Spain/Iberia Blackout of April 28th 2025

Nick Miller, HickoryLedge

Integrated Planning: Assuring Stability in Modern Systems

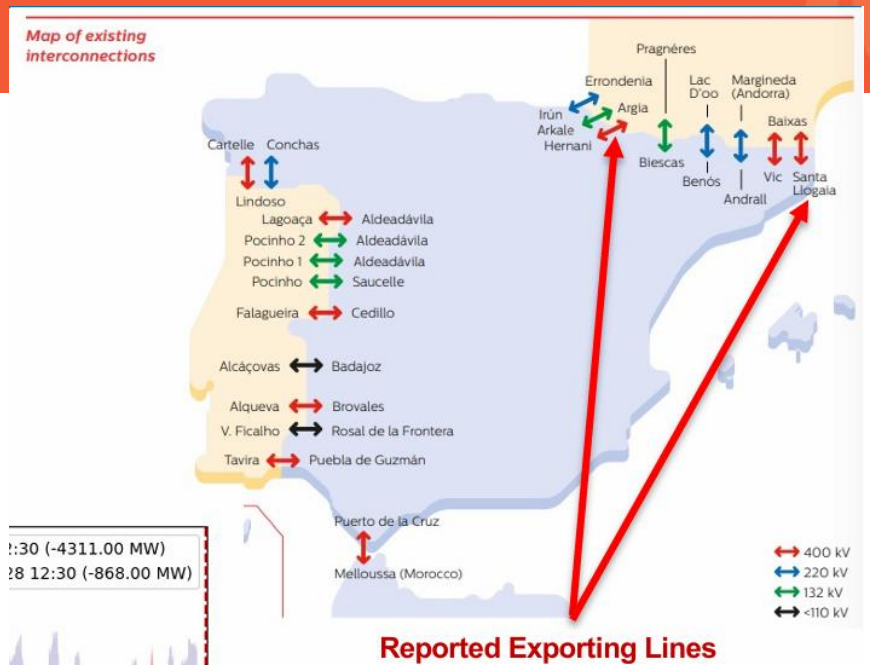
Day 1: Session 2

Monday September 15, 2025

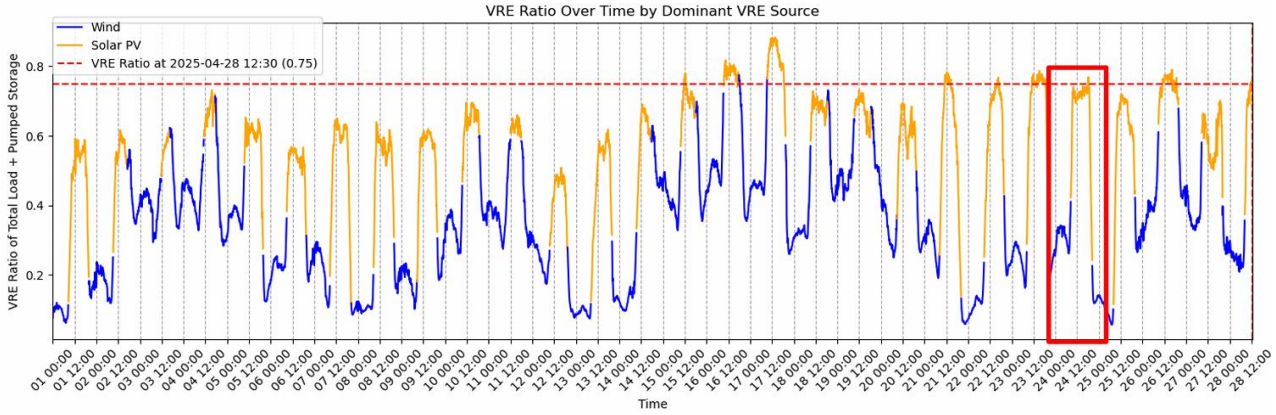
April 28th 2025 Spain/Iberia Blackout

- Why do we care?
  - Spain and Portugal have a long, leading history of renewable energy development
  - Many public discussions echo the US
  - This was a stability failure: Not resource adequacy, not forecasting
- A day in the life - conditions just before*:
  - 32 GW generation, serving
  - 25GW demand (Spain)
  - 2.6 GW to Portugal, 0.9 GW to France**, 0.8 GW to Morrocco
  - 3GW to pumped hydro energy storage
  - NOT outside of normal exports
- 75% from renewables, mostly solar. Representative of April

