

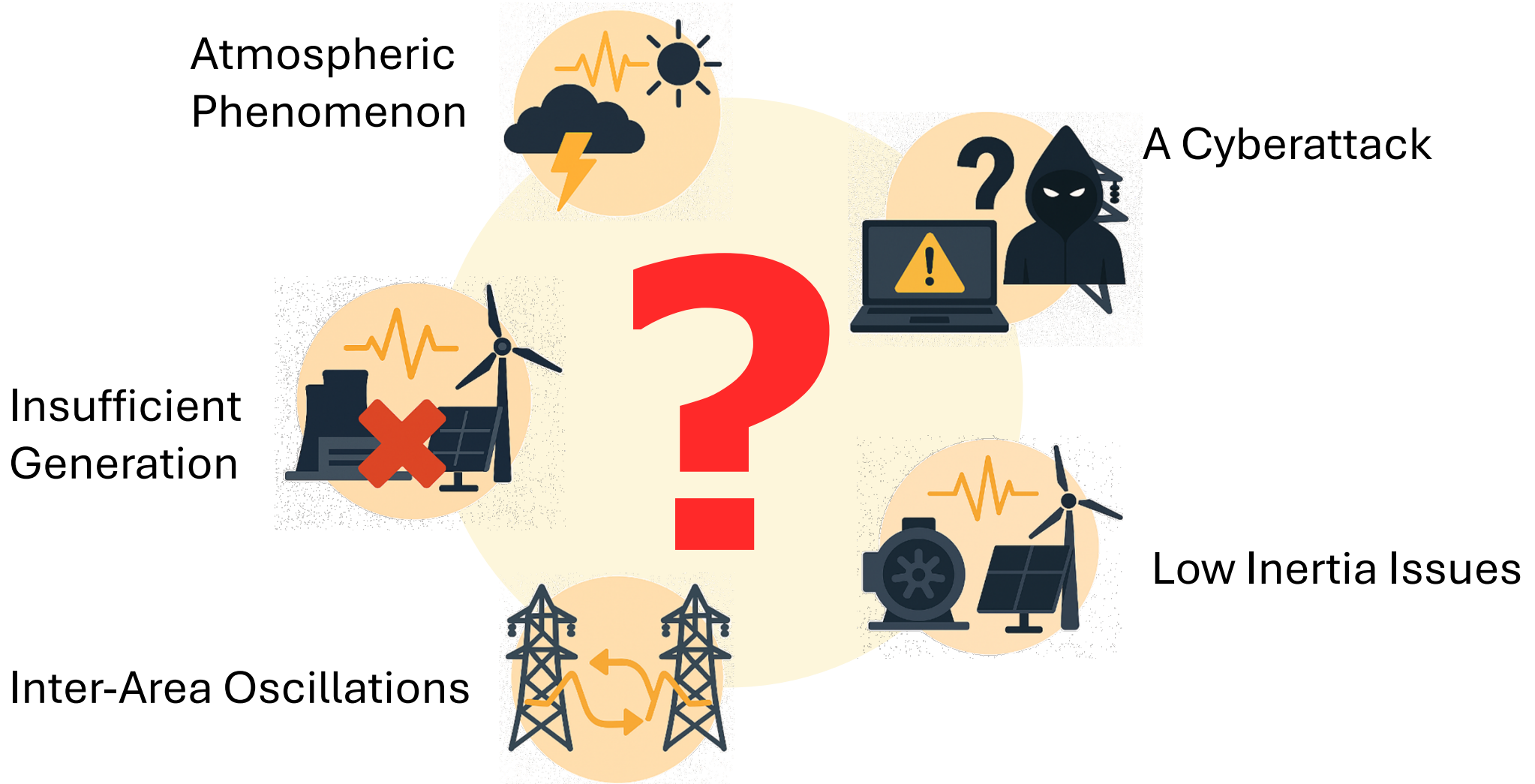
CIGRE Generalforsamling

On the Blackout of the Iberian Peninsula

Johanna Vorwerk

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What caused the Blackout? - Some Wild Speculations



The visuals on this slide have been AI generated.

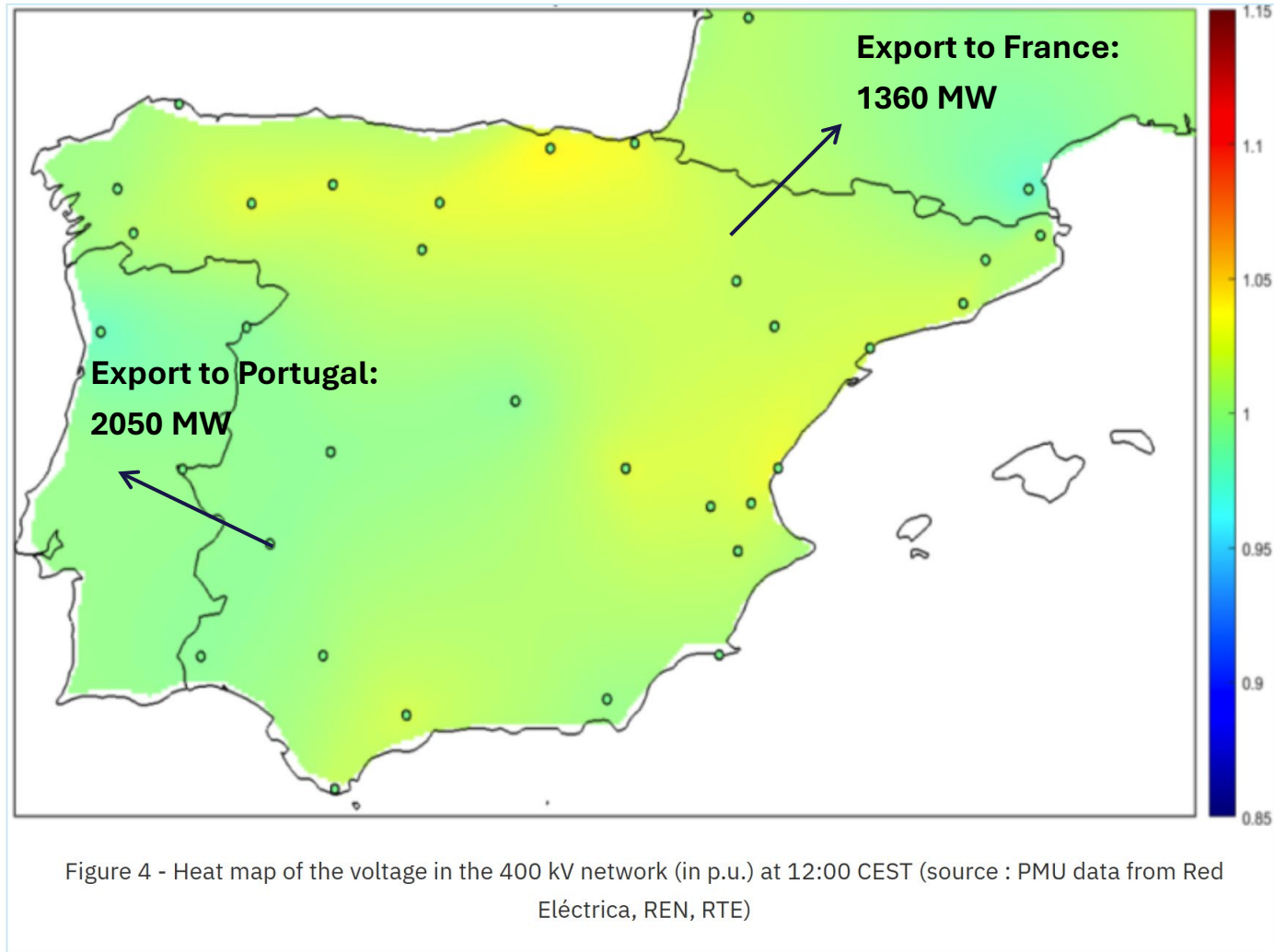
So what happened on Apr 28th?

