# Power Quality Measurements from the Spain – Portugal Blackout

Thomas Ottosson
Managing Director, Unipower AB

www.unipower.se
Thomas.Ottosson@unipower.se

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# Global Wind and Solar production

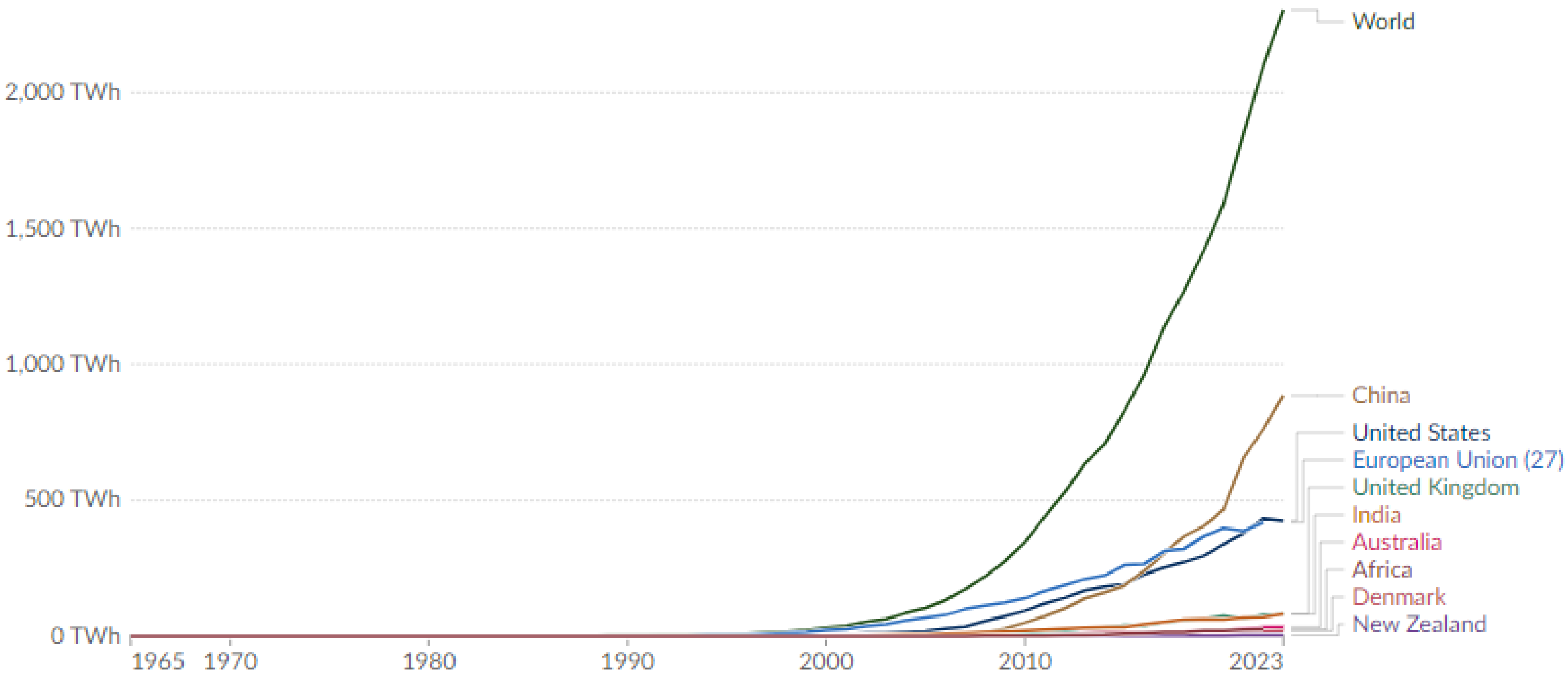
Slides from PQSynergy 2024

# Wind

Wind power generation between 1965 and 2023

0 => 2300 TWh

4x Germany's yearly consumption

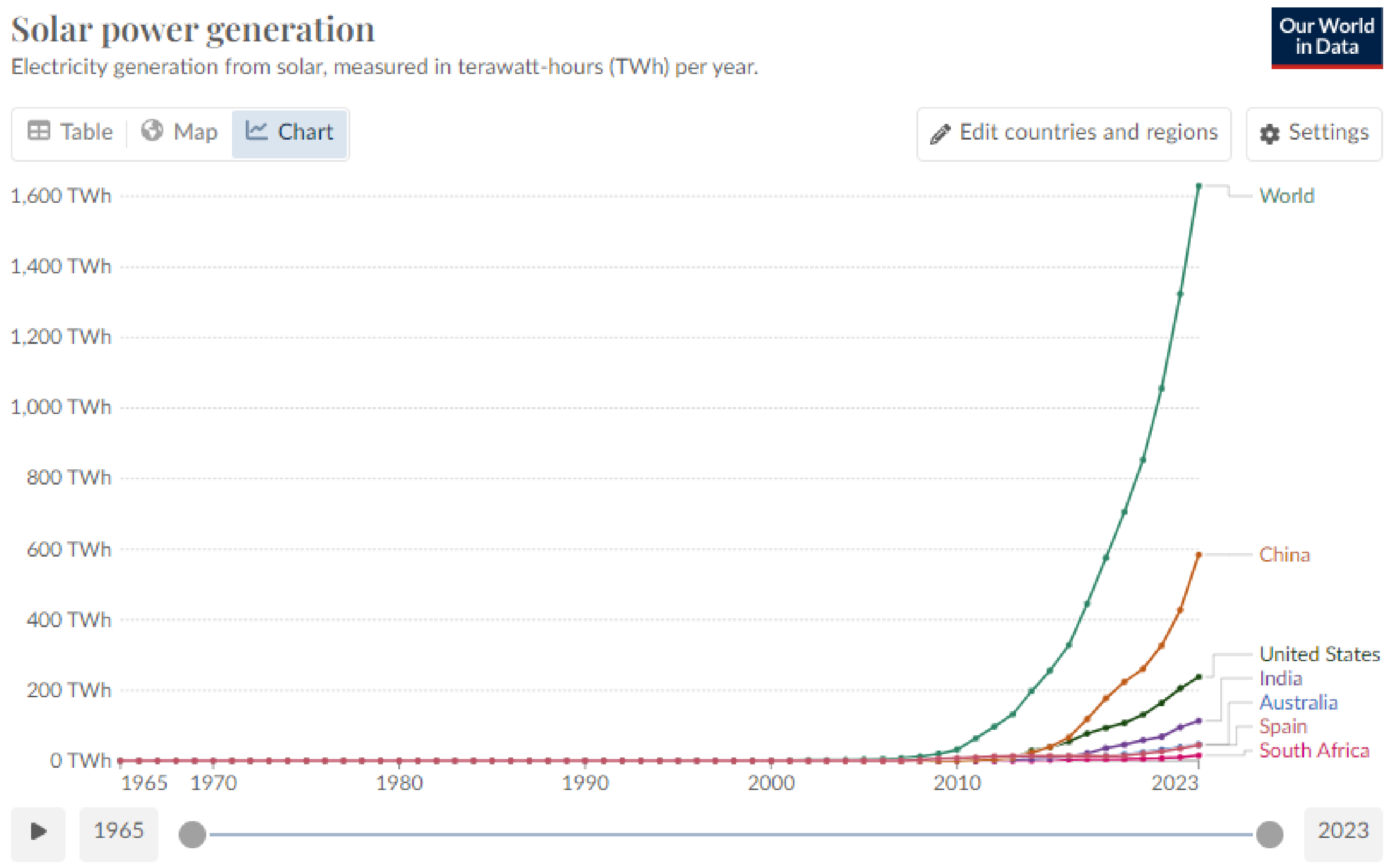


