machines and there is great penetration of wind and photovoltaic (PV) plants, reducing the mechanical inertia present in the grid?
- The problems are diverse, and the solutions are not unique.



Hydroelectric power plant
Wind power plant
Photovoltaic power plant
Thermoelectric power plant

Figure 4. Northeastern map with generations.

Impact of the new energy matrix on the behavior of northeastern system

- An analysis is made to demonstrate this growth in the last five years by calculating **energy penetration level**.

- Energy penetration is the ratio of the amount of energy obtained from the generation to the total energy consumed in the power system, normally on an annual basis. It can be calculated according to (1) with data extracted from Brazilian Transmission System Operator (TSO).

$$Energy\ penetration = \frac{Total\ energy\ produced\ (Wh)}{Total\ energy\ consumption\ (Wh)} x100\% \quad (1)$$

Impact of the new energy matrix on the behavior of northeastern system

Month 2016	Wind energy (GWh)	PV energy (GWh)	Hydro energy (GWh)	Energy consumption (GWh)
Jan	892	2	2.157	7.147
Feb	1.490	2	1.913	6.935
Mar	1.565	2	1.954	7.740
Apr	1.856	2	1.746	7.292
May	1.903	2	1.840	7.500
Jun	2.215	2	1.741	7.080
Jul	2.684	2	1.803	7.112
Aug	2.822	2	1.809	7.207
Sep	2.879	2	1.766	7.125
Oct	2.783	2	1.842	7.509
Nov	2.667	2	1.776	7.334
Dec	2.318	2	1.752	7.488
Total	**26.074**	**24**	**22.099**	**87.469**

Table I . Wind, PV and hydraulic generation and energy load in the Northeast region (**2016**)

Month 2021	Wind energy (GWh)	PV energy (GWh)	Hydro energy (GWh)	Energy consumption (GWh)
Jan	4.960	344	2.400	8.751
Feb	3.141	278	1.971	7.876
Mar	3.547	374	2.110	8.484
Apr	3.968	375	2.477	8.056
May	4.839	412	2.473	8.116
Jun	5.244	438	2.172	7.866
Jul	6.647	435	2.035	8.135
Aug	7.543	446	2.142	8.283
Sep	7.087	619	2.974	8.541
Oct	6.524	603	2.389	8.983
Nov	5.173	578	2.469	8.586
Dec	5.304	542	2.355	8.368
Total	**63.977**	**5.444**	**27.697**	**100.045**

Table II. Wind, PV and hydraulic generation and energy load in the Northeast region (**2021**)

Impact of the new energy matrix on the behavior of northeastern system

Table III. Summary of energy penetration.

Year	Wind (%)	PV (%)	Hydroelectric (%)
2016	29.8	0.02	25.3
2021	63.9	5.44	27.7

- Thermoelectrical energy penetration was also calculated and is 27.2% since 2016. It increased at same rate of consumption.

- Comparing the two scenarios with a difference of only five years, a drastic change can be seen in relation to the amount of energy generated from wind and solar sources.
- It is noted that consumption remained with a natural increase over time and hydraulic generation had a slight increase.
- It is noteworthy that the data presented are exclusively from the northeast region of the country.

Impact of the new energy matrix on the behavior of northeastern system

- With this brief comparison of scenarios, it is possible to understand the challenges that the electrical system faces.

- In proportion to what is generated, there are fewer machines operating in hydroelectric plants and with this there is a reduction in mechanical inertia and in the possibilities of control as well.

- The presence of thermoelectric plants is relevant in the Brazilian electrical system, especially those that depend on fossil fuels.

Impact of the new energy matrix on the behavior of northeastern system

- With the high level of penetration of variable renewable energy comes concerns about flexibility of operation.

- Flexibility of operation is the ability of a power system to respond adequately to change in demand and supply.

- Flexibility is especially prized in power systems with higher levels of grid connected variable renewable energy, primarily, wind and solar.

Impact of the new energy matrix on the behavior of northeastern system

- According to the generation level, the flexibility of the system changes and needs different approaches.