An overview provided with study of the following resources:

- Information provided by ENTSO-E expert panel: [28 April Blackout](#)
- English report by Red Electrica: [Blackout in Spanish Peninsular Electrical System the 28th of April 2025](#)
- Summary of report provided by Red Electrica: [The report of the Committee for the Analysis of the Electricity Crisis of April 28 is presented](#)

Voltage and Power Flows of Spain prior to the Blackout

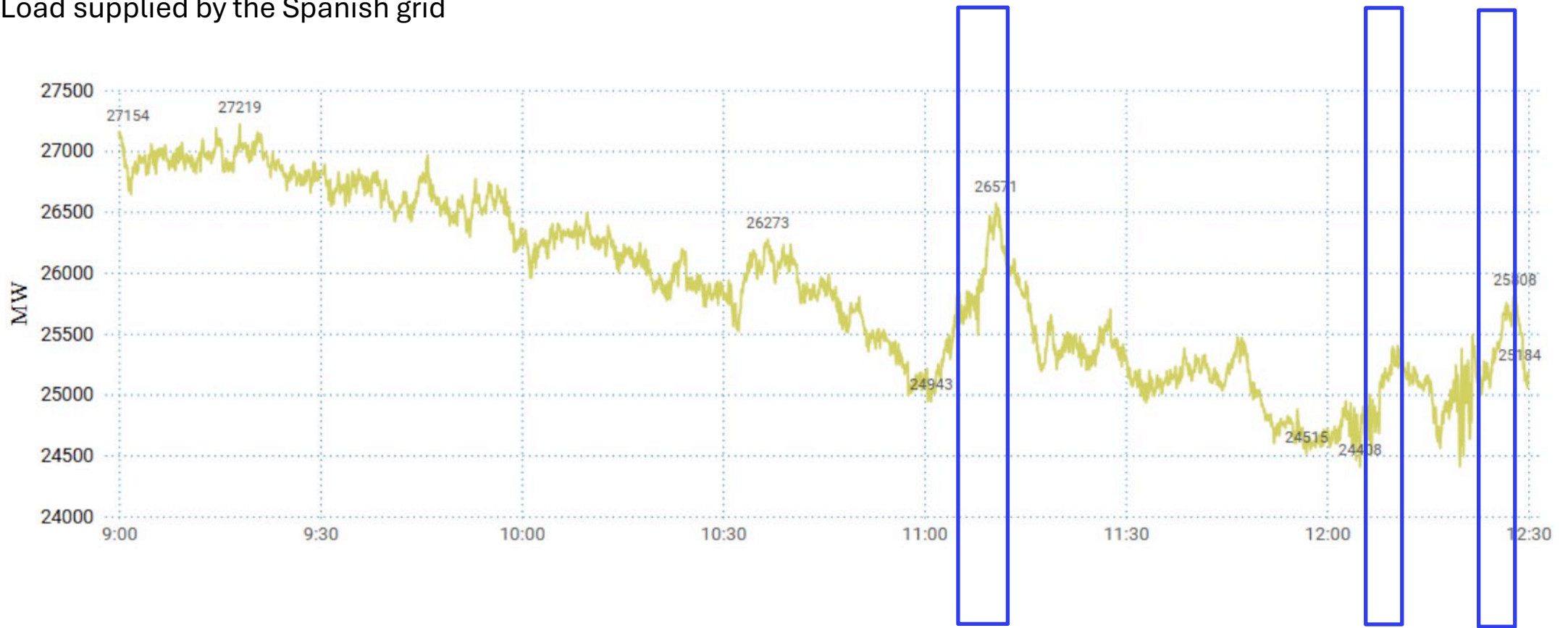
Voltages from 12:00, Power flow data from 12:32



Source: ENTSOE, "28 April 2025 Blackout", <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

Load Profile prior to the Blackout

Load supplied by the Spanish grid



Several sharp load increases:

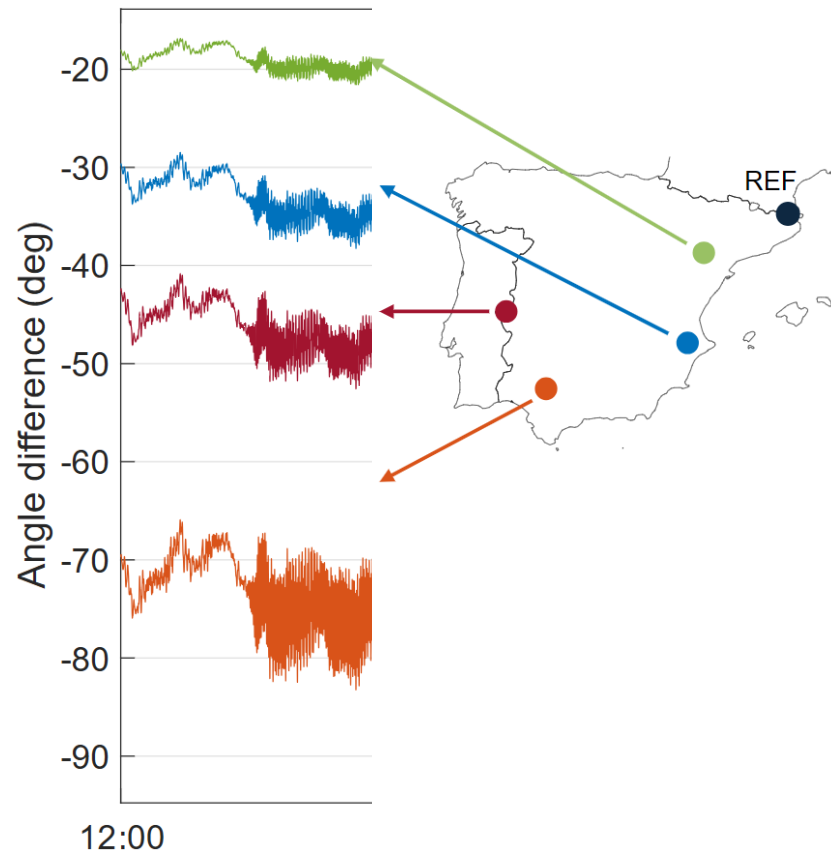
1 GW

600 MW 500 MW

ENTSOE-Panel: Loss of small embedded generation units in distribution level?

Source: ENTSOE, “28 April 2025 Blackout”, <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

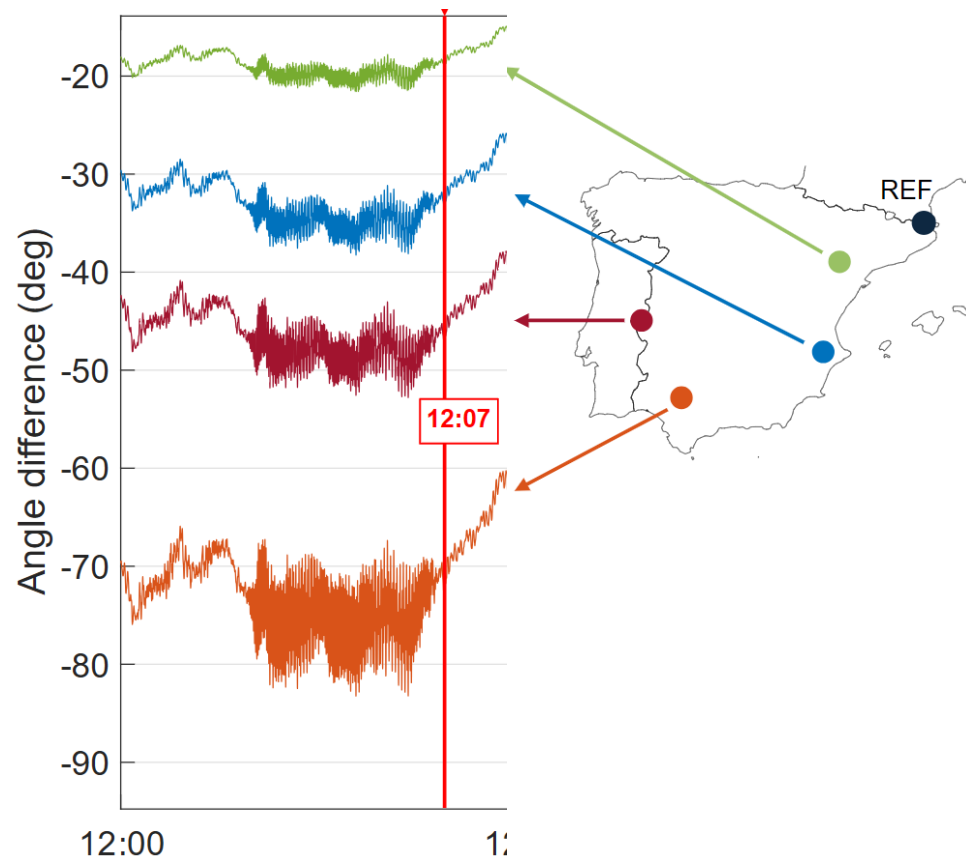
Oscillations Prior to the Blackout



First Oscillation

- 12:03: initial oscillation with frequency of **0.64 Hz** occurred
- Followed by the inter-area mode **East-Centre-West** at **0.21 Hz** with small amplitude

