INVESTIGATION BY THE ENTSO-E EXPERT GROUP INTO THE IBERIAN BLACKOUT OF 28 APRIL 2025

Assessment of the investigation following the meeting on 15 July 2025

On 28 April 2025, at 11:33 a.m. (12:33 p.m. CEST), the power systems of Portugal and Spain experienced a blackout that also affected, for a very short period, a small area of France close to the border with Spain. It is now known that this interruption affected several industrial consumers and generators, more notably a nuclear power unit that 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.

Following the blackout incident, on 12 May 2025, in accordance with European regulations, ENTSO-E (European Network of Transmission System Operators for Electricity) set up an Expert Panel to investigate the causes of the incident, produce a comprehensive analysis and make recommendations in a final report that will be published. The ENTSO-E Expert Panel has met four times so far. **The last meeting was on 15 July 2025 and the information updates are described below.**

1. WHAT'S NEW ABOUT RESEARCH?

The Expert Panel - of which ERSE is a member - reported after its fourth meeting on 15 July that it had continued to analyse the available data on the incident and confirmed that, despite initial challenges in collecting data from several Distribution System Operators (DSOs) and generation companies in Spain, all parties had provided the requested data. The experts are currently assessing the completeness and quality of the latest data received.

Based on the data available so far, the Expert Panel can provide additional information on its ongoing investigation, such as a more detailed description of the forced oscillations observed around 12:05 in Southern Spain and of the counter-measures taken to mitigate them.

The Expert Panel can also provide new preliminary information related to the generation trips that took place just before the blackout.

The Expert Panel is looking particularly at the cascading series of generation disconnections and 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. If confirmed, this high-voltage blackout mode will require a thorough analysis and investigation by all power system experts of the ENTSO-E community.

The exceptional character of this incident highlights the need to improve the resilience of the power system in case of cascading voltage increases. ENTSO-E sees at least two important lines to consider:

- enhancing voltage control management procedures and capabilities of all active actors of the electricity system to prevent such major voltage-related incidents in the future;
- assessing how the system defence plans can better protect the European power system against this new type of phenomena.

2. PRELIMINARY CHRONOLOGY OF EVENTS

A preliminary chronology based on the information known so far has been identified regarding the complex sequence of events which have occurred prior to the blackout.

i. System conditions on the morning of 28 April (09:00 - 12:00 CEST)

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.

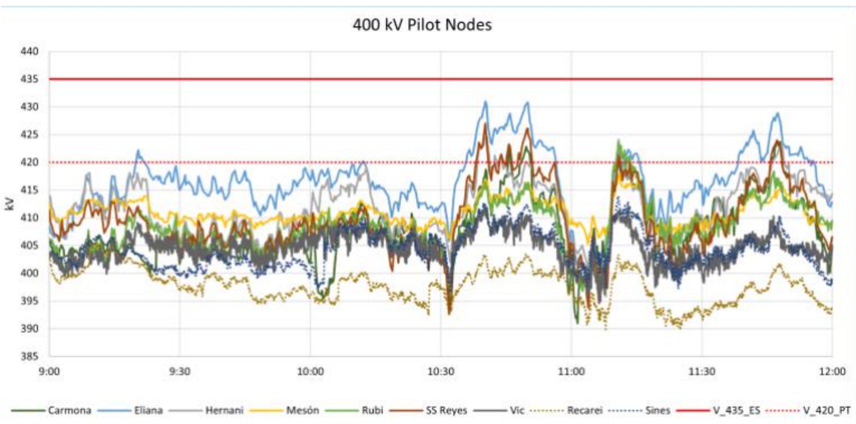


Figura 2a - Evolução da tensão das 9:00 às 12:00 CEST nas principais subestações de transmissão de 400 kV em Espanha e Portugal. [fonte: Telemedidas a cada 4'' da Red Electrica e REN]

Figure 3 - Location of substations where voltage measurements were taken

ii. System conditions prior to the incident (12:00 - 12:30 CEST)

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 of the available information indicates that this was a local, forced oscillation (i.e. induced by an external source: a power plant), with a dominant frequency of 0.64 Hz, primarily affecting the Spanish and Portuguese power systems. As shown in Figure 5, the forced oscillation also excites the interarea mode East-Centre-West (0.21 Hz) with a small amplitude.