- Northeast would be on phase 4
    - System export energy to other regions

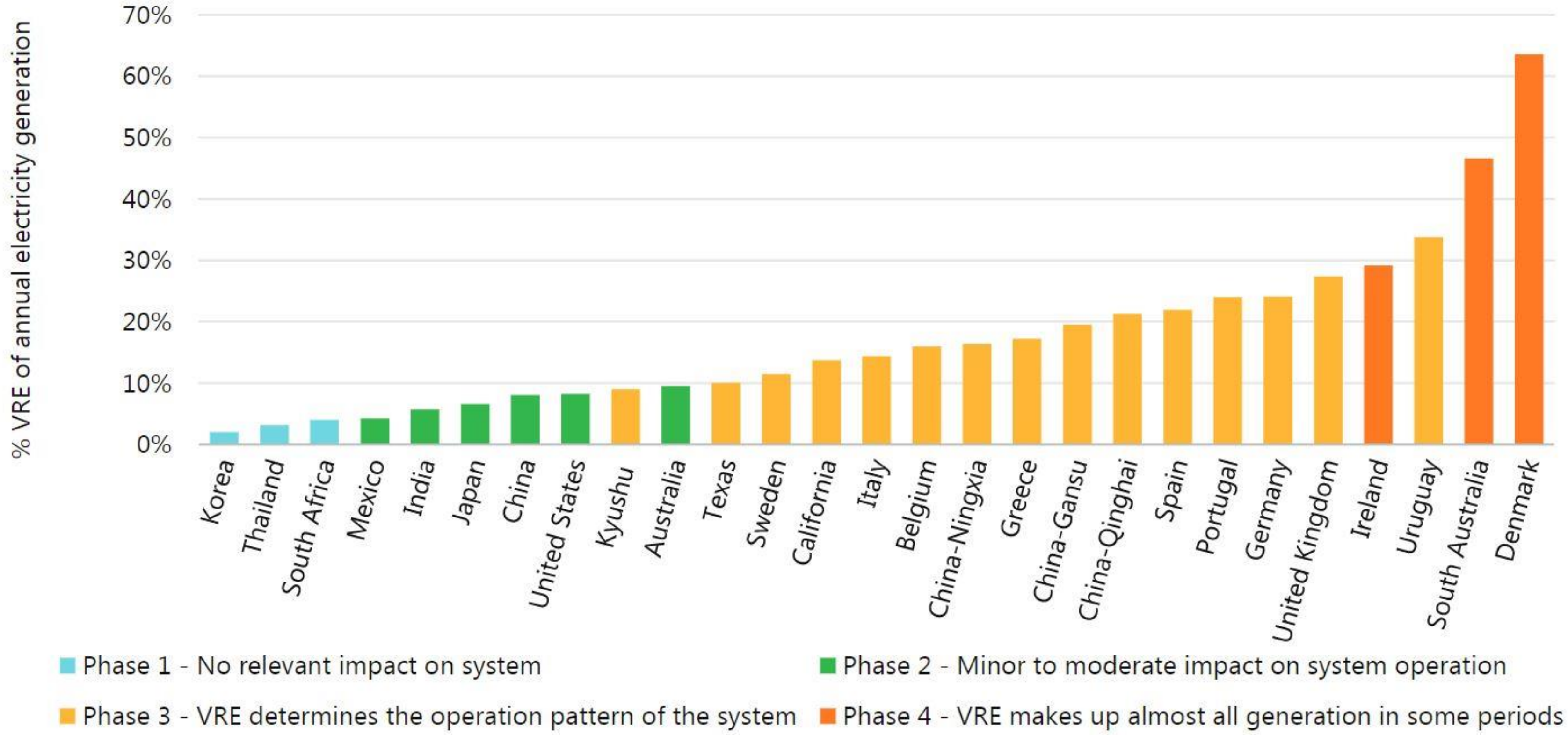


Figure 5. Annual VRE share and corresponding system integration phase in selected country/region, 2018.

Impact of the new energy matrix on the behavior of northeastern system

From what was stated, it is possible to highlight some vulnerabilities of the system:

- Hydroelectric plants operating under hydric crisis and proportionally with few machines.
- Use of fossil fuel powered thermoelectric plants.
- Reduction of mechanical inertia in the electrical system (large presence of RES).
- Problems arising from low inertia in the electrical system.

Inertia and grid frequency stability

- Inertia is only one of several grid services that help maintain power system reliability.
- There is an interplay of inertia and the other services, particularly primary frequency response, which is largely derived from relatively slow-responding mechanical systems.
- The importance of inertia to a power system depends on many factors, including the size of the grid and how quickly generators in the grid can detect and respond to imbalances.
- A grid with slower generators needs more inertia to maintain reliability than a grid that can respond quickly.

Alternatives to compensate for inertia losses

- Using power electronics, inverter-based resources including wind, PV, and storage can quickly detect frequency deviations and respond to system imbalances.
- Electronic-based resources for this fast frequency response can enable response rates many times faster than traditional mechanical response from conventional generators, thereby reducing the need for inertia.
- Replacing conventional generators with inverter-based resources, including wind, PV, and certain types of energy storage, has two counterbalancing effects.
  - First, these resources decrease the amount of inertia available.
  - But second, these resources can reduce the amount of inertia needed - and thus address the first effect.

Alternatives to compensate for inertia losses

- Alternative technologies such as synchronous condensers, pumped hydroelectric energy storage, compressed air energy storage, flywheels and batteries, and ultra-capacitors can provide the required fast response to balance the power.
- Also, literature review shows diverse techniques for inertia and frequency control form wind and PV power plants:
  - Wind power plant
    - Inertial response: droop control, fast power reserve and hidden inertia emulation.
    - De-loading technique: over speed control and pitch angle control.
  - PV power plant
    - De-loading technique
    - Using energy storage system (ESS)

Ancillary services

- Ancillary services are services provided to the system (transmission network) for the purpose of transporting the energy sold under conditions of quality, reliability, and safety.
- It is defined by each local TSO.
- Frequency control takes a very important role in these services, which are required from the power generation units to provide.

