Blackout in Spain and Portugal:

Latest update

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Sources: Red Eléctrica, ENTSO-E, public data

28th of April 2025 (CET)

Full Blackout

~12:20pm

FACT

Inter-area **oscillations** in Europe

(possibly related to later generation losses)

12:32:57

FACT

Generation loss

(size unknown)

12:33:16

FACT

Generation loss

in the Southwest of Spain

(size unknown)

12:33:18

FACT

Generation loss

in the Southwest of Spain

(size unknown)

Total loss of 2.2 GW

12:33:20

FACT

Iberia becomes an **electric island**, and a "**massive disconnection of generation**" happens in Spain

PERSONAL HYPOTHESIS

The "**massive disconnection of gen.**" could be due to **RoCoF relays**

What caused the first generation outages?

Cause unknown

Two or more generators tripping almost simultaneously is considered a **very unlikely event**, as generator outages are assumed to be uncorrelated

This is why **almost every system operator in the world sizes their reserve market for covering an N-1 contingency**

(in Europe it is true that we cover an N-2 corresponding to 3 GW of Frequency-Containment Reserve, but this is for a huge interconnected power system, and only works if there is no loss of synchronism)

What caused the first generation outages?

Cause unknown

Two contingencies happening in just 1.5 s means that **they are somehow correlated**

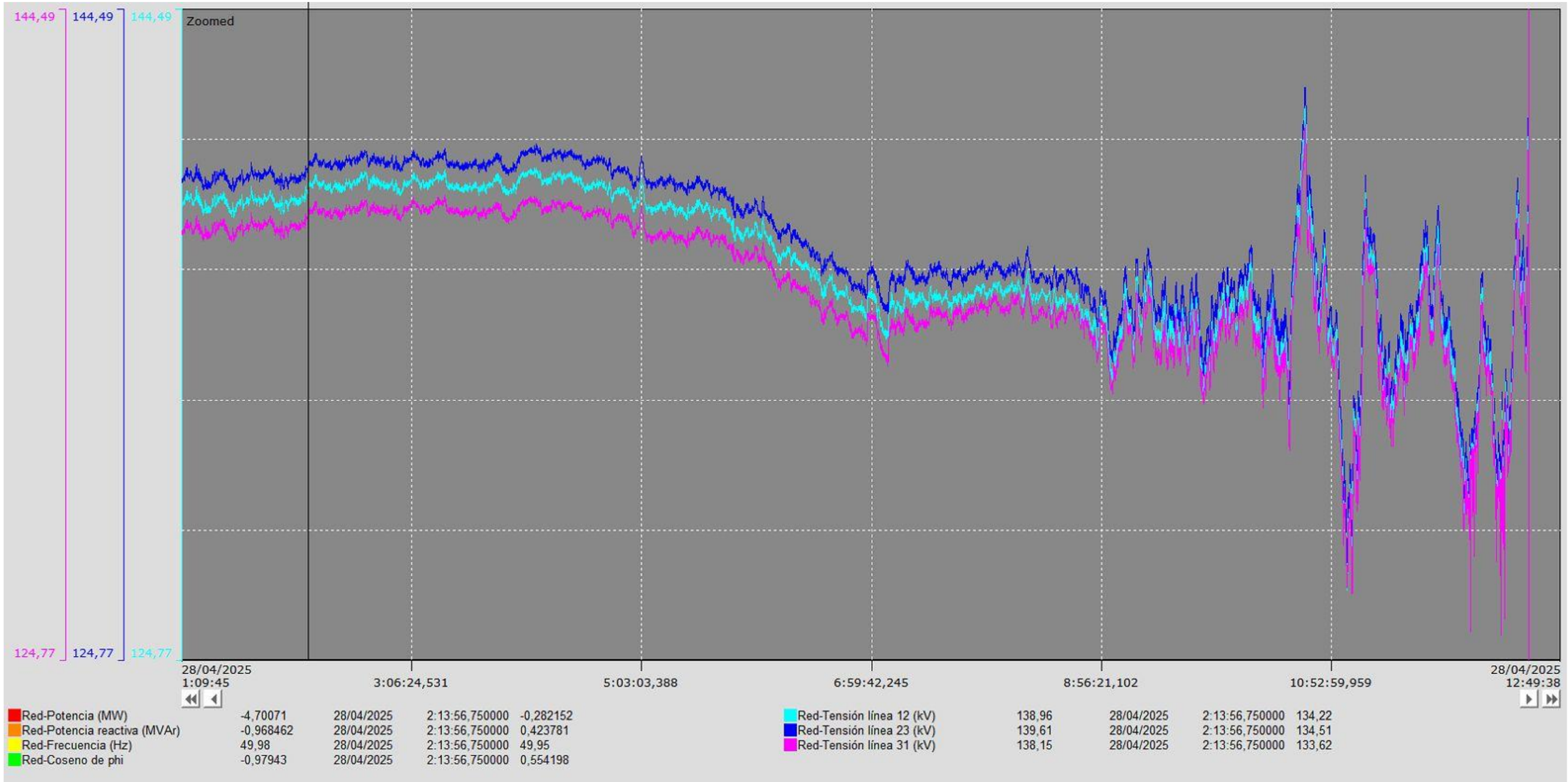
An N-2 event was the starting point of the 2019 GB power outage, and it was triggered by **lightning strikes**