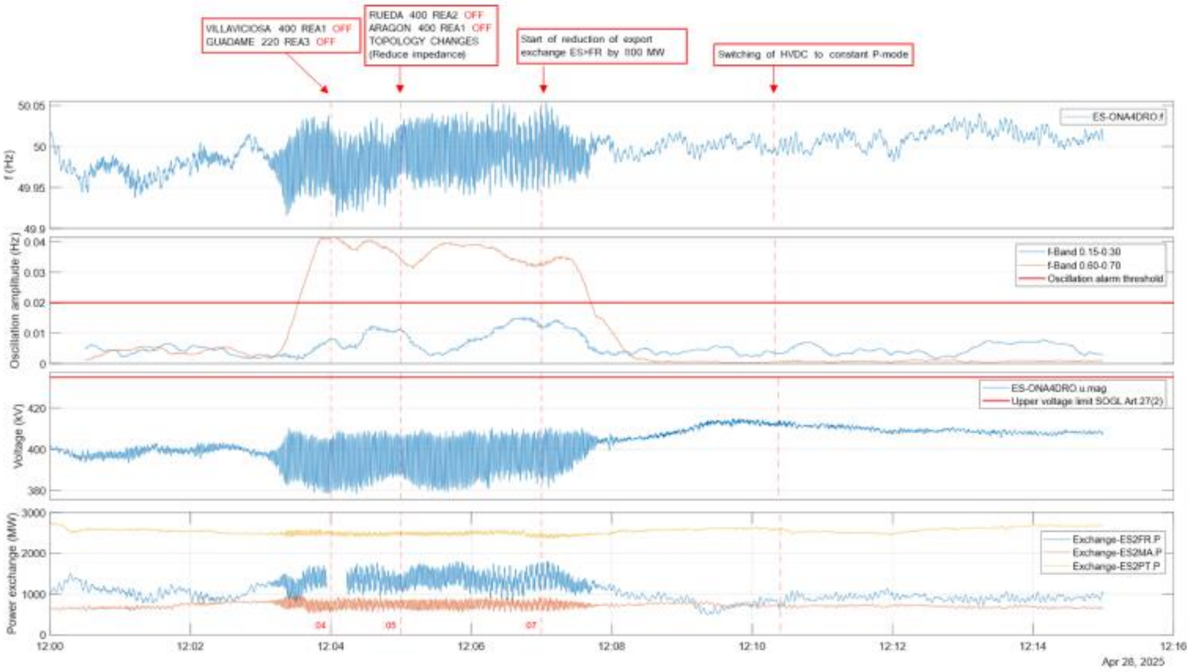


Figure 5 - Characteristic data of the first oscillations (source: WAMS sampling rate 100 ms at the 400 kV Carmona substation) and countermeasures

The mode shapes of the first oscillation suggests that this is 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.

In order to damp these oscillations, the operators in the control rooms of the relevant TSOs took several mitigating measures (defined in the established operation protocols):

- 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 decrease Iberian centre of inertia angle against the rest of the Continental Europe power system.

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

Several electricity producers connected to the Spanish transmission system confirmed that these oscillations were clearly visible on their generators.

The **second** oscillation occurred between 12:19 and 12:22 CEST. This was an inter-area oscillation, with a dominant frequency of 0.21 Hz, corresponding to the well-known East-Centre-West Continental mode.

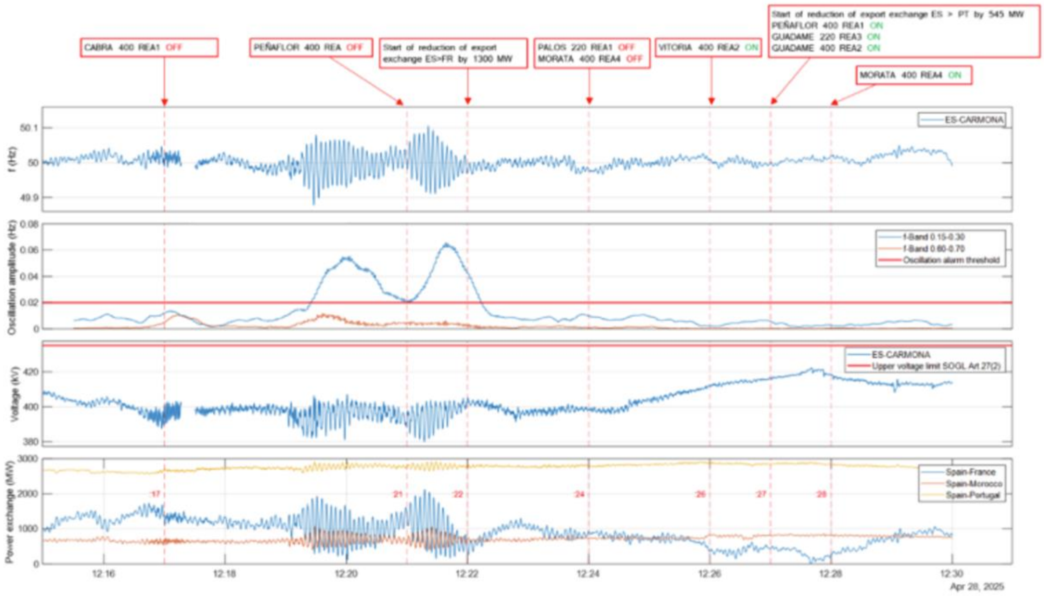


Figure 7 - Characteristic data of the second oscillation and voltage increase (source: 100 ms WAMS sampling rate at the 400 kV Carmona substation) and countermeasures

Analysing the second oscillation clearly demonstrates the nature of an inter-area oscillation in which the entire Iberian Peninsula oscillates coherently and with similar amplitude against the entire continental European system. This second oscillation was effectively mitigated through further countertrading measures, which again reduced power flows between Spain and France, and also with the coupling of the internal power lines in South of Spain.

Figure 9 allows to visualize the evolution of the voltage angle difference at various locations of the Iberian system (compared to a reference location at border between France and Spain) after 12:00 CEST. The global effect of the applied countermeasures after the first oscillations is visible at 12:10 CEST, when the angles between different locations in Spain were significantly reduced; the unavoidable effect in closing the lines was an increase of injected reactive power into the system, and so an increase of voltages.

