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The collapse of the power system on the Iberian peninsula: what lessons for us in Britain?

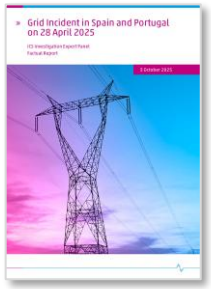
Keith Bell

Holder of the *Scottish Power Chair in Future Power Systems*, University of Strathclyde
and a *co-Director* of the UK Energy Research Centre

Risk Day
Edinburgh, March 19th 2026

The Iberian peninsula collapse, April 28 2025

Before the collapse: voltages



https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/#Publications_&_Documents

- Voltages quite high during the morning
- Action taken by the system operator to keep voltages down included switching shunt reactors in, dispatching generation to absorb reactive power, switching circuits out

Voltages in the 400 kV transmission network from 09:30 to 12:30 h

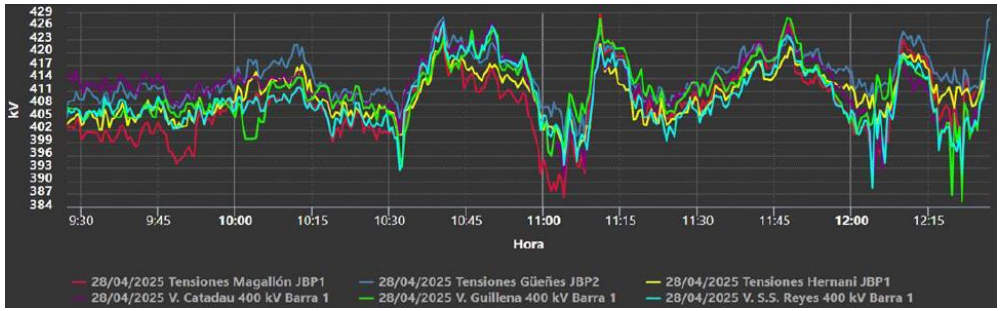
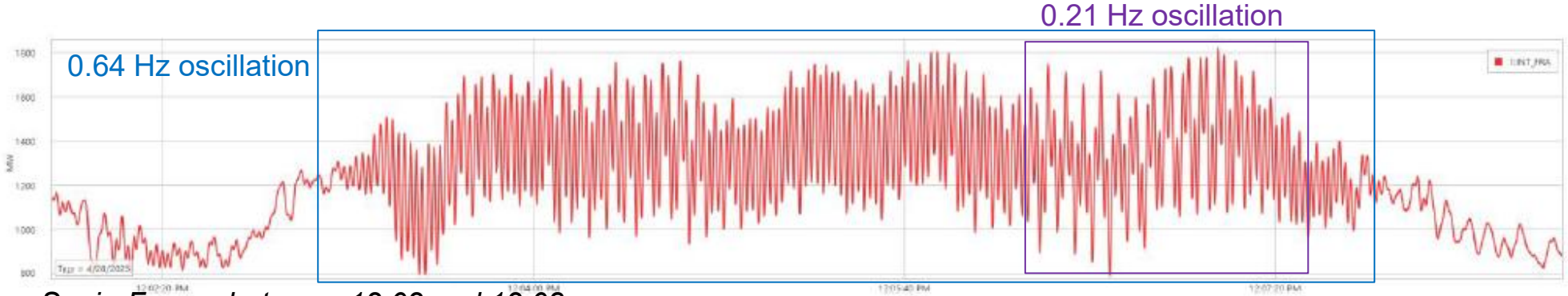


Figure: Red Eléctrica, *Blackout in the Spanish Peninsula Electrical System the 28th of April 2025*, 18/06/2025

- Between 10:30 and 11:23, 0.2 Hz voltage oscillations appears three times
- At 12:03, a significant 0.6 Hz voltage oscillation appeared



Exchange Spain-France between 12:02 and 12:08

Figure: Red Eléctrica, *Blackout in the Spanish Peninsula Electrical System the 28th of April 2025*, 18/06/2025

The Iberian peninsula collapse, April 28 2025

Action to mitigate oscillations

https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/#Publications_&_Documents

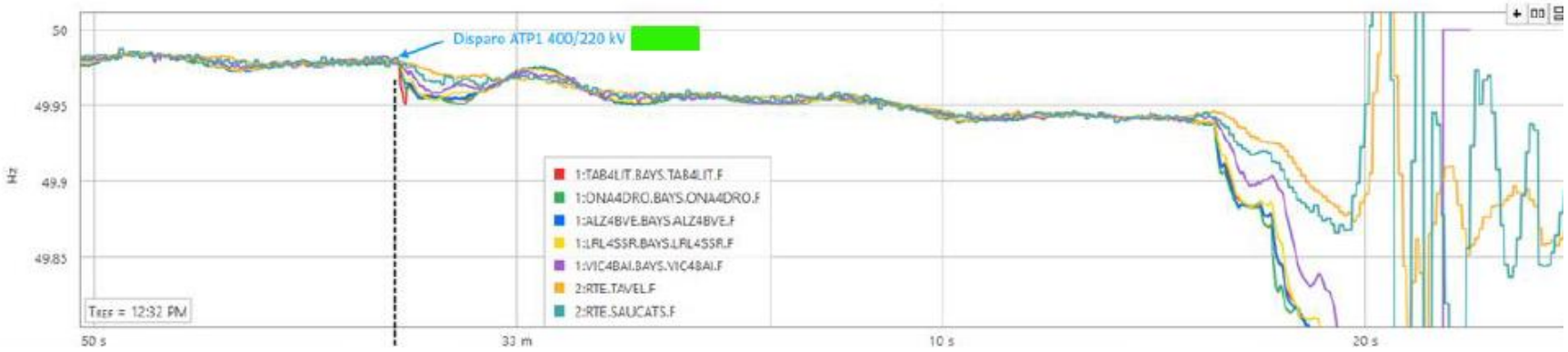
- REE Control Center activated the “pre-established measures to improve oscillation damping” and attempt to eliminate it:
  - “Coupling 400 kV transmission lines to reduce the system impedance”.
  - Reduction of export exchange with France by 800 MW to 1,500 MW.
- Also:
  - shunt reactors were disconnected to mitigate the undervoltages.
  - exports to Portugal reduced to improve damping
    - Reduced solar PV output in southern Spain which led to reduced power flows (higher voltages) and less reactive power absorption (higher voltages)
- At 12:16, the 0.6 Hz oscillation reappeared
- At 12:19, the 0.2 Hz oscillation reappeared
- Exports to Portugal and France reduced further; partitioned sections of network recoupled
- Certain generators failed to provide voltage control
- Between 12:32:00 and 12:33:17.368, 2.35 GW of generation tripped (due to high voltage?)

