Blackout of the Iberian Peninsula April 28th 2025

Summary of Available Information

June 5th, 2025

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Agenda and Objectives

- Iberian/European Grid Context
- Confirmed April 28 Event Details
- System Restoration Details
- Potential Influencing Factors

Disclaimers

- Publicly available information only
- Data from public data systems during and after the event may be determined to be inaccurate and subject to change
- **Highly limited ability to draw conclusions at this stage due to lack of confirmed data**

We will not speculate on unconfirmed specifics of this event.
The investigation is on-going, and further information is expected to be made available in time.

Iberian & Continental European Systems Background

Spain

Population (Peninsular)
~44M

Peak Load
~45 GW (2007)

Transmission System Operator
Red Electrica de Espana (REE)

Grid Size:
~25,000 miles of 400 kV and 220 kV network

Generation Type	Installed capacity [GW]
Solar PV	32
Wind	31
Gas – CCGT	24
Hydro	17
Nuclear	7
Combined Heat & Power	5.5
Pumped storage	3.3
Solar thermal	2.5
Coal	1.8
BESS	0.023
Total	**>125**

50 Hz

Continental European Synchronous System

https://openinframap.org/#6.05/40.289/3.057

Portugal

Population
~11M

Peak Load
~9 GW (2009)

Transmission System Operator
Redes Energeticas Nacionais (REN)

Grid Size:
~6,000 miles of 400 kV, 220 kV and 150 kV network

Generation Type	Installed capacity [GW]
Hydro	8.3
Wind	5.4
Gas – CCGT	4.4
Solar PV	3.9
Pumped storage	3.6
BESS	0.01
Total	**>25**

https://datahub.ren.pt/en/networks/electrical-grid/

50 Hz

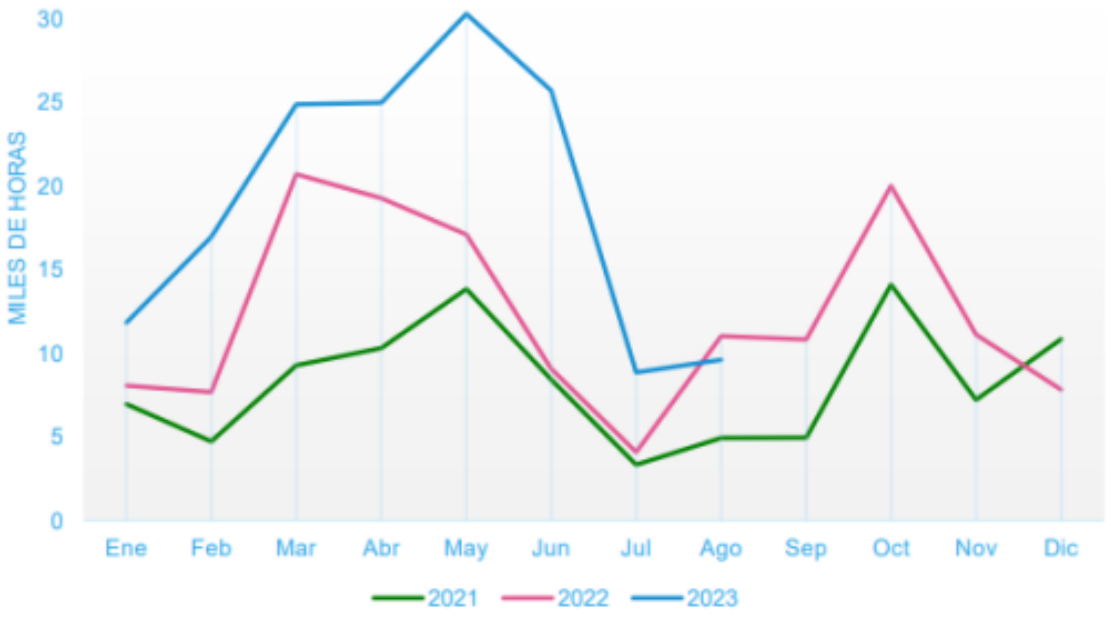
Continental European Synchronous System

https://openinframap.org/#6.05/40.289/3.057

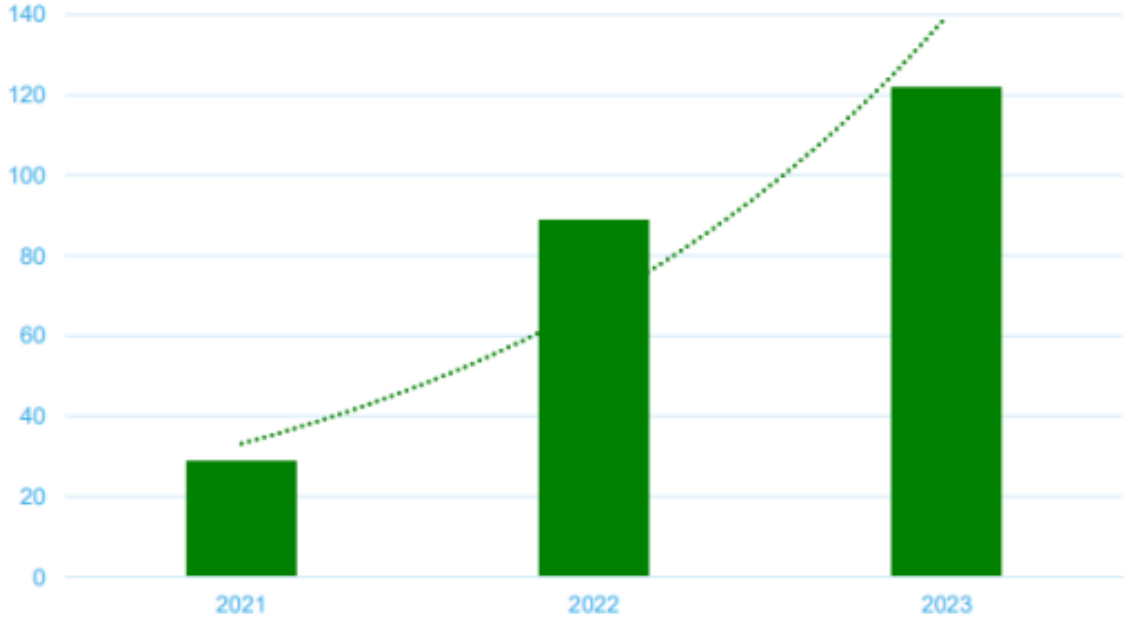
Voltage Control Spain

Most renewable generation in Spain operates in fixed power factor control mode.
Voltage control capability has been required for many years, but not used.
The system operator is scheduled to start using it from Q4-2025