After this first action, the voltage angles of the system at 12:15 CEST came back to the values before the first oscillation due to an increase of exchanges between Spain and France, invalidating the previous countertrading action. The angle increase again created the conditions for the second oscillation.

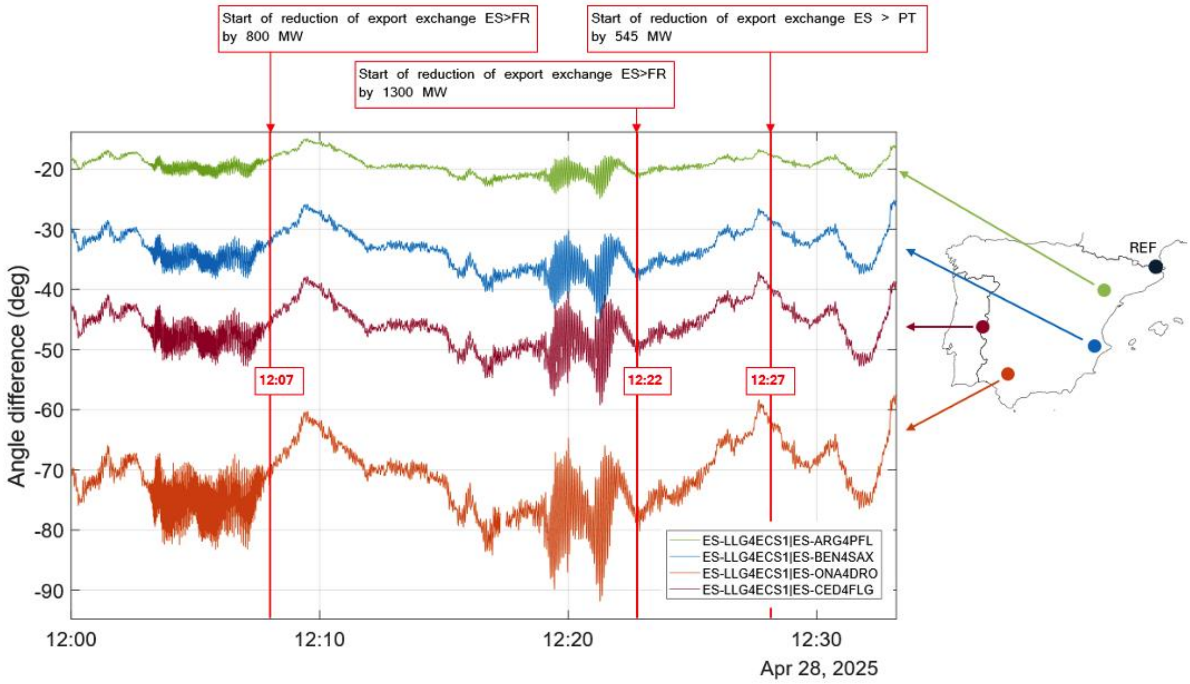


Figure 9 - Evolution of the voltage angle difference after 12:00 CEST, and the effect of countermeasures, at 4 locations on the Iberian Peninsula (source: data from Red Eléctrica's PMU)

Following the second oscillation, the voltage was within the range of 390–420 kV, before increasing again, but still within the operational voltage range in the transmission network. At that moment, Spain's international scheduled exchanges – all in the export direction – were 1,000 MW to France, 2,000 MW to Portugal and 800 MW to Morocco.

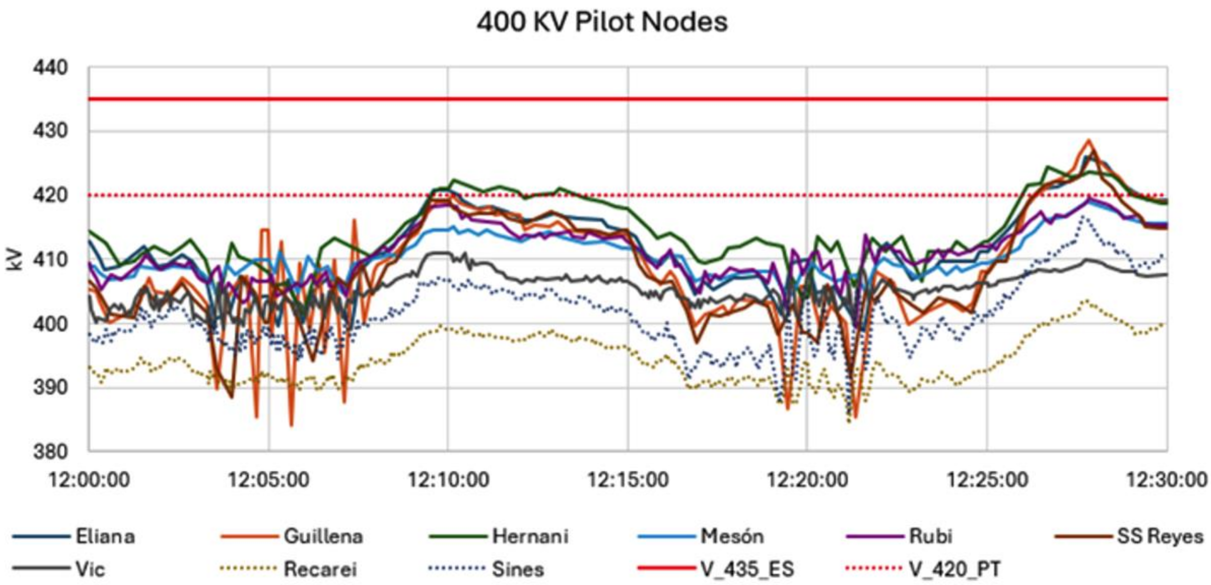


Figure 10a - Voltage evolution from 12:00 to 12:30 CEST at the main 400 kV transmission substations in Spain and Portugal. [source: Telemeasurements every 4'' by Red Eléctrica and REN]

