The Iberian Peninsula Blackout

Prof.dr.techn.ir. Sonja Monica Berlijn MBA

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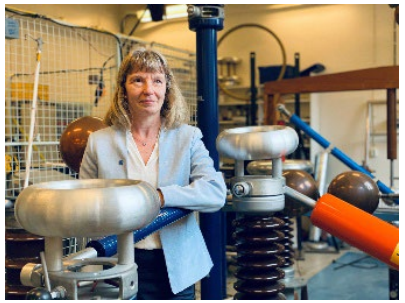
prof.Sonja.Berlijn
sonja-monica-berlijn-144ab1a/
@sonja_berlijn
prof. Sonja Berlijn

Prof.dr.techn.ir. Sonja Monica Berlijn MBA

Current

- DNV – Business Director
- UiO – Professor secure power systems

- Previous
  - Professor - KTH
  - SVP R&D Statnett - Norway
  - Prof II - NMBU – Norway
  - Research, Development and & Quality





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The Iberian Peninsula Blackout 28 April 2025 12:33

- On 28 April 2025, at 12:33 CEST, the power systems of Spain and Portugal experienced a blackout. A small area in France, close to the border with Spain, was also affected for a limited duration.
- Several industrial consumers and generators were affected, more notably a nuclear power unit tripped around the same time as the incident in the Iberian Peninsula.
- The remainder of the power system of Continental Europe did not experience any significant disturbance.



More than the loss of power

- The blackout caused widespread disruption to essential services and infrastructure.
- It led to the shutdown of public transportation, telecommunications, and many businesses.
- Hospitals relied on backup generators, and digital payment systems were severely impacted. While air traffic operations continued safely, public transport experienced significant delays and suspensions.
- The incident served as a stark reminder of the interconnectedness of modern society, the critical dependence on a stable and reliable electricity supply and the vulnerability of critical infrastructures to power outages.
- It also highlighted the need for robust emergency response plans, investment in grid infrastructure, and a diversified energy portfolio to mitigate the risks associated with power outages.

Overview on Continental European System disturbances

- Europe_2006-11-04_system split
- Europe_2016-12-01_inter-area oscillations with Iberia
- Europe_2017-12-03_Central Europe oscillation event
- Europe_2021-01-08_system split
- Europe_2021-05-17_3.3 GW trip PP Rogowiec (Poland)
- Europe_2021-07-24_system split
- Europe_2022-03-24_ENERCON cyber attack_loss of control 11 GW
- Europe_2023-11-03_2.66 GW trip PP Paluel 2 and 2 (France)
- Europe_2024-06-21_South-East Europe partial blackout
- Europe_2025-02-08_Baltics system disturbance (due to islanding)
- Europe_2025-04-28_Iberia blackout
- Europe_2025-05-18_North Macedonia_Partial blackout
- Europe_2025-07-04_Czech Republic_Partial black-out

With thanks to: Matthias Müller-Mienack

Oscillations in grid of the Iberian Peninsula

introduction

- The Iberian peninsula has had two major incidents 2016 and 2021 (system split)
- Oscillations has been a reoccurring phenomenon in grid of the Iberian Peninsula
- From the investigation 2016: This event shows that power transport over long distances together with too high impedance can cause a too low system damping with respect to inter-area oscillations and should, therefore, be treated carefully.
- Aspects such as HVDC influence and PSS settings across the CE system will be further investigated

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

Relevant regulation

regulation

- COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO or SO GL)
- Requirements and principles concerning operational security
- COMMISSION REGULATION (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration (ER)
- Preparing and activation of the system defence plan and the restoration plan.
- COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators (RfG)
- Production facilities must be able to stay connected to the grid during disturbances and help prevent any major disruption or to facilitate restoration of the system after a collapse
- National regulation

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

The investigation following the incident

regulation

- An independent investigation – regulated in SO GL.
- The Expert Panel consists of representatives from TSOs, the Agency for the Cooperation of Energy Regulators (ACER), National Regulatory Authorities (NRAs), and Regional Coordination Centres (RCCs).
- The Panel is led by experts from TSOs not directly affected by the incident and includes experts from both affected and non-affected TSOs.
- Data collection and Factual report - legal deadline to produce this report is 28 October 2025 – planned to be published in the beginning of October
- The Expert Panel reviews all collected data and the reports etc, discuss details on meetings.

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

Analysis is still on-going

regulation

- Final report
  - the root causes of the incident
  - evaluate the actions undertaken to control the voltage and to mitigate the oscillations
  - assess the performance of generators in regard to protection settings and contribution to voltage control
  - assess the performance of the system defence plan and analyse the various steps of the restoration phase
  - the incident in a broader context, such as by examining the behaviour of the Iberian power system on the days preceding the blackout.
- Recommendations and Final report - expected to be delivered 3 to 4 months after the factual report.

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

Disclaimer



regulation

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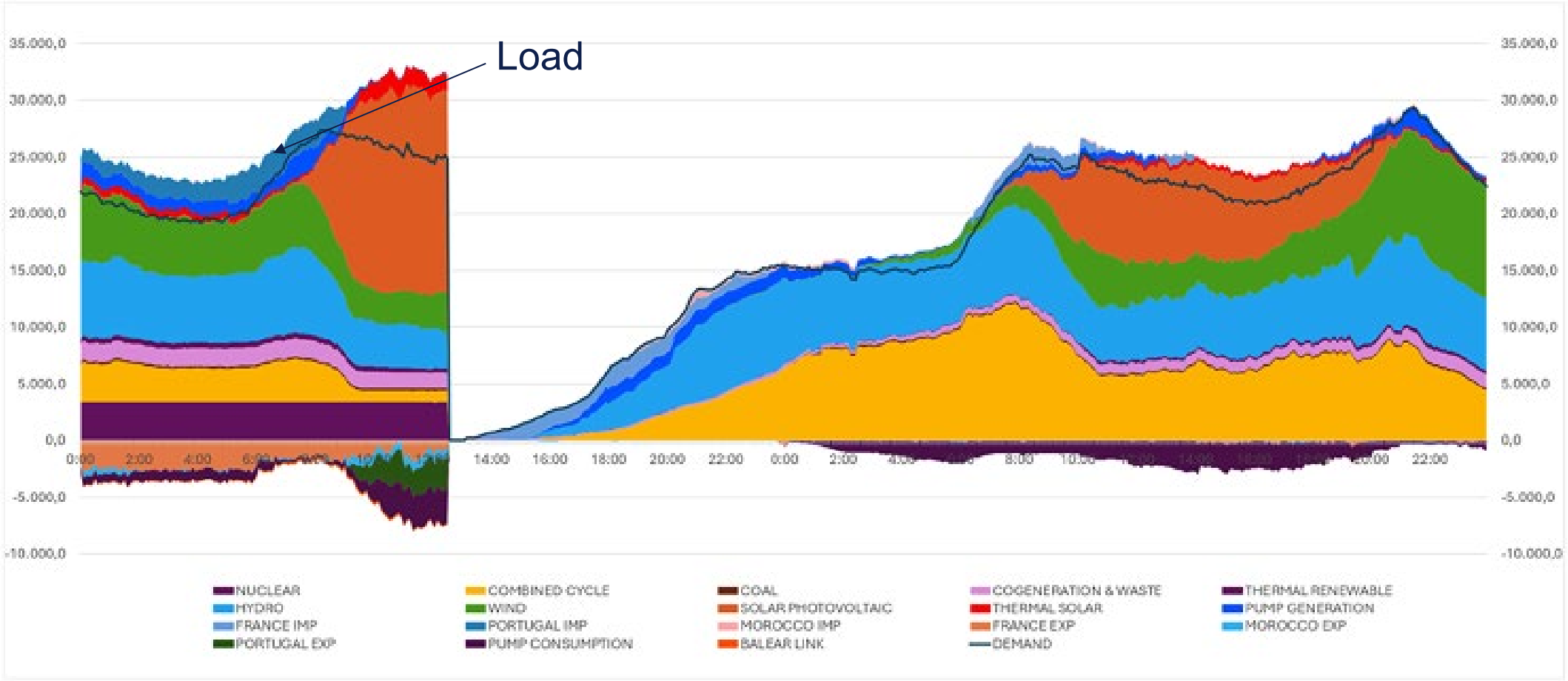
- Users are encouraged to verify the information independently.
- For clarity, this webpage does not constitute factual or final report under the Incident Classification Scale Methodology.
- The information has been updated.
- More information: 28 April Blackout