The Iberian peninsula collapse, April 28 2025

A cascade of outages

https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/#Publications_&_Documents

- At 12:33:19.620, the maximum import from France is reached, 3807 MW, with 4609 MW through the AC network.
  - This leads to the loss of synchronism between Spain/Portugal and France.
- System frequency begins to fall in Spain causing generators to trip
- Interconnection with Morocco has begun to import and is then tripped at the Morocco end
- More generators in Spain trip plus the HVDC link with France
- At 12:33:24 the Spanish Iberian Peninsula system collapses
- Just 1 minute, 24 seconds from the start of unexpected trips to complete collapse

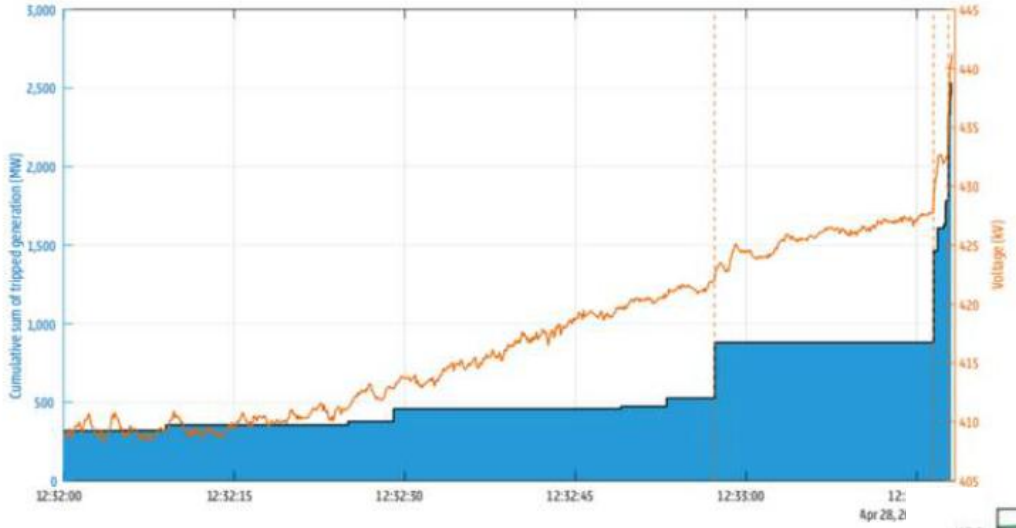


"Evolution of the system before and after the trip in Granada"

Figure: Red Eléctrica, *Blackout in the Spanish Peninsula Electrical System the 28th of April 2025*, 18/06/2025

The Iberian peninsula collapse, April 28 2025

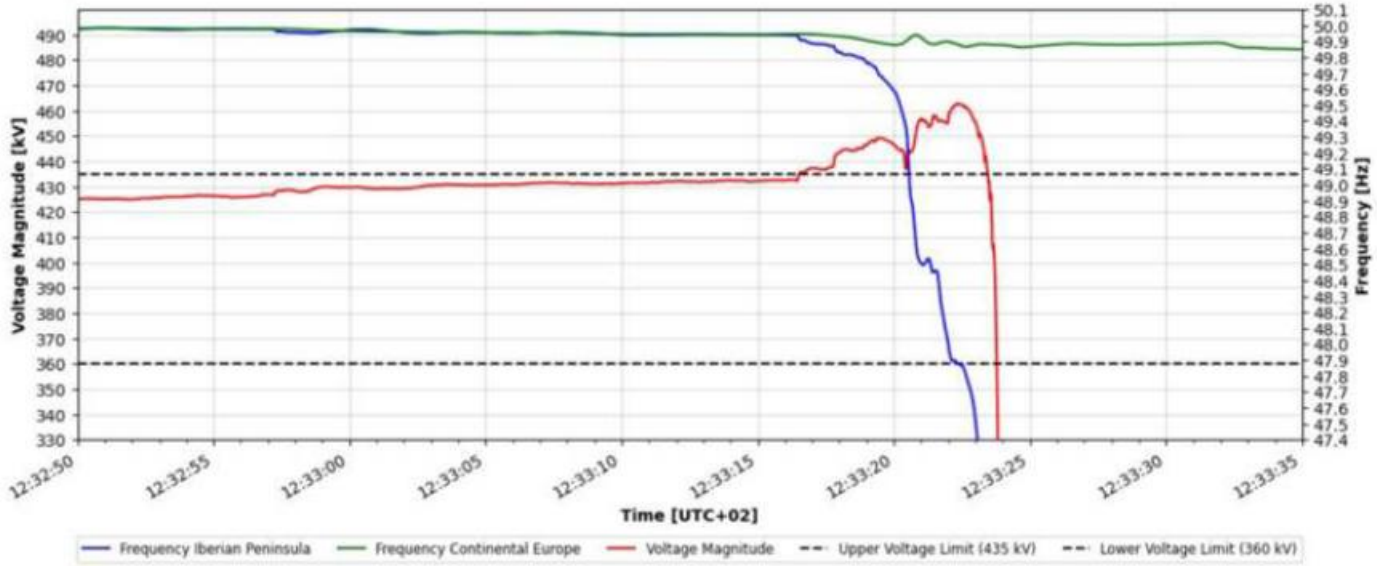
In summary



Figures: ENTSO-E, sourced from André Merlin, “What lessons can be learned from Iberian blackout?”, *Electra*, issue no. 334, February 2026

Warning: the above article fails to acknowledge the role of fossil-fuelled plant in causing past major incidents