*from Wikipedia



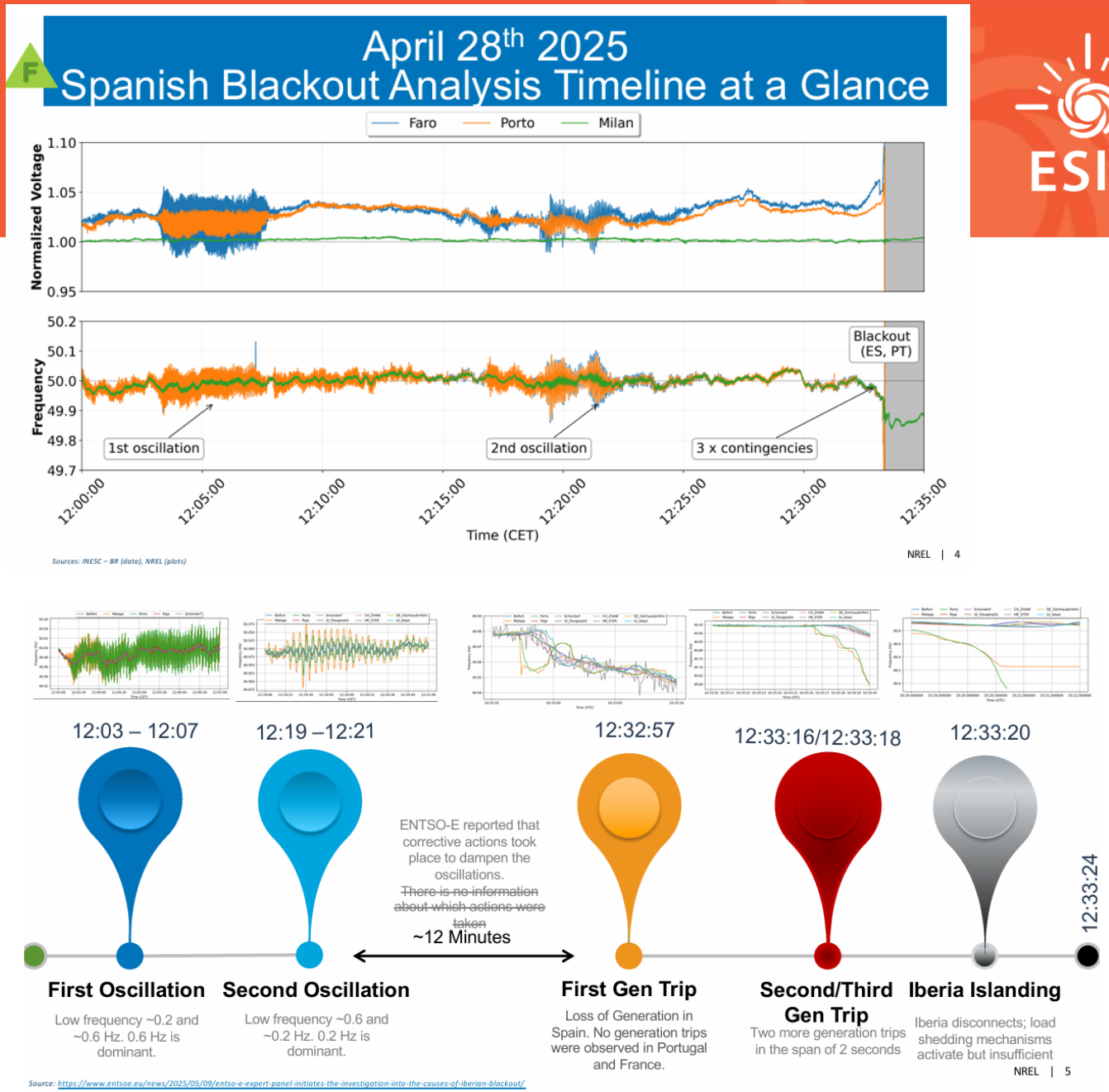
CIGRE Report: Inter-area oscillations in the Continental European power system: events analysis and countermeasures. 2020



1.Data obtained from Red Electrica API Portal

What happened?