# Solar

Solar power generation between 1965 and 2023

0 => 1600 TWh

12x Sweden's yearly consumption

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# What happened during 2024?

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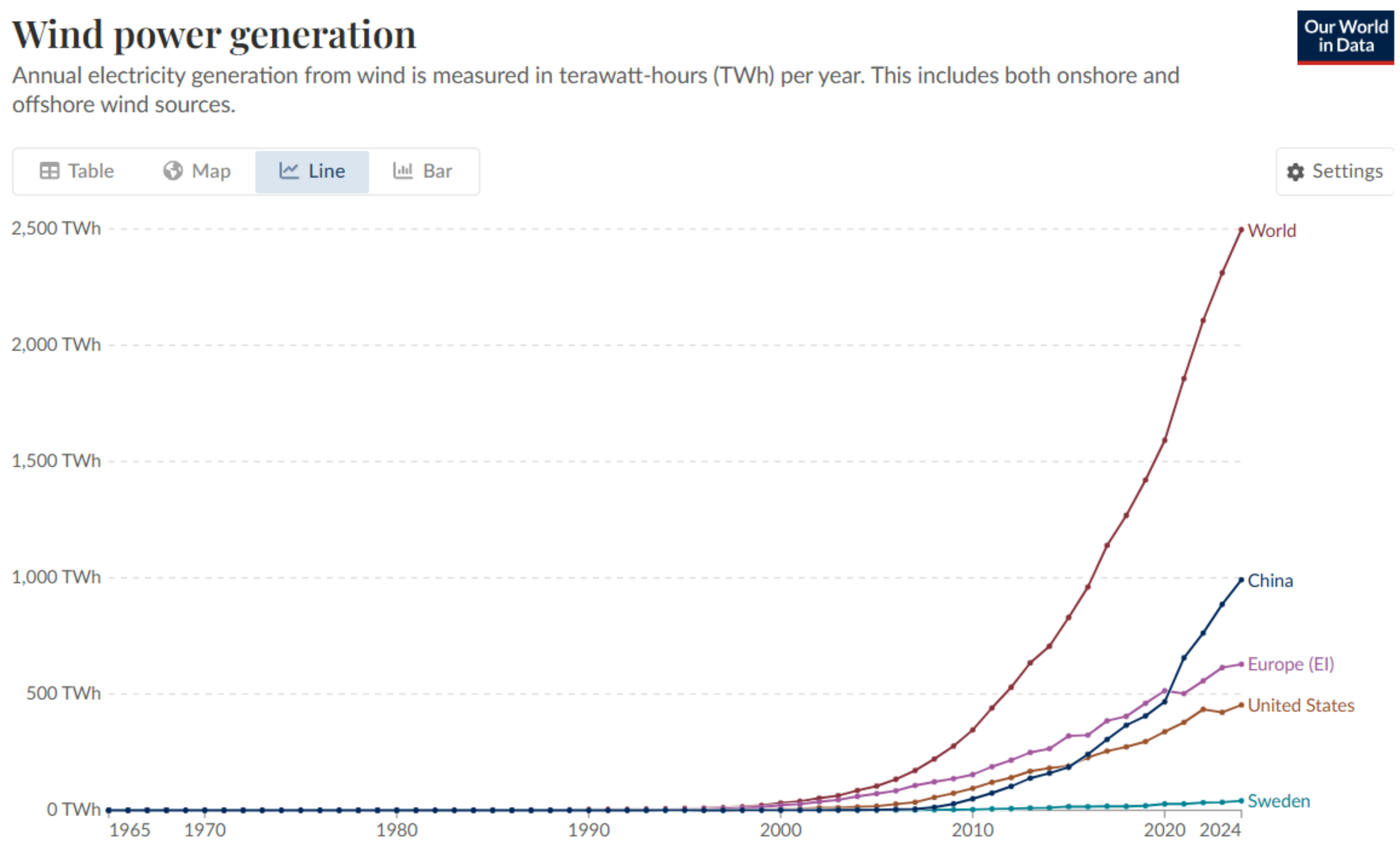
# Wind

Increased by:

200 TWh during 2024

In comparison:

| | | |
|---|---|---|
| 23 | Thailand | 224.04 |
| 24 | Egypt | 218.54 |
| 25 | Malaysia | 186.66 |
| 26 | Pakistan | 171.18 |
| 27 | Poland | 168.14 |