iii. Sequence of events during the incident

The figure below shows the evolution of the voltage and of the net active power exchange position of Spain starting from 12.32 CEST. It indicates that, around the time when the net active power exchange position of Spain began to decrease, the voltage started to rise.

The Expert Panel is examining if and to what extent the rise in voltage is related to the following possible causes, all associated with an increase in reactive power:

- the reduction of reactive power absorption by generators which decreased their active power operating with a fixed power factor, and/or
- the reduction of reactive power absorption by the transmission lines, associated to their loading, and/or
- increased reactive power injection from distribution systems. This potential correlation could have been exacerbated by the fact that the reduction of active power (and hence of reactive power absorption) took place mainly in the southern part of the system, leading to a longer low-loaded transmission path of the export towards France.

Figure 11: Voltage evolution at the Carmona substation and Spain's net active power exchange position in the minute before the blackout (source: Red Eléctrica PMU data)

The currently available preliminary data indicates the following sequence of events taking place after the described increase of voltage between 12:32:00 and 12:32:57 CEST. Before the events described below, the voltage in the transmission network was below the upper operational limit.

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

Loss of generation was observed in the regions of Granada, Badajoz and Sevilla, accounting to an initially estimated total of 2200 MW.

The first event was due to the tripping of a generation transformer, due to a problem in the lower voltage side, in the area of Granada, which connected different generation facilities (photovoltaic, wind and thermo-solar) to the transmission grid and which was injecting 355 MW. The tripping of the transformer and consequently the loss of infeed options also explains the disconnections of some of the generation units connected to this transformer due to over-frequency while others trip due to overvoltage, as reported by the operators of the power plants.

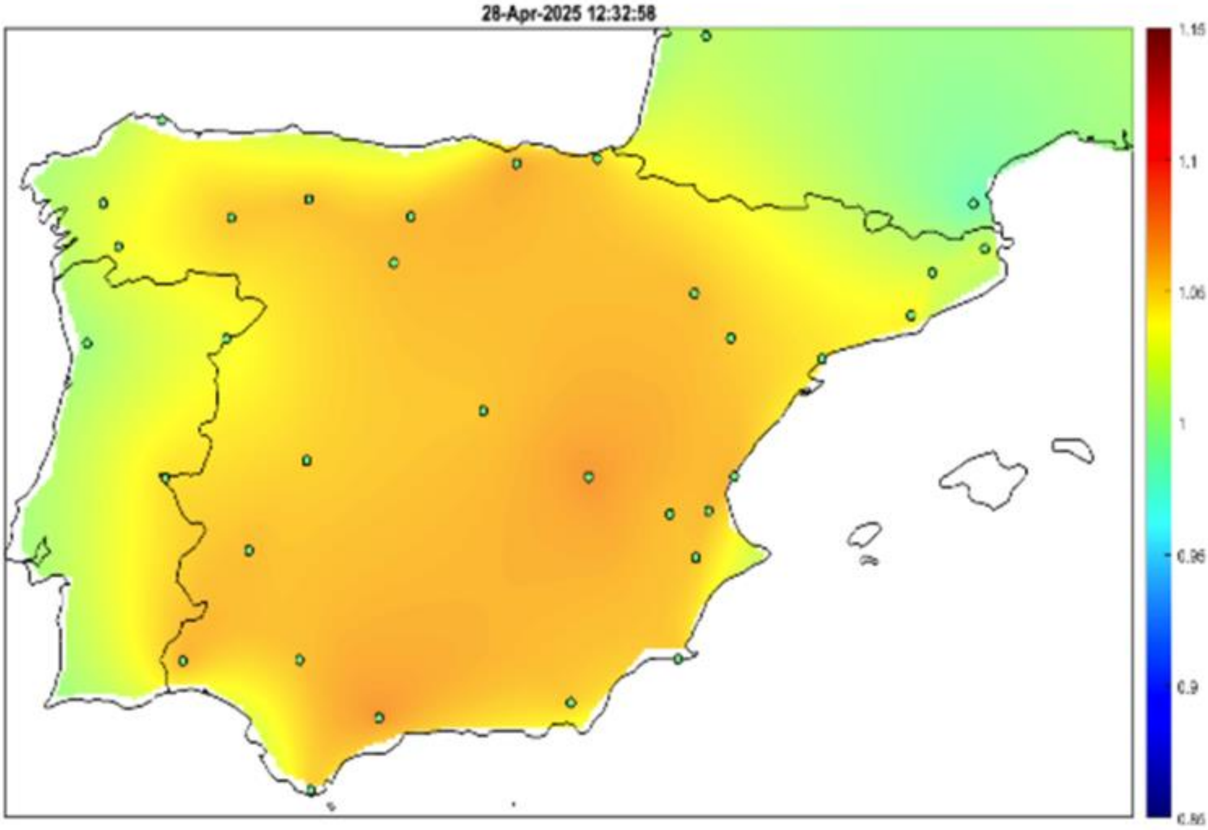
The second event included trips of PV and thermo-solar facilities connected to two transmission 400 kV substations, in the area of Badajoz, with a total interrupted injection of around 720 MW.