Number of hours with voltage above 240 / 420 kV at a substation



Number of power plants tripped by overvoltage protection

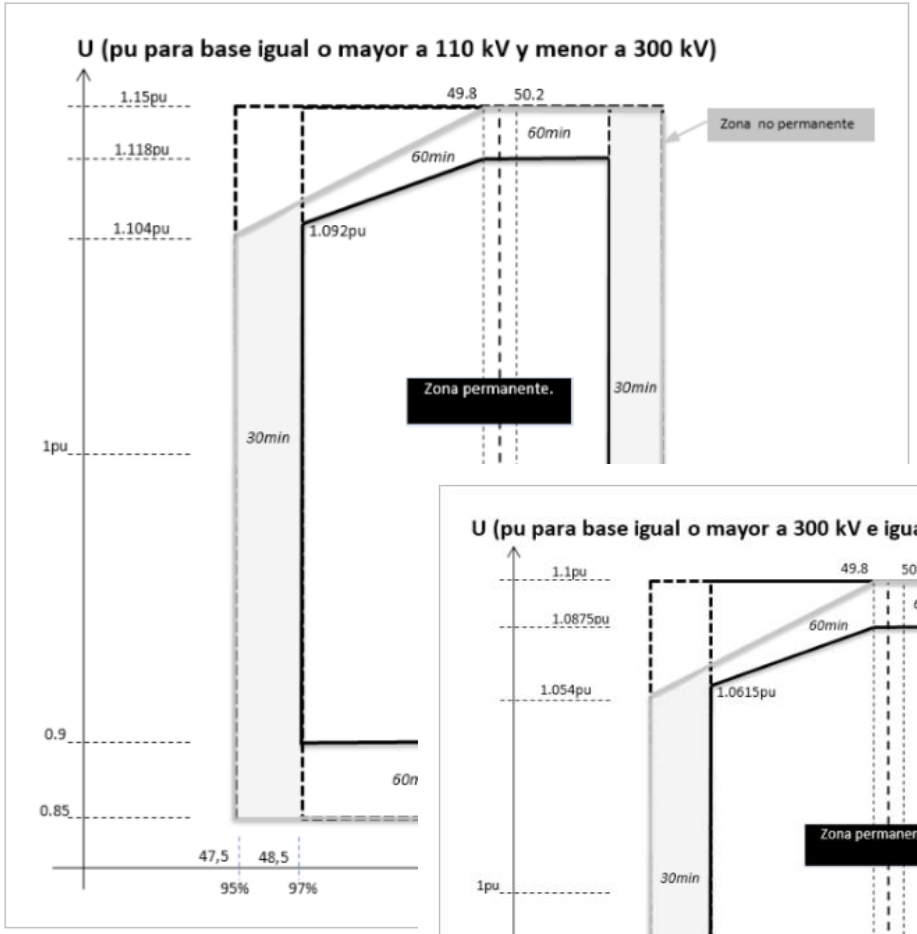


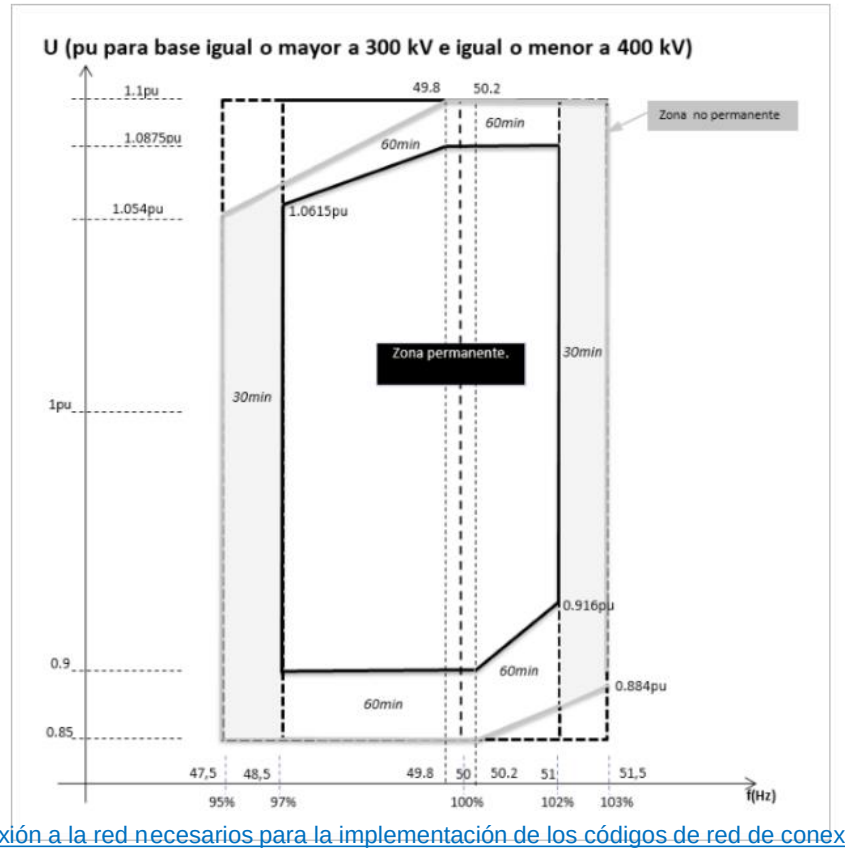
Why overvoltages? Improving load power factor.
Regional solar PV means 400 kV grid is very lightly loaded

Sources:
PO_resol_10mar2000_correc.pdf P.O. – 7.4
https://www.boe.es/buscar/act.php?id=BOE-A-2007-10556 Real Decreto 661/2007, de 25 de mayo, por el que se regula la actividad de produ
CIGRE Jornadas Technicas, 2023, PABLO MARTÍNEZ-FRESNEDA CERECEDA, REE

Voltage Ride-Through

- Most IBR overvoltage protection set to trip like:
  - <400kV: ~1.16pu for ~1 second
  - 400kV: ~1.11pu for ~1 second
  - ~1.2pu for ~0.2 seconds





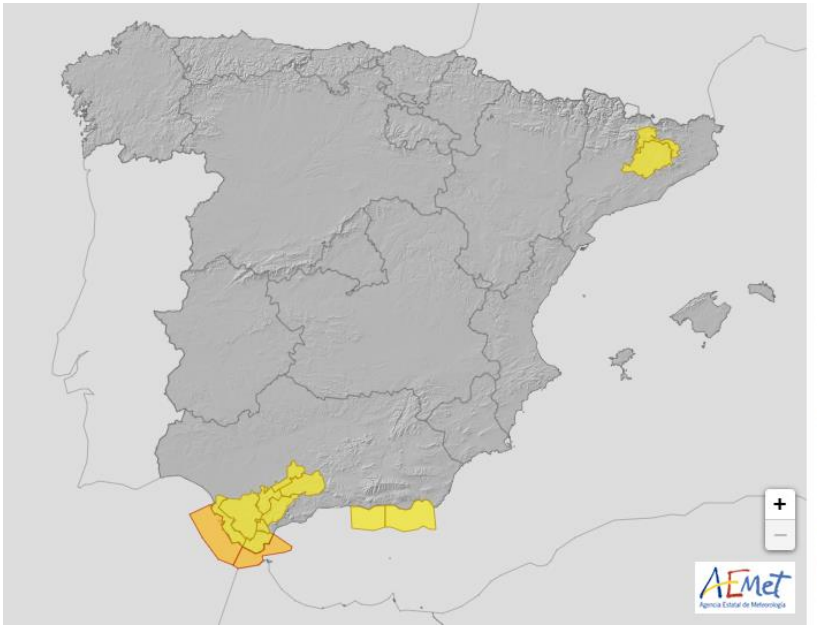
BOE-A-2020-8965 Orden TED/749/2020, de 16 de julio, por la que se establecen los requisitos técnicos para la conexión a la red necesarios para la implementación de los códigos de red de conexión.

Pre-Disturbance

Pre-Disturbance System Conditions

- **Demand:** **~28 GW** /45 GW_{peak} **~7.7 GW** /9 GW_{peak}
  - DER output not published
  - 25 GW IBR/37 GW total production (66%)
- **Weather conditions:**
  - Sunny, no rain, high winds in south
- **Outage season underway**
  - Several generation units on seasonal outage
  - Many lines out of maintenance/upgrades
- **Reserves**
  - Sufficient reserve for 2 GW event (2x Nuclear units)
  - Plenty of inertia as many sync gens were at min load

Weather advisories active before event (source: AEmet)



Recent Changes:

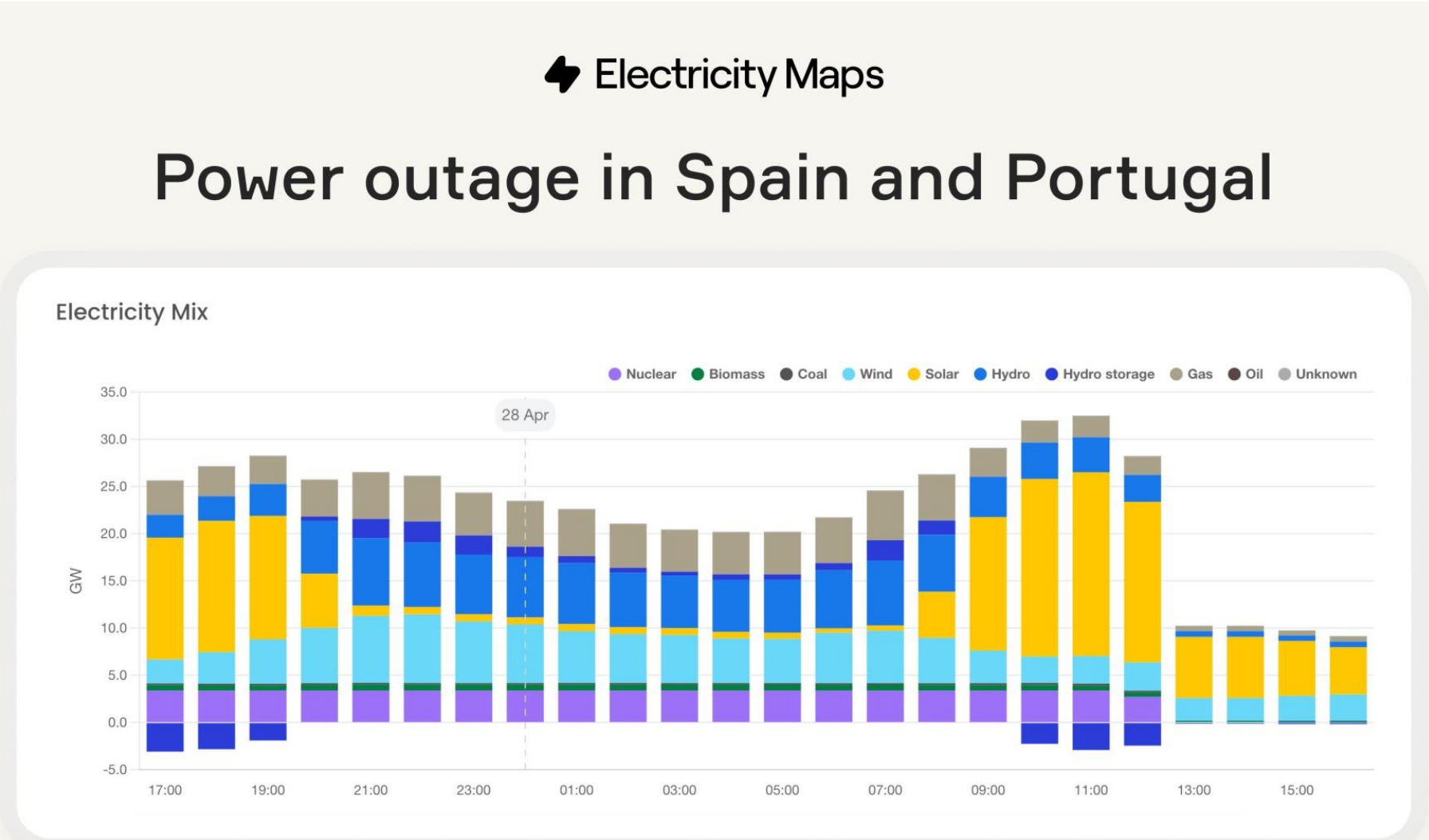
February 8: Baltic countries synchronized to the North-East of the continental EU grid +10GW

March 18: Spain switched from hourly to 15-minute intra-day markets

Pre-Disturbance Dispatch (Portugal plus Spain)