- We'll start with "what did we see?" ("why did it happen?" comes later)*
- Unrolling event over about ½ hour.
- Sequence:
  - Oscillations (we'll look more at this topic later today)
  - Operator reaction (to address oscillations)
  - Instability... Leading to the system unraveling:
  - Unit trips, then separation (islanding), then final chaos



*This is deliberately high level; there are good references that dive much deeper than we'll go today.
https://www.entsoe.eu/news/2025/05/09/entso-e-expert-panel-initiates-the-investigation-into-the-causes-of-iberian-blackout/

Immediate Fog of Speculation and Misinformation

- Jump to conclusions.
  - In early days of May, the exact cause remained under investigation
  - But prompted discussion of high share of renewables
    - "early analysis suggest the blackout is unlikely to have been caused by Spain's high share of renewable energy"..." but, highlighted need for continued investment in power grid stability..." (from grid operator)
- Nevertheless, the lack of facts didn't silence many, e.g.:
  - Spanish far-right Vox party attributed blackout to over-reliance on renewables..
  - "...greater amounts of renewables may have made the grid susceptible to outages..."
  - ..."easier to keep the system functioning if conventional oil & gas had larger presence" (Eurasia Group)
  - "...brought attention to mechanical inertia..." "at the time 80% of supply from grid-following inverters with little rotating mass on the grid"...
- From the fringes: "cyberattack", "Ursula von der Leyen's fault", "induced atmospheric vibration", "solar flares", faked photographs,...etc.

Nick's commentary *same ol' same ol'* : "we need inertia", "it's the renewables fault", blah blah blah
When things fall apart, there's always a frequency term...doesn't equate to causality.
Forensics take time. We have a NERC process (NTSB parallel)

What (probably) caused it?

- Mostly facts, still some informed speculation
- Cause of oscillations still not fully understood. Oscillations do not appear to have *caused* the event, but
  - Operator actions to reduce them pushed system to operating condition that was somewhat unfamiliar
  - *Something* was just enough different this time to cause a stability failure
- Voltage situation when from bad to worse. Towards 'loss of voltage control'..i.e. "voltage instability"
- Some conventional resources failed to respond or even did the wrong thing; Some distributed resources tripped.
- Widespread, relatively chaotic tripping of resources.
  - THEN, the frequency went south. A consequence, NOT a cause.

- NREL "April 28th 2025 Iberian Blackout: Analysis of available information"; Jose Daniel Lara, Ben Kroposki, Tarek Elgindy, Rodrigo Henriquez-Auba, Jarrad Wright
- https://research-hub.nrel.gov/en/publications/april-28th-2025-iberian-blackout-analysis-of-available-informatio

IEEE Spectrum

NEWS ENERGY

Rules, Not Renewables, Might Explain the Iberian Blackout › Grids of the future may need to incentivize reactive power management

BY LUCAS LAURSEN PUBLISHED 16 JUN 2025 UPDATED 19 JUN 2025

What did we learn?

- Where renewables to blame? Not directly.
  - High levels pushed system (economically) towards somewhat unfamiliar territory (planning issue)..but not *terra incognita* – they'd been near here often before!
  - Some convention (synchronous) generation misbehaved (compliance/monitoring issue)
  - Rules/practice under-utilized beneficial contribution from renewables (rules/requirements issue)
- Unintended consequences
  - Actions known to aid one observed problem – oscillations – had unstudied (note word choice) impact on a different stability concern – voltage collapse
- Could it happen here (US/NA interconnections)?
  - US voltage practice is better (Nick's opinion), but far from ideal (also Nick's opinion)
  - NERC rules requiring regular testing and model validation reduce the risk of all generating resources failing to act as expected and mandated. Perfection is not possible.
  - Planning practice does somewhat better at looking for 'unintended consequences'
  - Attention to voltage, especially high voltage, is less good than it could be (Nick's opinion)
  - Focus on frequency may be distracting us from other risks (especially voltage) (Nick's opinion)

Stability worries aren't just for specialists

Thanks

Nicholas.miller@hickoryledge.com

Julia@esig.energy

ESIG
ENERGY SYSTEMS
INTEGRATION GROUP

Parking Lot

outline

- April 28th 2025 Spain/Iberia Blackout; (why do we care?)
- What happened? (High level overview)
- Near-term reaction. (Immediate Fog of Speculation and Misinformation)
- What really seems to have happened (What (probably) caused it?)
- Lessons learned