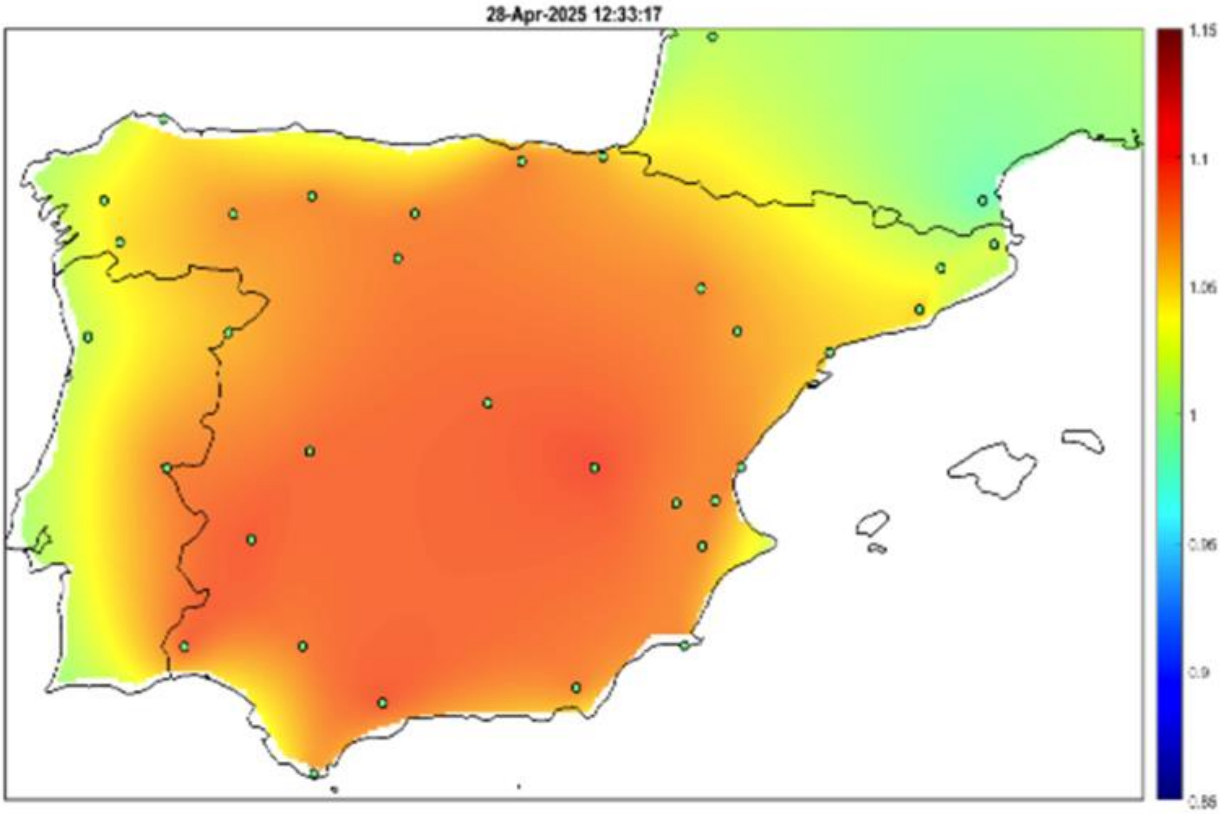
The third event included several trips, in different areas, in less than one second: wind farms in Segovia and Huelva, photovoltaic in Badajoz, Sevilla, Caceres and Huelva and thermo-solar in Badajoz, and other generators in different locations for a total of more than 1100 MW, as confirmed by the variation of frequency.

The causes of these three events are still under further investigation.

No generation trips were observed in Portugal and France within this timeframe. As a result of these events a voltage increase was observed in Spain, leading to a similar increase in Portugal, while the frequency decreased.

The following figures show the voltages on the 400 kV transmission network in colour and for each second following the outages in the Granada, Badajoz and Seville regions. It can be seen that at 12:33:18 CEST the voltages on the transmission network in Spain are above the threshold value of 435 kV.