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

Produktion Spanien

Vattenkraft och värmekraft användes för återuppbyggnaden.

production



With thanks to: Magnus Olofsson

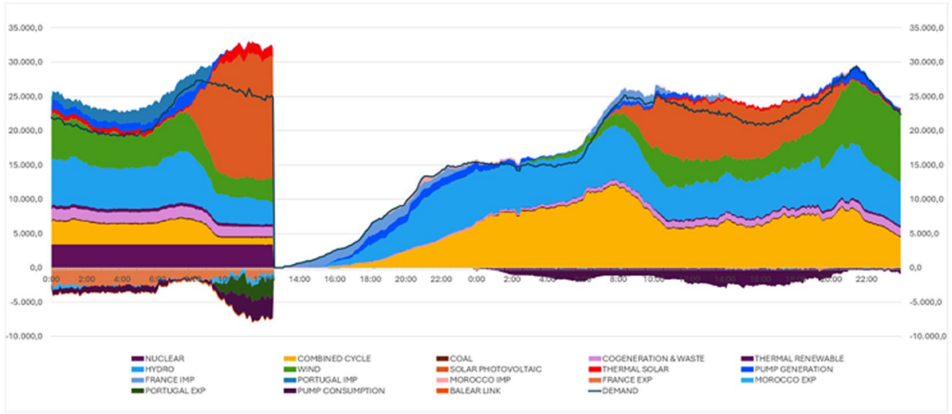
Initial situation in Iberia on Monday, April 28, 2025

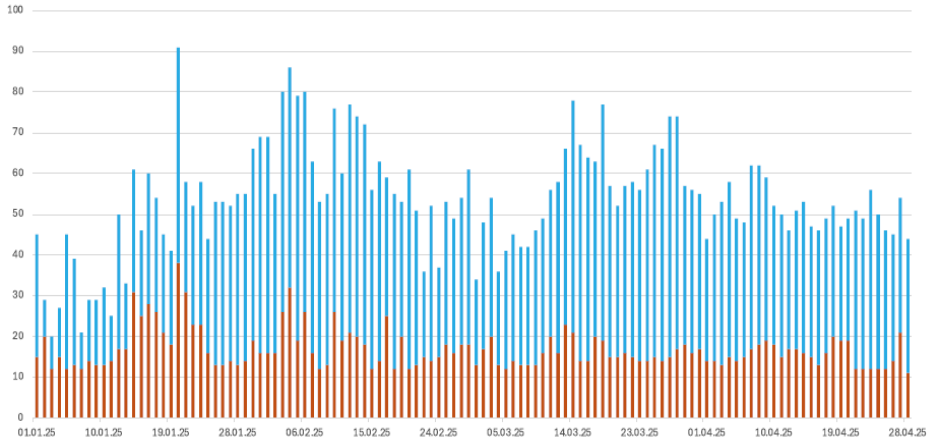
Grid operation in Spain and Portugal still without any major incidents during the morning

production

Focus on Spain:

- Load is in between 25 and 30 GW
- Calculated Spanish midday load approx. 25 GW (but incl. DER < 1 MW, uncertainty!)
- High exports: ca. 5 GW (11:00), ca. 4 GW (12:00) and about 3 GW pump consumption
- Up to 21.2 GW from wind + PV (60 % of the load)
- Only 11 thermal power plant units > 30 MW connected to the grid
- Around midday, approx. 11 GW of additional generation (including 3.4 GW from nuclear power plants)





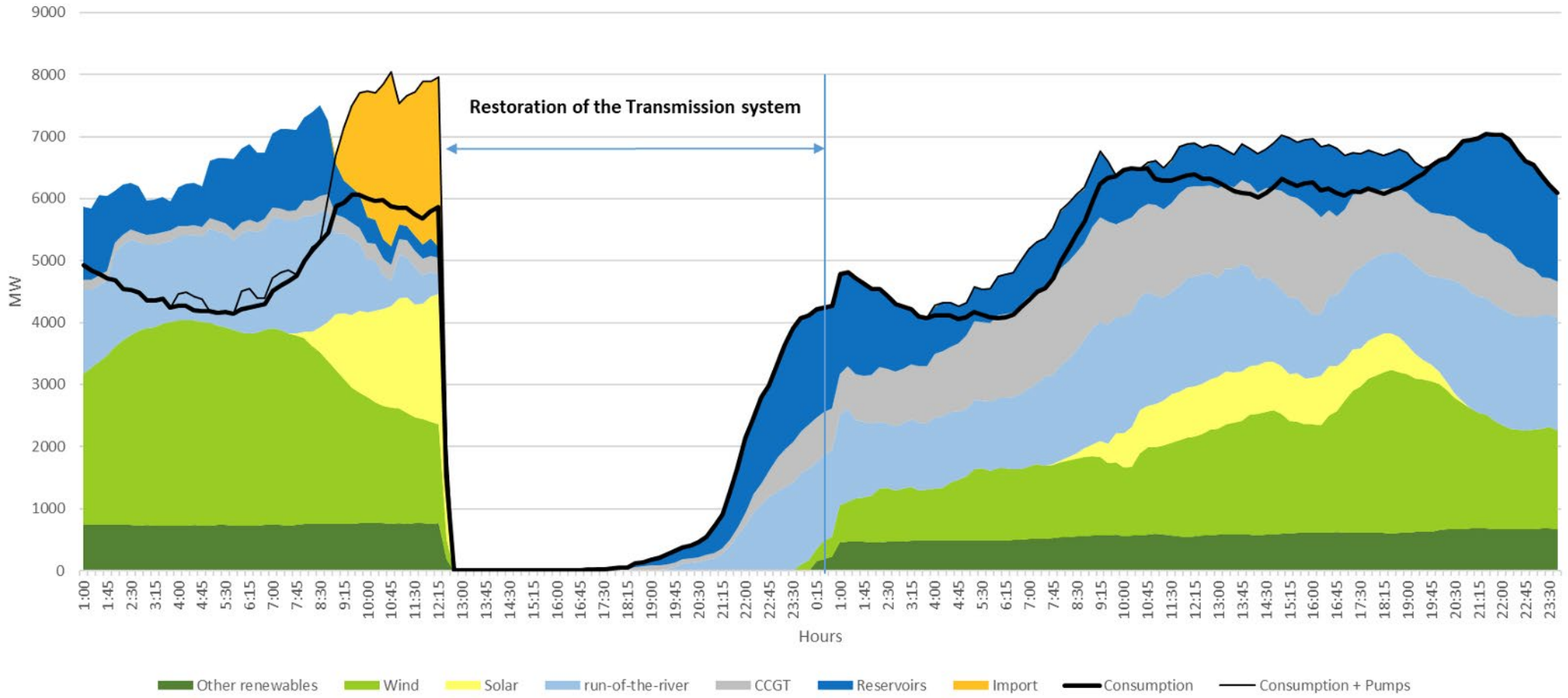
Source: Grid Incident in Spain and Portugal on 28 April 2025, ENTSO-E report from Oct. 3rd, 2025

With thanks to: Matthias Müller-Mienack

Produktion Portugal

Vattenkraft och värmekraft användes för återuppbyggnaden.