# Solar

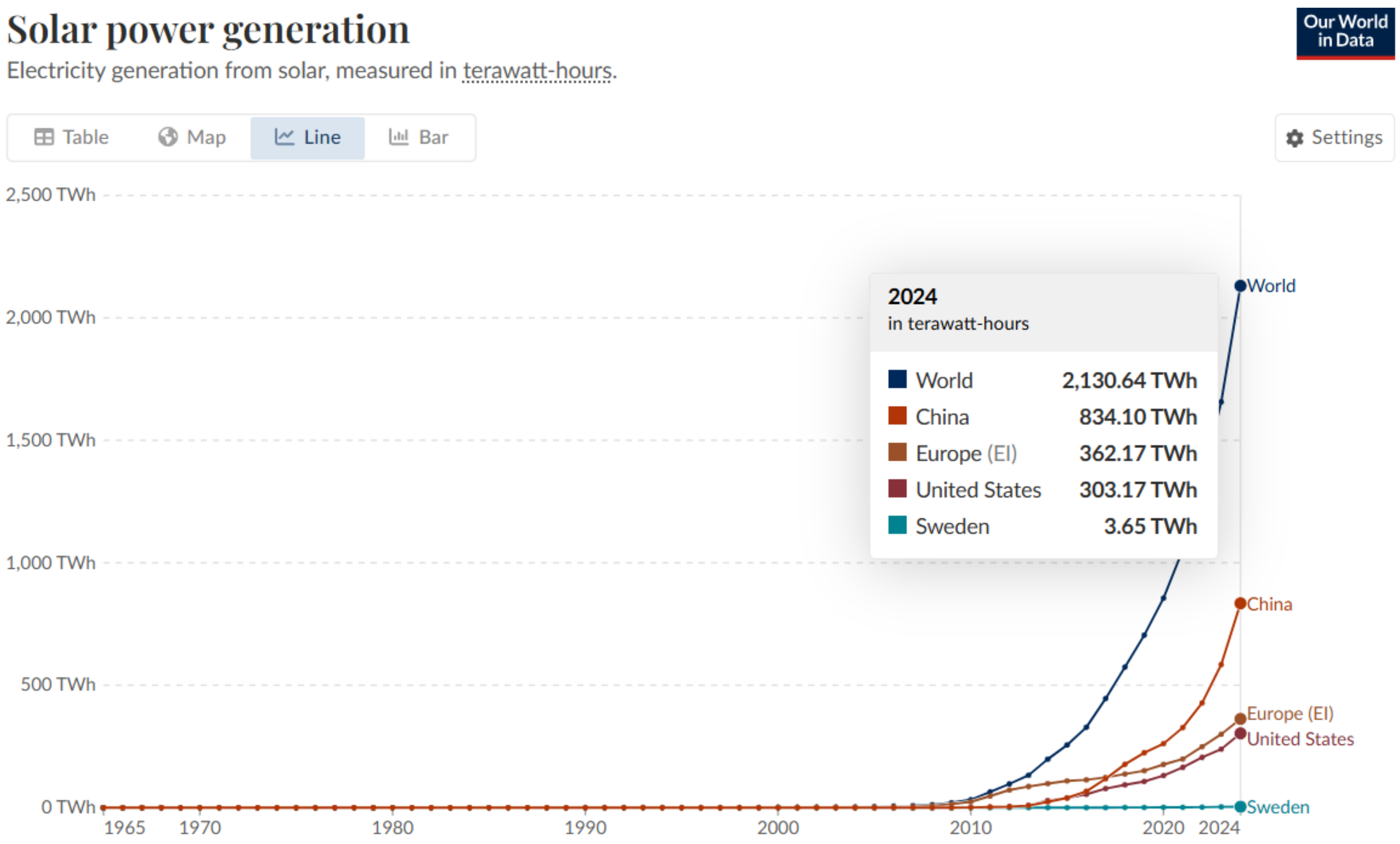
Increased by:

500 TWh during 2024

X2 compared to 2021

In comparison:

| | |
|---|---|
| South Korea | 617.92 |
| Canada | 605.52 |
| Germany | 505.76 |
| France | 467.81 |
| Saudi Arabia | 422.83 |

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# Why is this interesting?

Is this connected to the blackout in Spain and Portugal?

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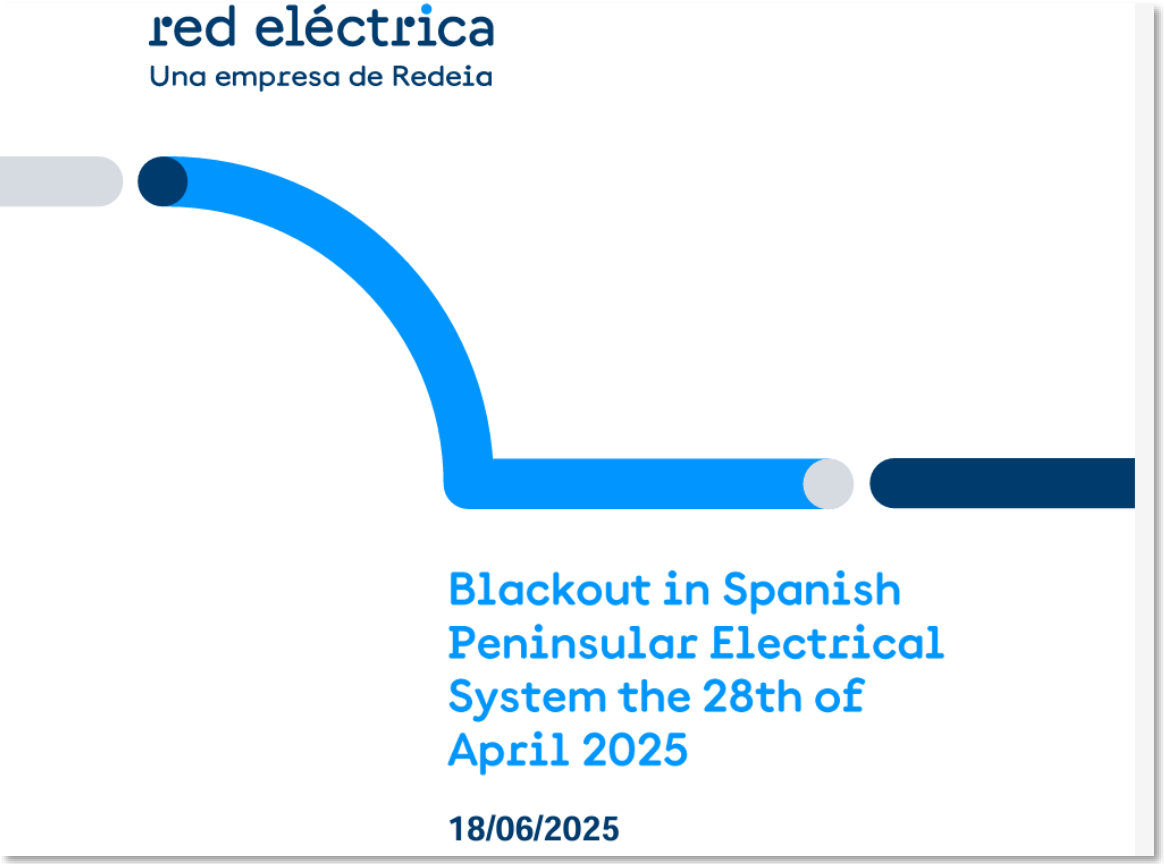
European Network of Transmission System Operators for Electricity