28-Apr-2025 12:32:58
1.15
1.1
1.05
1
0.95
0.9
0.85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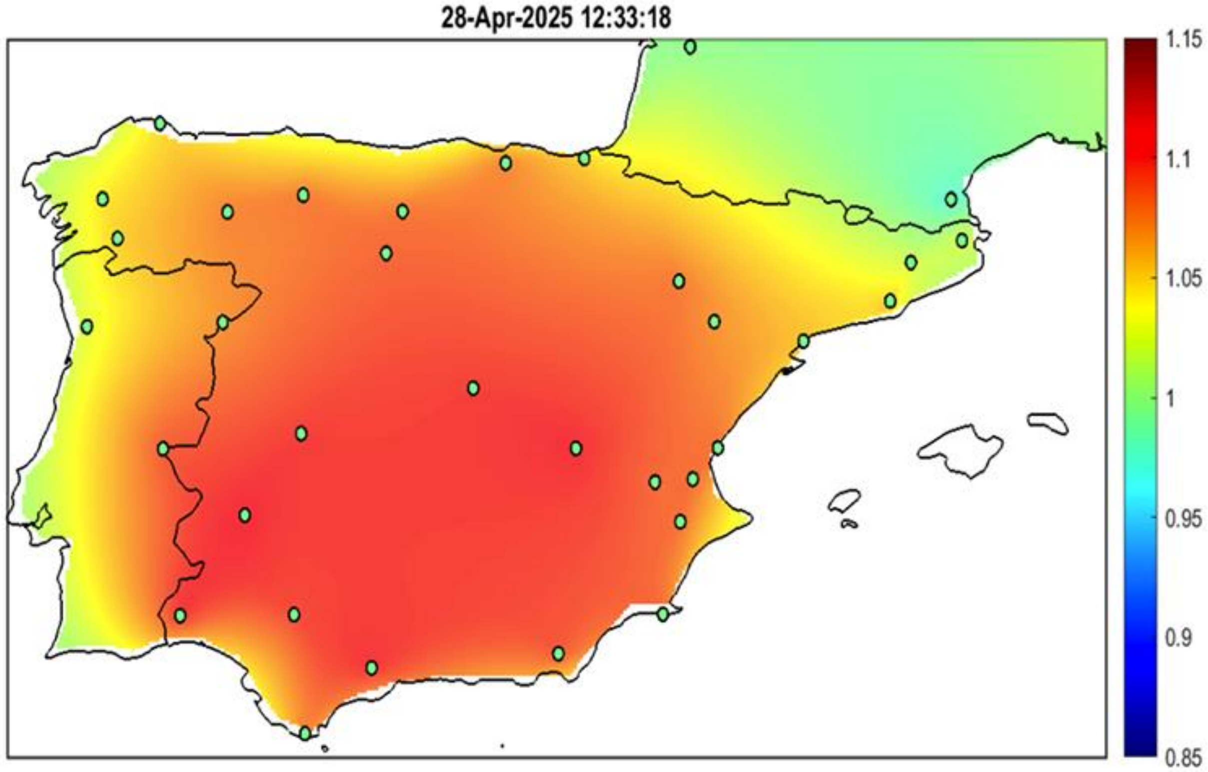

Figures 12a, 12b & 12c - Heat maps of the voltage on the 400 kV transmission network in values per unit (p.u.) every second after the firing of the three sets of generators (source: PMU data from Red Eléctrica, REN and RTE)

- 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.

- At 12:33:19 CEST

The power systems of Spain and Portugal started to lose synchronism with the European System.

- Between 12:33:19 and 12:33:22 CEST

The automatic load shedding and System Defence Plans of Spain and Portugal, elaborated in accordance with Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO GL), were activated but were unable to prevent the collapse of the Iberian power system.

- At 12:33:21 CEST

The Alternating Current (AC) overhead lines between France and Spain were disconnected by protection devices against loss of synchronism.

- At 12:33:24 CEST

All system parameters of the Spanish and Portuguese electricity systems collapsed, and the direct current interconnector (HVDC) between France and Spain stopped transmitting power.

The following figure shows that at 12:33:18 CEST the voltages on the Spanish transmission network were above the limit value of 435 kV.

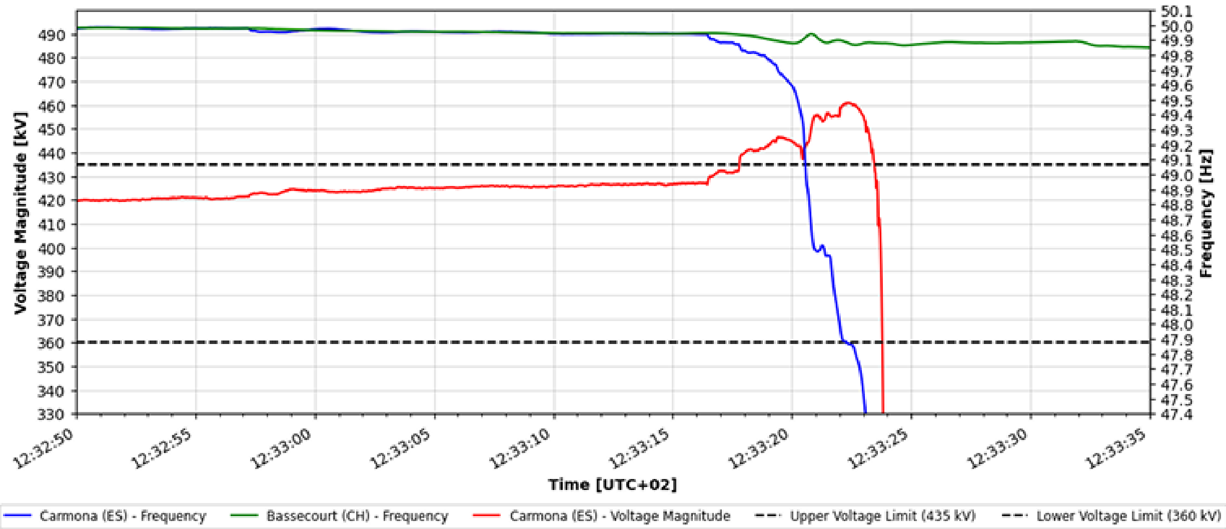

Figure 14 - Evolution of frequency and voltage at the Carmona substation (Spain) and frequency in the rest of continental Europe (Bassencourt substation, Switzerland) during the incident (sources : Red Eléctrica, Swissgrid)

3. RESTARTING THE SYSTEM

Following the incident, each impacted Transmission System Operator (TSO), in the case of Portugal, REN, immediately activated their respective system restoration plans.