We will have to wait to learn what caused the first outages in Spain

What caused the first generation outages?

Voltage issues have been reported

Voltage for some lines in Cuenca, [source]



What caused the first generation outages?

Voltage issues have been reported

There have been reports of **voltages reaching up to 470 kV in 400 kV lines**, supposedly in the Southwest region where everything started

- I have not found data to support this claim, but the statement can be found in several news articles such as this one (in Spanish)
- Other mentions to overvoltages here and here

There could be a relation with the previous inter-area oscillations

(this is completely speculative, but **see next slide**)

What caused the first generation outages?

Voltage issues led to **generation tripping in the Southwest of Spain** just **3 months ago**

Almaraz nuclear plant (one reactor operating at 1 GW) **tripped**

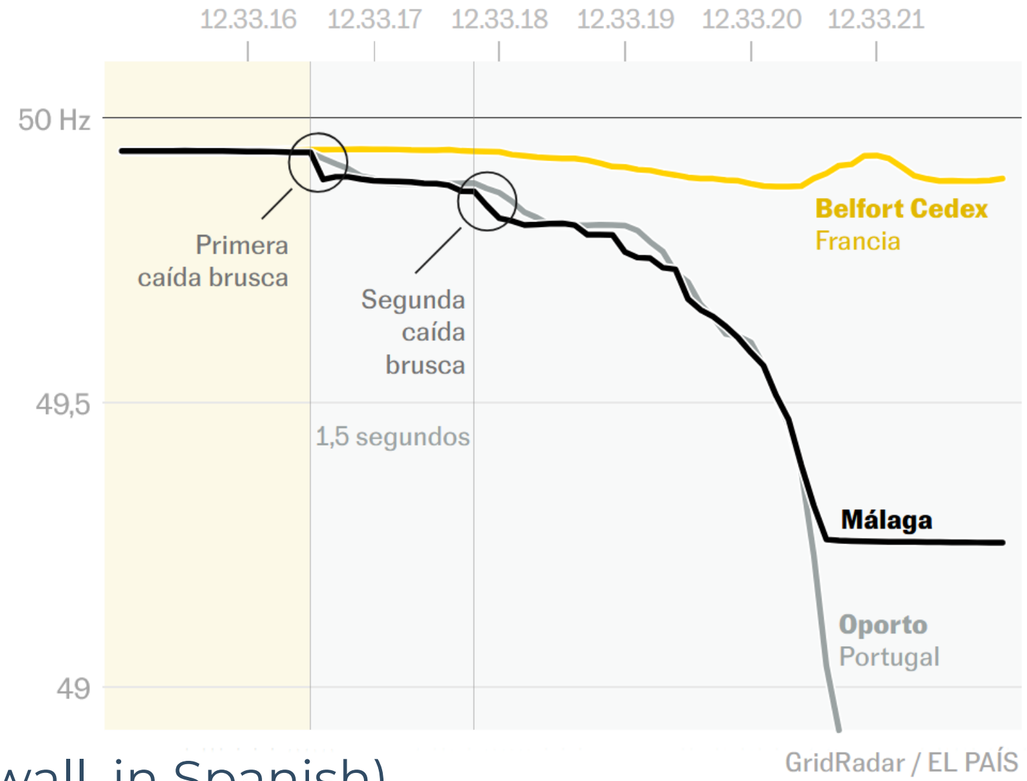
Source

Oscillations are mentioned in the report for the January 2025 event (see above link)

Under-Frequency Load Shedding (12:33:18 - 12:33:21)

"Between 12:33:18 and 12:33:21 CET, the **frequency of the Iberian Peninsula power system** continued decreasing and **reached 48,0 Hz**. The **automatic load shedding** defence plans of Spain and Portugal **were activated**." (ENTSO-E, 9th of May)

UPDATE from **May 9th**



The **48 Hz cannot be seen** in the available frequency data

Source (behind a paywall, in Spanish)

Under-Frequency Load Shedding (12:33:18 - 12:33:21)

Why wasn't Under-Frequency Load Shedding (UFLS) effective enough?