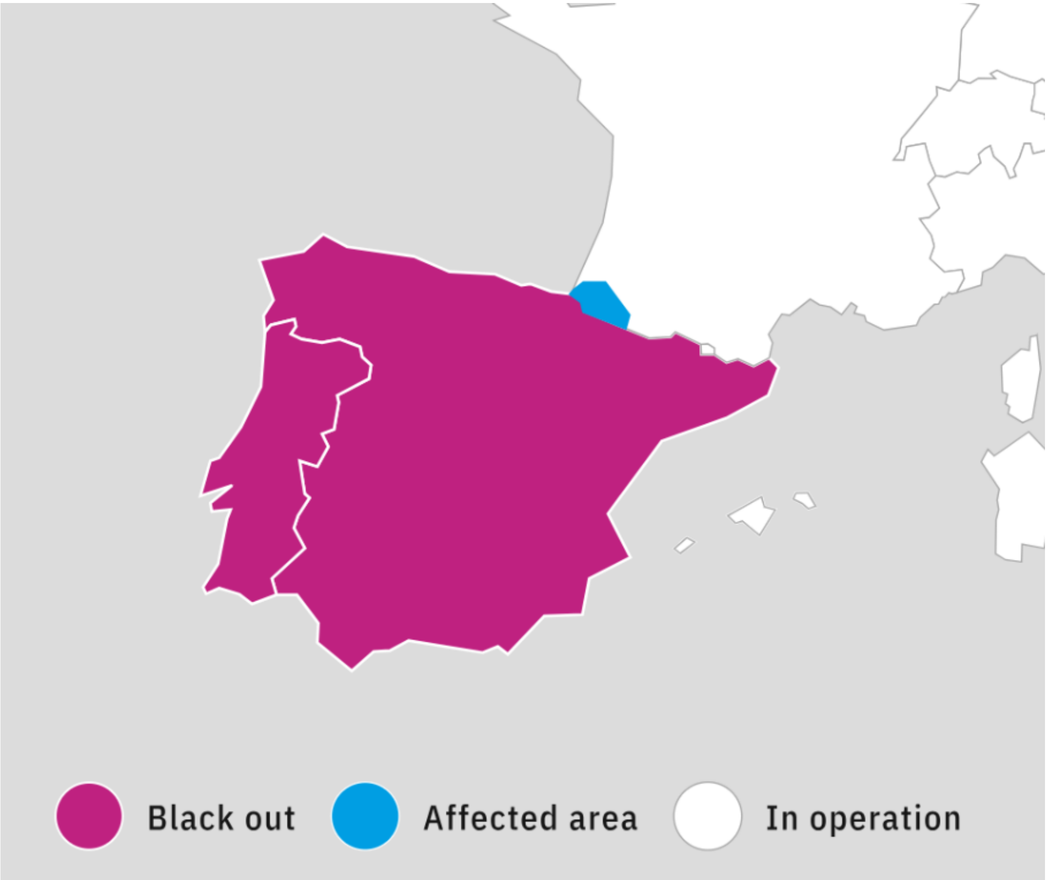

Transmission system operator (TSO) for the Spanish electricity system

# The blackout

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

6 persons lost their lives



# Before the blackout

Normal operations during the morning

From 10:30 h to 12:00, a greater variability in voltages was observed, attributable to the change in the generation mix and demand variations

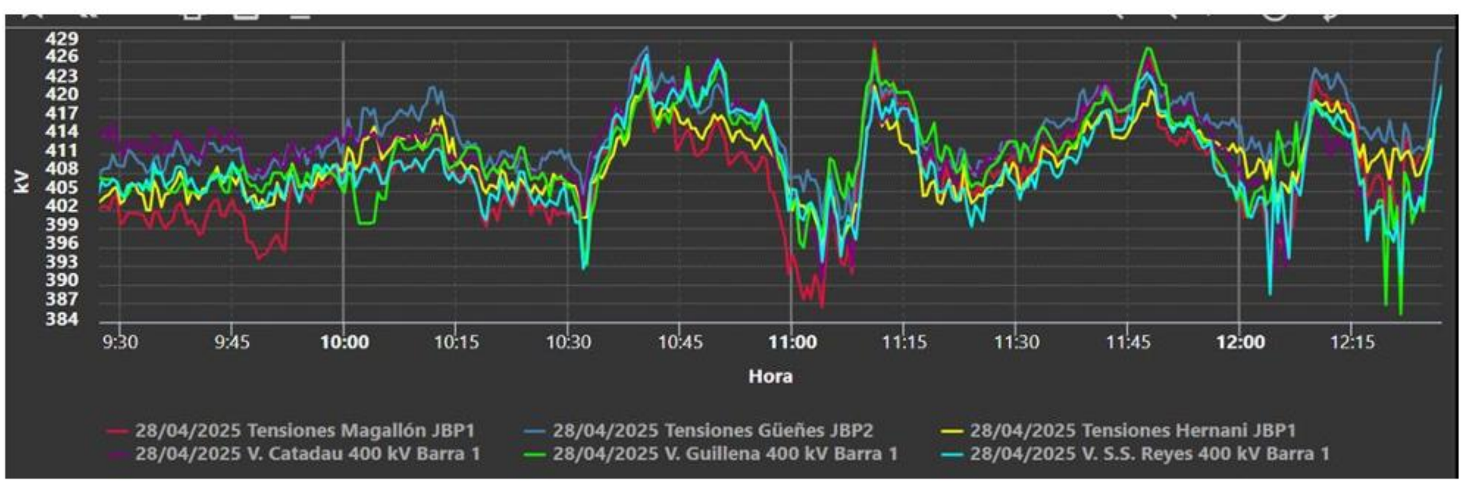
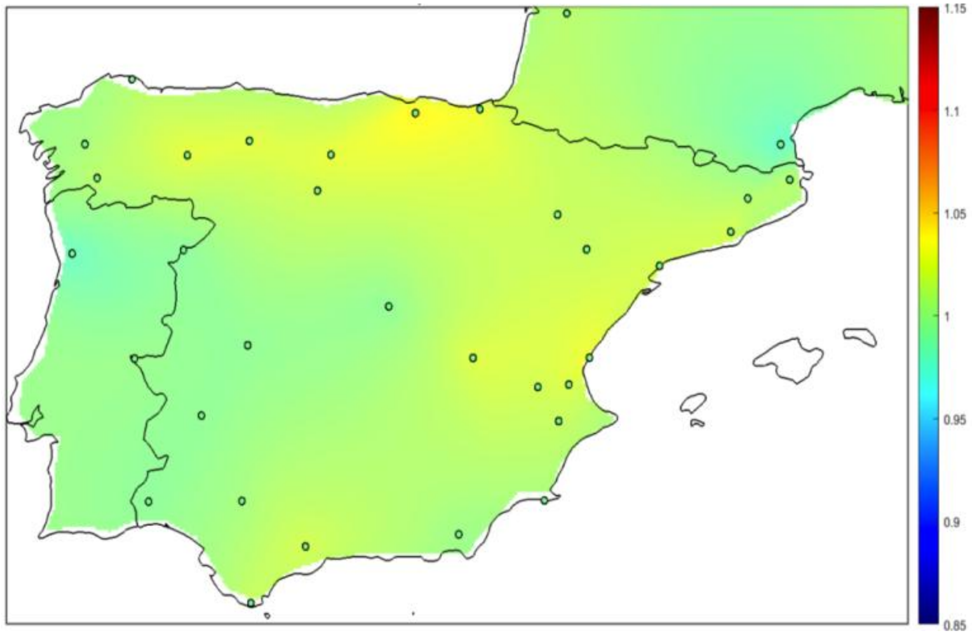