Power system restoration in some regions of the Portuguese and Spanish systems was facilitated, among others, by the activation of the power system resources such as black-start processes in certain power plants, as well as by the existing interconnections with France and Morocco

In Portugal, two power plants restarted the system with autonomous start-up capacity: Castelo de Bode (hydropower plant) and Tapada do Outeiro (combined cycle gas turbine plant).

According to ENTSO-E, the rapid restoration of supply in Spain and Portugal demonstrated the preparedness and efficiency of the affected transmission system operators (TSOs), Red Eléctrica and REN, with the support and collaboration of the French transmission system operator RTE, as well as the Moroccan utility company ONEE. This was possible by the joint work and cooperation of TSOs developed over the years, both between the control centres and within ENTSO-E. In addition, the real-time monitoring and coordination of the status of the European electricity systems was achieved by the European Awareness System platform, a tool developed by all the TSOs within ENTSO-E.

The main steps taken by the TSOs for the restoration process were as follows:

- At 12.35 and 12.43 CEST

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 (group 2).

- At 12.44pm CEST

A first 400 kV line between France and Spain was re-energised (Western part of the border).

- At 12.45 CEST

The hydropower plant of Castelo do Bode, operating in black-start mode, was connected to the 220 kV of the neighbouring REN substation.

- At 13:04 CEST

The interconnection between Morocco and Spain was re-established.

- From the start of the restoration until approximately 13:30 CEST several hydropower plants in Spain with black-start capability launched their black-start processes to initiate the restoration of the system.

- At 13:35 CEST

The Eastern part of the France-Spain interconnection was re-energised.

- At 16:11 CEST and 17:26 CEST

REN had established two restoration islands and was progressing and rapidly restoring the supply of demand in these regions, using the Castelo do Bode hydropower plant and the Tapada do Outeiro combined cycle gas turbine power plant.

- At 18:36 CEST

The first 220 kV tie-line between Spain and Portugal was re-energised, allowing to speed up the restoration of the Portuguese system.

- At 21:35 CEST

The Southern 400 kV tie-line between Spain and Portugal was re-energised.

- At 00:22 CEST on 29 April 2025

The restoration process of the transmission grid was completed in Portugal

- Around 04:00 CEST

The restoration process of the transmission grid was completed in Spain.

The following figures show the evolution of consumption and the generation mix in Spain and Portugal before the blackout, during and after the restoration process.