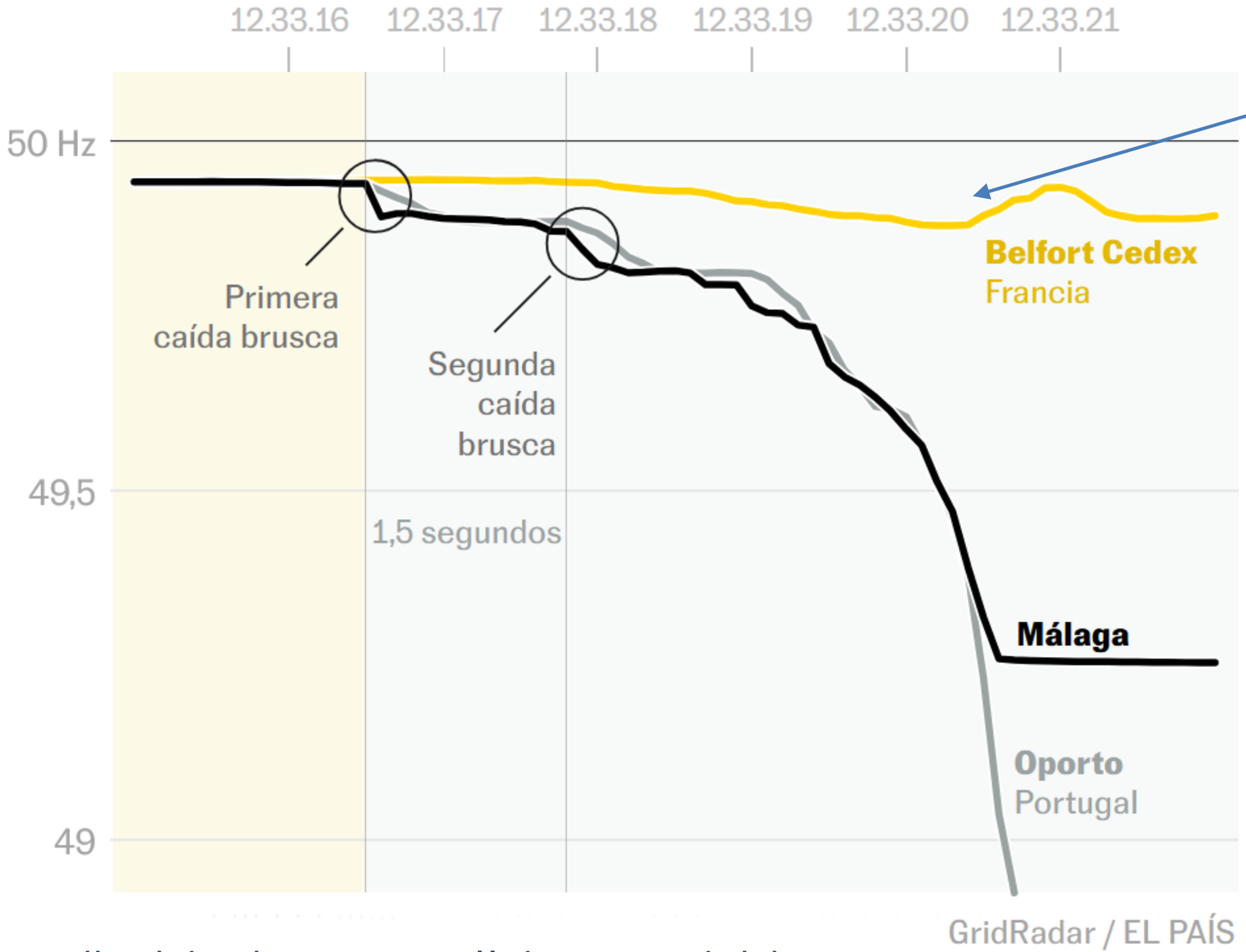
UPDATE from **May 9th**

Possible explanation:

Some Under-Frequency Load Shedding was reportedly triggered at 48 Hz (amount unknown). But the **net load disconnected could have been small**, as **distributed generation could have been disconnected too**