6 seconds



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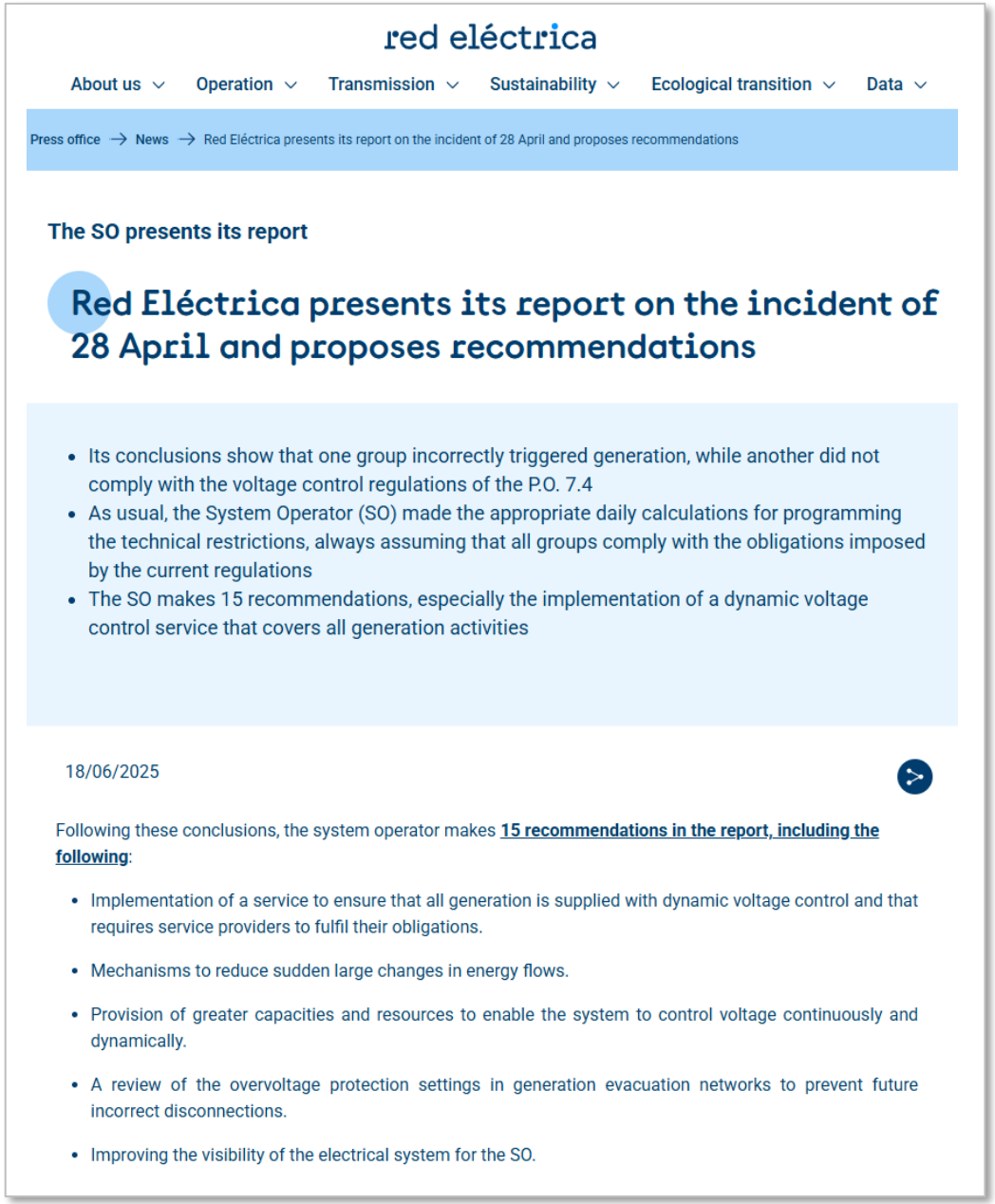
Should we be worried about voltages?

What happened on April 28 reminds us to

- pay attention to dynamic voltage control
- pay attention to the consequences of high volts (and high frequency) and for the potential for lots of things to trip in quick succession
- ensure that
  - the Grid Code is fit for purpose
  - connectees comply with the Grid Code
- have a clear idea of what both active and reactive demand are and what DG is up to
- model voltages and contingencies properly in system operation, operational planning and investment planning
- make full use of the capability of what's on the system (and maintain it properly)
- make sure defence plans are adequate



red eléctrica

About us Operation Transmission Sustainability Ecological transition Data

Press office → News → Red Eléctrica presents its report on the incident of 28 April and proposes recommendations

The SO presents its report

Red Eléctrica presents its report on the incident of 28 April and proposes recommendations

- Its conclusions show that one group incorrectly triggered generation, while another did not comply with the voltage control regulations of the P.O. 7.4
- As usual, the System Operator (SO) made the appropriate daily calculations for programming the technical restrictions, always assuming that all groups comply with the obligations imposed by the current regulations
- The SO makes 15 recommendations, especially the implementation of a dynamic voltage control service that covers all generation activities

18/06/2025

Following these conclusions, the system operator makes **15 recommendations in the report, including the following**:

- Implementation of a service to ensure that all generation is supplied with dynamic voltage control and that requires service providers to fulfil their obligations.
- Mechanisms to reduce sudden large changes in energy flows.
- Provision of greater capacities and resources to enable the system to control voltage continuously and dynamically.
- A review of the overvoltage protection settings in generation evacuation networks to prevent future incorrect disconnections.
- Improving the visibility of the electrical system for the SO.

https://www.ree.es/en/press-office/news/press-release/2025/06/red-electrica-presents-report-incident-28-april-and-proposes-recommendations

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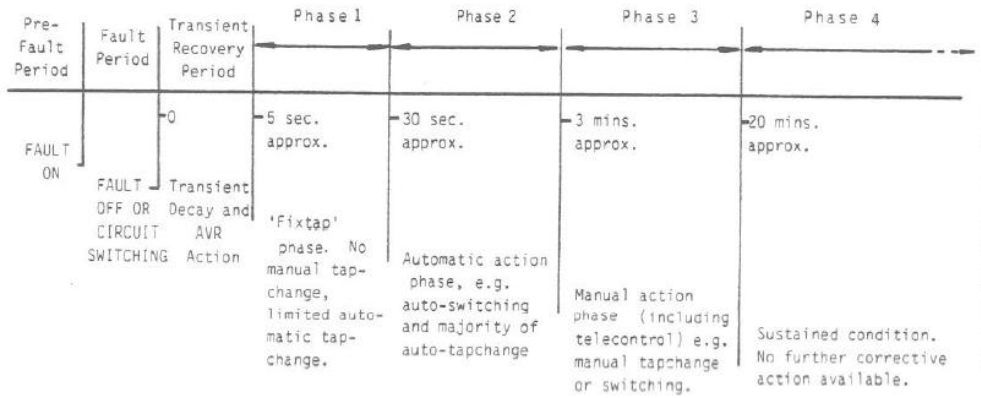
Voltage Step Change Limits in All Timescales

6.7. *Voltage step change* limits must be observed at every interface point between the *national electricity transmission system* and Users' plant. The *voltage step change* limits do not apply where no User is connected.