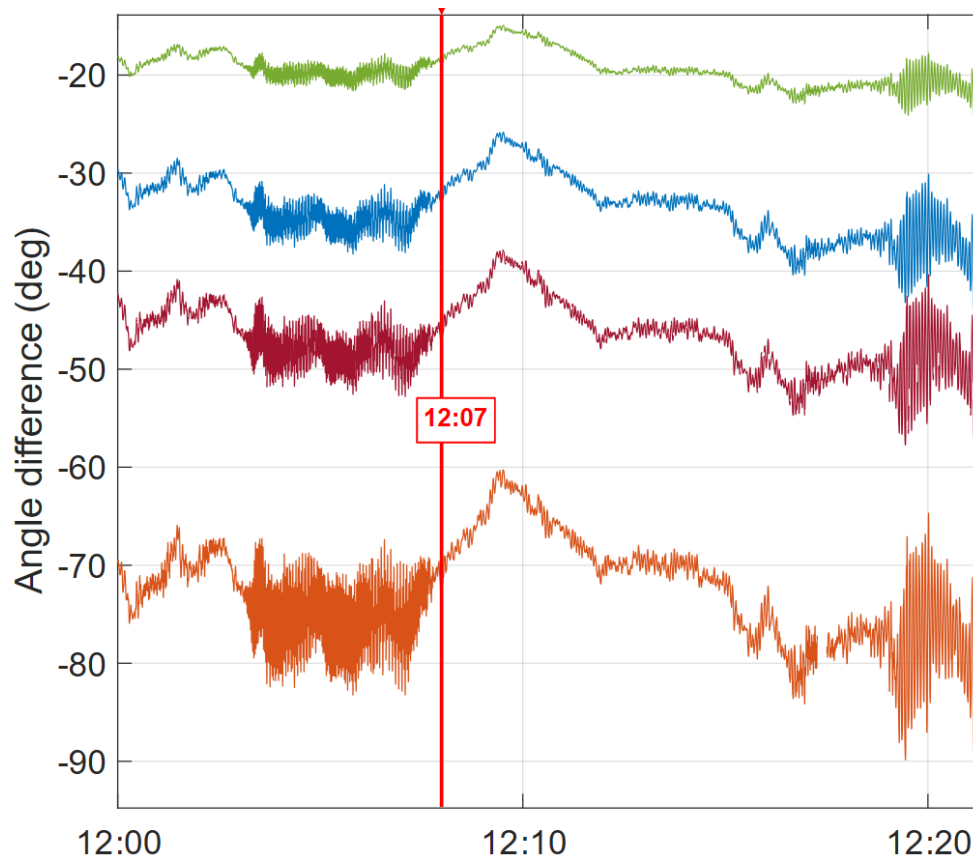
Oscillations Prior to the Blackout



Mitigation Actions

- **Damp oscillations** by activating **protocols** previously agreed upon between France (RTE) and Spain (REE)
- Angle differences reduce and reach pre-oscillatory level

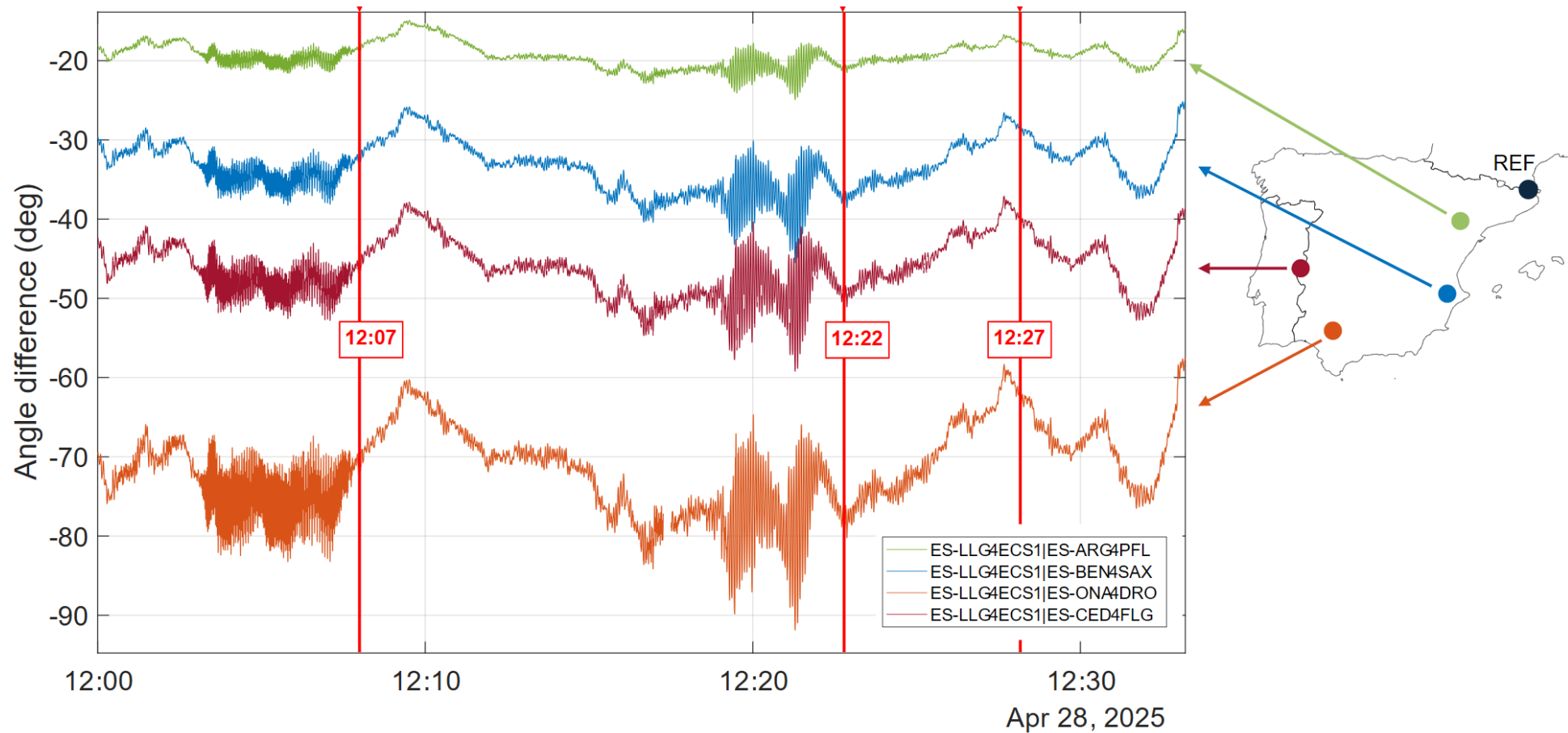
Oscillations Prior to the Blackout



Second Oscillation:

- **Well-known** inter-area oscillation corresponding to 0.21 Hz East-Centre-West Continental mode
- Further counteracting measures **reduce power flow between Spain and France**