WIKIPEDIA
The Free Encyclopedia

2025 Iberian Peninsula blackout

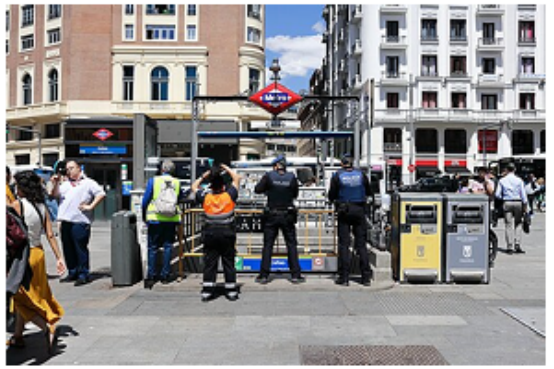
On Monday, 28 April 2025, at 12:33 CEST (11:33 WEST; 10:33 UTC), a major power blackout occurred across the Iberian Peninsula affecting mainland Portugal and peninsular Spain, where electric power was interrupted for about ten hours in most of the Peninsula and longer in some areas. The power cut caused severe difficulties in telecommunications, transportation systems, and essential sectors such as emergency services. At least seven people in Spain and one in Portugal may have died due to outage-related circumstances like candle fires or generator exhaust fumes.[1][3] The total disconnected load can be estimated at 30 GW.[5]

Minor power cuts lasting seconds or minutes occurred in adjacent regions of Andorra and parts of southwestern France.[6] Reports indicated problems with the European synchronous electricity grid. Traffic lights in many places stopped working, and metro lines had to be evacuated.[7]

Grid conditions in Spain

According to the website of the Spanish electrical operator Red Eléctrica de España (REE) that documents the power grid,[9] there was sufficient power supplied to the grid leading up to the outage. At 12:30 on 28 April, the grid was supplied with 32 gigawatts (GW) of power to meet 25 GW of demand, and was exporting 2.6 GW to Portugal, 0.87 GW to France and 0.78 GW to Morocco. The remainder was used for hydropumping (3 GW).[10][11] More than half of the power supply was from solar,[8] and electricity price was slightly negative.[10]

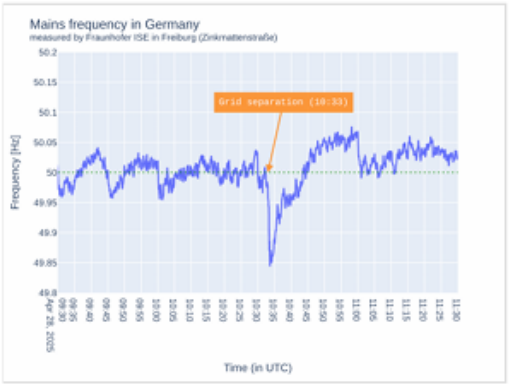
2025 Iberian Peninsula blackout



Metro stations were closed during the blackout.

Date	28 April 2025
Time	12:33 (CEST); 11:33 (WEST)
Location	Mainland Portugal, peninsular Spain, Andorra, and parts of southwest France
Type	Power outage
Cause	Undetermined
Deaths	±7 in Spain,[1][2] ±1 in Portugal[3]
Non-fatal injuries	>25[4]

- **12:03 – 12:07 CEST** – first period of oscillations in the grid detected and mitigated.
- **12:19 – 12:21 CEST** – second period of oscillations in the grid detected and mitigated. Since then the grid appeared stable, with no oscillations detected.
- **12:32:57 – 12:33:17 CEST** – series of generation trips in southern Spain causes loss of 2200 MW in generation capacity. Frequency decreased and voltage increased.
- **12:33:18 – 12:33:21 CEST** – grid frequency of the Iberian Peninsula drops below 48.0Hz. Automatic load shedding is activated.
- **12:33:21 CEST** – AC lines between France and Spain tripped.
- **12:33:24 CEST** – grid collapsed completely, DC line between France and Spain tripped.
- **12:44 CEST** – first 400kV Spain–France AC line is re-energized.
- **13:04 CEST** – Spain–Morocco interconnect re-energized
- **?? – 13:30 CEST** – Spanish hydro power stations capable of black start begin their black start procedures.
- **13:35 CEST** – AC line between Spain and France on the eastern coast is re-energized.
- **16:11 CEST** – first black start capable power plant in Portugal manages to start.
- **17:26 CEST** – second black start capable power plant in Portugal manages to start.
- **18:36 CEST** – 220kV line between Spain and Portugal is re-energized.
- **21:35 CEST** – 400kV line between Spain and southern Portugal is re-energized.
- **00:22 CEST** – grid fully restored in Portugal.
- **04:00 CEST** – grid fully restored in Spain.