6.8. The *voltage step change* limits must be applied with load response taken into account.

Table 6.5 Voltage Step Change Limits in Planning and Operational Timescales

Type of Event	Voltage Fall	Voltage Rise
(a) At substations supplying *User Systems* at any voltage		
1. Following *operational switching* at intervals of less than 8 minutes	In accordance with Figure 6.1	
2. Following *operational switching* at intervals of more than 8 minutes, 3. except for *infrequent operational switching* events as described below	-3%	+3%
4. Following *infrequent operational switching* ***(Notes 8, 9)***	-6%	+6%
5. In planning timescales, following a *fault outage* of a *double circuit supergrid* overhead line ***(Note 10)***	-6%	+6%



From PLM-ST-9

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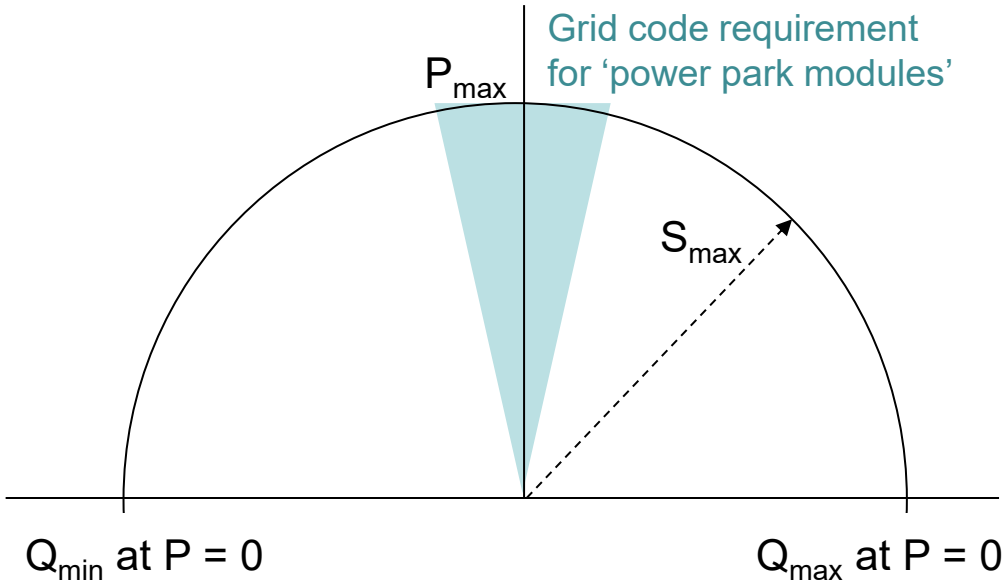
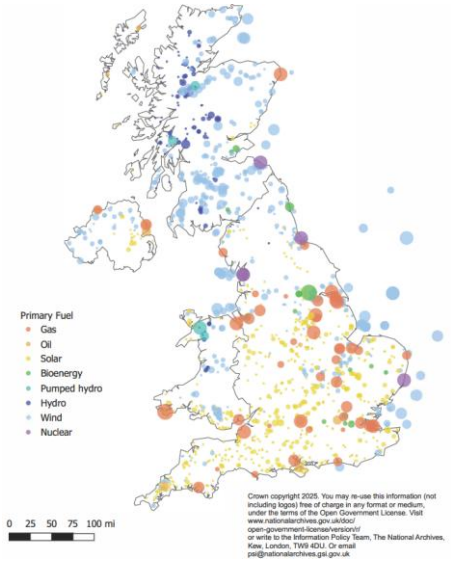


Reactive power capability of voltage source converters



How do wind farms comply with Grid Code reactive power capability requirements?

- With statcoms?
- With type 4 turbines?

Are solar farms asked to control voltage?

https://assets.publishing.service.gov.uk/media/688a296176f68cc8414d5bd1/Major_Power_Producers_map_2025.pdf

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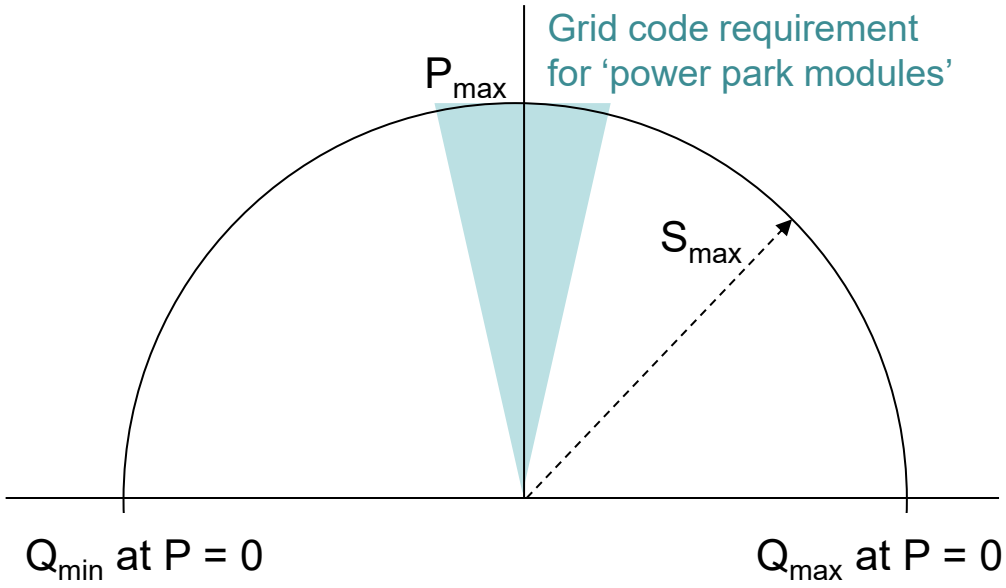
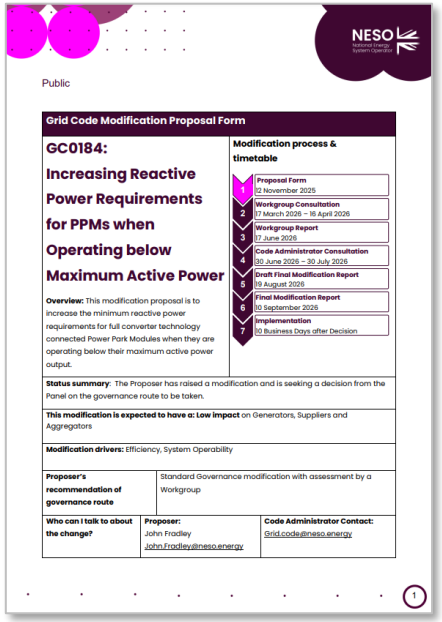