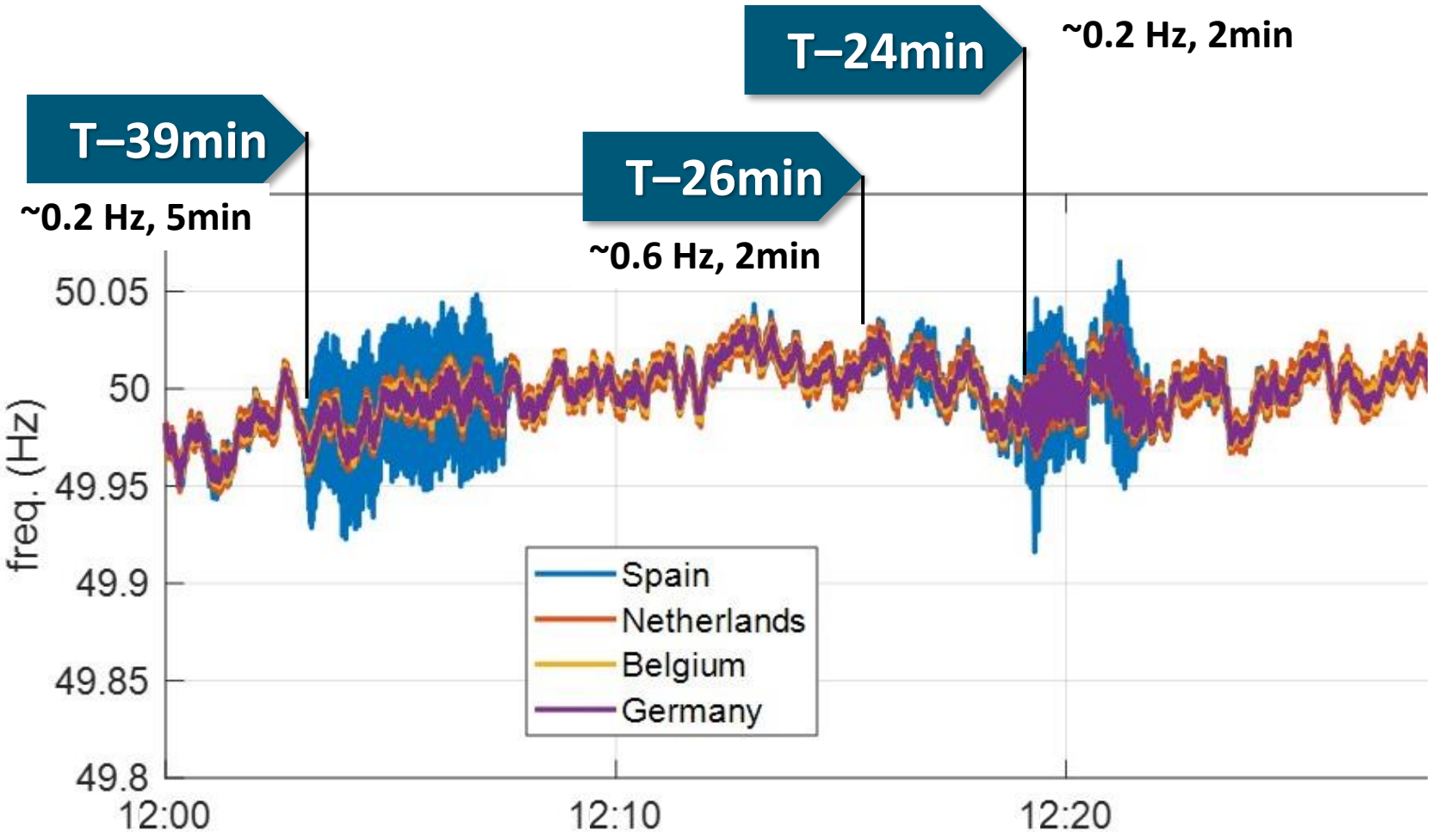
Values based on ENTSO-E Transparency Platform https://transparency.entsoe.eu

Plant	Output (GW)
Solar PV	20.1
Solar thermal	1.0
Wind	4.7
Hydro	4.5
Nuclear	3.4
Gas, coal, biomass	2.8
Pumped Hydro	**-5.0 (pumping)**
Spain to France	1.0
Spain to Morocco	0.8
Spain to Portugal	2.3
Total Production	37.5
Iberian Demand	**30.7**
IBR/Total Gen	**66%**



Event Details

Inter-area Oscillations



Possible Operator Actions:

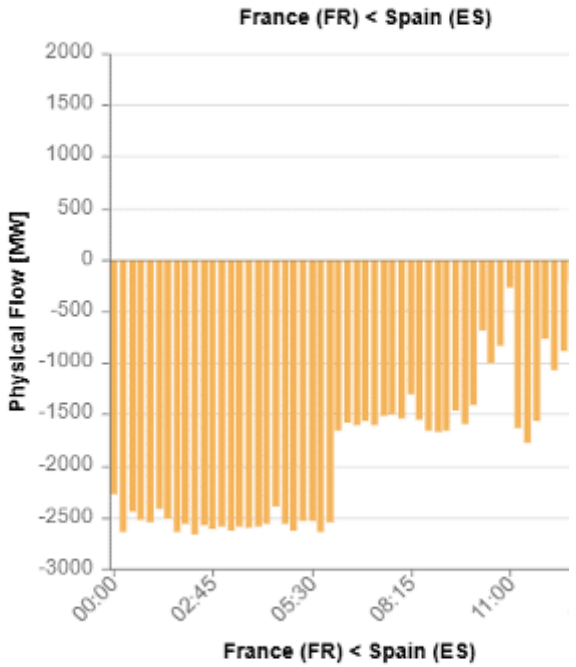
- Re-dispatch plants
- Counter-trades
- Switched HVDC to fixed P (HVDC normally operates in AC-line-emulation mode)
- Switching lines back in

Comment:

- Looks like operator actions might have mitigated the oscillations?

Source: **UTK FNET/GridEye**

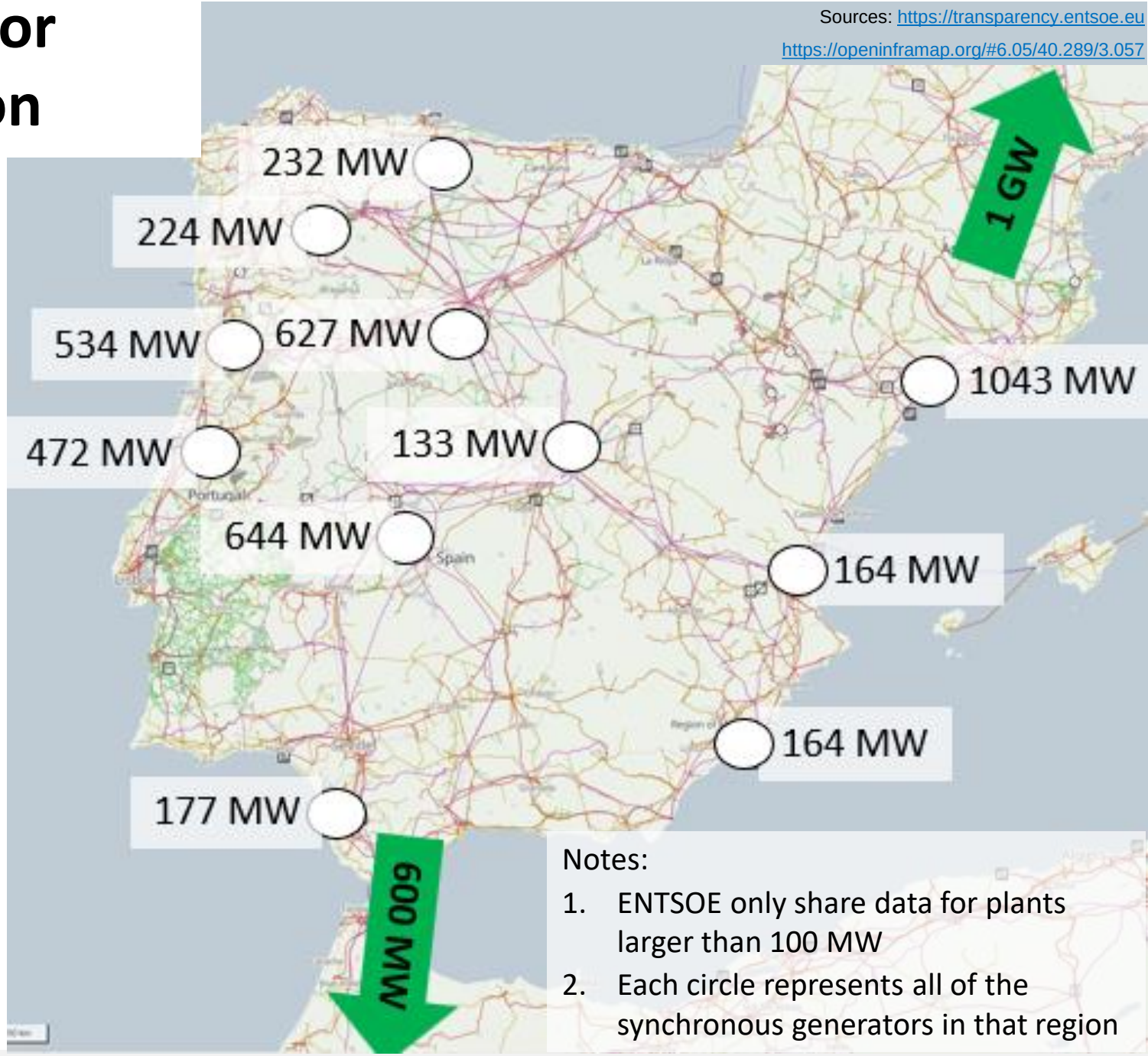
Map of Synchronous Generator Output at 12:00 in Each Region



Market & System operator trades

Note that in March, day-ahead trade intervals changed from hourly to 15-minute.