production



With thanks to: Magnus Olofsson

Tidslinje för händelseförloppet

Initial situation

09:00 – Normal drift

09:00 – 11:30 – spänningsändringar

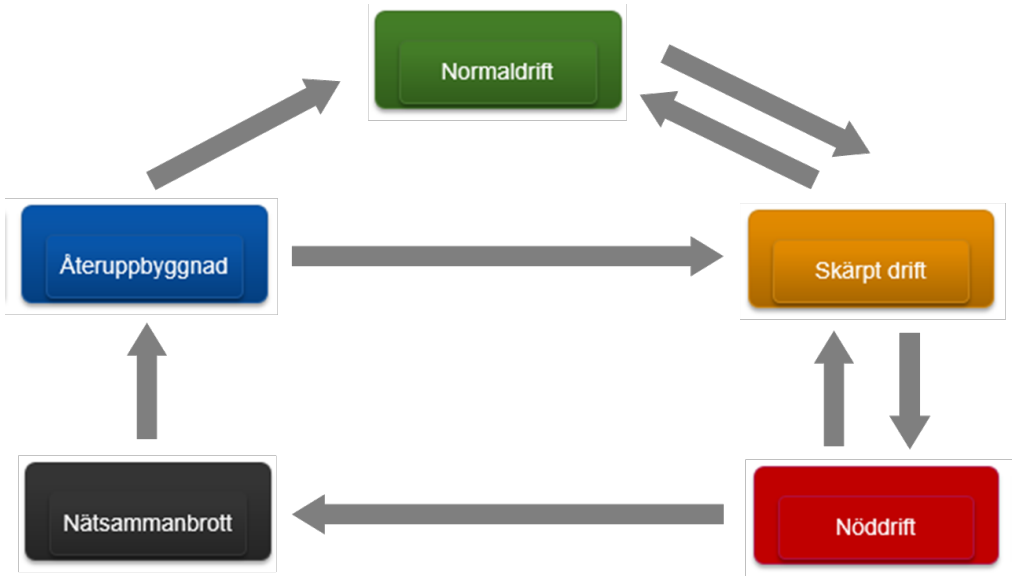
12:03 – Första pendling

12:19 – Andra pendling

12:32 – Spänningsökning

12:33 – Blackout

Eftermiddag – Återuppbyggnad

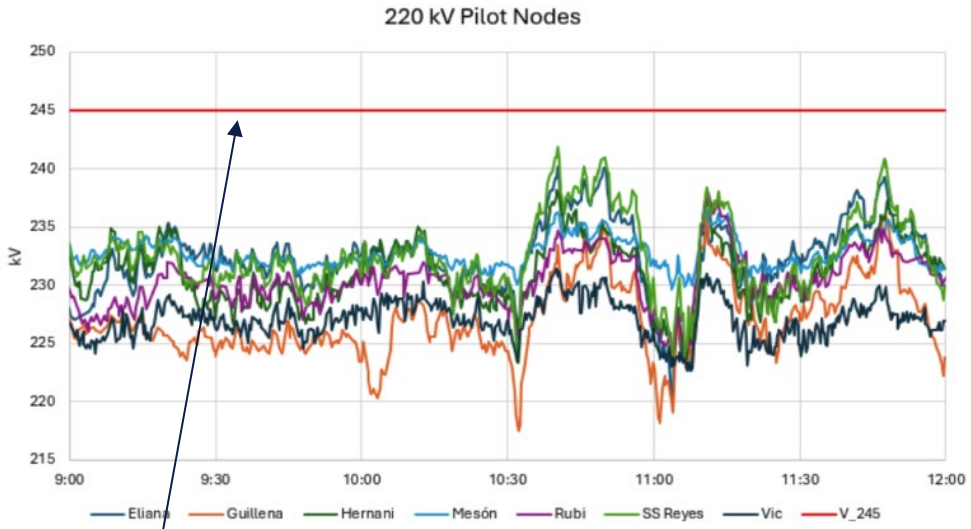


With thanks to: Magnus Olofsson

System conditions on the morning of 28 April (09:00 – 10:30)

Initial situation

- During the night of 27 to 28 April, the Iberian power system operated normally, without notable variations in the voltage profile.
- From approximately 09:00 CEST, the variability of the voltage in Spain started increasing but without significant variations until 10:30 CEST.
- From 10:30 CEST, more significant voltage variations started to occur.
- The voltage in the transmission system remained below the upper operational limits.



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With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

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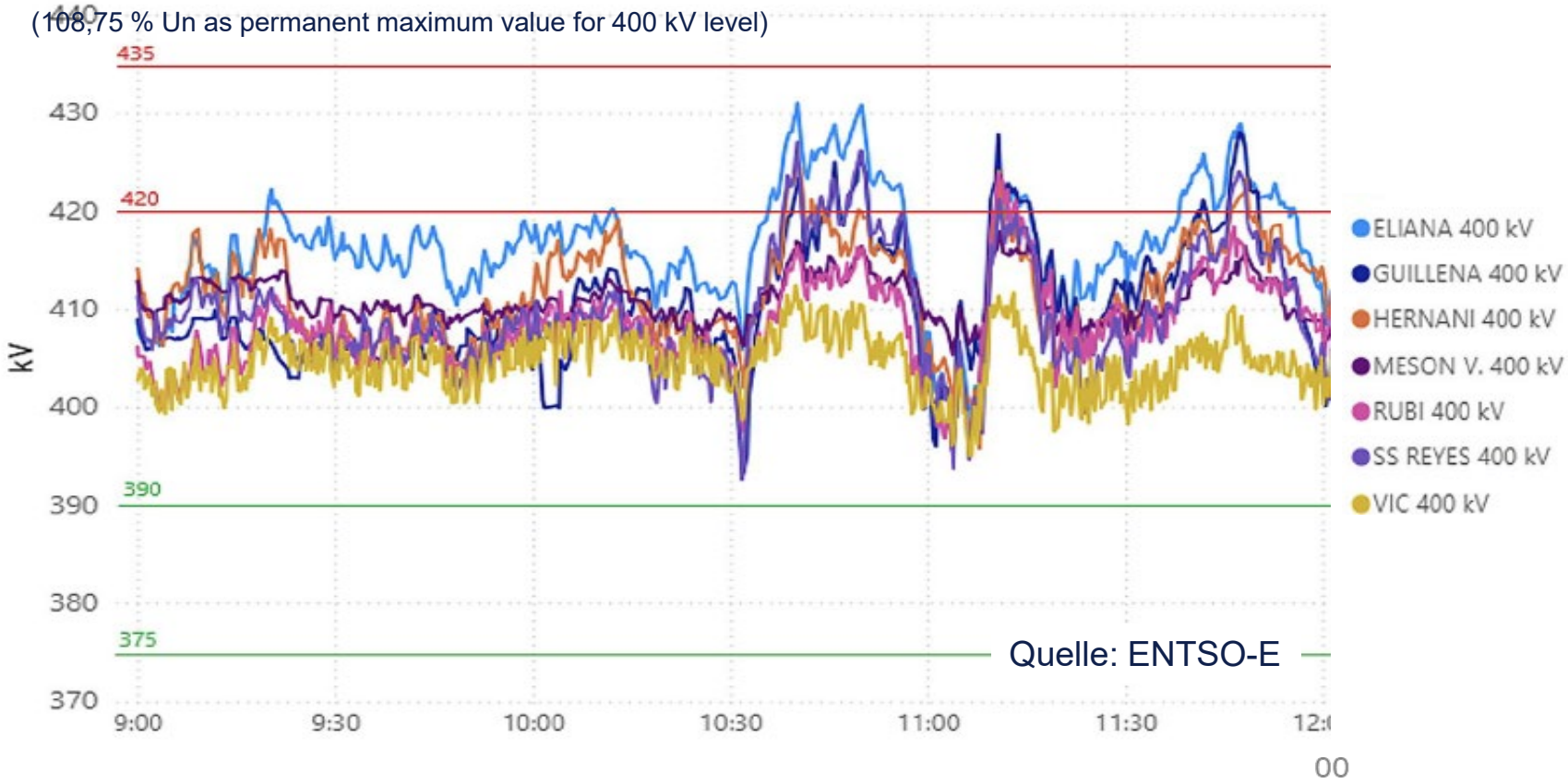
Voltage fluctuations and oscillations in the morning after 10:30

Initial situation

Focus on Spain:

- First voltage fluctuations from 9:00 a.m., more significant from 10:30 a.m. – but still within permissible limits
- First oscillations were recorded between 11:06 and 11:10 a.m., but still uncritical with 3% damping and < 20 mHz amplitude



With thanks to: Matthias Müller-Mienack

System conditions prior to the incident (12:00 – 12:30 CEST)

After 12:00

- During the half hour preceding the blackout, two main periods of oscillations (power, voltage and frequency swings) were observed in the Continental Europe Synchronous Area (CE SA).
- The first one took place from 12:03 to 12:07 CEST.
- A preliminary analysis: a local, forced oscillation (i.e. induced by an external source)
- The forced oscillation also excites the interarea mode East-Centre-West with a small amplitude.
- A local mode between two generation clusters in the Iberian Peninsula system, one in the north-east part of Spain and another in the south-west of Spain and Portugal.