(it was **noon on a** sunny day across a country with ~8 GW of rooftop solar PV)

Paper related to this topic here

Iberia becomes an electric island (12:33:20)



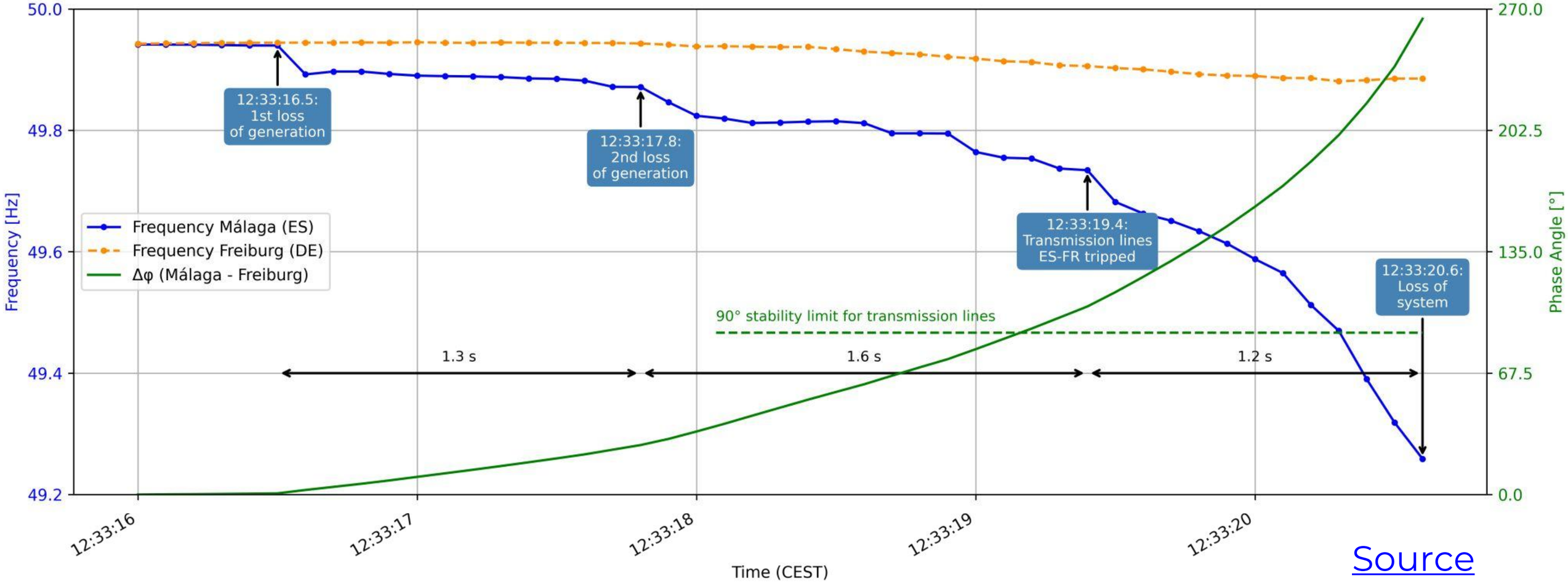
Iberia is **disconnected from the European synchronous area**, as shown by the **small frequency bump** in France