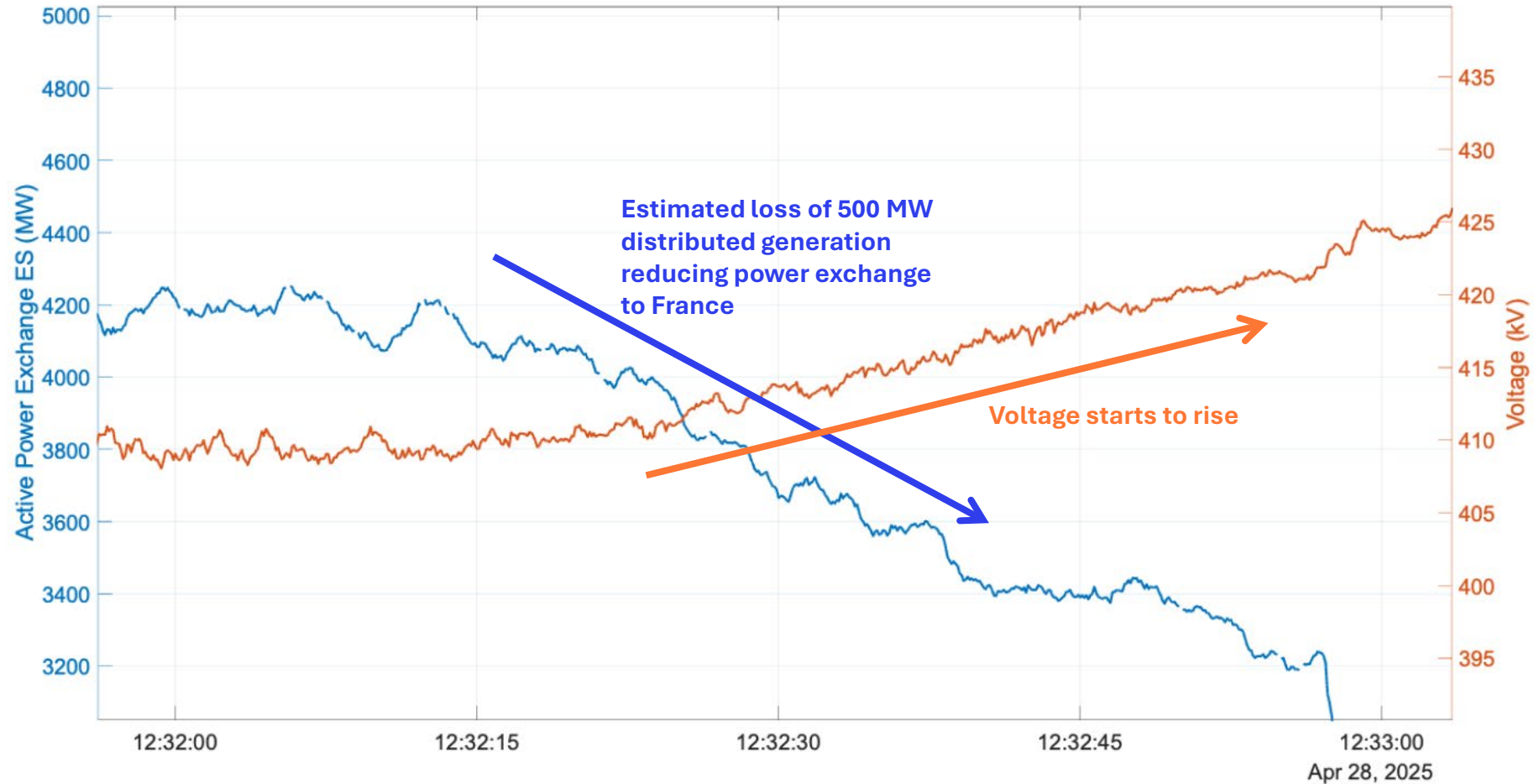
Oscillations Prior to the Blackout



Source: ENTSOE, “28 April 2025 Blackout”, <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

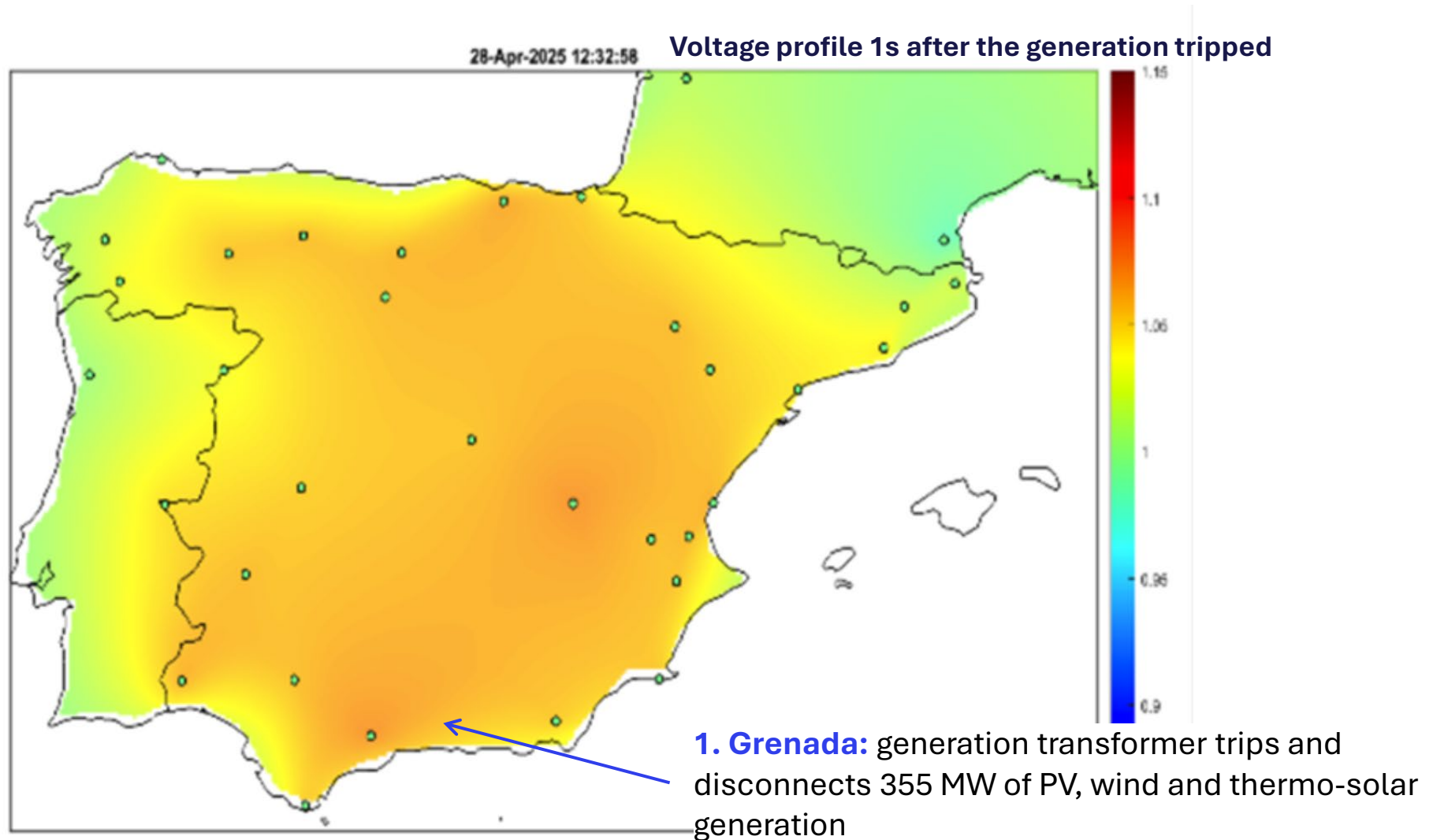
Voltage and Power Exchange Prior to the Blackout

Voltage in Carmona substation (south west Spain) and Net Active Power Exchange of Spain