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

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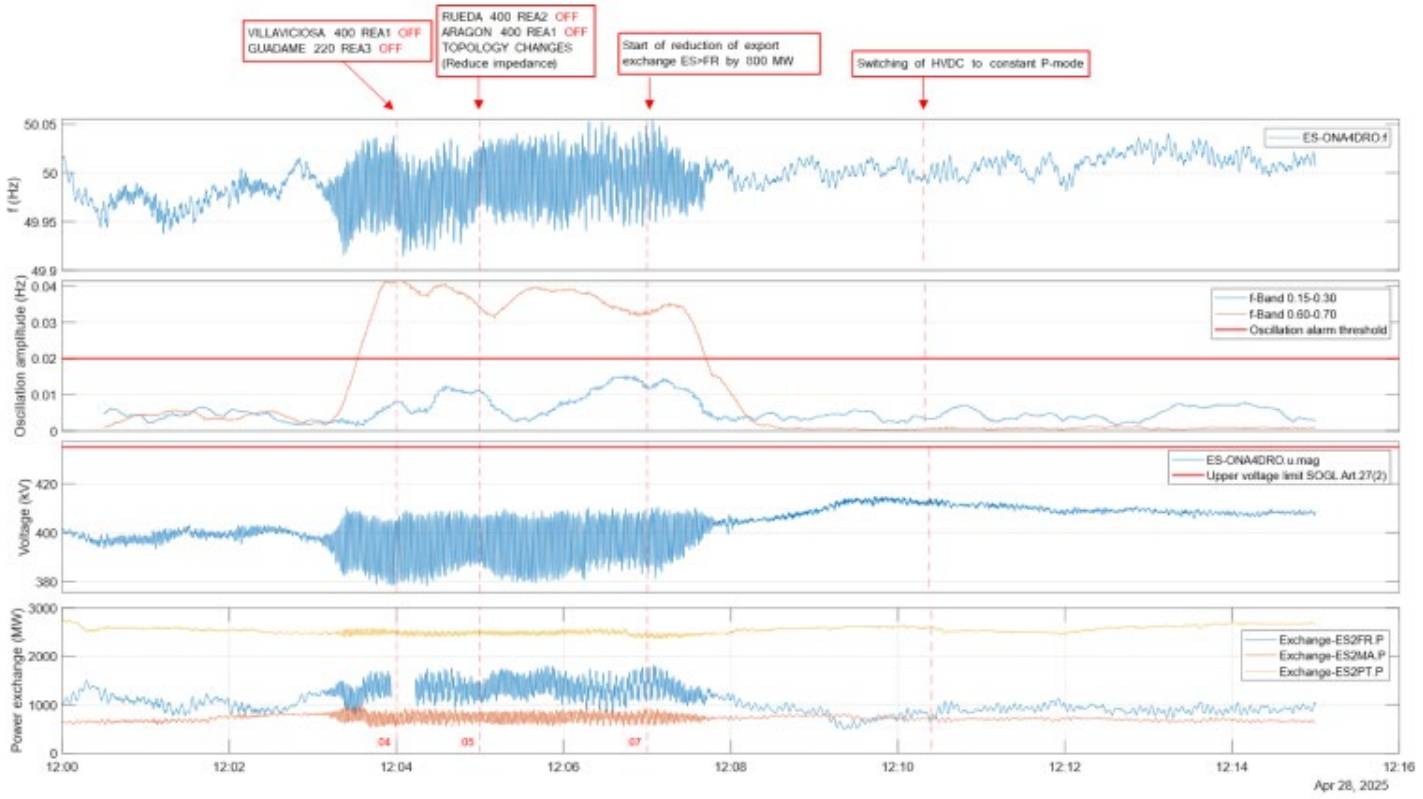
To damp the oscillations the TSOs took action

The flow between Spain and France was reduced with 800 MW.

In addition, shunt reactors manouvers were taken to recover voltage, that reached low values transiently during the oscillation.

After 12:00
First oscillation



Lines were switched on to decrease the system impedance

Fixed power operation mode was set up on the HVDC link between Spain and France

12:03–12:07 CEST: Lokal effektpendling (0,64 Hz) mellan nordost och sydväst i Spanien.

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

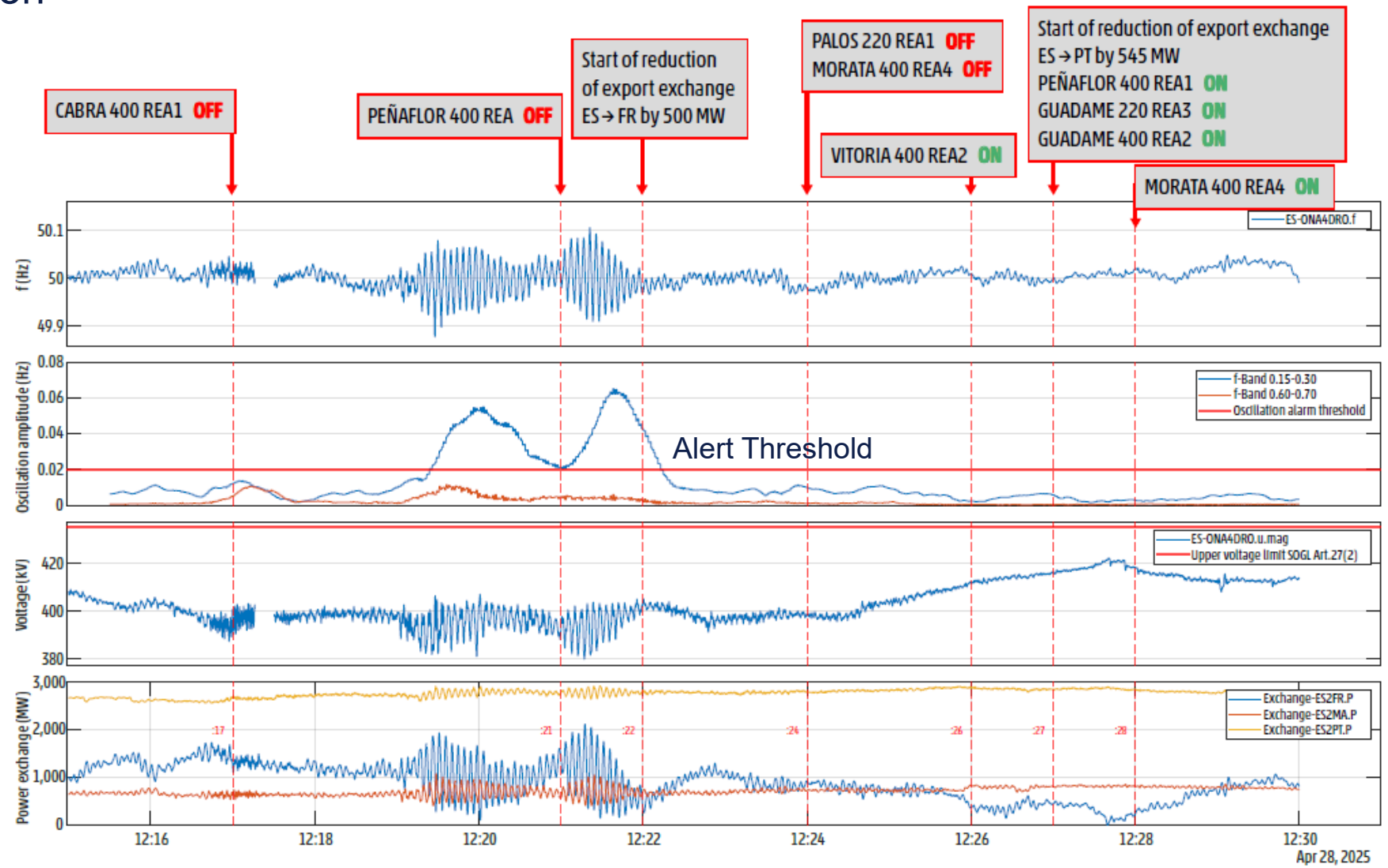
Inter-area sub-synchronous oscillations: P, U and frequency