Reactive power capability of voltage source converters

GC0184: Increasing Reactive Power Requirements for PPMs when Operating below Maximum Active Power


Public

Grid Code Modification Proposal Form

GC0184:
Increasing Reactive Power Requirements for PPMs when Operating below Maximum Active Power

Modification process & timetable

1. Proposal Form — 12 November 2025
2. Workgroup Consultation — 17 March 2026 – 16 April 2026
3. Workgroup Report — 17 June 2026
4. Code Administrator Consultation — 30 June 2026 – 30 July 2026
5. Draft Final Modification Report — 19 August 2026
6. Final Modification Report — 10 September 2026
7. Implementation — 10 Business Days after Decision

Overview: This modification proposal is to increase the minimum reactive power requirements for full converter technology connected Power Park Modules when they are operating below their maximum active power output.

Status summary: The Proposer has raised a modification and is seeking a decision from the Panel on the governance route to be taken.

This modification is expected to have a: Low impact on Generators, Suppliers and Aggregators

Modification drivers: Efficiency, System Operability

Proposer's recommendation of governance route	Standard Governance modification with assessment by a Workgroup
Who can I talk to about the change?	**Proposer:** John Fradley, John.Fradley@neso.energy; **Code Administrator Contact:** Grid.code@neso.energy

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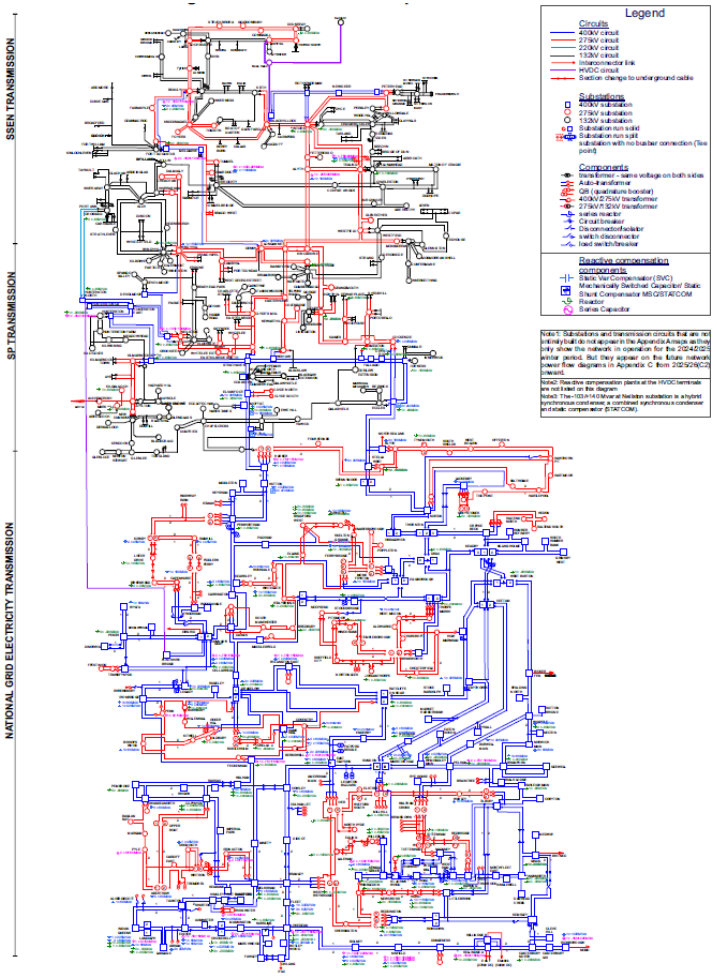
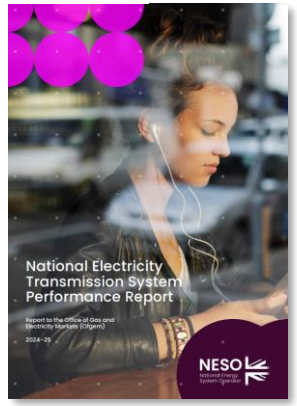


Map: ETYS 2025, https://www.neso.energy/document/351911/download

GB % Annual Reactive Comp. Equipment Availability				
2020-21	2021-22	2022-23	2023-24	2024-25
N/A	N/A	N/A	75.19	75.56



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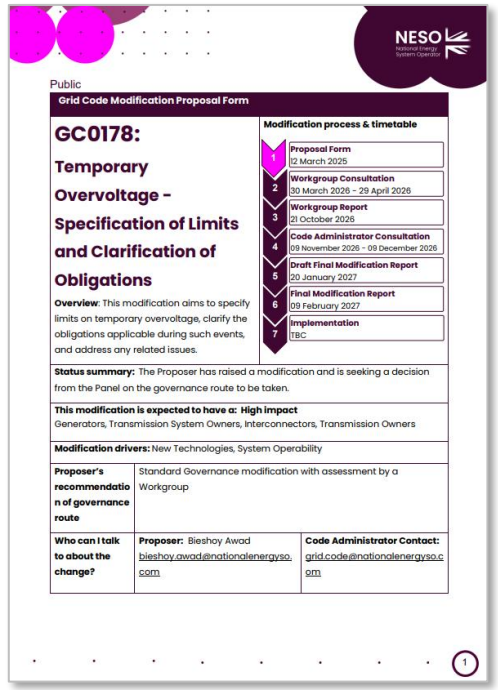
GC0178: Temporary Overvoltage – Specification of Limits and Clarification of Obligations



Public

Grid Code Modification Proposal Form

GC0178: Temporary Overvoltage - Specification of Limits and Clarification of Obligations

Overview: This modification aims to specify limits on temporary overvoltage, clarify the obligations applicable during such events, and address any related issues.