Sources: https://transparency.entsoe.eu
https://openinframap.org/#6.05/40.289/3.057



Notes:

1. ENTSOE only share data for plants larger than 100 MW
2. Each circle represents all of the synchronous generators in that region

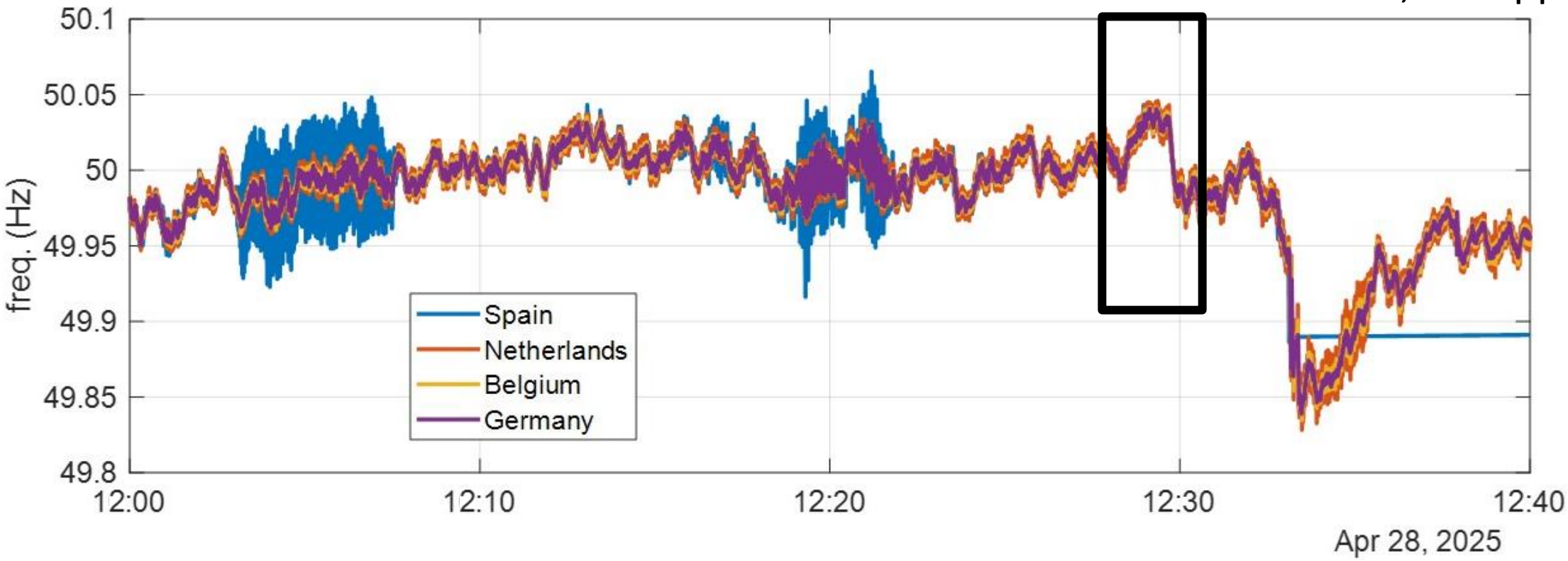
Inter-Area Oscillations Mitigation Actions

France – Spain HVDC switched from AC line emulation to fixed P

Source: https://www.youtube.com/live/RxWztgbxeOo

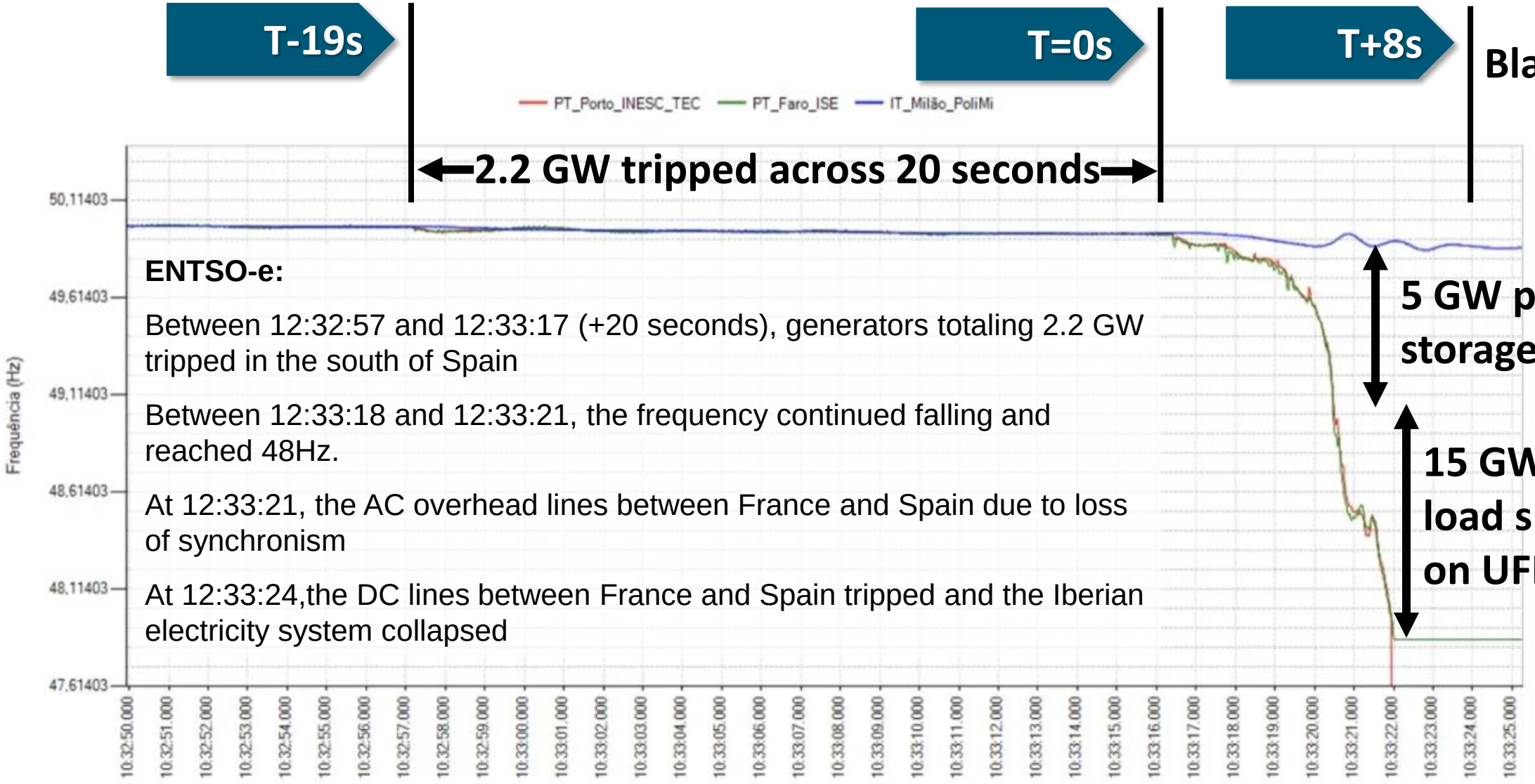
Noticeable frequency step-change at 12:30

ΔFrequency: ~0.05 Hz
May be market interval effect, curtailment, or tripping



Source: **UTK FNET/GridEye**

Evolution of the Event: Frequency in Portugal



ENTSO-e:

Between 12:32:57 and 12:33:17 (+20 seconds), generators totaling 2.2 GW tripped in the south of Spain

Between 12:33:18 and 12:33:21, the frequency continued falling and reached 48Hz.

At 12:33:21, the AC overhead lines between France and Spain due to loss of synchronism

At 12:33:24,the DC lines between France and Spain tripped and the Iberian electricity system collapsed

5 GW pumped storage should trip

15 GW customer load should trip on UFLS

Note: UTC is -2hours from the time in Spain

Sources: https://www.rinnovabili.net/environment/scientific-reports/spain-blackout-renewable-grid-warning/
https://www.entsoe.eu/news/2025/05/09/entso-e-expert-panel-initiates-the-investigation-into-the-causes-of-iberian-blackout/

Evolution of the Event

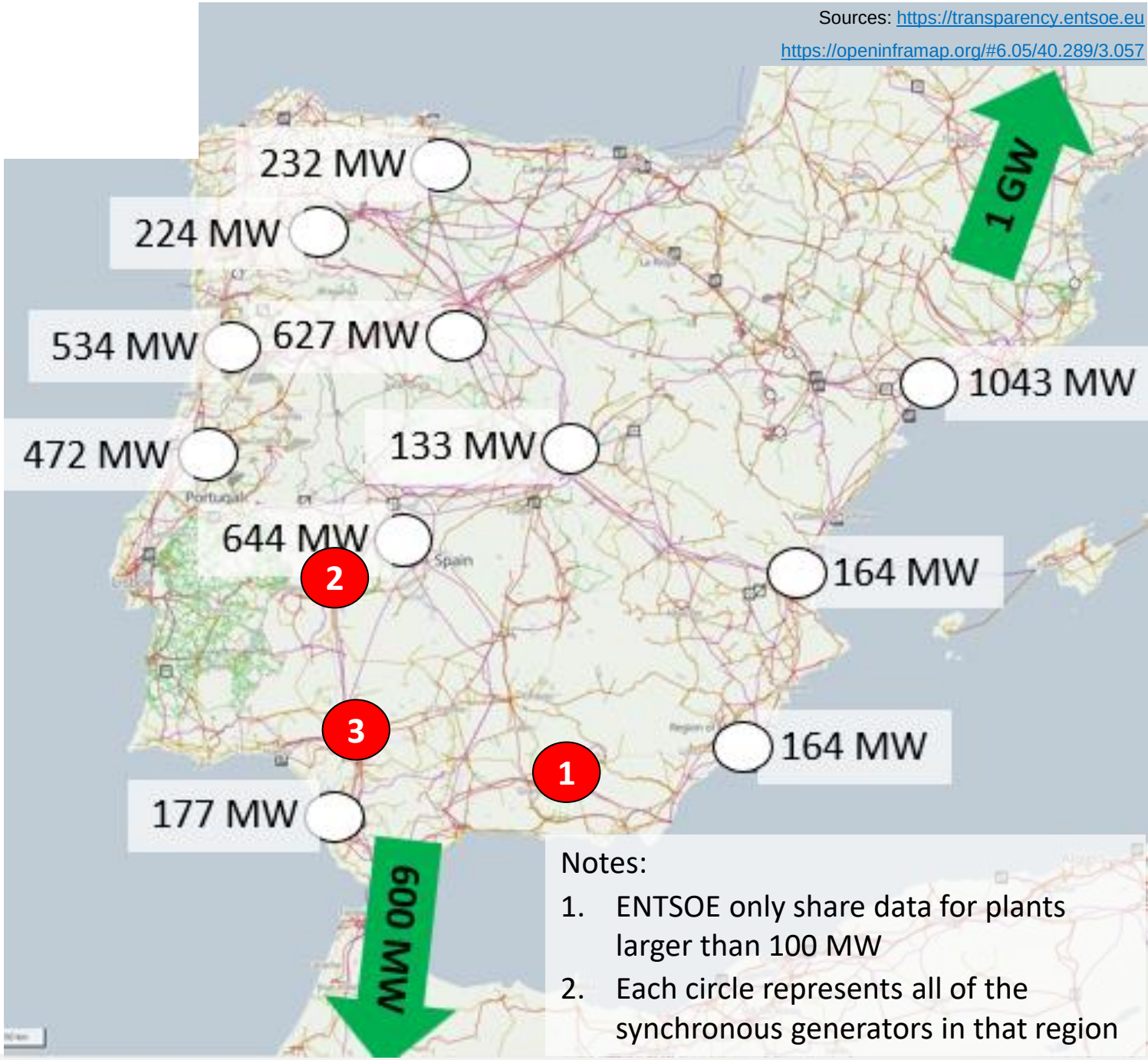
Initial 2.2 GW disconnected:

1. Granada
2. Badajoz
3. Seville

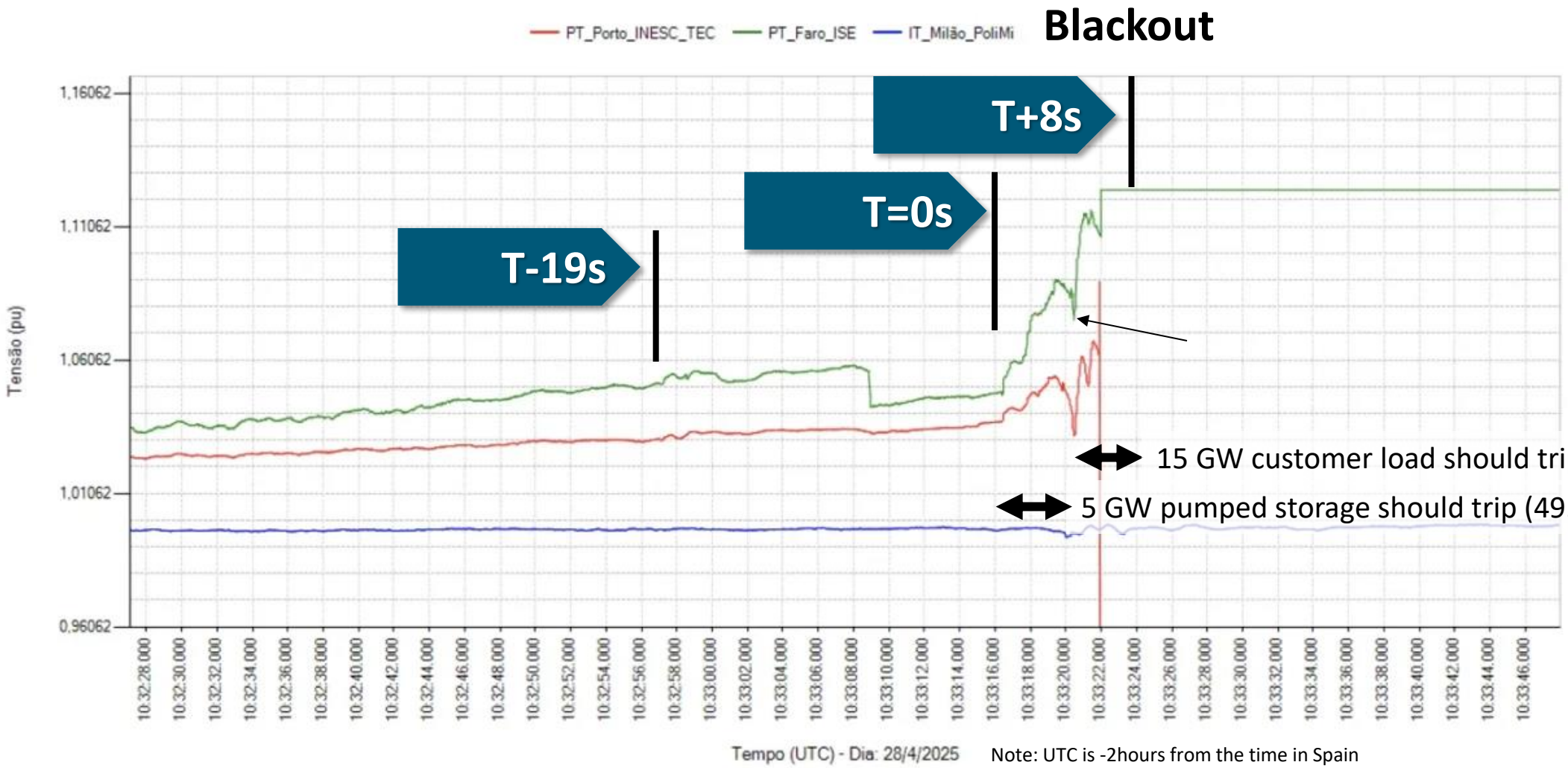
Only one sync gen (SG) left in the South

Next nearest sync gens:

- 250 miles North
- 440 miles East



Evolution of the Event: LV Voltage in Portugal



15 GW customer load should trip on UFLS (49 - 48 Hz)

5 GW pumped storage should trip (49.8 - 49 Hz)

Note: UTC is -2hours from the time in Spain

Sources: https://www.rinnovabili.net/environment/scientific-reports/spain-blackout-renewable-grid-warning/

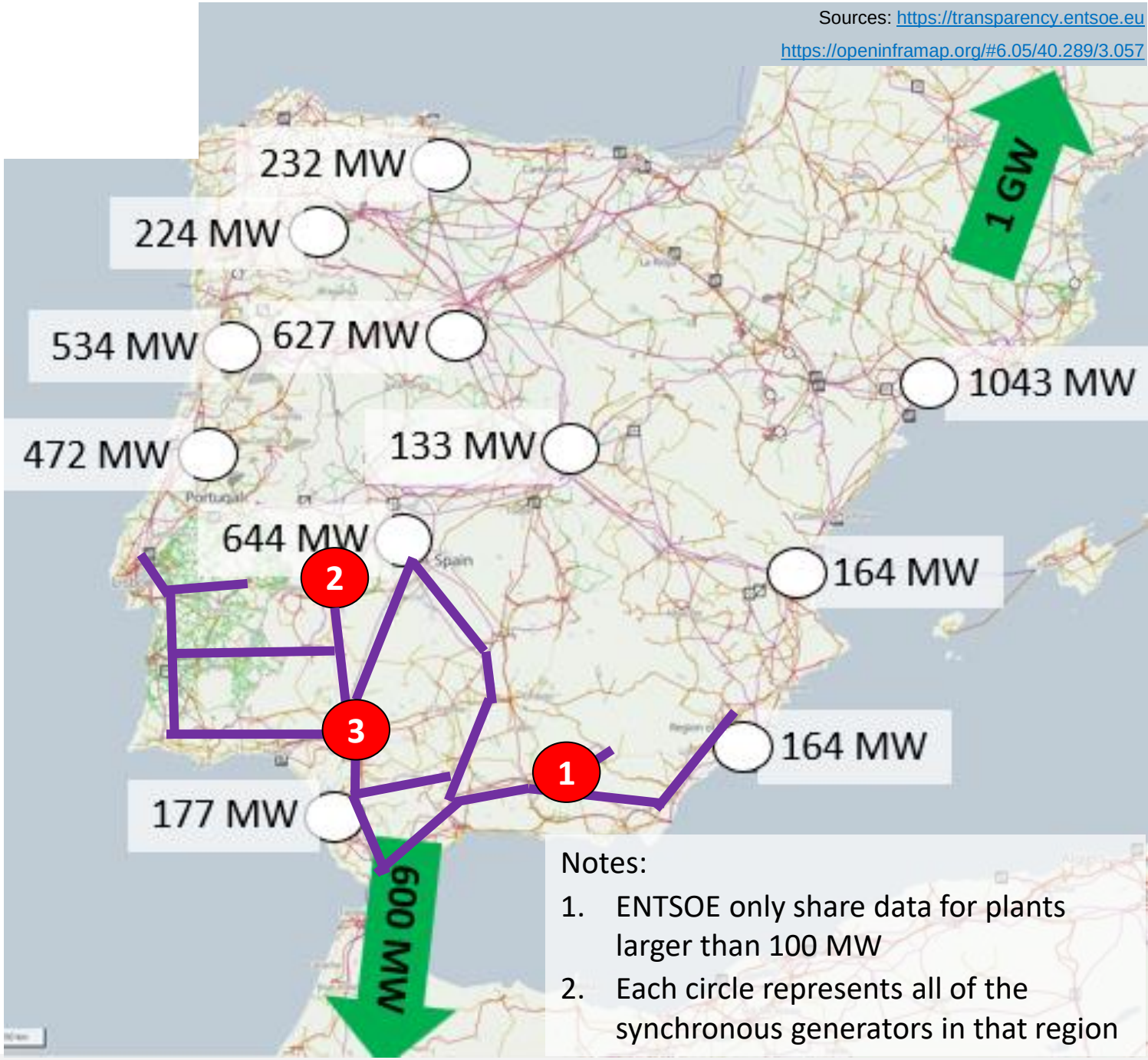
Evolution of the Event

Initial 2.2 GW disconnected:

1. Granada
2. Badajoz
3. Seville

Notes:

- Many long 400 kV lines



Red Electrica Public Statements

- No transmission faults or abnormal conditions at 12:32
- Power plants did not provide expected reactive power

- **“Could REE have operated the system differently to avoid the consequence?”**
  - *“**No**. With the information that exists today, the operators are absolutely convinced that the actions taken were the correct ones complying with the established operating protocols.”*
  - *“Our network did not fail. The operation did not fail. There was no excess of renewables or shortage of synchronous power. It is also known that there was sufficient inertia, there was no short circuit, no overload, or cyberattack.”*

Source: https://www-lavanguardia-com.cdn.ampproject.org/c/s/www.lavanguardia.com/economia/20250528/10727221/beatriz-corredor-energias-convencionales-controlaron-tension-dia-apagon.amp.html

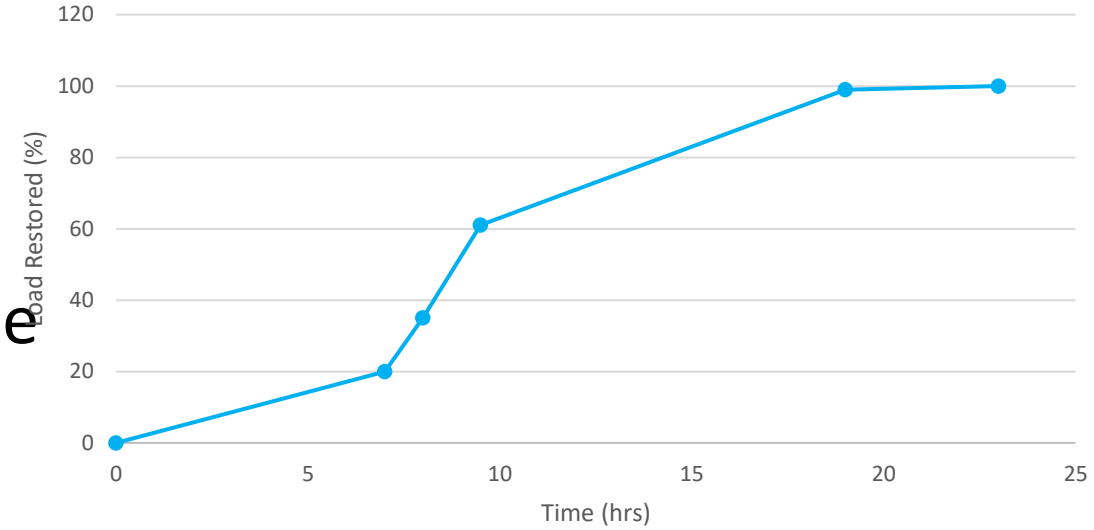
Restoration

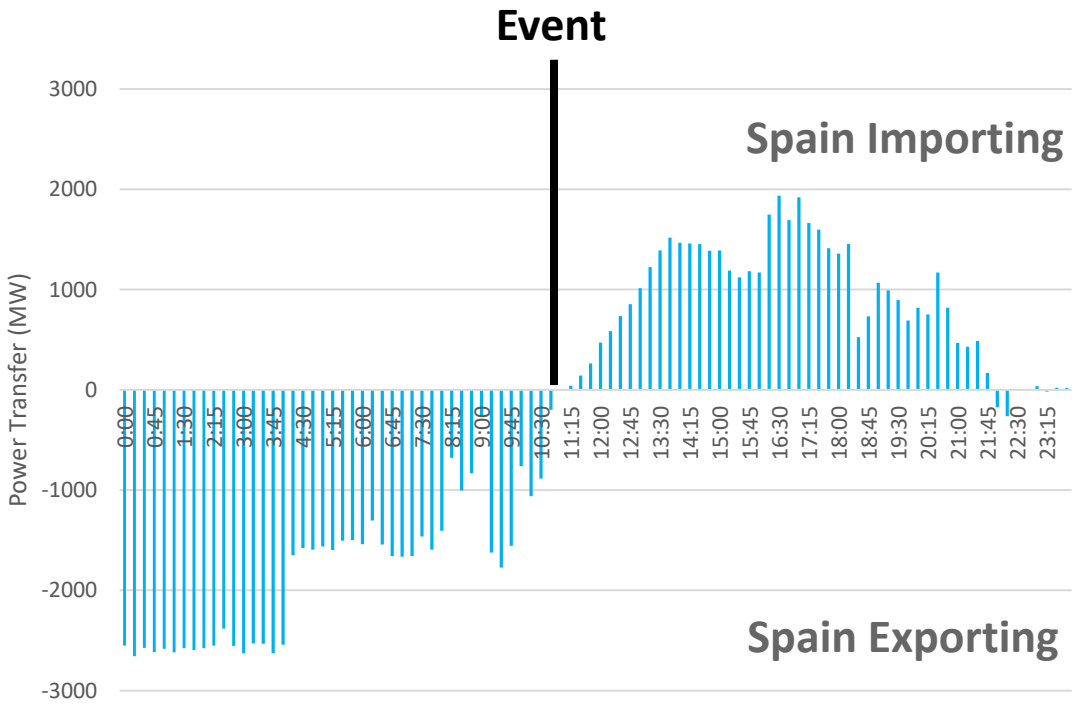
Spanish Grid Restoration

- Blackstart began at 12:44
- 0 to 1500 MW ramp on the ties from France
- Hydro units provided initial blackstart
- CCGTs later picked up

- **Transmission substations:**
  - **62%** of substations restored after **9.5 hrs**
  - **100%** of substations restored after **15.5 hrs**

- **Load fully restored after 23 hrs**

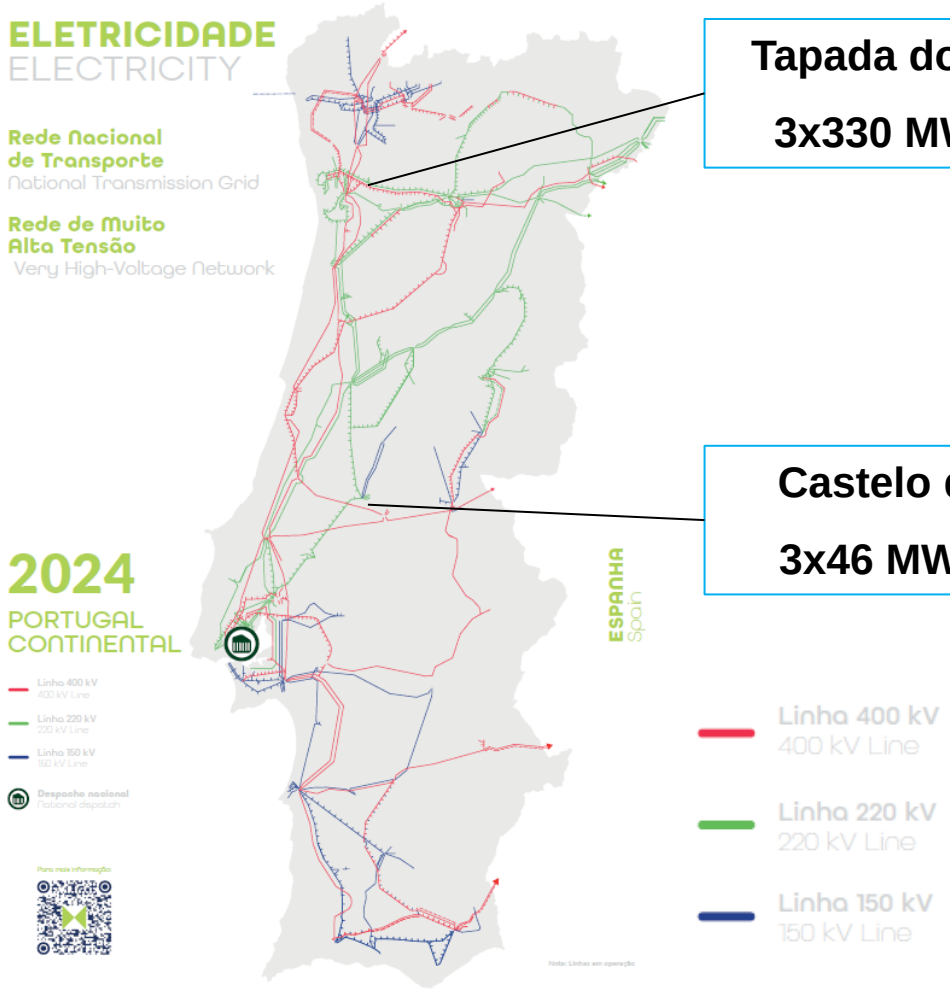




Sources: https://www.politico.eu/article/99-percent-spain-power-supply-restored-national-electric-system-says-blackout-portugal/

https://www.bbc.com/news/articles/c175ykvjxyeo

Portuguese Grid Restoration



Tapada do Outeiro

3x330 MW CCGT

Castelo de Bide

3x46 MW Hydro

- Blackstart began within minutes
- 3xCCGT and 3xhydro units
- **First two blackstart attempts failed**
- Plants successfully started at 16:11 and 17:26 respectively

- **Transmission substations:**
  - **96%** of substations restored within **10.5 hrs**

- **Load Restoration:**
  - **12 hrs to 100%** load restored

Source: https://www.ren.pt/en-gb/media/news/national-grid-stabilised

https://www.entsoe.eu/news/2025/05/09/entso-e-expert-panel-initiates-the-investigation-into-the-causes-of-iberian-blackout/

Factors to Consider in the Context of Events like the April 28 Blackout

Factors Potentially Influencing the Event

Factors for Consideration	Potential Influence
Voltage Control	Insufficient reactive capability, or capability at limits could risk cascade tripping. UFLS and IBR tripping can increase grid voltage, accelerating cascade overvoltage tripping
Protection Coordination	Insufficient voltage protection coordination may result in simultaneous tripping of large numbers of power plants. Coordination of UFLS and overvoltage protection.
Oscillations	Undamped oscillations can result in abnormal voltage and frequency that drive protection trips. Operator mitigation actions may impact grid resiliency
Synchronizing Torque	Reduced torque increases potential for oscillations and loss of synchronism. Operating plants at min load or switching lines out for voltage control may reduce torque.
Ride Through Capability	Power plant protection and controls may not meet required performance.
Inertia	Reduced inertia can lead to higher rate of change of frequency and loss of synchronism.