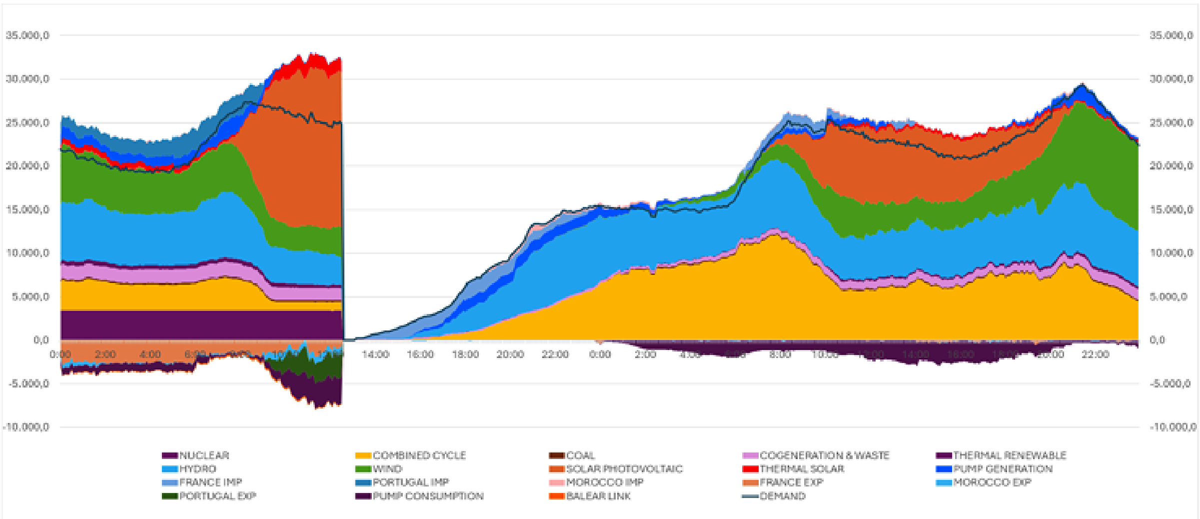

Figure 16a - Generation and consumption mix in Spain on 28 and 29 April

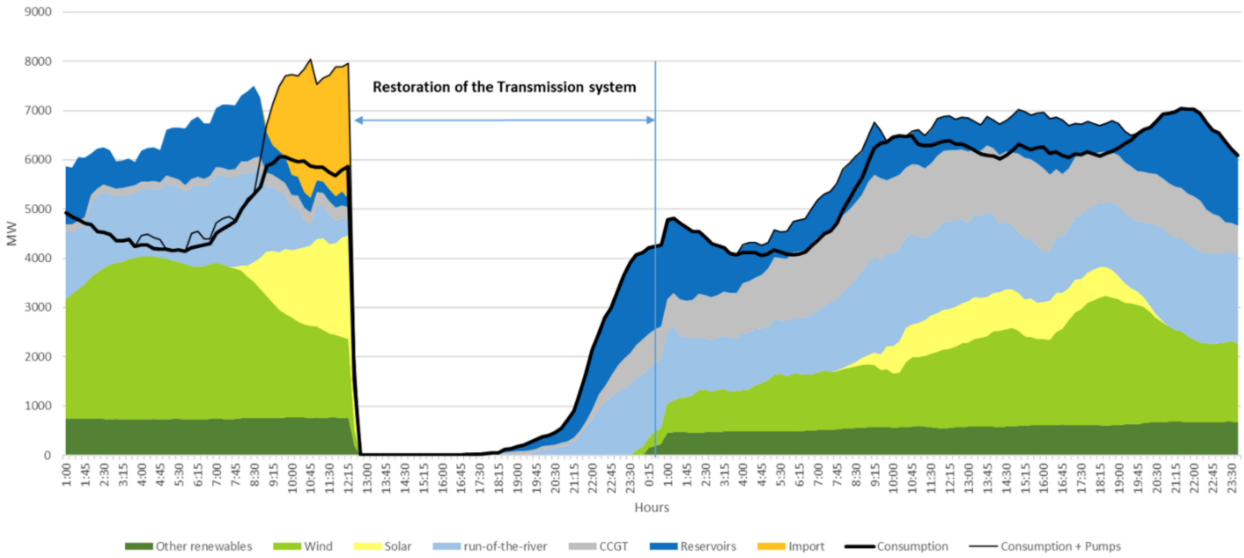

Figure 16b - Generation and consumption mix in Portugal on 28 and 29 April

4. BACKGROUND INFORMATION

4.1 WHO MAKES UP THE PANEL OF EXPERTS?

The Expert Panel consists of representatives from TSOs, the Agency for the Cooperation of Energy Regulators (ACER), National Regulatory Authorities (NRAs), including ERSE, and Regional Coordination Centres (RCCs).

The Panel is led by experts from TSOs not directly affected by the incident and includes 45 experts from both affected and non-affected TSOs.

ENTSO-E has launched a dedicated webpage to provide updated information on the incident. This page serves as the central source for updates on the investigation of the blackout. The information published is based on preliminary findings and analysis of the Expert Panel, and is subject to change at any time as the investigation progresses.

4.2 WHAT ARE THE STEPS OF THE INVESTIGATION?

The expert group began its investigation into the causes of the blackout on 12 May 2025.

The investigation, according to the ENTSO-E is conducted in two phases:

i. Data collection and Factual report

In the first phase of the investigation, the Panel collects and analyses all available data on the incident to reconstruct the events of 28 April and determine the causes of the blackout.

For the data collection task, the Expert Panel has been receiving information from all affected TSOs. In addition, to facilitate the provision of third-party data to the Expert Panel, two letters were sent – one to Red Eléctrica and the other one by ENTSO-E to Spanish authorities. As a result, on July 15th, the Panel confirms that it has received data from all contacted parties. The Panel is still in the process of assessing the completeness and quality of the data delivered by these parties and, based on this assessment, has sent additional data requests to several of them.

At the end of this first phase, the Expert Panel will deliver a factual report, to present the facts and data about the incident. Although the legal deadline to produce this report is 28 October 2025, six months after the incident, the Panel intends to deliver it earlier.

ii. Recommendations and Final Report:

In the second phase, the Panel will perform a detailed analysis and will establish recommendations to help prevent similar incidents in the future. These will be published as a final report, which is expected to be delivered 2 to 3 months after the factual report. This report will be published and presented to the European Commission and Member States via the Electricity Coordination Group.

The ENTSO-E notes that conducting a rigorous, fact-based analysis of incidents of this magnitude and technical complexity requires time. In particular, it involves a detailed reconstruction of the precise operation of the Iberian, French and broader European electricity system in the hours leading up to the blackout. This approach is in line with the Incident Classification Scale Methodology (ICS Methodology) developed in accordance with Regulation (EU) 2019/943 on the internal market in electricity and Commission Regulation (EU) 2017/1485 establishing a guideline on electricity transmission system operation (SO GL). The ICS Methodology establishes the framework for reporting and classifying incidents on the power system and for organising the investigation of extensive and major incidents. Past experience has shown that such analyses are essential for drawing meaningful conclusions and implementing improvements across the European power system.

4.3 - What is the timetable for the expert panel meetings?

- 12 May 2025
- 3 June 2025
- 23 June 2025
- 15 July 2025
- **18 August 2025**

- 2nd September 2025
- 19 September 2025
- 14th October 2025

Lisbon, 21 July 2025