Modification process & timetable

1. **Proposal Form** 12 March 2025
2. **Workgroup Consultation** 30 March 2026 - 29 April 2026
3. **Workgroup Report** 21 October 2026
4. **Code Administrator Consultation** 09 November 2026 - 09 December 2026
5. **Draft Final Modification Report** 20 January 2027
6. **Final Modification Report** 09 February 2027
7. **Implementation** TBC

Status summary: The Proposer has raised a modification and is seeking a decision from the Panel on the governance route to be taken.

This modification is expected to have a: High impact
Generators, Transmission System Owners, Interconnectors, Transmission Owners

Modification drivers: New Technologies, System Operability

Proposer's recommendation of governance route	Standard Governance modification with assessment by a Workgroup

Who can I talk to about the change?	**Proposer:** Bieshoy Awad bieshoy.awad@nationalenergyso.com	**Code Administrator Contact:** grid.code@nationalenergyso.com

1

ENTSO-E investigation of the 28 April 2025 Blackout

- "On the basis of the preliminary facts established to date, the Expert Panel is currently looking at the cascading series of generation disconnections and voltage increases ('cascading voltage increases') as the most probable trigger for the blackout.
- "Such cascading voltage increases have never before been linked to a blackout in any part of the European power system. [Emphasis added].
- "If confirmed, this high voltage blackout mode will require a thorough analysis and investigation by all power system experts of the ENTSO-E community."

https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/#Investigation_Steps

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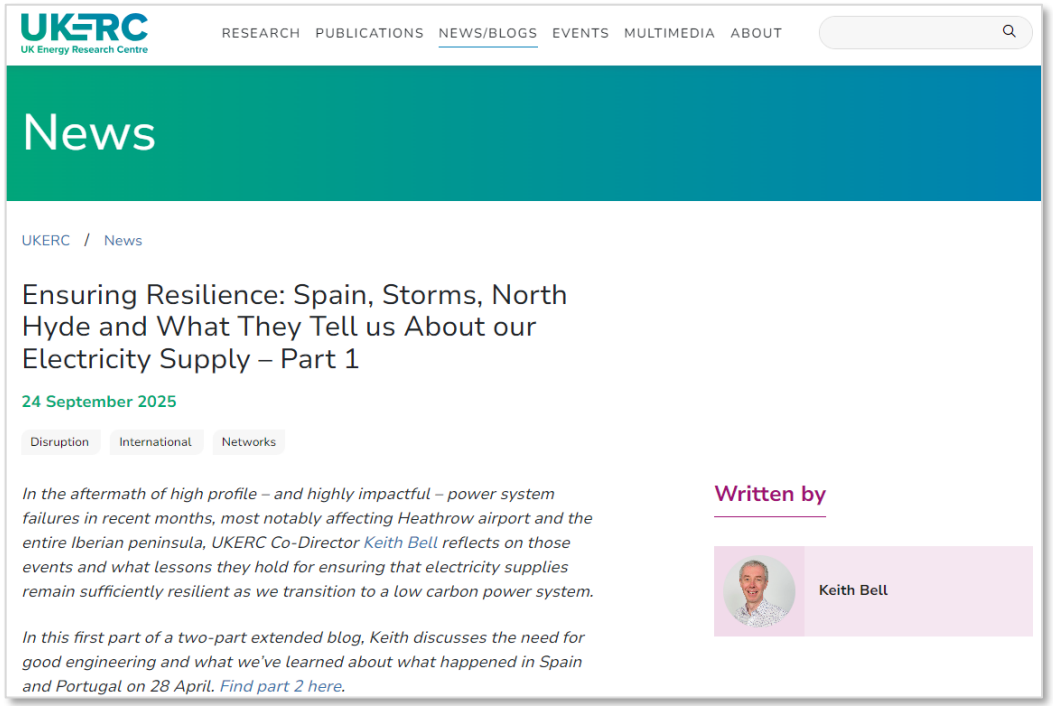
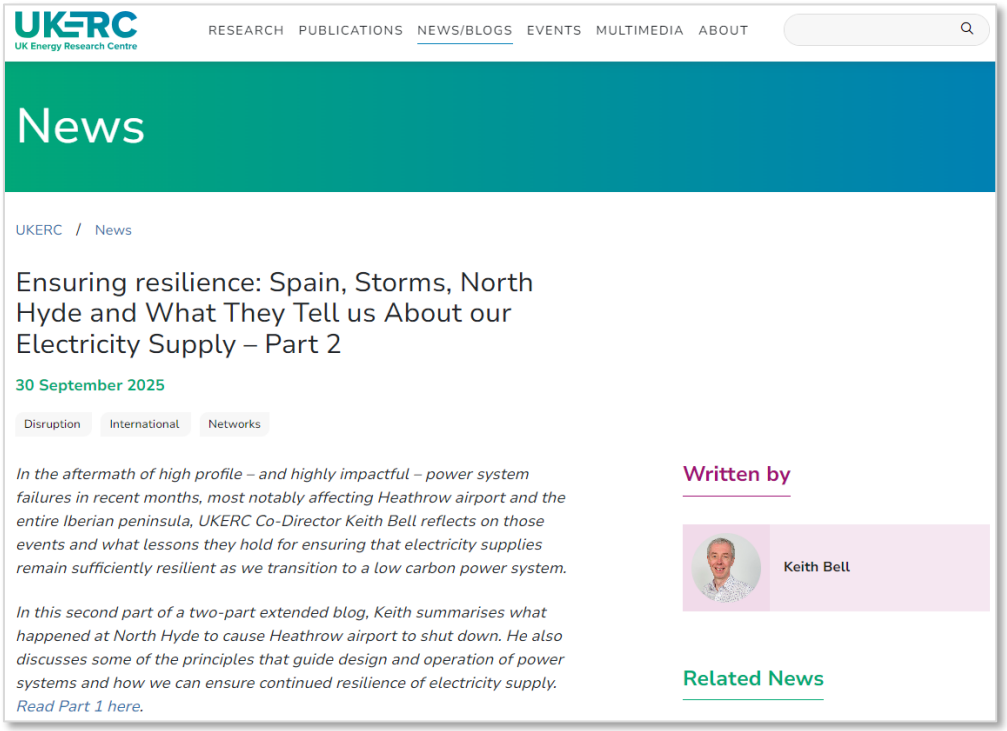
Any questions?