The extent to which any of these factors contributed to the April 28 event is unknown. Many challenges were happening simultaneously: voltage, oscillations, market trades

General Considerations for Evolving Grids

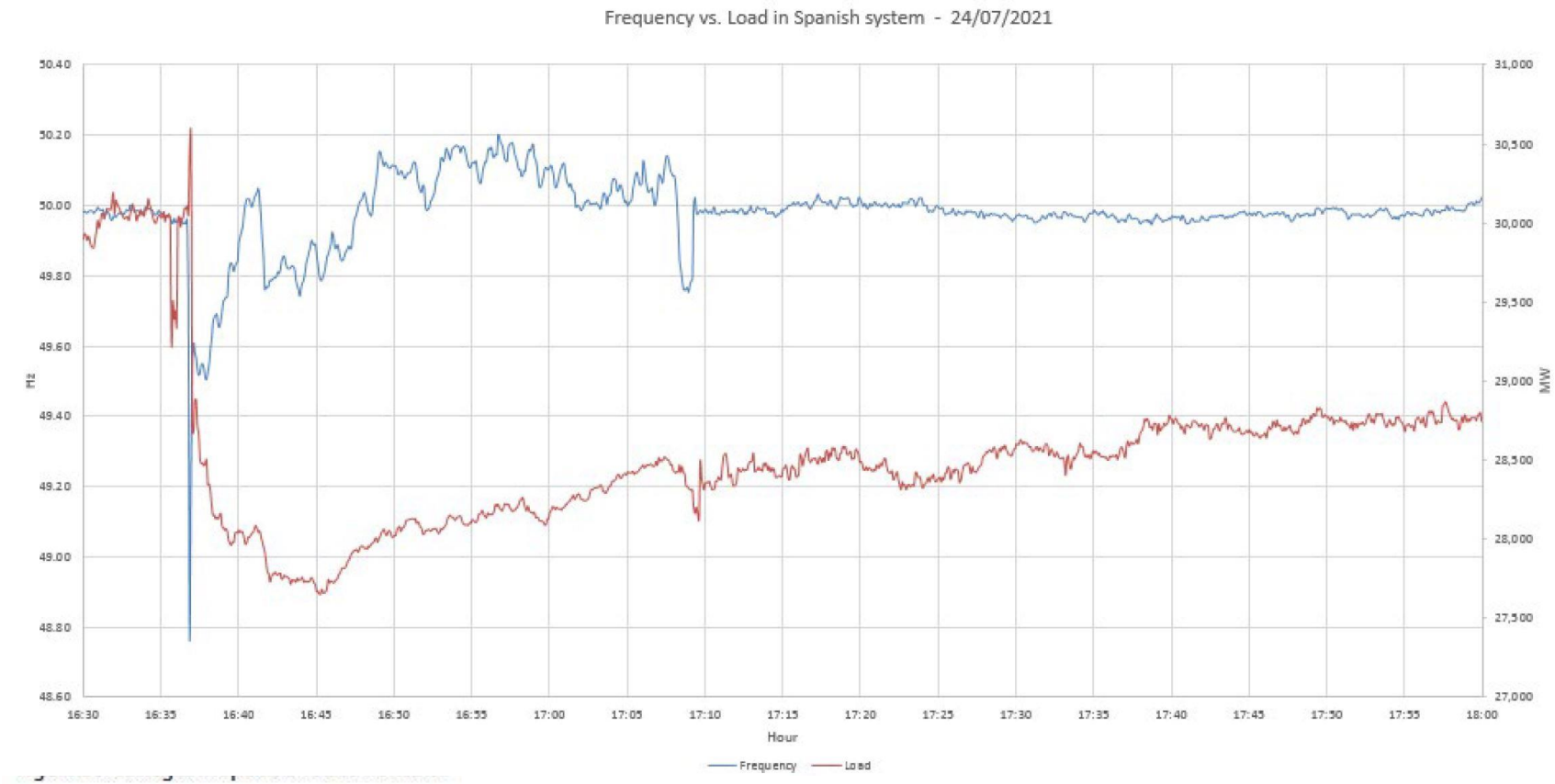
- A more dynamic system requires reliability resources, faster controls, improved coordination of protection
- Clearer visualization and understanding of system resilience during multi-factorial, abnormal/stressed conditions
- More rigorous reliability standard and security assessments are needed for more dynamic and complex grids
- Maintaining dynamic reactive support, synchronizing torque is critical as resources retire
- Power plant protection and control should be coordinated to avoid cascade events

Audience Q&A

www.epri.com

2021 Continental European System Separation

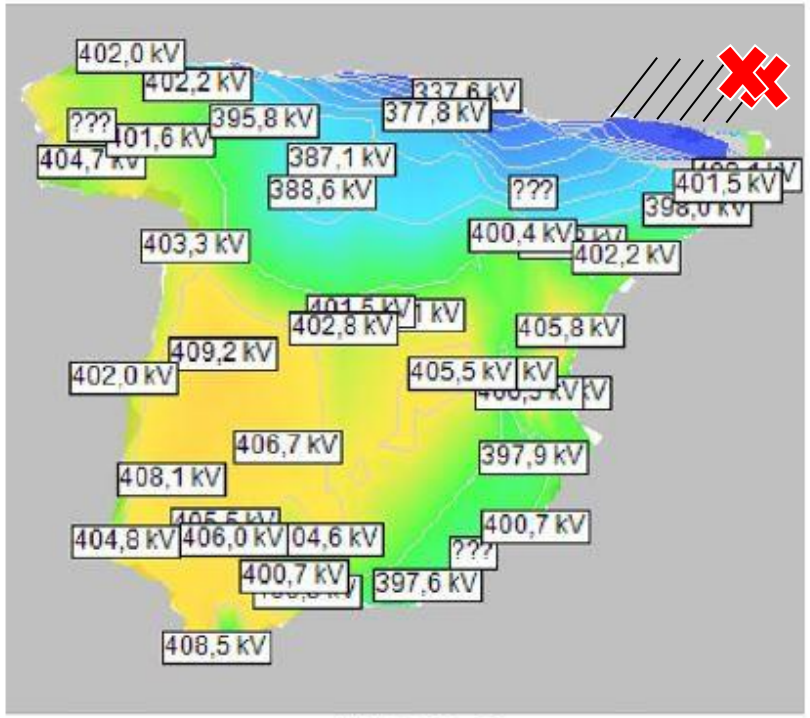
- **Initiated by N-2 of 400 kV lines carrying 2.5 GW in SE France**
- **Overloads and power swings tripped the 4xFrance-Spain ties**
- **2.6 GW of generation tripped in Spain**
  - **<u>Overvoltages caused ~1GW</u>**
- **6.4 GW Load disconnected by 1st and 2nd stage UFLS**
  - 2.3 GW pumped storage
  - 0.4 GW industrial customers
  - 3.6 GW end-customers



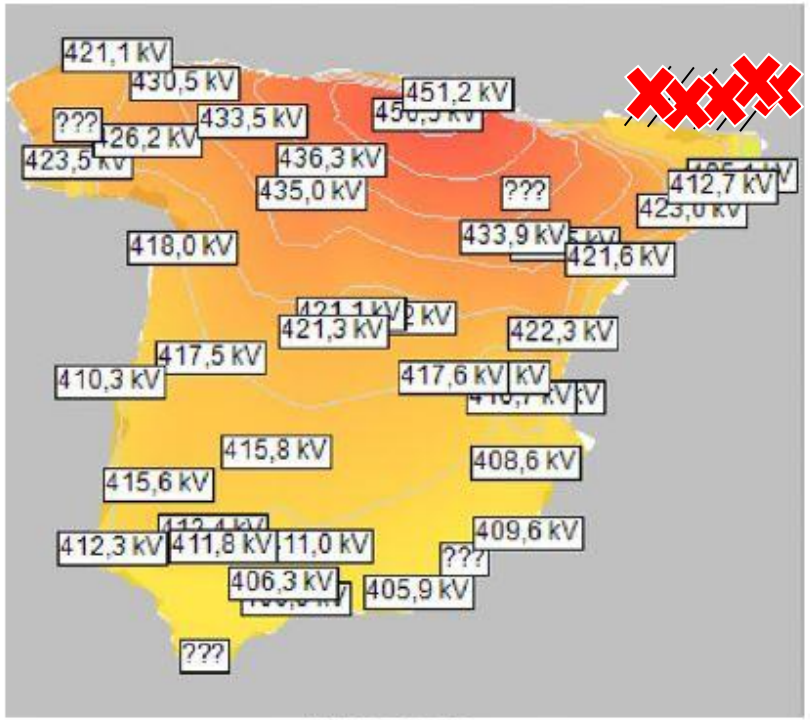
https://eepublicdownloads.entsoe.eu/clean-documents/SOC%20documents/SOC%20Reports/entso-e_CESysSep_210724_211112.pdf#:~:text=On%20Saturday%2C%2024%20July%202021%20at%2016%3A36%20CET%2C,the%20rest%20of%20the%20Continental%20European%20power%20system