Mains frequency measured in Germany dropped by 150 mHz as a consequence of the blackout.[12]

Secondary effects

Morocco

Internet providers such as Orange experienced problems in Morocco due to servers in Spain being offline.[57]

Greenland

Telecommunications in the villages of Qaanaaq, Ittoqqortoormiit, and Tasiilaq in Greenland were disrupted from 18:30 to 00:36 WGST (19:30–01:36 UTC) because Tusass and other telecommunications companies lost connection with equipment in Maspalomas Station on Gran Canaria island.[58][59] Although the antenna is on Gran Canaria, the cable goes through mainland Spain before transmission to the antenna and then satellite.[60]

Variable renewable energy

The exact cause of the blackout remains under investigation, but it has prompted discussion about the stability of electricity systems with high shares of variable renewable energy. Early analysis suggests the blackout is unlikely to have been caused by Spain's high share of renewable energy; however, it has highlighted the need for continued investment in power grid stability and resilience as Spain and other countries transition toward higher shares of renewable energy.[13]

Some political groups, including the Spanish far-right Vox party, attributed the blackout to over-reliance on renewables and called for a more diversified energy mix.[13] An energy analyst at Rystad Energy, Pratheeksha Ramdas, said that greater amounts of renewables in the power system may have made the grid susceptible to outages, but that there are multiple possible causes of the disturbance. Henning Gloystein, director for energy at the Eurasia Group research firm, claimed it might have been easier to keep the system functioning if conventional energy sources like oil and gas had a larger presence.[82]

The incident has also drawn attention to the concept of mechanical inertia in power systems, which refers to the stabilising effect of spinning turbines in hydropower and thermal power stations (the latter including fossil-fueled, nuclear and solar thermal).[13] A major aspect of moving away from electricity systems based on coal, gas, or nuclear power is the reduction in inertia on the grid. Solar, which accounted for the majority of Spain's electricity at the time, uses grid-following inverters[87][20] for 80% of the supply[69] and provides little rotating mass to the grid.[88] Commentators such as Adam Bell, director of policy at strategy consultancy Stonehaven, argued that a lack of inertia due to renewable energy was not the "main driver for the blackout" as inertia was still present at the time of the blackout due to nuclear, hydroelectric, and grid-supporting technologies like synchronous condensers. Bell said that solar, wind, and hydro remained operational after the event, while fossil fuel generation did not.[13] An energy consultant also pointed to the small amount of controllable inertia, comparing the blackout to the 2016 South Australian blackout, and suggesting the same solutions for Spain as Australia did; syncons and large batteries.[89][90] REE and Experts at Montel Analytics pointed to the relative isolation of the Iberian grid as a contributing factor to the blackout, as neighbouring grids were less able to provide stability.[91][92][93]

Misinformation

Several false and misleading claims were circulated regarding the origins of the power cut. Messages were spread online (at 12:56, 23 minutes after the blackout) claiming that it was caused by a Russian cyberattack, falsely attributed to CNN International and European Commission president Ursula von der Leyen.[101][102] It was also falsely attributed to the Portuguese electricity company EDP Group.[42]

Some media outlets, including CNN and Reuters, reported that REN claimed it was because of a supposed "rare atmospheric event" called "induced atmospheric vibration", causing "synchronization failures between the electrical systems". REN has denied releasing either of these statements.[103][101] A claim of solar flare received 1.9 million views, and was rejected by the Space Weather Prediction Center.[104] Several false satellite photos showing a blacked out peninsula at night were also spread.[102]

IEEE Spectrum

NEWS ENERGY

Rules, Not Renewables, Might Explain the Iberian Blackout › Grids of the future may need to incentivize reactive power management

BY LUCAS LAURSEN PUBLISHED 16 JUN 2025 UPDATED 19 JUN 2025

> The findings note some unusual voltage oscillations across the grid in both the days preceding and during the morning of the blackout. Stabilizing the oscillations following normal rules caused a slightly higher-than-usual voltage. Some power plants on contract to provide reactive power control, which might have corrected the overvoltage, failed to do so, and in one case added rather than absorbed reactive power. Other plants tripped before reaching their target voltage tolerance, raising voltages for the remaining plants until the cascade overwhelmed the grid.