https://ukerc.ac.uk/news/ensuring-resilience-spain-storms-north-hyde-and-what-they-tell-us-about-our-electricity-supply-part-1/



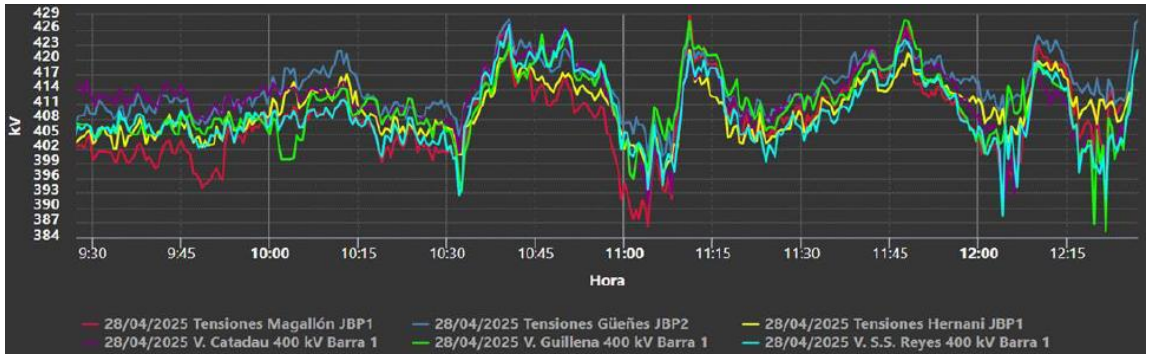
https://ukerc.ac.uk/news/ensuring-resilience-spain-storms-north-hyde-and-what-they-tell-us-about-our-electricity-supply-part-2/

More detail on what happened on April 28, 2025

The Iberian peninsula collapse, April 28 2025

Before the collapse: voltages

- Voltages quite high during the morning
  - Under normal operating conditions:
    - at the 400 kV level should be between 390 and 420 kV
    - at the 220 kV level should be between 205 and 245 kV
  - Anything connected “should be able to withstand”
    - at the 400 kV level, between 375 and 435 kV
    - at the 220 kV level, above 200 kV
- Action taken by the system operator to keep voltages down included
  - Switching shunt reactors in
  - Dispatching generation to absorb reactive power
  - Switching circuits out (I think)



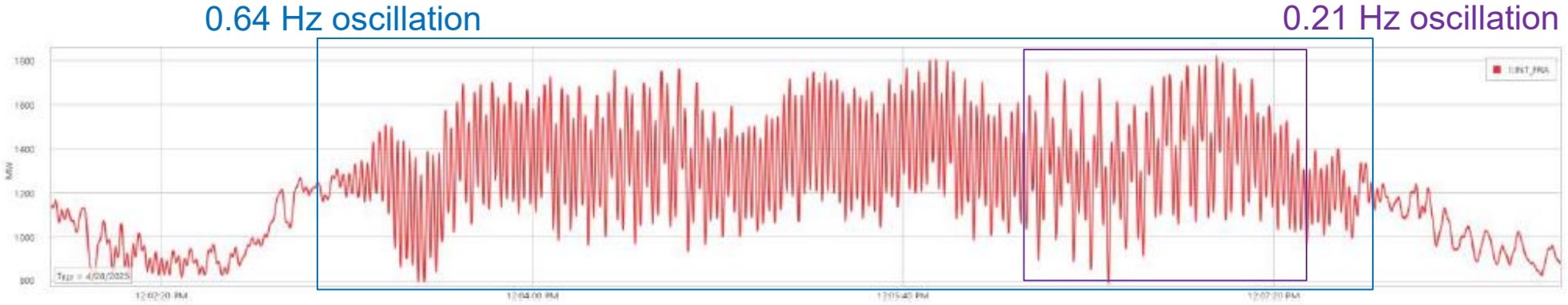
Voltages in the 400 kV transmission network from 09:30 to 12:30 h

Figure: Red Eléctrica, *Blackout in the Spanish Peninsula Electrical System the 28th of April 2025*, 18/06/2025

The Iberian peninsula collapse, April 28 2025

Before the collapse: oscillations seen on 400 kV network

- At 10:30 h, an inter-area oscillation in the European synchronous system of 0.2 Hz (typical West-Center-East) appears causing voltage oscillations of up to 4 kV in the 400 kV network
- At 11:03 h, an inter-area oscillation of 0.2 Hz appears again, causing oscillations of up to 7 kV
- At 11:23 h, an inter-area oscillation of 0.2 Hz appears again, causing oscillations of up to 6 kV
- At 12:03 h, for a duration of 4 minutes, 42 seconds, a significant 0.6 Hz oscillation was observed.
  - Coinciding with this, the damping of the 0.2 Hz frequency range dropped from 20% to 5%
  - The oscillation caused “a decrease in average voltage, with fluctuations reaching up to 30 kV in the most extreme cases, ranging between 375 kV and 410 kV depending on the substation.”
  - The oscillation could also be seen in the power exchange with France.