Source (behind a paywall, in Spanish)

Iberia becomes an electric island (12:33:20)

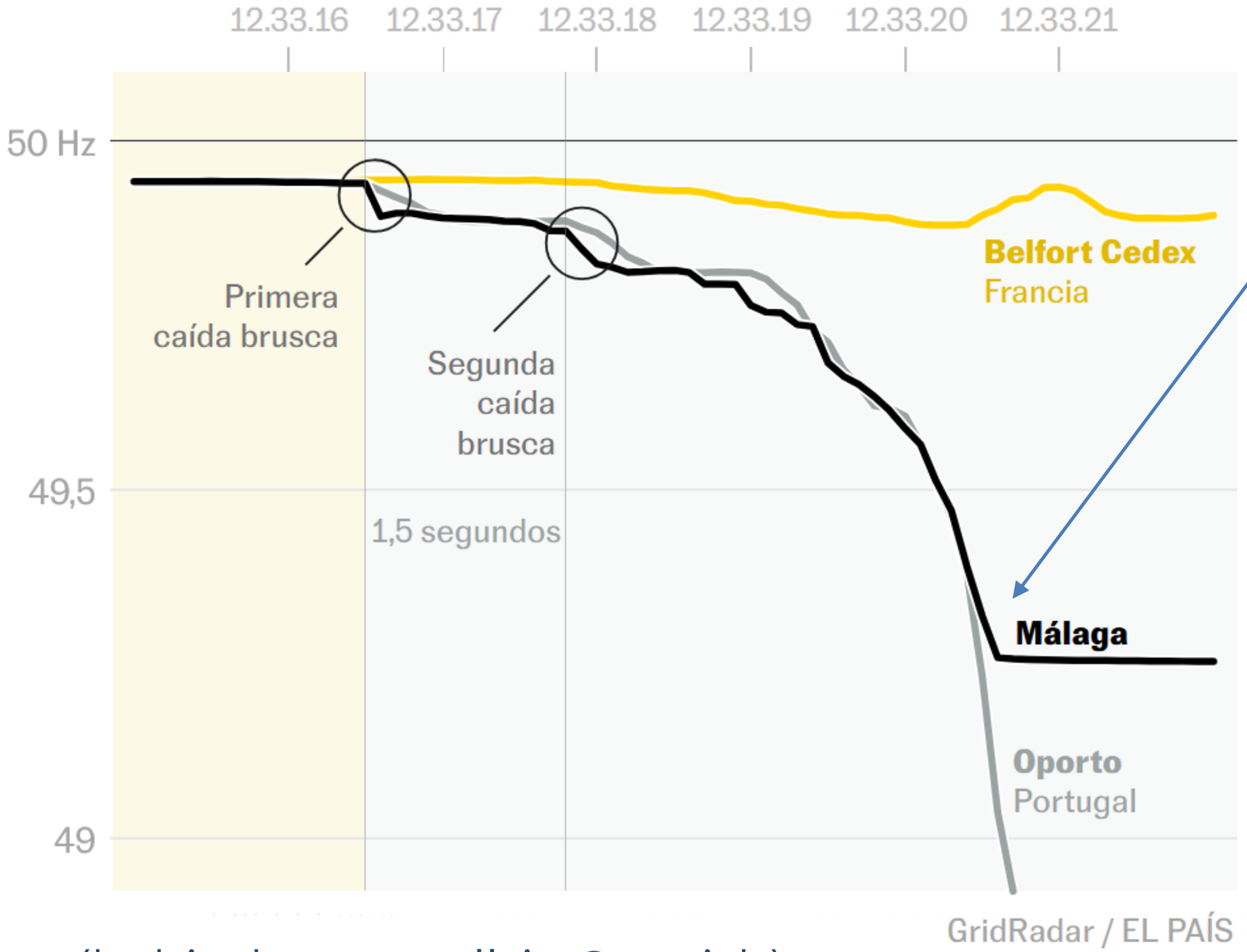
Confirmed cause (see ENTSO-E's press release):