Figure 2. Voltage in 400 kV transmission network from 09:30 to 12:30 h

# 12:00

The voltage in the 400 kV network is back to normal



# Event 1

*“At 12:03 h, and for a duration of 4 minutes and 42 seconds, a significant 0.6 Hz oscillation was observed in the electrical system…”*

*“…the oscillation caused a decrease in average voltage…”*

*“…fluctuations reaching up to 30 kV in the most extreme cases, ranging between 375 kV and 410 kV…”*

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# Event 1

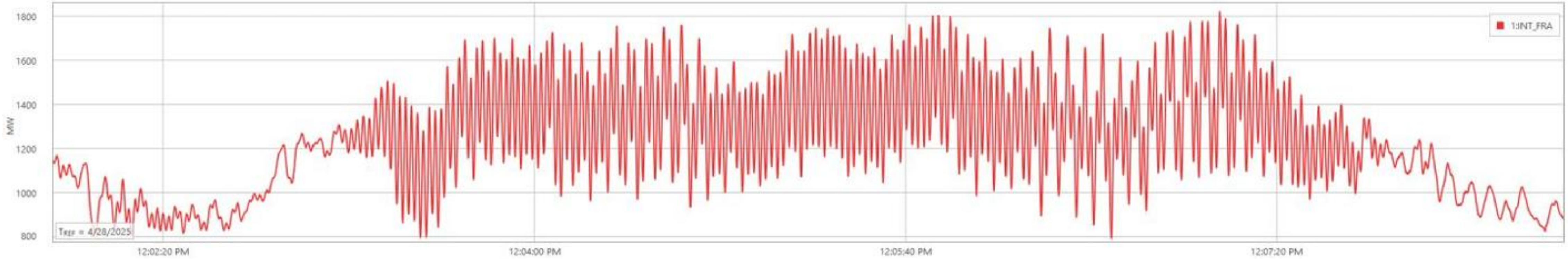


Figure 3. Exchange Spain-France between 12:02 to 12:08 (0.6 Hz oscillation)

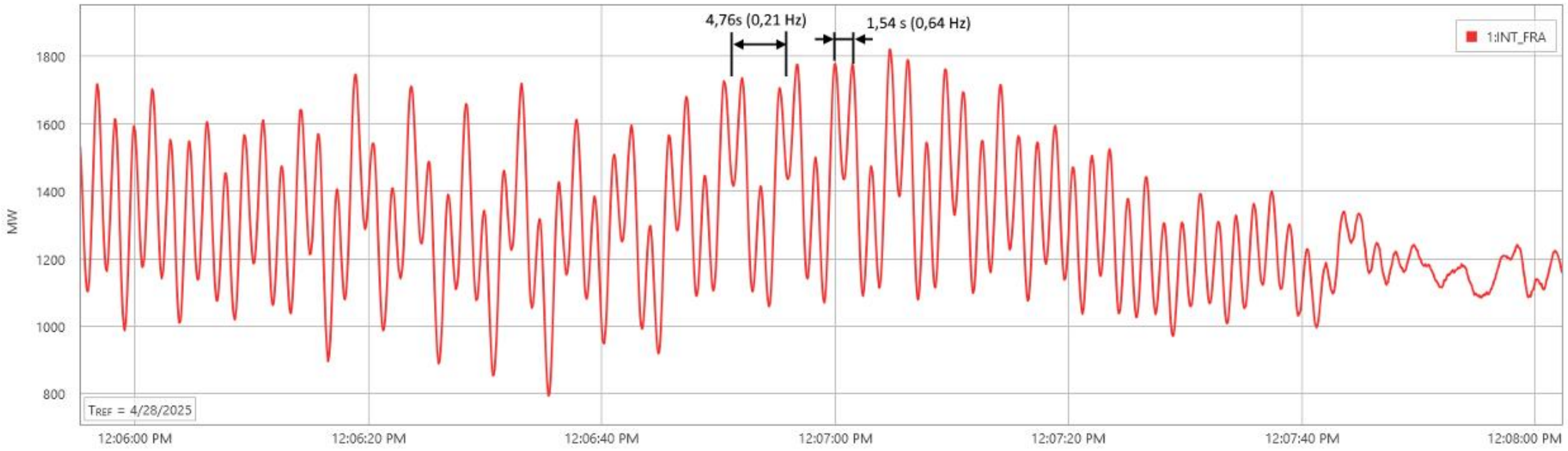


Figure 4. Exchange Spain-France between 12:06 to 12:08 (0.6 Hz oscillation)

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# Actions taken to damp these oscillations

- Lines were switched on to decrease the system impedance and improve the generators stability,
- Fixed power operation mode was set up on the HVDC link between Spain and France as this is an effective measure to mitigate oscillations,
- The flow between Spain and France was reduced, as additional countermeasure to reduce system exposure to oscillation phenomena