East-Central-West oscillation

- PMU measurement (right) at Carmona
- Second inter-area oscillation (12:19–12:22 p.m., 0.21 Hz with up to 200 mHz amplitude, negative damping)

After 12:00 Second oscillation

- Measures: Additional shunt reactors switched off, further export reduction to FR by 500 MW, later to PT by 545 MW (countertrading)
- However, due to voltage increase from 12:26 p.m., shunt reactors were then switched on



Source: ENTSO-E

With thanks to: Matthias Müller-Mienack

Between 12:32:00 and 12:32:57 CEST

- Around the time when the net active power exchange position of Spain began to decrease, the voltage started to rise.
- A loss of more than 500 MW of numerous wind and solar generation units, connected to the distribution networks in Spain,
- This is one main driver of the development.

Escalation to blackout

The cause of these trips still remains unknown, due to the limited observability at the medium/low voltage level – both in spatial and temporal granularity.

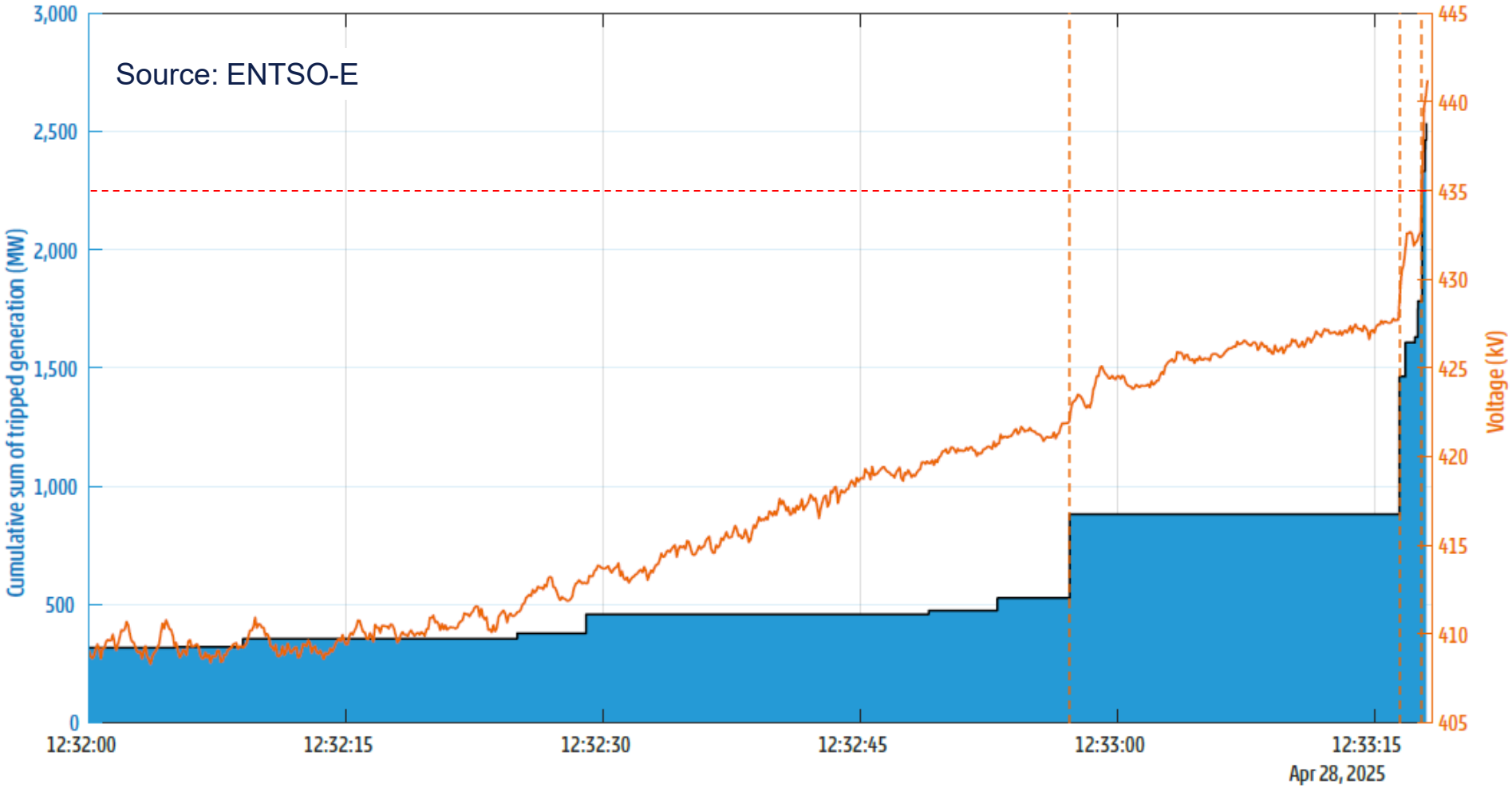


Generation tripping leads to further voltage increases

Lack of data leads to assumptions regarding load increases and, in some cases, generation outages

- Diagram: Gradual (assumed) generation failure in the distribution network from 12:32 p.m. (blue)
- Parallel voltage increase in the Carmona substation (orange)