- **Loss of synchronism** due to phase angle deviations



Source

Massive disconnection of generation (12:33:20)



Massive disconnection of generation

(as reported by Red Eléctrica)

This led to the **full blackout**

[Source](#) (behind a paywall, in Spanish)

Massive disconnection of generation (12:33:20)

Personal hypothesis

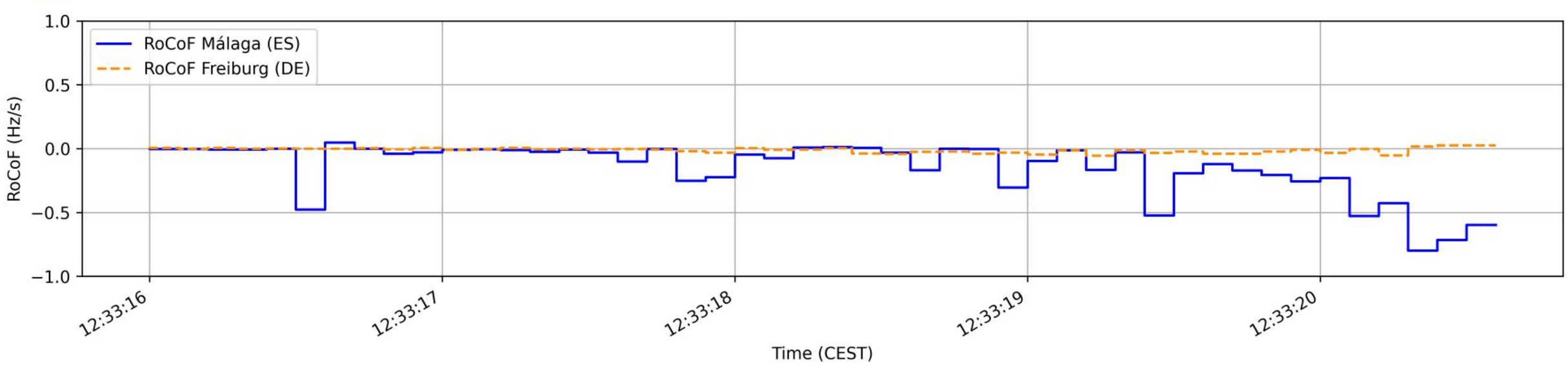
Most generation **could have tripped due to RoCoF relays**

- Once Iberia became an electric island, **inertia was likely low**
  - The Spanish grid had 59% solar PV generation and 11% wind generation right before the blackout (source, in Spanish)
- Generation in Europe is equipped with **RoCoF-sensitive relays** that are triggered for absolute **values exceeding 1 Hz/s**
  - Sources: ENTSO-E and REE (called “derivada de frecuencia” in the latter)

Massive disconnection of generation (12:33:20)

Personal hypothesis

Most generation **could have tripped due to RoCoF relays**



Source

No |RoCoF| > 1 Hz/s is seen in this data, but RoCoF is a very local magnitude, so **some other buses could have seen higher values**