These actions stabilized the grid

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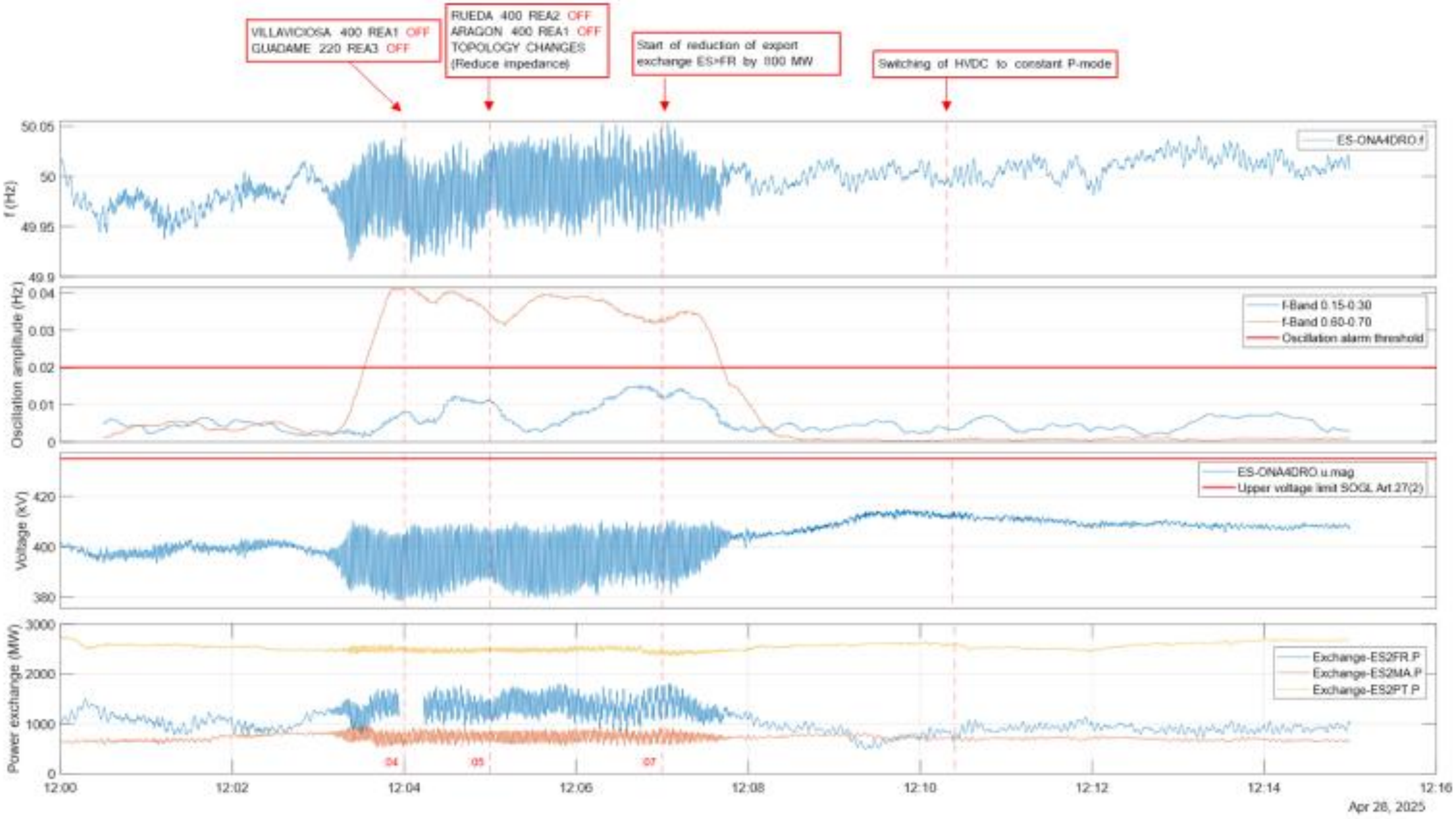
# Event 1, between 12:03 and 12:07

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# At 12:16 h, the 0.6 Hz oscillation reappeared

*“...the oscillation was not natural to the system but rather forced. This oscillation is observed with significant amplitude at a Photovoltaic Plant located in province of Badajoz (PV Plant A)”*

*“...at the time of the oscillations, the plant was generating approximately 250 MW. Since the oscillation was forced, it ceased once the plant stabilizes it”*

*“...likely that the oscillation was originated from an internal control malfunction or anomaly within the plant “*

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# Event 2

*“A detailed analysis revealed that the oscillation initially began at 0.6 Hz, and quickly afterwards the 0.2 Hz oscillation started. Although PV Plant A had increased its output from 250 MW to 350 MW at 12:15 h “*

*“At 12:19 h, while actions were still being implemented to improve damping following EVENT 1, a new frequency oscillation of 0.2 Hz appeared in the system “*

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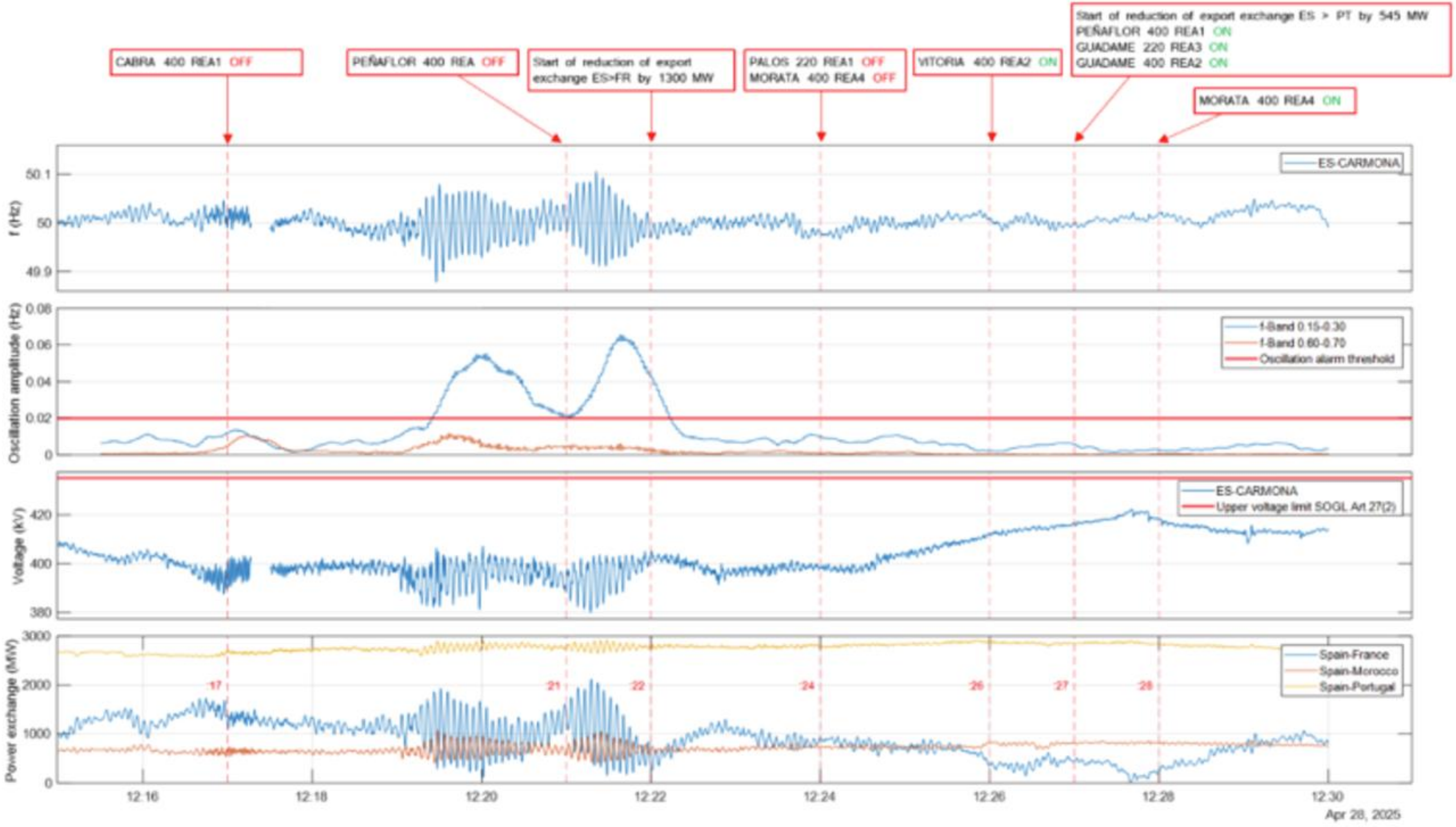
# Event 2, between 12:19 and 12:22