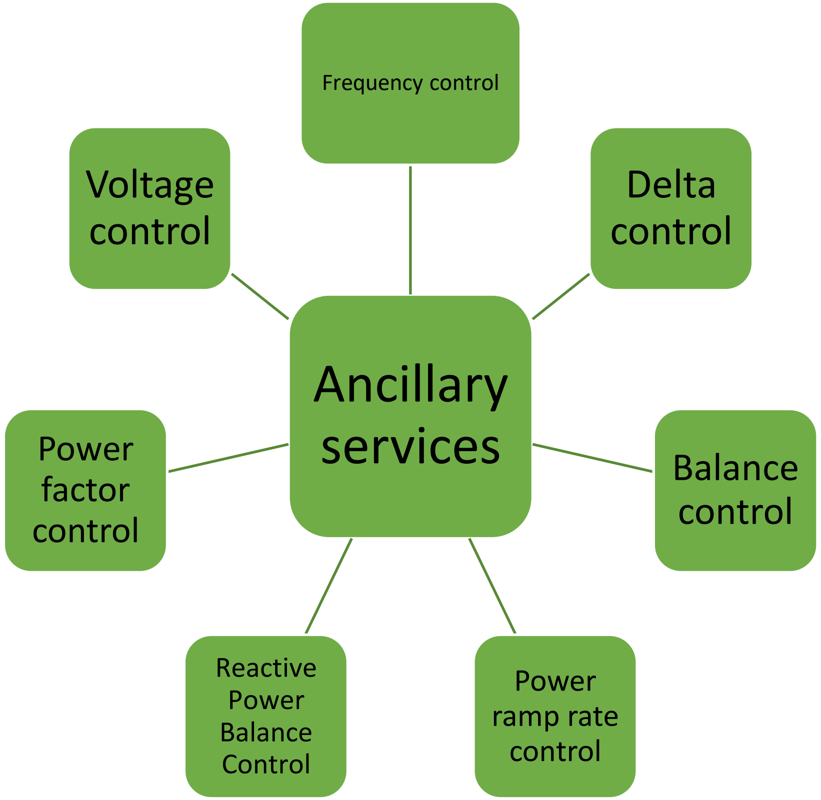


Figure 6. Basic ancillary services provided by power system generation

Brazilian Ancillary services

Local TSO grid codes and normative resolution establish the following ancillary services:

- **Self-recovery**: capacity of a generator to go from a total stop condition to an operating condition, contributing to the restoration of the electrical system.
- **Frequency control**: speed control of generating units to maintain or restore the system frequency when there is an imbalance between load and generation.
- **Reactive Support**: supply or absorption of reactive by generating units. Used for system voltage control.
- **Special Protection System**: comprises systems that, from the detection of risk to the electrical network, perform automatic actions to preserve the integrity of the national interconnected system.
- **Maintenance of operating power reserve**: thermoelectric dispatch to maintain water in the hydroelectric reservoir that provides frequency control.

Brazilian Ancillary services under review

- Brazilian electrical matrix has undergone transformations marked by the reduction in the regularization of hydroelectric power plant reservoirs and strong penetration of renewable sources with intermittent generation.
- The provision of services naturally imposes costs on systems, related to the implementation of additional equipment, operation and maintenance, fuel consumption and opportunity costs.
- The National Electric System Operator (ONS) promoted discussions to evaluate ways to increase the incentive to provide quality ancillary services, to identify the costs of delivery and to allocate costs efficiently.
- Discussions are about modifying existing ancillary services, cited before, and proposing new services.

Brazilian Ancillary services under review

A. Self-recovery: increase the incentive to avoid failures in real situations

B. Reactive support as a synchronous compensator

C. Other services for reactive support: creation of new services

- Remuneration for Photovoltaic plants to provide reactive support in periods with little or no light.
- Reactive support in Wind Power Plants when they are turned off.
- Remuneration for time in operation outside the allowed range in generating units.
- Reactive support in the distribution network.
- Payment for service availability.

Brazilian Ancillary services under review

D. Secondary frequency control: change the remuneration methodology to encourage greater service availability

E. Inertia as ancillary service

- Implementation of equipment for the provision of inertia to the system.
- Use of thermoelectric plants to increase inertia.

Conclusions

- Moving towards the expansion of renewable energy sources in the electrical matrix in addition to the existing and predominant hydro source, solar and wind sources have already been consolidated with accelerated expansion in recent years.

- Northeastern region stands out for having the most favorable conditions for these two sources in the country.

- Linked to the numerous advantages related to RES, there are the questions associated with low mechanical inertia due to sources connected to the grid by inverter-based technologies.

Conclusions

- Ancillary services can be an important source of revenue to enable new enterprises and to facilitate RES integration.
- These services are under review to precisely meet the demands of this new scenario, following the trend of encouraging the participation of all sources in the various controls of the network.
- With hydric crisis is mandatory to have another way to provide the services.

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