Exchange Spain-France between 12:02 and 12:08

Figure: Red Eléctrica, *Blackout in the Spanish Peninsula Electrical System the 28th of April 2025*, 18/06/2025

The Iberian peninsula collapse, April 28 2025

Action to mitigate oscillations

- REE Control Center activated the “pre-established measures to improve oscillation damping” and attempt to eliminate it:
  - “Coupling 400 kV transmission lines to reduce the system impedance”.
  - Reduction of export exchange with France by 800 MW to 1,500 MW.
  - Changing the HVDC link operational mode with France to constant power mode (setpoint: 1,000 MW from Spain to France).
- Additionally,
  - due to the voltage drops caused by the oscillations, a series of shunt reactors were disconnected to mitigate the undervoltages.
  - exports to Portugal reduced to improve damping
- Reductions in exports achieved by reducing solar PV production in the south
  - Reduced power flows result in increased voltages
  - Reduced active power production results in reduce reactive power absorption. (Fixed power factor control mode)

The Iberian peninsula collapse, April 28 2025

Further action to mitigate oscillations

- At 12:16 h, the 0.6 Hz oscillation reappeared, causing voltage oscillations and drops, with values ranging between 405 kV and 380 kV in the most affected substations.
  - Mitigation of the oscillation becomes the top priority again.
- As voltages dropped again, additional shunt reactors were disconnected to mitigate the resulting low voltages.
- At 12:19 h, while actions were still being implemented to improve damping, a new frequency oscillation of 0.2 Hz appeared
  - System voltages were close to nominal (between 395 and 410 kV), but the oscillation caused voltage fluctuations of up to 28 kV at the Almaraz 400 kV substation, with values ranging between 375 kV and 412 kV depending on the substation.
- In accordance with standard protocols:
  - Coupling of 400 kV transmission lines to reduce system impedance.
  - Reduction of export exchange with France to 1,000 MW (with the HVDC link set to 1,000 MW from Spain to France, resulting in zero net export via AC lines).
  - Reduction of export exchange with Portugal from 2,545 MW to 2,000 MW

The Iberian peninsula collapse, April 28 2025

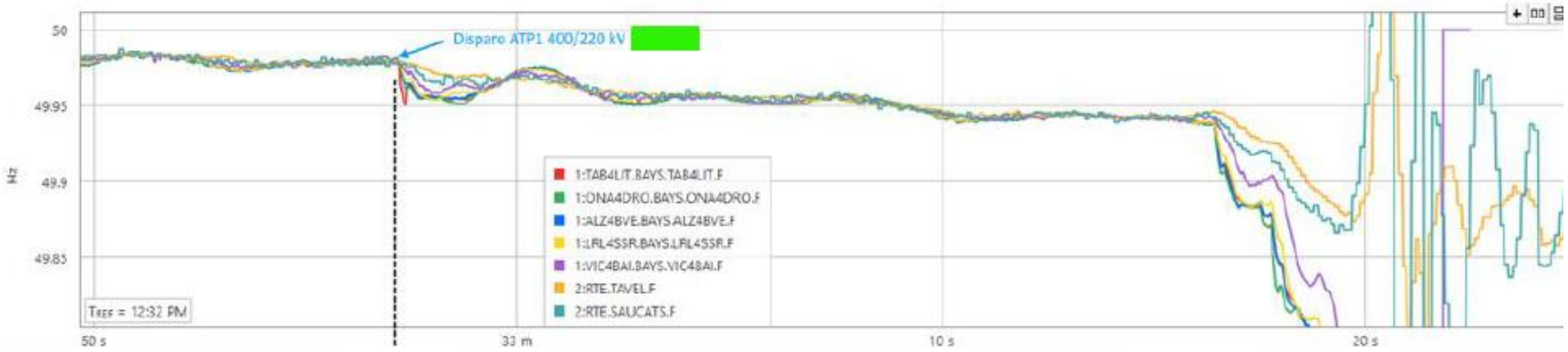
Generation tripping

- Between 12:32:00 h and 12:32:57 h, an additional “anomalous variation in effective demand” (increase) of approximately 434 MW was detected.
  - This led to a reduction in energy exports to France, further contributing to the voltage increase in the transmission grid.
  - “Demand is inherently voltage-dependent, thus, as voltage increases, so does demand, further amplifying the previous effect.
  - “As power flows through the network [to France] decreased, transmission lines consumed less reactive power, contributing to the voltage rise.
  - “Generation units … which are required to provide dynamic voltage control, did not absorb the expected amount of reactive power particularly on the main generators located in Andalusia, Extremadura and Castilla la Mancha.”
- At 12:32:57 h, a trip occurred at a substation located in the province of Granada which at the time was supplying 355 MW to the transmission grid and absorbing 165 Mvar.
  - Following the trip, voltages increased to 424 kV.

The Iberian peninsula collapse, April 28 2025

A cascade of outages

- Beginning at 12:33:16.460 h – around 19.5 seconds after the Granada trip – 727 MW of generation was lost along with the associated reactive power absorption within 360 ms.
- Beginning at 12:33:17.368 h, an additional 834 MW of generation was disconnected along with the associated reactive power absorption within a 650 ms window.
  - ROCOF measurements suggest the loss of generation may have been 1150 MW.
- At 12:33:19.620, the maximum import from France is reached, 3807 MW, with 4609 MW through the AC network.
  - This leads to the loss of synchronism between Spain/Portugal and France.
  - Only 22.5 seconds have passed since the disconnection in Granada



"Evolution of the system before and after the trip in Granada"

Figure: Red Eléctrica, *Blackout in the Spanish Peninsula Electrical System the 28th of April 2025*, 18/06/2025

The Iberian peninsula collapse, April 28 2025

System collapse

- Undesired disconnection of CCGT located in the east occurs when the frequency reaches 49.5 Hz and the substation voltage is 419.6 kV.
  - Loss of voltage control capability
- When frequency is 49.5 Hz, the shedding of pumping load is activated. When the frequency reaches 49 Hz, load shedding of industrial customers begins.
  - “Load shedding … causes an increase of the voltage because when a demand is disconnected the voltage naturally rises.”
- Interconnection with Morocco (an AC interconnection) is tripped by UFLS in Morocco
  - Before the event, Spain was exporting to Morocco.
  - When the interconnection tripped, Spain was importing 314 MW.
- When the frequency reaches 48.46 Hz, the AC interconnection lines with France trip
  - The HVDC link is in constant power mode, exporting 1 GW to France.
- In the next 2 s, various nuclear and CCGT units trip plus the HVDC link to France.
- “At 12:33:24 h the Spanish Iberian Peninsula system collapses.”