Causes of failure partly due to overvoltage tripping, partly unclear

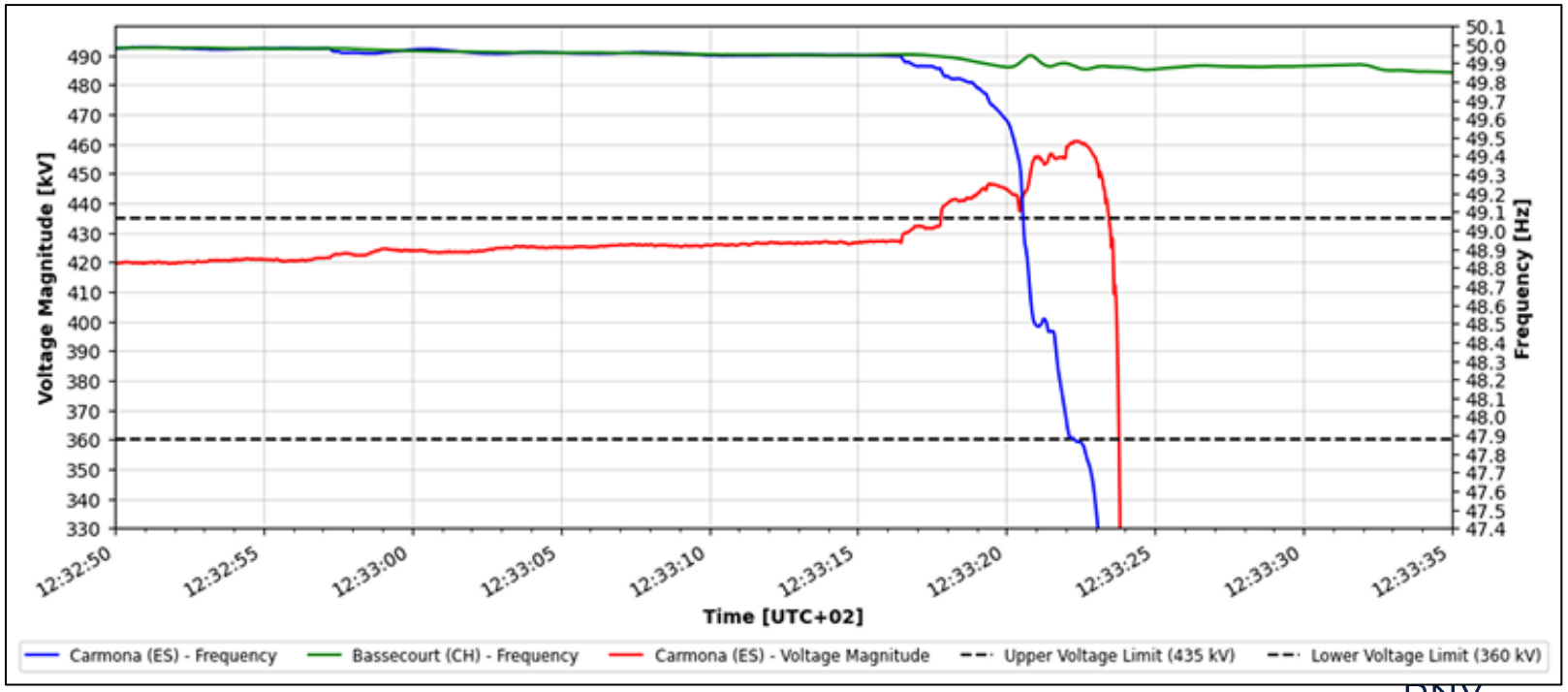


Escalation to blackout

Kollaps och konsekvenser

- Produktionsunderskott ledde till sjunkande frekvens och spänningskollaps.
- Synkron produktion (termisk/vattenkraft) kopplades bort p.g.a. överspänningar vilket förvärrade kaskaden.
- Blackout i stora delar av Spanien och Portugal; återuppbyggnaden tog flera timmar.
- Sju (indirekta) dödsfall rapporterades från Spanien och ett i Portugal.

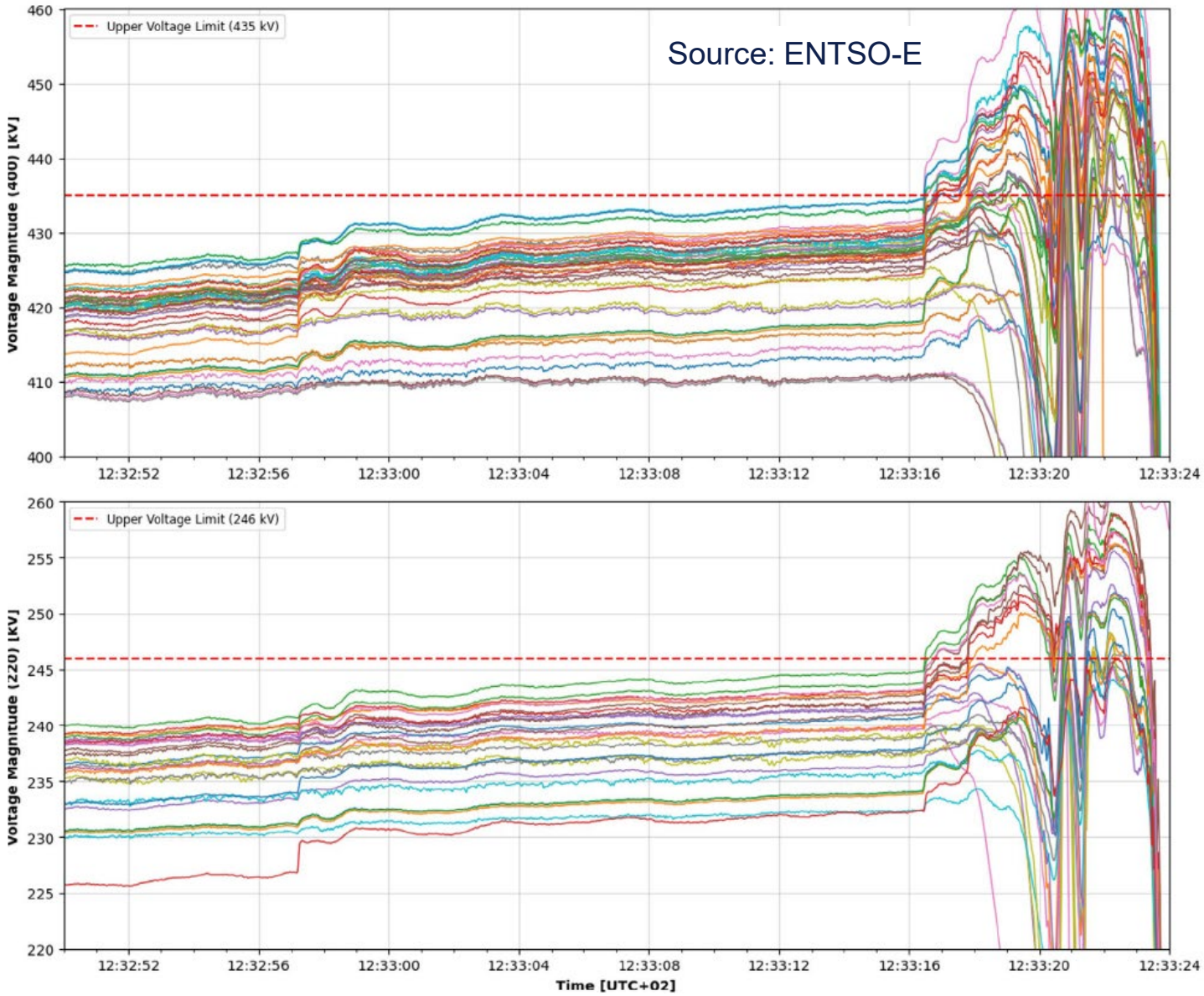
Escalation to blackout



Escalation to blackout: Generation failures and voltage increase

The final seconds...

- Approx. 12:33:16 p.m.: Disconnection of PP Badajoz 1 and 2 → Voltage exceedance in several substations
- Approx. 12:33:17 p.m.: Disconnection of approx. 930 MW PV and also of wind farms → Expansion of voltage exceedance
- Now loss of voltage regulation à Cascading shutdown of generation
- Start of noticeable frequency drop in Iberia