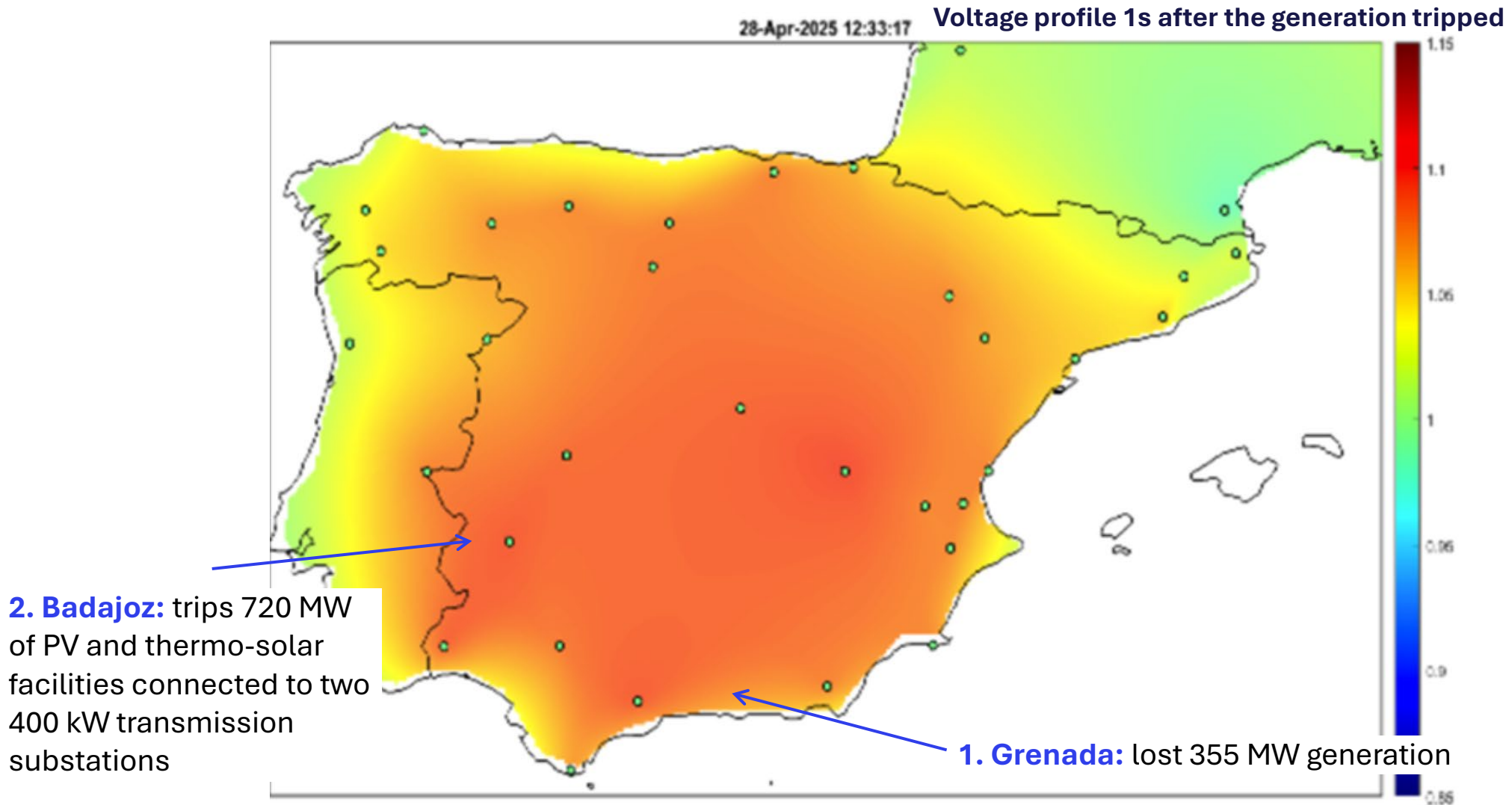
Source: ENTSOE, "28 April 2025 Blackout", <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

12:32:58: Generation Transformer Trip in Grenada



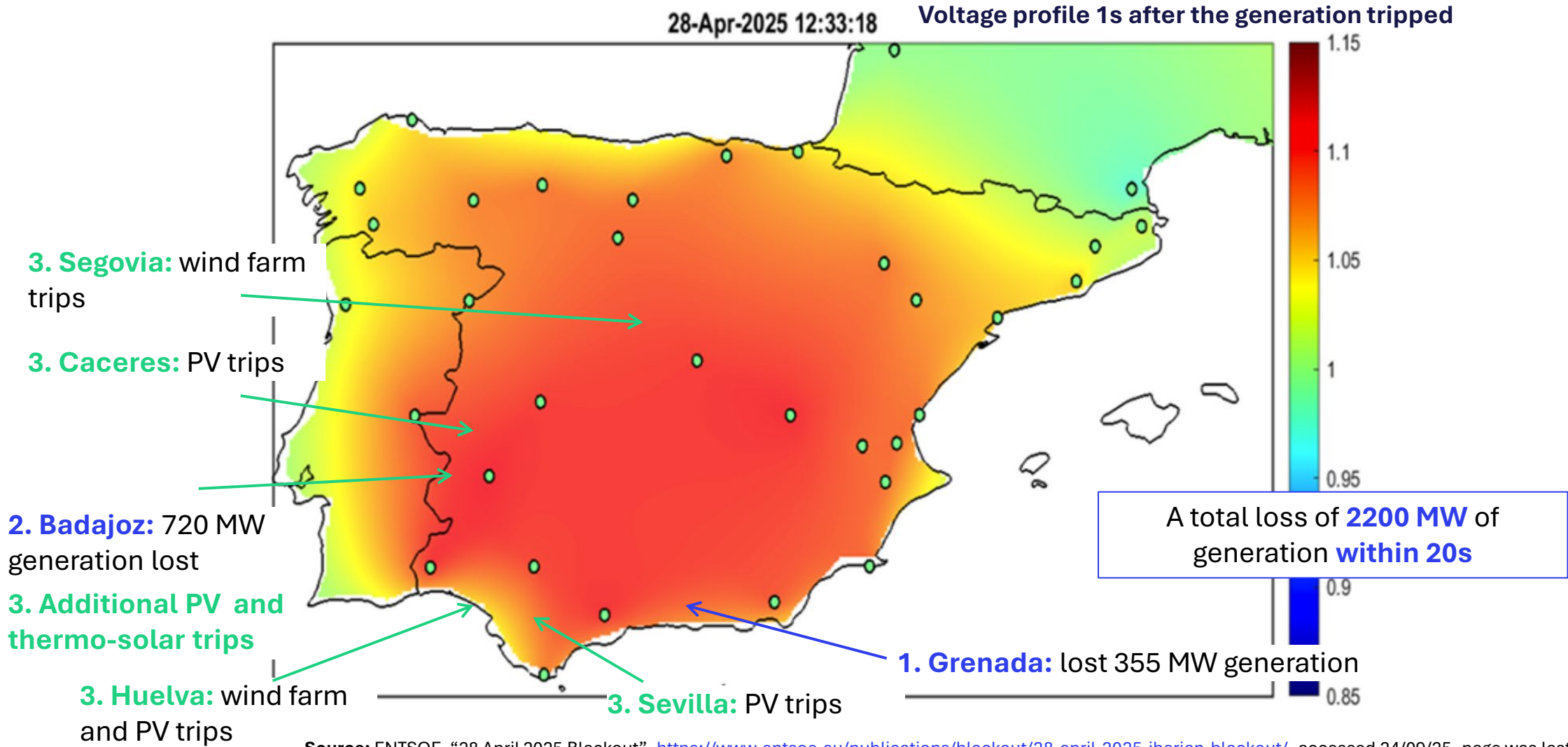
Source: ENTSOE, "28 April 2025 Blackout", <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

12:33:16: Additional Trip in Badajoz



Source: ENTSOE, "28 April 2025 Blackout", <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