# Actions taken

- 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). This represents a total reduction of 1,300 MW.
- Reduction of export exchange with Portugal from 2,545 MW to 2,000 MW, a decrease of 545 MW.

These actions stabilized the grid

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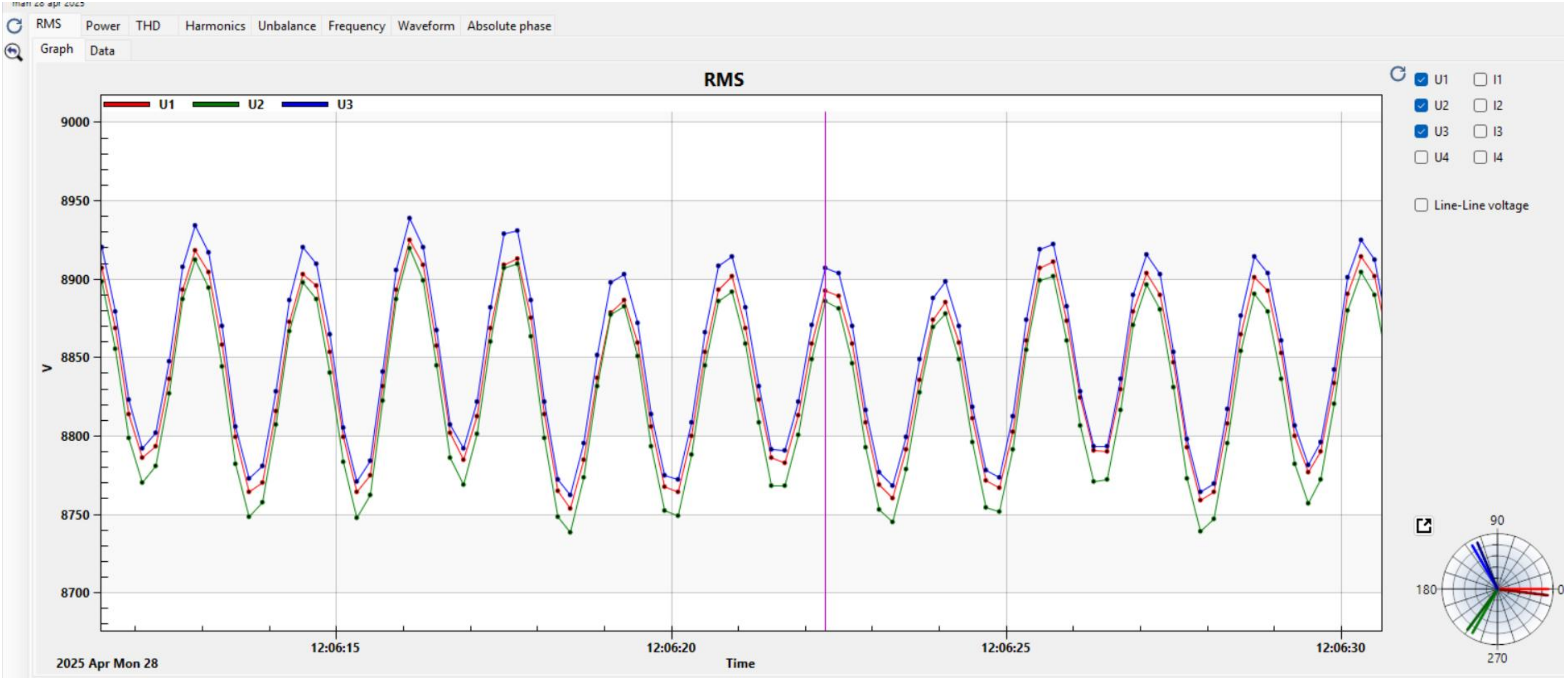
# Measurements from Portugal

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# The grid collapsed in 30 seconds

Started at 12:32:57

# First substation disconnected

*“At 12:32:57 PM, a trip occurred at a substation located in the province of Granada involving the 220 kV side of 400/220 kV generation transformer, which at the time was supplying 355 MW to the transmission grid and absorbing 165 Mvar.”*

*“Since there were no overvoltages on the transmission network 400 kV side —and the values were well below such thresholds—. It could be inferred that the cause lies in the generator transformer tap setting. As the system was recovering from previously low voltages”*

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# From bad to worse

*“At 12:33:16.460 h —approximately 19.5 seconds later— a new generation disconnection occurred … which is connected to a 400 kV … while generating 582 MW … 360 milliseconds later, a PV photovoltaic plant, connected to a different 400 kV transmission network substation …also tripped while generating 145 MW”*

*“the information available indicates that the voltage level was within limits before the disconnections”*

*“once again contributed to a rise in system voltage due to the loss of reactive power absorption”*

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# From worse to catastrophic

*"In total, an additional 834 MW of generation was disconnected within a 650 ms window, along with the associated reactive power absorption"*

*"once again led to a rise in system voltage due to the loss of reactive power absorption"*

…

*"At 12:33:24 h the Spanish Iberian Peninsula system collapses. At 12:33:27,300 h the voltage at 400 kV grid is below 1 kV, marking in this moment the TOTAL BLACKOUT of the system"*