In the first days after the blackout, many outlets and experts focused on the frequency of the grid and the need for inertia, which refers to how spinning generators carry physical momentum that makes them slow to change the frequency of the alternating current (AC) they generate. Most equipment on an electrical grid must operate within a fairly narrow range of a set frequency. Conventional power plants, such as combined-cycle natural gas or hydroelectric plants, can provide inertia, but newer sources such as photovoltaic solar power do not, unless they use so-called grid-forming technology. So the inertia discourse was in part a discussion of how to incorporate direct current sources such as photovoltaics into an AC grid.

If overvoltages, rather than frequency drops, were larger contributors, then the discussion is still about renewables, but it depends more on reactive power than on frequency management. Reactive power is one component of any AC electrical distribution grid. It

The shift toward more decentralized power production means that the amount of reactive power absorbed by transmission lines is changing, and the direction of flows of reactive power are also changing, making its regulation more complex. For example, Austria, Germany, and Japan have all begun regulating reactive power management to account for the effect of more distributed production.

In early June, Beatriz Corredor, the president of Spain's grid operator, Red Eléctrica de España (REE), blamed the blackout on up to five near-simultaneous failures of conventional generators with sub-standard voltage control. REE is not blaming the failure on transmission short circuits, lack of electrical inertia, an information technology hitch, a reserve shortage, or excess voltage, she said in an interview on Spanish television. Corredor

or the Ecological Transition and the Demographic Challenge

REPORT ON THE ELECTRICAL CRISIS OF APRIL 28

The Council of Ministers has taken note of the Report of the Committee for the Analysis of the Circumstances of the Electricity Crisis of April 28, 2025, previously approved by the National Security Council. The document concludes that the incident had a multifactorial origin, with a temporal cascade of events that progressively unbalanced the system and culminated in the peninsular electricity grid being shut down due to overvoltage. It also includes a series of recommendations ranging from improving the control and supervision of the behavior of agents to increasing the level of interconnection with France.

Main conclusions

The Committee's analysis of the incident allows us to conclude that the electrical failure had a multifactorial origin, in which three elements converged:

1. The system showed insufficient voltage control capacity for two reasons. First, on the 27th, prior to the incident, the System Operator scheduled the operation of 10 synchronous plants capable of regulating voltage on the 28th, according to their schedule. The final number of synchronous plants connected was the lowest since the beginning of the year.

And two, several of the plants capable of regulating voltage—and specifically compensated for it, having been programmed for this purpose due to technical restrictions—did not respond adequately to the System Operator's instructions to reduce it; some even produced reactive power, the opposite of what was required, contributing to the problem.

2.- The oscillations occurred. The oscillations—the first of which, the atypical one, originated at a facility on the Iberian Peninsula—required modifications to the system configuration, increasing the difficulty in stabilizing the voltage. After the second oscillation, the System Operator requested the availability of a plant capable of helping regulate the voltage, but it was technically impossible to do so before the collapse.

3.- Generating plants were disconnected, some of them apparently improperly. Some of the power plant disconnections occurred before the voltage thresholds established by regulations (between 380 kV and 435 kV on the transmission grid) were exceeded, while other disconnections occurred after these limits were exceeded to protect the facilities.

Once the chain reaction began, the usual protections of the electrical system were unable to stop or contain this process. Some of these protections, such as load shedding, may have even contributed to the surge phenomenon by further discharging the lines, contributing to the rise in voltages, because they acted to compensate for the drop in generation rather than to manage the voltage.

In short, there was a lack of voltage control resources, either because they were insufficiently scheduled, or because those scheduled did not provide adequate power, or because of a combination of both, but not because of a shortage in the country; there was more than enough generating capacity to respond.