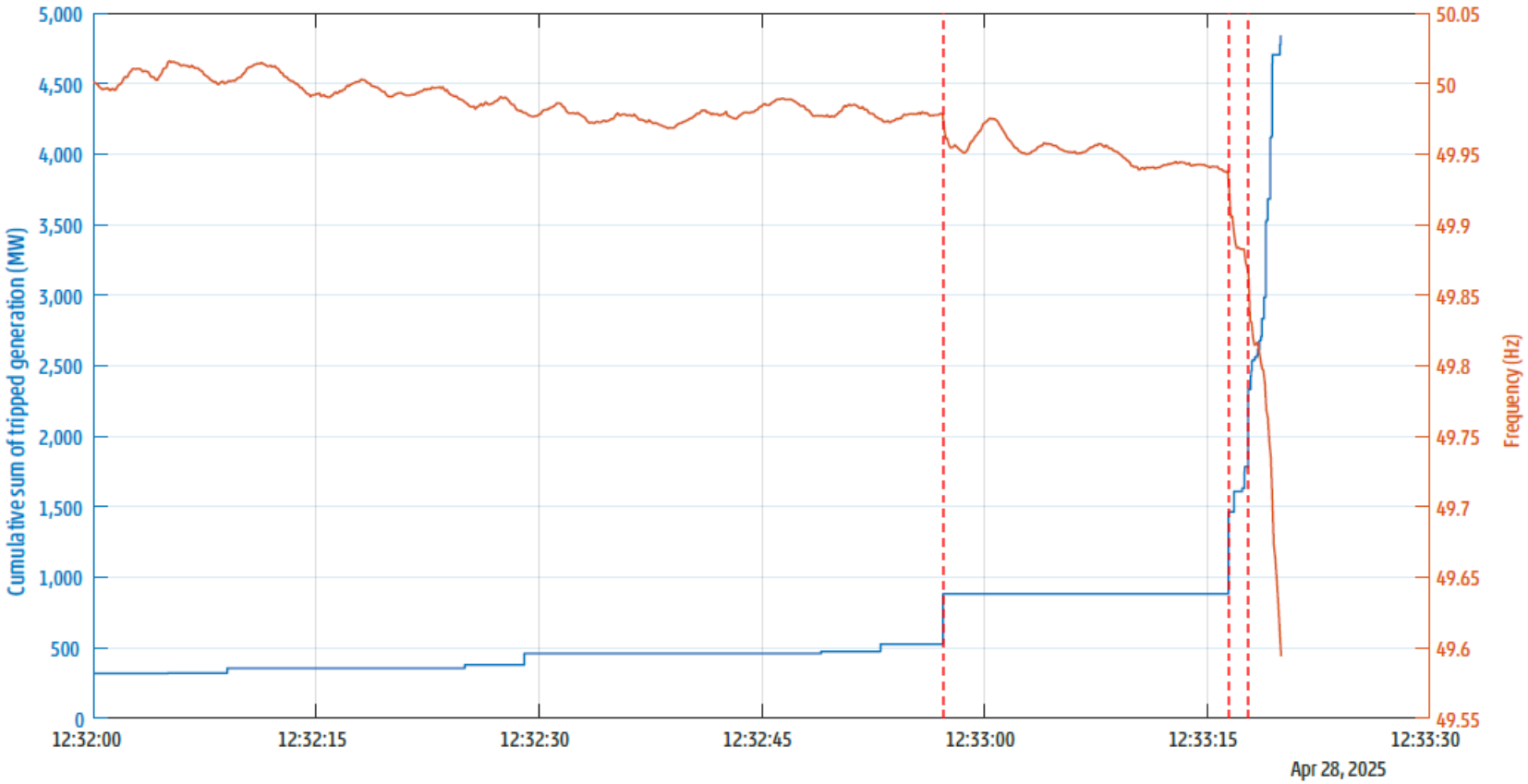


Escalation to blackout

Escalation to blackout: EZE failures and voltage increase

The final seconds...

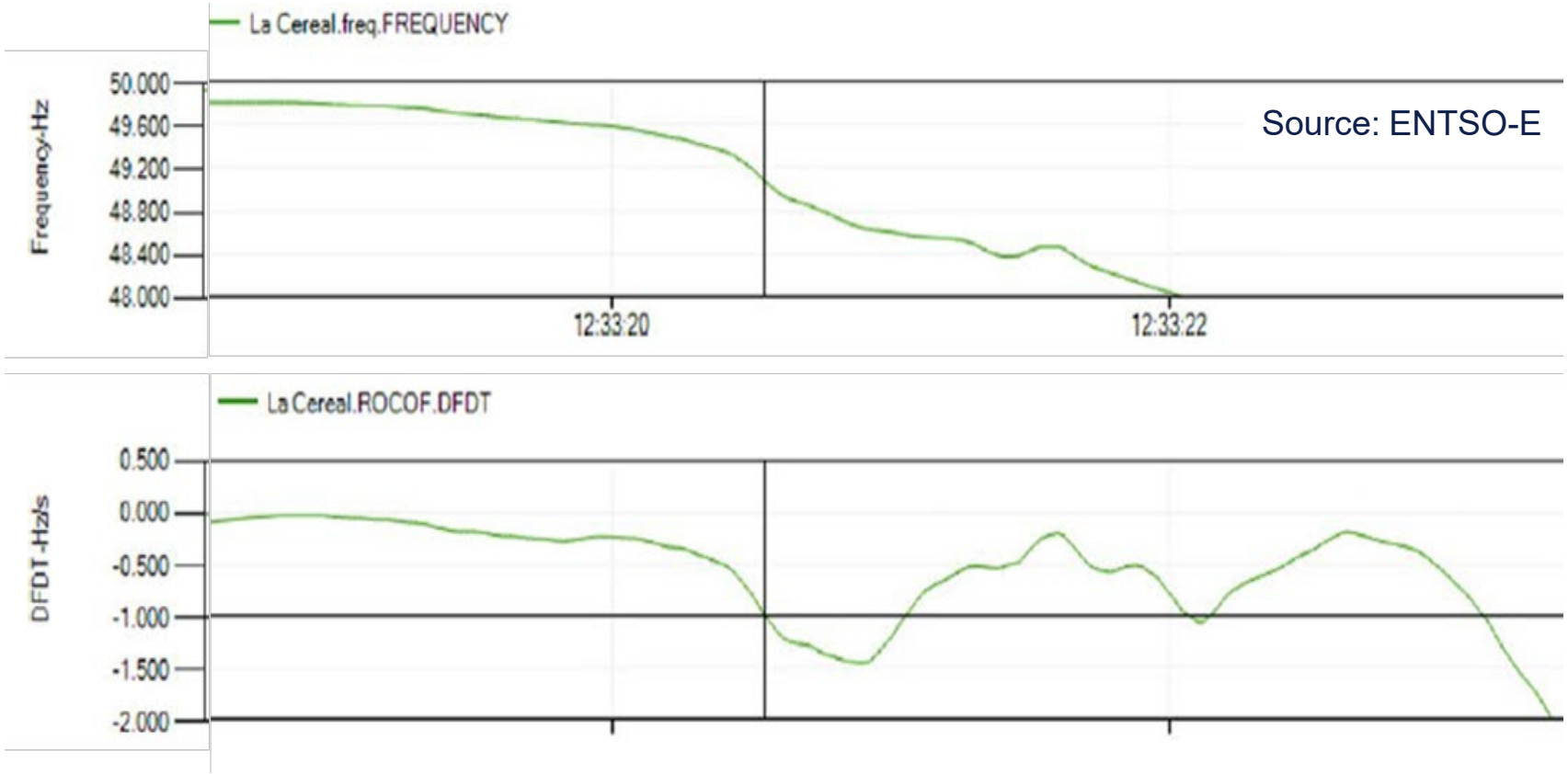
- Approx. 12:33:20 p.m.: AC interconnector to Morocco disconnects (underfrequency protection)
- Approx. 12:33:21 p.m.: AC interconnectors to France shut down (out-of-step protection)
- Approx. 12:33:24 p.m.: Shutdown of HVDC to France → complete isolation of Iberia
- Approximately 12:33:27 p.m.: Complete blackout in Spain and Portugal → voltage & frequency in Iberia at zero



Source: ENTSO-E

Frequency and rate of change of frequency (RoCoF)