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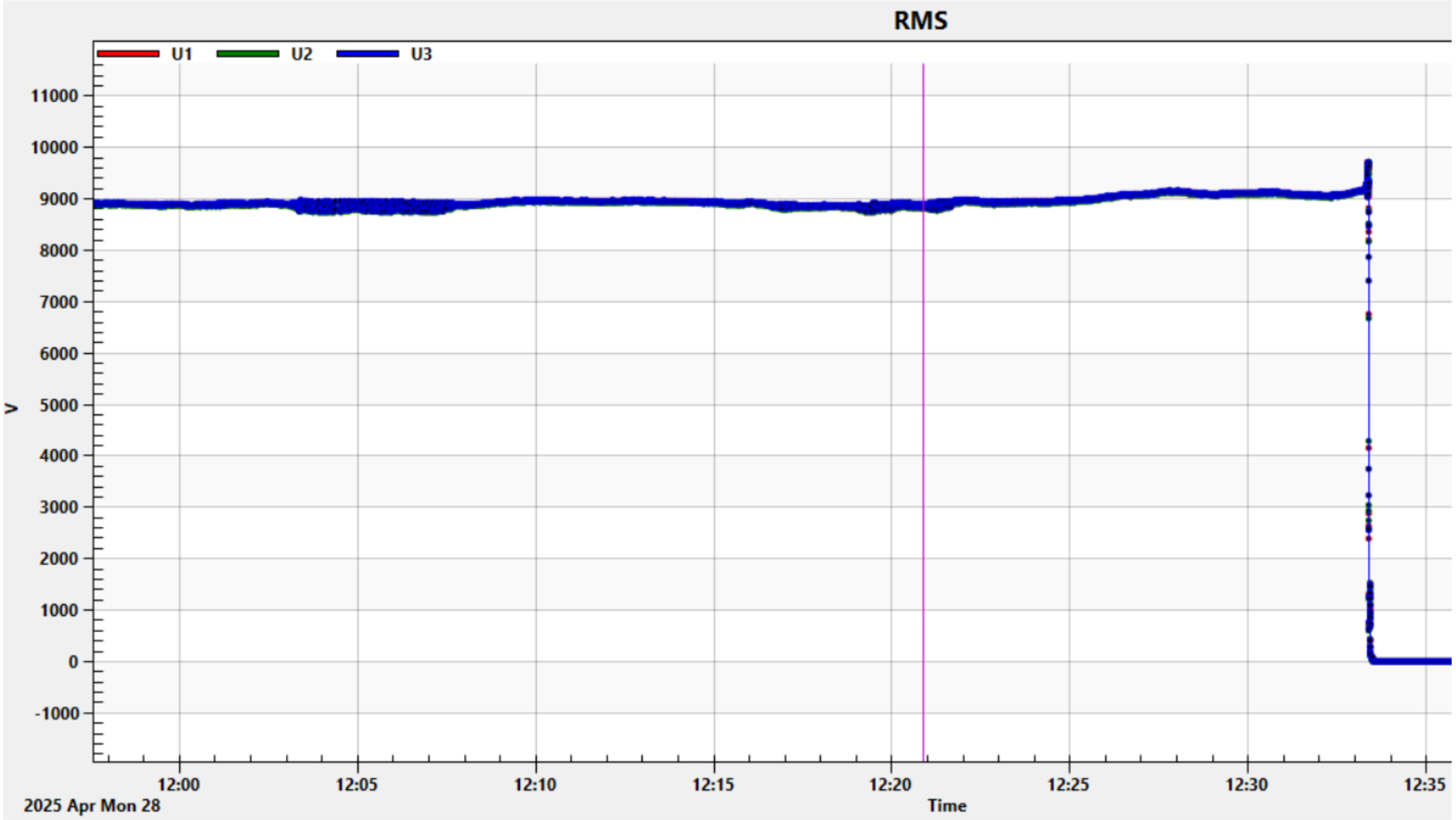
# Measurements from Portugal

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# Relevant aspects

From Red Electrica

# Voltage Control

*“Generation subject to failed to comply with its dynamic voltage control obligations”*

*“Generators typically respond only when voltage deviations become significant, suggesting that their response is primarily driven by internal plant protection mechanisms.“*

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# Voltage

*"A generator must withstand 440 kV for at least 60 minutes without disconnection, and up to 480 kV on a transient basis, at the point of connection to the 400 kV transmission network.*

*Some installations were found to have tripped without maintaining the minimum margin required to ensure compliance with the 60-minute criterion.*

*Several plants either tripped below the specified threshold or lacked the necessary operating margin, typically >2%, or with a minimum delay"*

# Frequency

*“It has been observed that the 0.6 Hz oscillation was present at a very low magnitude as early as 10:30 h”*

*“Despite Spain being in an underfrequency condition and France operating normally, the scheduled power export to France was maintained*

*As a result, the effective demand in Spain and Portugal at the moment of the AC interconnection trip with France was 1,000 MW higher than the actual demand within the Iberian Peninsula. “*

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# Inertia

*"The incident was NOT caused by a lack of system inertia. Rather, it was triggered by a voltage issue and the cascading disconnection of renewable generation plants, as previously indicated"*

*"Higher inertia would have only resulted in a slightly slower frequency decline. However, due to the massive generation loss caused by voltage instability, the system would still have been unrecoverable"*

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red eléctrica

*It is important to highlight the rate at which generation output can change within the system. New technologies based on power electronic inverters are capable of adjusting their output within a matter of seconds. While this capability is highly beneficial for the economic optimisation of individual generating plants, it is not necessarily ideal from a power system stability perspective in general.*

*A clear example of this is the rapid schedule changes in photovoltaic generation driven by price fluctuations in electricity markets. From an electrical standpoint, such abrupt changes in inverter-based generation introduce significant imbalances into the system, because regulation mechanisms haven´t operated yet. These imbalances must be compensated mainly through interconnections, particularly the one with France.*

*Severe imbalances lead to drastic shifts in power flows across the network, which in turn alter the capacitive and inductive behaviour of the grid. Consequently, system voltages can vary rapidly. This effect is further exacerbated when such generation operates under power factor control and doesn´t provide dynamic voltage control, as it limits the dynamic reactive power support that could otherwise help stabilise voltage.*

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# The generation mix is rapidly changing

We need to pay close attention to:

- Grid stability
- Inertia
- Legislation
- Enforcement of rules and regulations
- Cross border connections
- Mitigation systems
- Power Quality

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