2021 Continental European System Separation

Over 1 GW of generation tripped on overvoltage



(a) 16:36:32



(b) 16:37:40

Figure 18: Voltages in Spanish 400 kV network.

https://eepublicdownloads.entsoe.eu/clean-documents/SOC%20documents/SOC%20Reports/entso-e_CESysSep_210724_211112.pdf#:~:text=On%20Saturday%2C%2024%20July%202021%20at%2016%3A36%20CET%2C,the%20rest%20of%20the%20Continental%20European%20power%20system

Voltage Control Practices in Spain

- Today:
  - Voltage control defined by operating procedure P.O. 7.4 (2005)
  - All IBR are required to be capable of voltage control (Qmin = 15% of Pmax)
  - Most IBR in Spain set in fixed power factor control mode between 0.987 and 1.0
  - IBR rarely actively control voltage, except in unusual cases
  - Sync gens provide dynamic reactive power
  - Many shunt reactors plus several STATCOMs and synchronous condensers

- Future:
  - 2025-Q4: Real-time voltage setpoint control of IBR
  - 2026-H2: Possible implementation of a reactive power market
  - There are also plans for a nodal voltage control system
  - Ten-year network plan includes shunt reactors and a few STATCOMs

BOE-A-2020-8965 Orden TED/749/2020, de 16 de julio, por la que se establecen los requisitos técnicos para la conexión a la red necesarios para la implementación de los códigos de red de conexión.

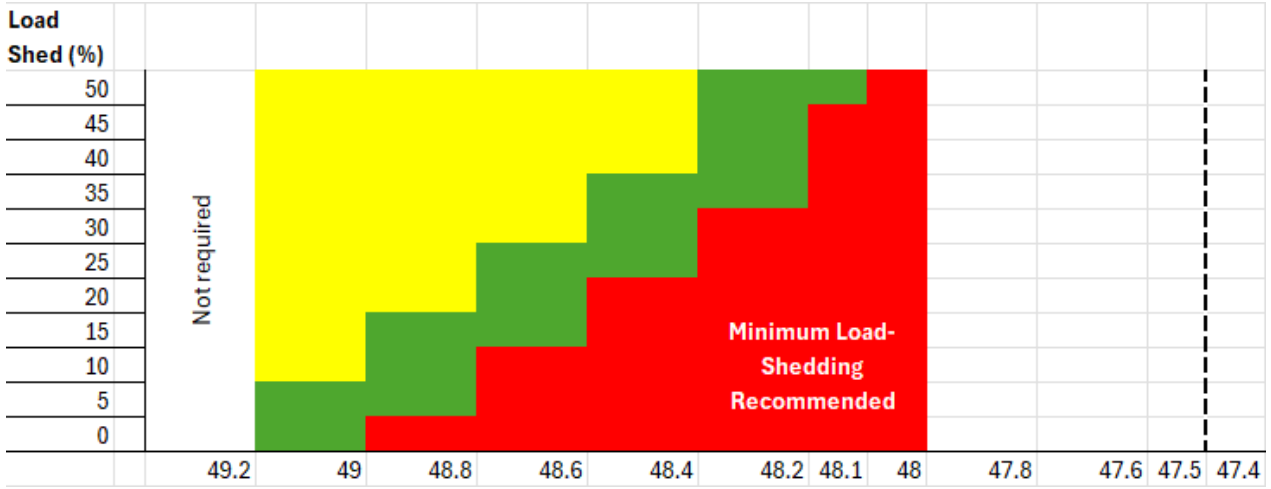
Underfrequency Load-Shedding

- Spain Pumped Hydro and Industrial Load Disconnection
  - Between 49.8 Hz and 49.0 Hz

Frequency Range (Hz)	Min Generator Trip Time (minutes)
>51.5	0
51-51.5	20 minutes
49.0 – 51.0	Unlimited
48.5- 49.0	30 minutes
47.5 – 48.5	30 minutes
<47.5	0

Customer UFLS in Spain

- Start tripping at 49.0 Hz
- >15% of load should trip once frequency breaches 48.8 Hz
- >50% of load should trip by 48.0 Hz
- Generators should remain connected down to 47.5 Hz

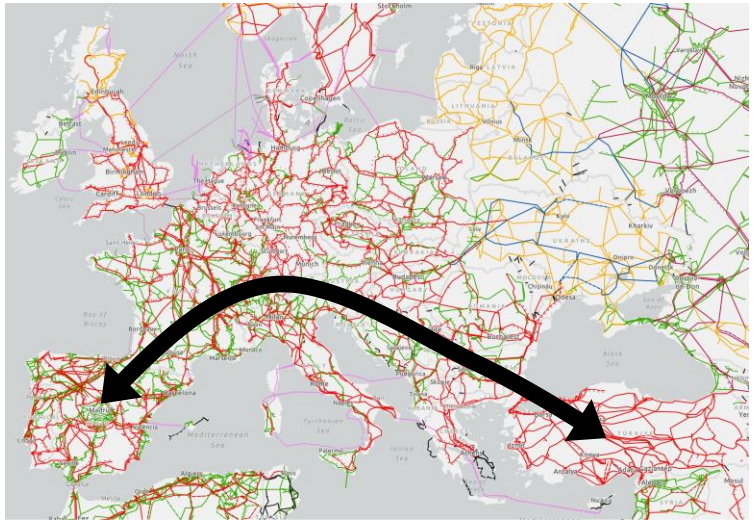


Source: https://www.entsoe.eu

Inter-Area Oscillations Occur in the European Power System

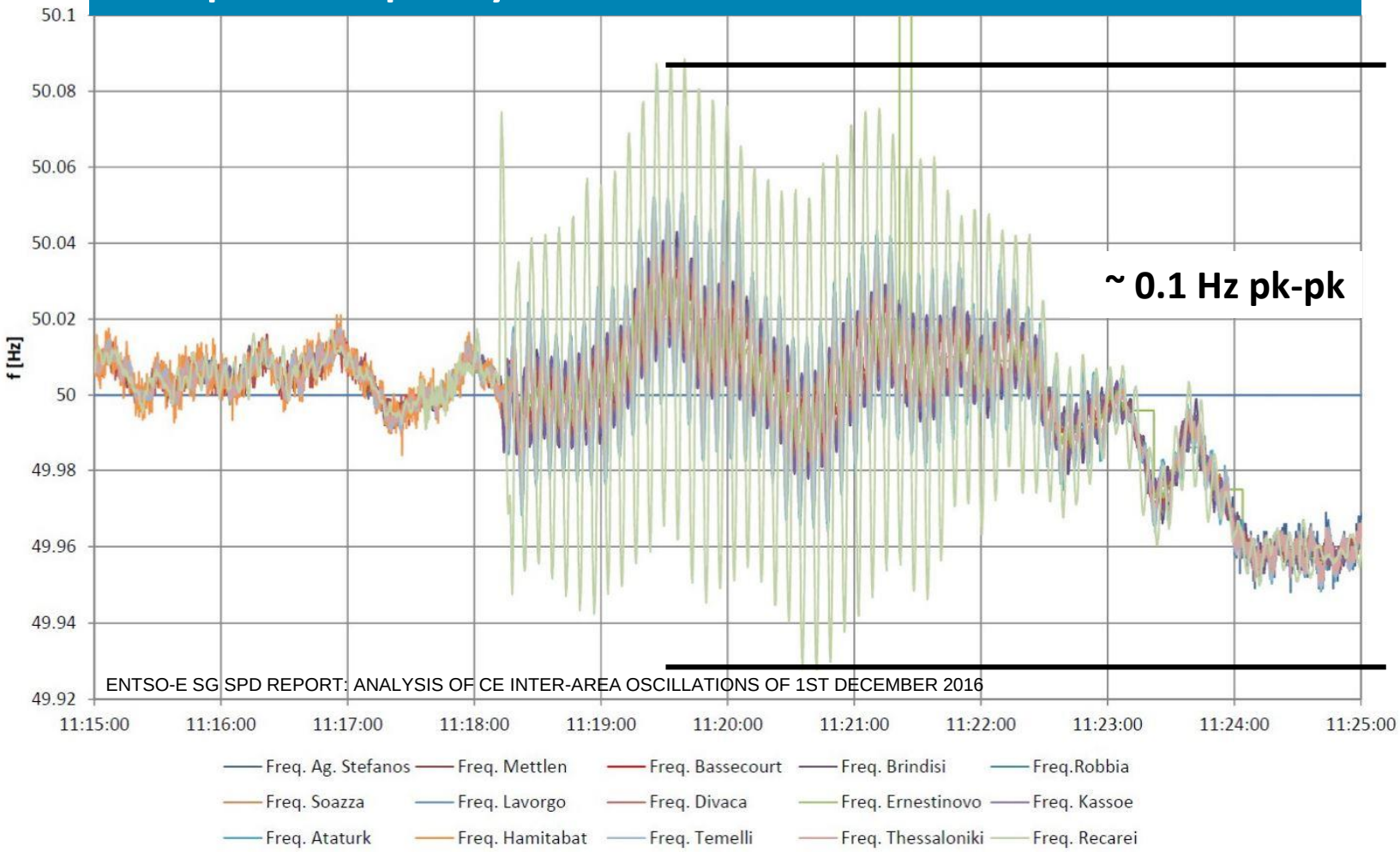
East – West oscillations
0.15 Hz - 0.21 Hz

Spanish PSS tuned to damp
0.1-0.3 Hz frequency range



** https://www.ree.es/sites/default/files/12_CLIENTES/Documentos/GT_POD_guia_implementacion_controles_POD_EN.pdf

European Frequency Measurements from December 2016 Event



https://www.entsoe.eu/data/map/