12:33:17: Tripping Spread Across the Spain



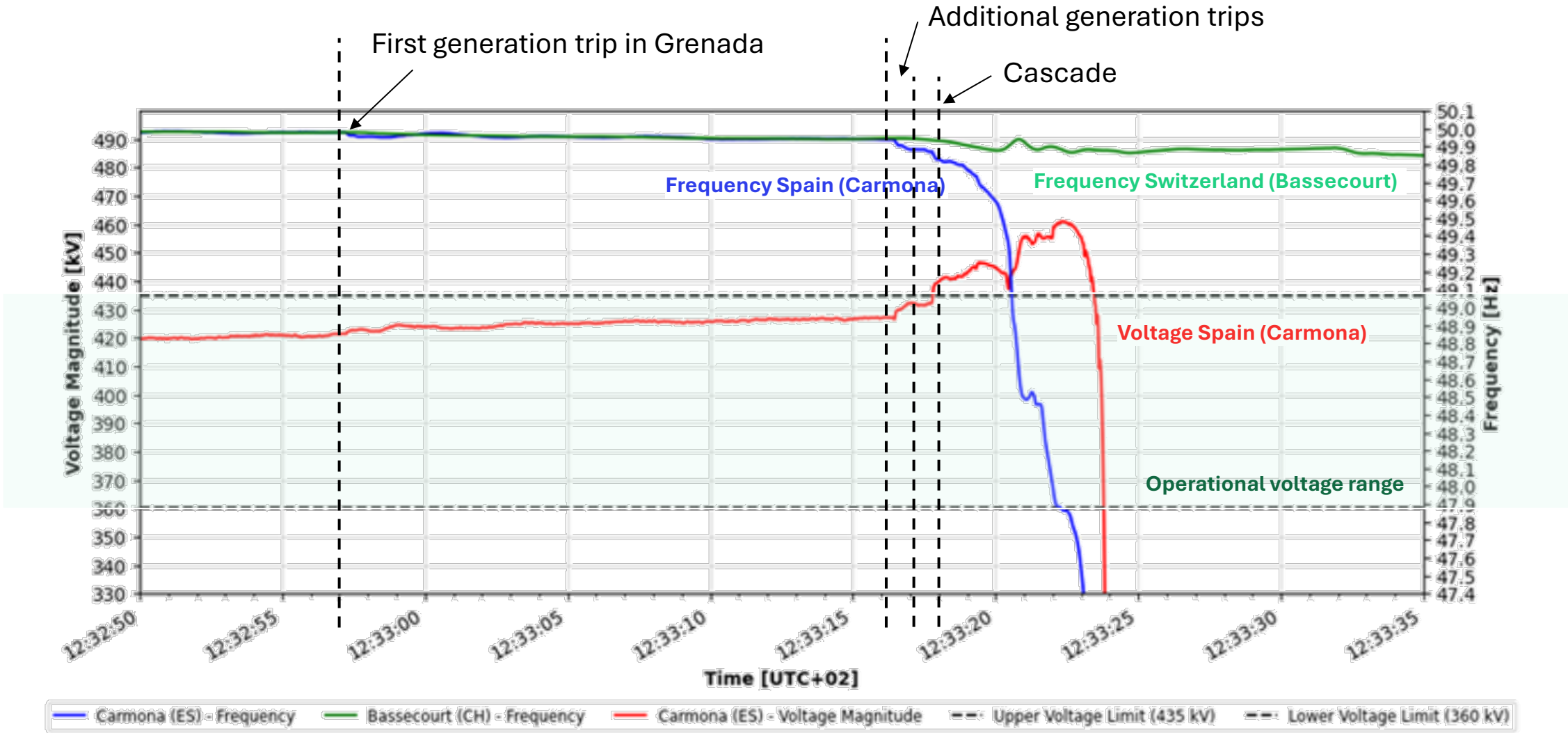
Source: ENTSOE, "28 April 2025 Blackout", <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

Sequence of Events

12:32:57	355 MW generation loss in Grenada	
+ 19s	720 MW generation loss in Badajoz	Total generation loss of 2200 MW within 20s
+ 20s	1100 MW generation loss across SE Spain	
+ 21 s	Cascading loss of additional generation due to sharp increase in voltage across Spain and Portugal	
+ 22 s	Start loss of synchronism with the European System	
+ 22 s	Automatic load shedding and System Defence Plans of Spain and Portugal activated but unable to prevent collapse of the Iberian System	
+ 24 s	AC overhead lines between France and Spain disconnect by protection devices against loss of synchronism	
12:33:24 + 27 s	All system parameters of the Spanish and Portugese electricity systems collapsed , HVDC lines between France and Spain stops transmitting power	

Source: ENTSOE, "28 April 2025 Blackout", <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

Evolution of Frequency & Voltage



Source: ENTSOE, "28 April 2025 Blackout", <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

What caused the Blackout? - Some Wild Speculations

Atmospheric Phenomenon



It was an overvoltage issue!

Inter-Area Oscillations



Low Inertia Issues



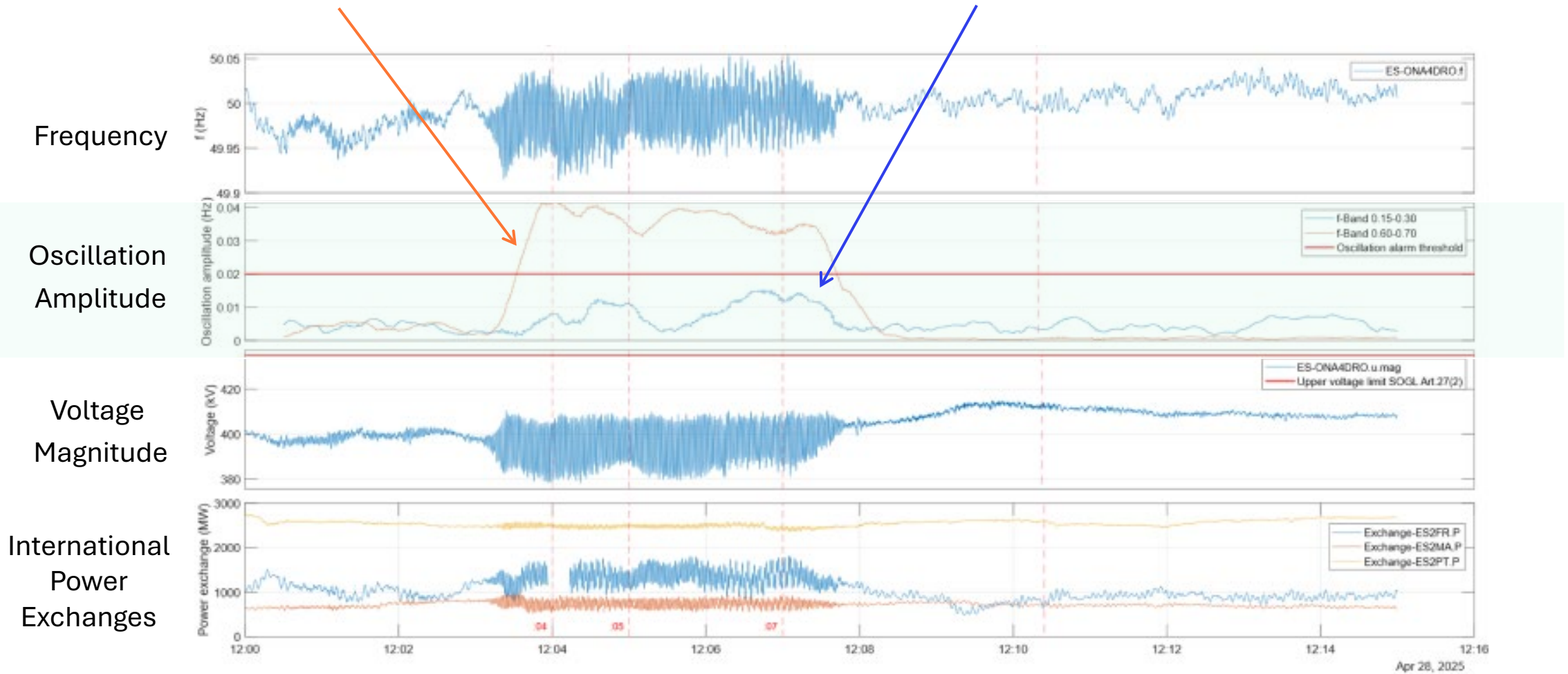
Let's Focus on Two Specific Questions

Question 1

What caused the initial oscillations?

What caused the first oscillations?

Fact: Local **0.64 Hz oscillation** occurs shortly before well-known **0.21 Hz oscillation**

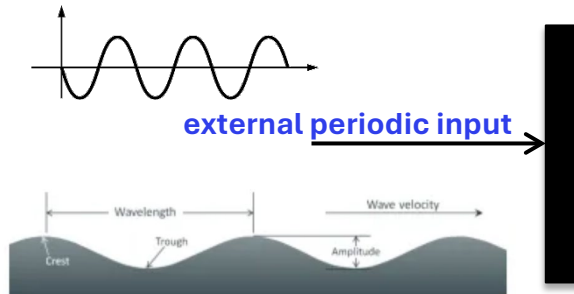


Source: ENTSOE, "28 April 2025 Blackout", <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>, accessed 24/09/25, page was last updated 03/09/25

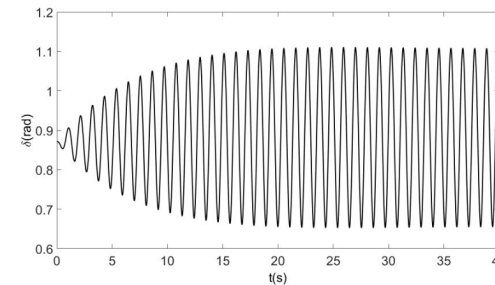
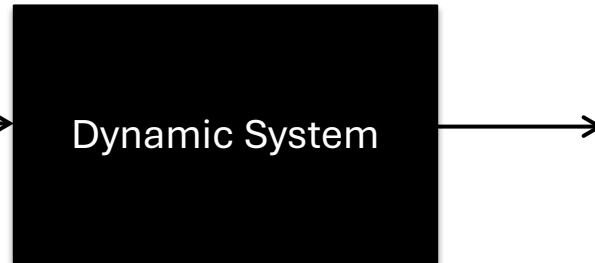
What are forced oscillations?