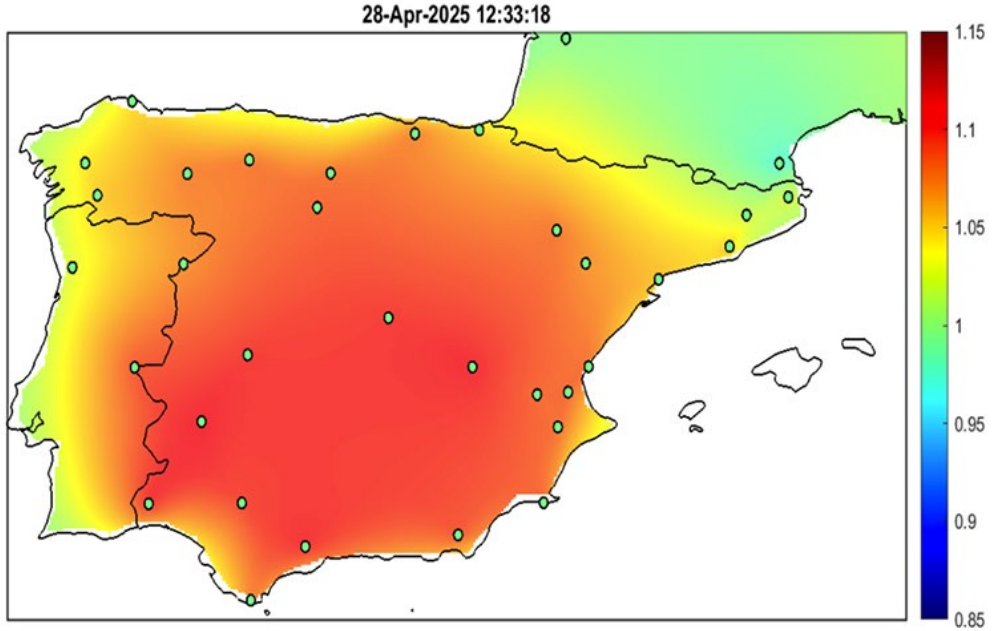
- Measurement at Cereal (near Madrid), using sliding measurement over 500 ms
- The RoCoF in the moments before the blackout shows that it remained within the range of 1 Hz/s until 12:33:20.400, when the minimum frequency was already around 49 Hz.
- After that, the absolute RoCoF value exceeded 1 Hz/s, up to about 2.0 Hz/s (thus also exceeding the grid code limit for PV!).



Source: ENTSO-E

Escalation to blackout

Between 12:33:18 and 12:33:21 CEST



- The voltage of the South area of Spain increased sharply, and consequently also in Portugal. The over-voltage triggered a cascade of generation losses that caused the frequency of the Spanish and Portuguese power system to drop.
- The power systems of Spain and Portugal started to lose synchronism with the European System.

Escalation to blackout

- The automatic load shedding and System Defence Plans of Spain and Portugal (regulated in EU regulation) were activated but were unable to prevent the collapse of the Iberian power system.
- The AC interconnection between Spain and Morocco tripped due to underfrequency.
- RoCoF in the area remains within the absolute range of 1 Hz/s up until 12:33:20

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

At 12:32:57, 12:33:16 and 12:33:17 CEST

- Tripping of a generation transformer, due to a problem in the lower voltage side. Why?
- Connected different generation facilities (photovoltaic, wind and thermo-solar) to the transmission grid and which was injecting 355 MW.
- The second event included trips of PV and thermo-solar facilities connected to two transmission 400 kV substations, in the area of Badajoz, with a total interrupted injection of around 725 MW. Why?
- The third event included several trips, in different areas, in less than one second: wind farms in Segovia and Huelva, photovoltaic in Badajoz, Sevilla, Caceres and Huelva and thermo-solar in Badajoz, and other generators in different locations for a total of more than 1100 MW, as estimated by the variation of frequency. Why?
- From this quantity, the Expert Panel was able to identify 930 MW of generation loss based on data provided by generators and from Red Eléctrica's monitoring equipment.

Escalation to blackout

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

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Restoration process

- REN requested black-start mode start-ups for the Castelo de Bode hydropower plant and the Tapada do Outeiro combined cycle gas turbine power plant.
- A first 400 kV line between France and Spain was re-energised (Western part of the border).
- At 00:22 CEST on 29 April 2025the restoration process of the transmission grid was completed in Portugal.
- At around 04:00 CEST the restoration process of the transmission grid was completed in Spain.
- Was it efficient and did it go as planned?

Restoration

With thanks to: Anna Carlén
Expert, Energimarknadsinspektionen

Conclusion of Spanish government report dated 17 June 2025

Source: Informe del Comité de análisis de la crisis eléctrica del 28 de abril

Insufficient voltage regulation capacity

- On 28 April, the number of synchronous, voltage-regulating power plants was lower than at any other time during the year.
- Several power plants designated and remunerated for voltage regulation did not respond correctly to the system operator's setpoints – in some cases, reactive power was even fed into the grid instead of being absorbed.

Oscillations exacerbated the situation

- The first, atypical oscillation originated from an Iberian plant and required system configuration changes, making voltage stabilisation more difficult.
- After the second oscillation, the system operator requested additional voltage assistance, but this could not be provided in time for technical reasons.

Tripping of generation plants

- In some cases, generation capacity was disconnected before the normative voltage thresholds (380–435 kV in the transmission grid) were reached.
- Other disconnections were in accordance with the rules after the voltage limits had actually been exceeded.

Conclusions

With thanks to: Matthias Müller-Mienack

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Conclusion of Spanish Energy Association AELEC (28 July 2025)

Source: Análisis de los acontecimientos que condujeron al apagón peninsular del 28 de abril de 2025

Technical factors

- Overvoltage cascade due to simultaneous tripping of many generators (~2 GW)
- Limited reactive power consumption (≈ 3.3 GVAr < usual 5.8 GVAr), too few synchronous generators active
- Incorrect grid manoeuvres (line connections, reactor control) exacerbated overvoltage
- High proportion of converter power, but the report lacks an analysis of voltage compliance by EZE

Operational factors

- Minimal operation of conventional PPs (only 11 units), lack of replacement calls for failed power stations
- Voltage band violations (16, 22, 24 April) ignored as early warnings
- AELEC: Blackout could have been avoided with forward-looking operational management!

Regulatory framework

- Renewables without voltage control obligation (fixed cos φ), outdated grid regulations
- N-1 criterion and voltage stability insufficiently monitored, lack of transparency regarding HVDC operation
- AELEC: Reform of voltage control requirements, mandatory reactive power contributions, independent system analyses!

With thanks to: Matthias Müller-Mienack

DNV

From ENTSO-E Factual report to recommendations

- The Panel will perform a detailed analysis of the events of 28 April: it will notably analyse the root causes of the incident, evaluate the actions undertaken to control the voltage and to mitigate the oscillations, assess the performance of generators in regard to protection settings and contribution to voltage control, assess the performance of the system defence plan and analyse the various steps of the restoration phase.
- The final report will also consider the incident in a broader context, such as by examining the behaviour of the Iberian power system on the days preceding the blackout.
- The Expert Panel will make recommendations aimed at preventing similar incidents from occurring in the future, not only in the Iberian peninsula but across the whole European power system.
- The final report is expected to be delivered in Q1 2026. It will be published and presented to the European Commission and Member States.
- The exceptional character of this incident highlights the need to improve the resilience the power system in such situations. ENTSO-E sees at least the following technical areas to be further investigated and analysed:
  - Voltage management instruments available
  - Assessment of grid users' behaviour in voltage control and disconnections
  - Performance of the system defence plan and possible improvement
  - Analysis of the various steps of the restoration phase
  - Data exchange with stakeholders to enhance relevance and accuracy of system operation

Some Questions

- Was the grid inertia insufficient due to high share of wind and solar?
  - The main problem was not inertia, it was voltage regulation
- Did the transmission grid operators have sufficient voltage information also from distribution grids as large solar production was connected at that level?
  - There was a lot of information but many of the power plants did not respond correctly. It could be so that they were not compliant with the grid codes
- Did they execute actions according to the situation or to manual?
  - Both, but the power plants did not react in time
- Could AI algorithms in SCADA systems have helped?
  - I doubt it in this case
- Could different settings for solar/wind inverters have helped?
  - yes

Take aways

- On 28 April 2025, at 12:33 CEST, the power systems of Spain and Portugal experienced a blackout
- The ENTSO-E report highlights the exceptional and unprecedented nature of this incident - the first time a cascading series of disconnections of generation components along with voltage increases has been part of the sequence of events leading to a blackout in the Continental Europe Synchronous Area.
- A root cause analysis, in the final report, will be presented Q1 2026
- As could be expected there is not one cause, there are multiple ones, but the main one is voltage control.
- Changes are necessary
  - Regulation
  - Certification that grid codes are met
  - Operational
  - Technical

Thank you!

Sonja.monica.berlijn@dnv.com

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