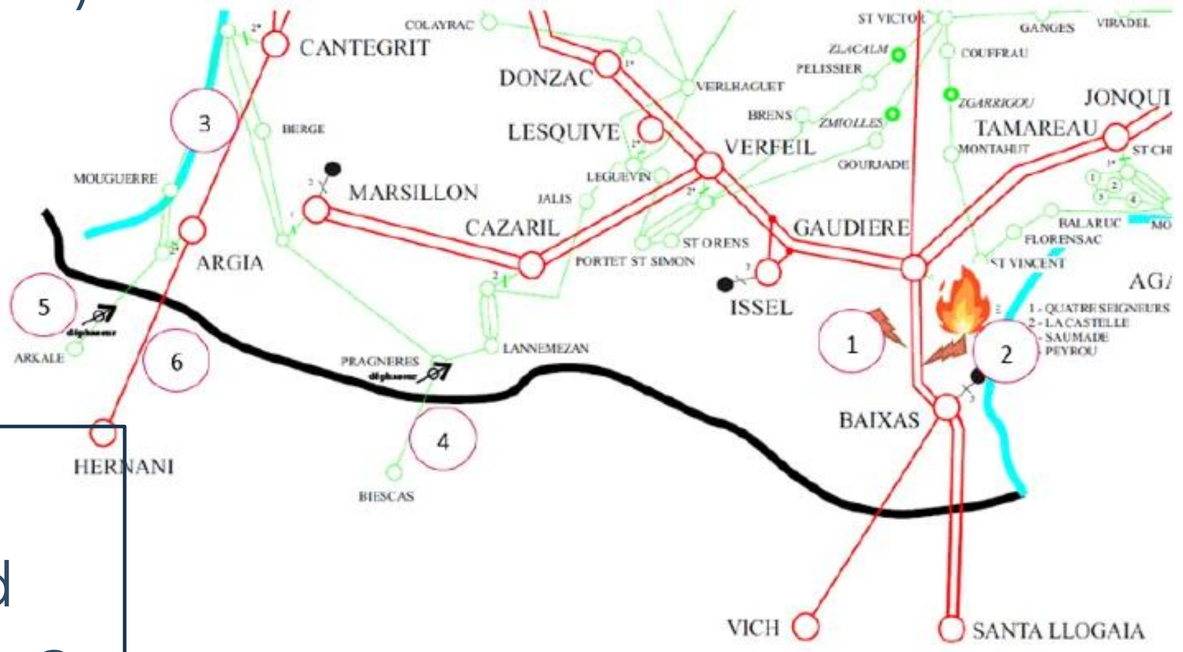
Related event: Iberia islanding in July 2021

Iberia became an **electric island** due to a fire in Southern France

- Some **load was disconnected** (~6 GW)

But **most of the system survived**

Graph: ENTSO-E



Then, **why didn't this "firewall" work this time**, why wasn't some load disconnected to avoid the full blackout?

Two options, either voltage issues or RoCoF issues (I see more likely the latter)

Massive disconnection of generation (12:33:20)

I think **RoCoF** is **more likely** than voltage issues for the final "massive disconnection of generation"

This is why:

- Voltage exceeding the critical value at the very same instant, for a wide geographical area that could simultaneously trip so much generation, seems less likely to me than RoCoF being the cause

Massive disconnection of generation (12:33:20)

UPDATE from **May 9th**

Important update from 9th of May:

ENTSO-E places the **full blackout at 12:33:24**, 4 seconds later than 12:33:20

This means that **publicly available data from 12:33:20 onwards is missing details**

RoCoF could have been high during these few seconds (although overvoltages too)

SUMMARY

- **Inter-area oscillations** in Europe **could have indirectly caused voltage problems** in the South and Southwest of Spain (completely speculative)

- There were at least **three losses of generation** within a ~20s period, as seen in the frequency data, **amounting to 2.2 GW**

- **First stage UFLS was triggered at 48 Hz**. It **could have been less effective due to distributed generation** (completely speculative)

- **Iberia losses synchronism** and there is a "**massive disconnection of generation**". This leads to **full blackout**

  - The final massive loss of generation could be mostly due to **RoCoF relays tripping** (completely speculative)

Can we blame low inertia for the blackout?

NO

Maybe low inertia did eventually cause the final massive disconnection of generation, if my hypothesis about RoCoF-sensitive relays is correct

(RoCoF is inversely proportional to inertia)

But **the actual problem happened earlier**: no TSO would carry sufficient inertia to withstand an N-3 generation contingency when operating as an electric island