Oscillations occur **naturally** in power systems due to physical characteristics

Forced oscillations are caused by an **external periodic input** and can manifest in **voltage, frequency and/or power swings, or mechanical stress**



e.g. sea waves on wind farm structure



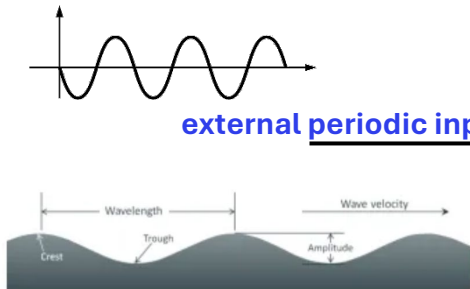
Sustained forced oscillation in voltage, frequency and/or mechanical stress

For further info check: Gilles Chaspierre, “Forced Oscillations Induced by Offshore Wind Parks: Mechanisms and Impacts” in GridStab News, <https://gilleschaspierre.substack.com/p/forced-oscillations-induced-by-offshore> , visuals are taken from this source

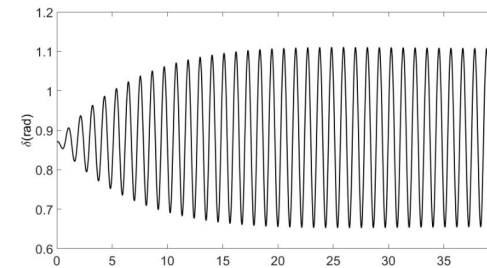
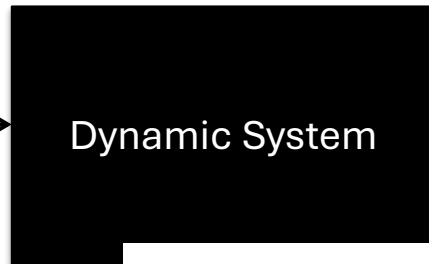
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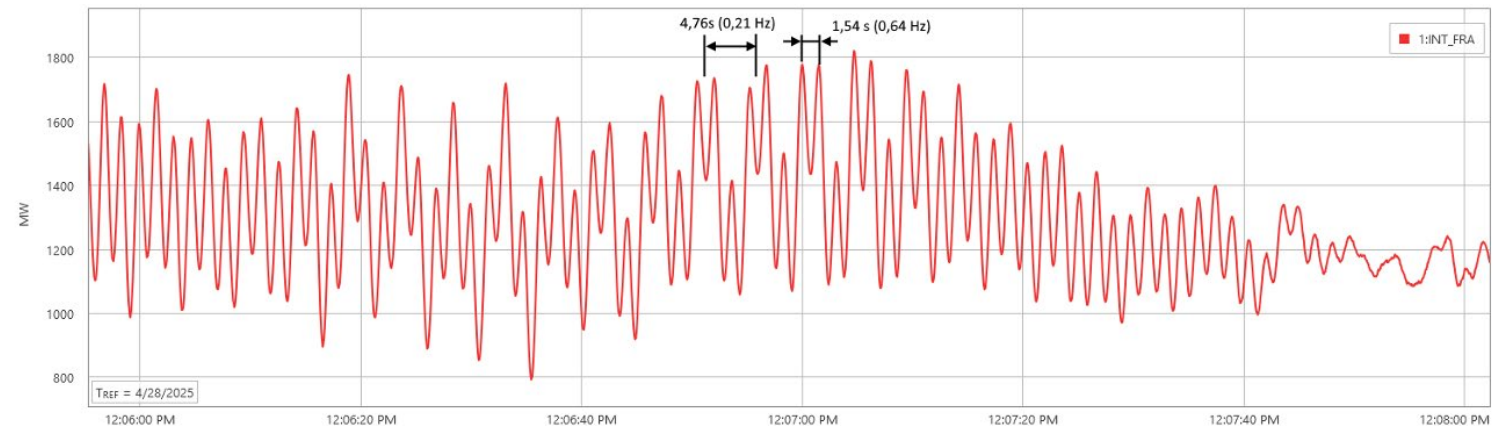


e.g. Sea waves on wind farm structure



Sustained forced oscillation in voltage, frequency and/or mechanical stress

Cause of forced oscillation in Spain currently still unknown, suspect a PV plant



For further info check: Gilles Chaspierre, “Forced Oscillations Induced by Offshore Wind Parks: Mechanisms and Impacts” in GridStab News, <https://gilleschaspierre.substack.com/p/forced-oscillations-induced-by-offshore> , visuals are taken from this source

Question 2

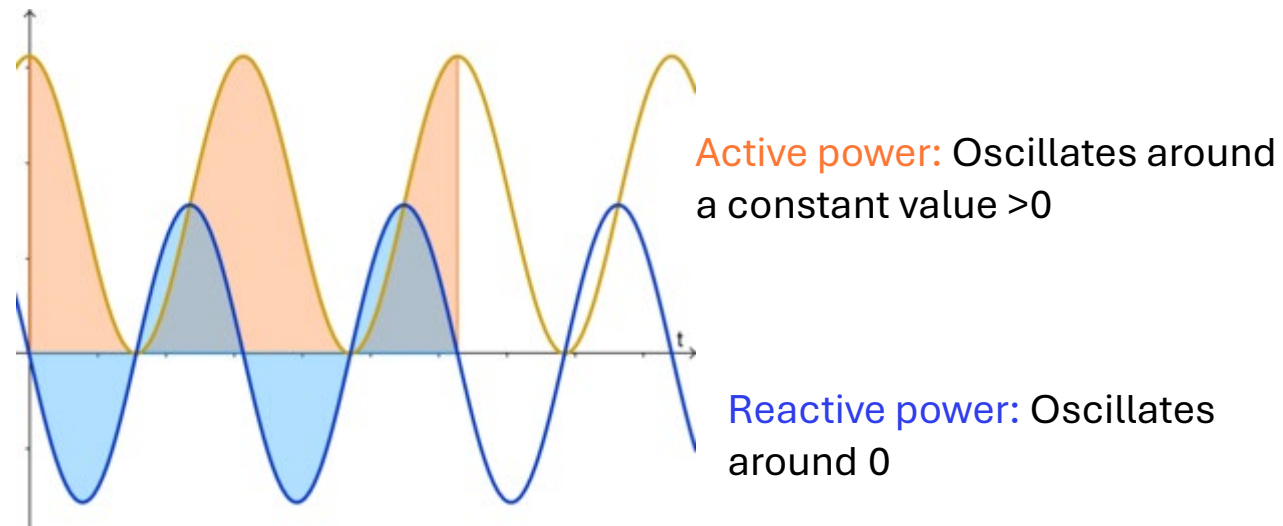
What caused the Over-Voltages?

Voltage Magnitude indicates Reactive Power Balance

Reactive power

- cannot be converted to useful work and results from phase difference in current and voltage
- inductive and capacitive components consume and generate reactive power

Power delivered or consumed can be **mathematically divided into two parts:**



Voltage magnitude is a **indicator of reactive power balancing**

For further info check: Gilles Chaspierre, “Topic 2: Voltage dynamics and control” in GridStab News, <https://gilleschaspierre.substack.com/p/gridstab-news-regular-posts-to-demystify-e0c>

What caused the reactive power surplus in Spain?

Low Line Loading

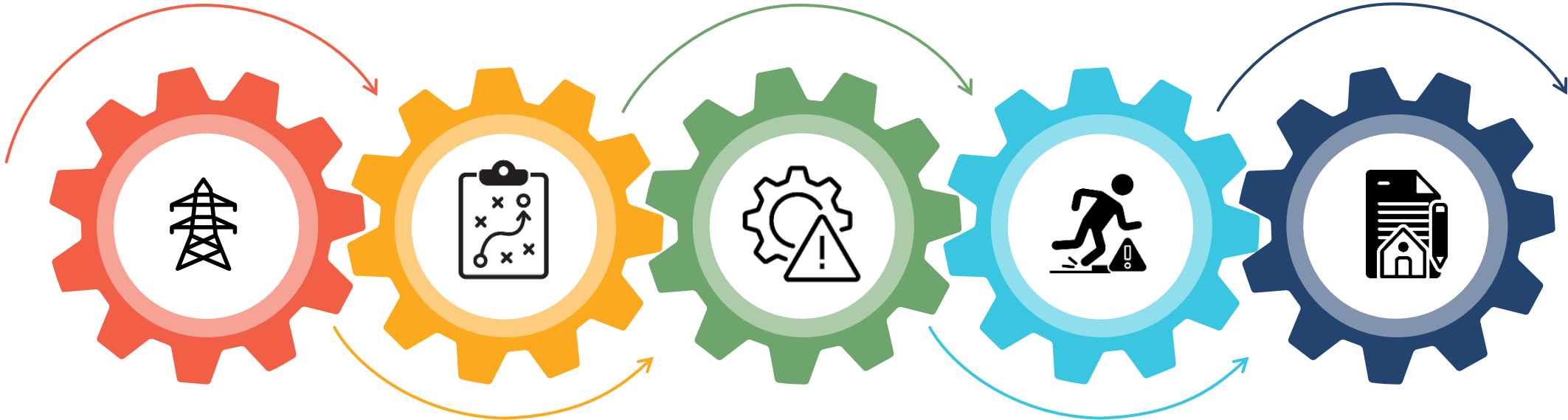
Transmission lines have been lightly loaded following required actions to damp oscillations → Ferranti-Effect

Control Failure

Contracted reactive power has not been delivered, in one case a power plant even absorbed reactive power

Legacy Grid Codes

Renewables can provide voltage support, however Spain currently requires constant power factor



Insufficient Voltage Control

Lowest number of synchronous sources since beginning of the year

Inadequate Tripping

Units tripped before reaching their target voltage intolerance

What can we learn?

Components for a Path to a More Resilient Grid

Strengthen the Foundation

- Enforce compliance with grid responsibilities
- Penalize or test for non-compliance
- Update outdated operational procedures

Modernize Voltage Control

- Require all capable units to support voltage
- Invest in dynamic voltage control devices
- Improve voltage control in distribution networks

Monitoring & Visibility

- Enhance system visibility by installing PMUs in substations
- Enhance operator visibility into self-consumption systems
- Standardize incident reporting

Embrace Digital & AI Tools

- Use digital twins for real-time simulation
- Leverage AI for fast operator decision-making
- Strengthen cybersecurity and event detection

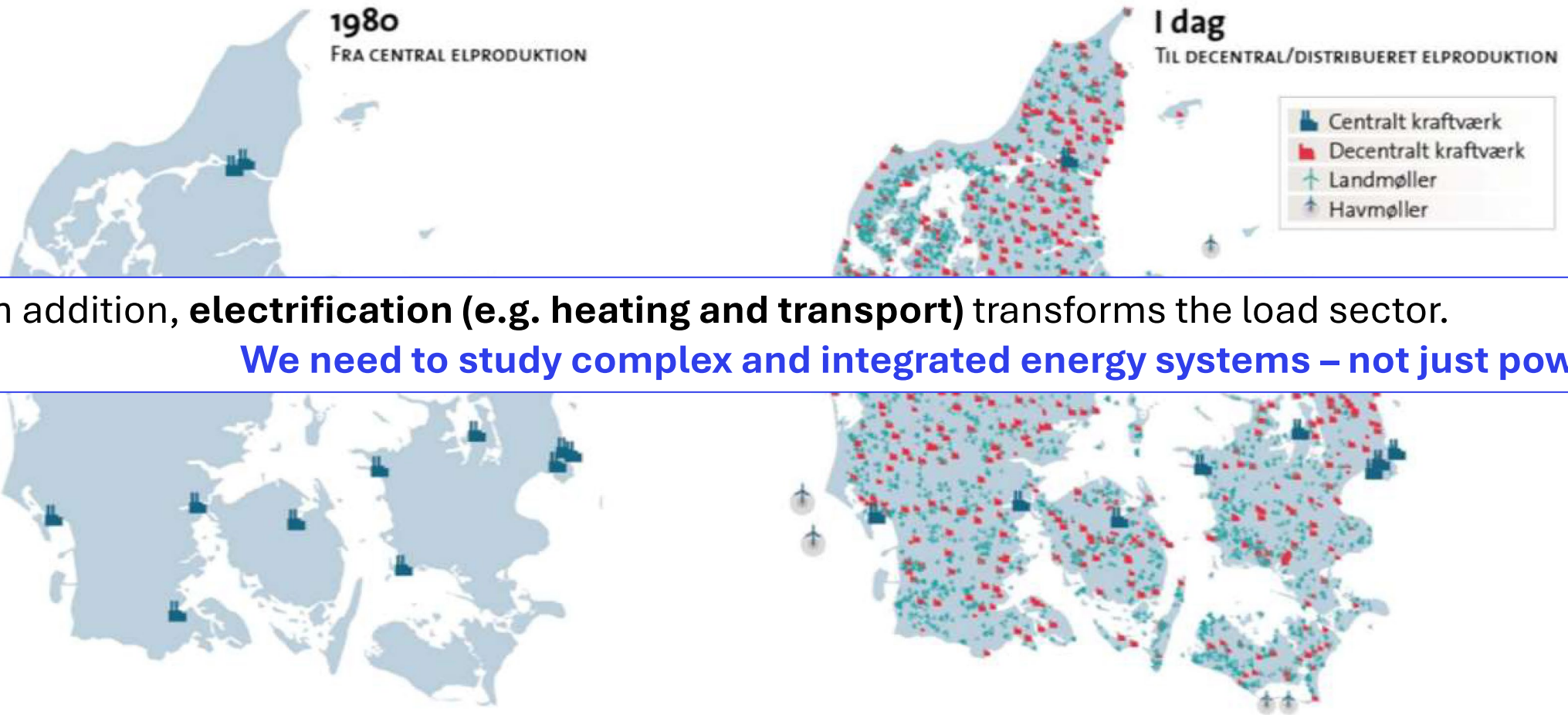
Build Flexibility & Resilience

- Expand storage
- Increase demand-side flexibility
- Reward reactive power support from providing resources, incl. renewables

And there will be more learnings once the blackout is fully understood.

System Complexity has Significantly Increased

Today's grid cannot be managed like grids of the 20th century when there were only few fossil fuel plants.



In addition, **electrification (e.g. heating and transport)** transforms the load sector.

We need to study complex and integrated energy systems – not just power!

Source: energinet

Technical Resources and Reports

- Spanish Ministry “The report of the Committee for Analysis of the Electricity Crisis of April 28 is resented”, June 2025, <https://www.miteco.gob.es/es/prensa/ultimas-noticias/2025/junio/se-presenta-el-informe-del-comite-de-analisis-de-la-crisis-elect.html> (translated with deepl)
- Red electrica: “Blackout in Spanish Paninsular Electrical System the 28th of April 2025”, June 2025, https://d1n1o4zeyfu21r.cloudfront.net/WEB_Incident_%2028A_SpanishPeninsularElectricalSystem_18june25.pdf
- ENTSO-E: “28 April 2025 Blackout”, latest update Sep 2025, <https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>

Recommended for further insights to the broader public:

- Gilles Chaspierre: GridStabNews, <https://gilleschaspierre.substack.com/>
- Lucas Laursen, “Rules, Not Renewables, Might Explain the Iberian Blackout” in IEEE Spectrum, June 2025, <https://spectrum.ieee.org/spain-grid-failure>

Thank you for joining!

DTU



Feel free to reach out:

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