The reason for the blackout in Spain last year:

Ineffective voltage control

New technologies create new vulnerabilities

A European expert group has submitted a 472-page final report on the power outage on the Iberian Peninsula on April 28, 2025. This note reproduces some of the main features of the report, but otherwise refers to the report itself[1].

The high security of supply that characterizes power systems in Europe and the United States is due to the sharing of experiences from serious operational incidents in many countries. That is why incident reports are so useful.

The Iberian Peninsula is a vulnerable corner of Europe

Europe's electricity supply consists of four synchronous alternating current systems, as well as some smaller islands (Fig. 1). The alternating current systems are interconnected by high-voltage direct current (HVDC).

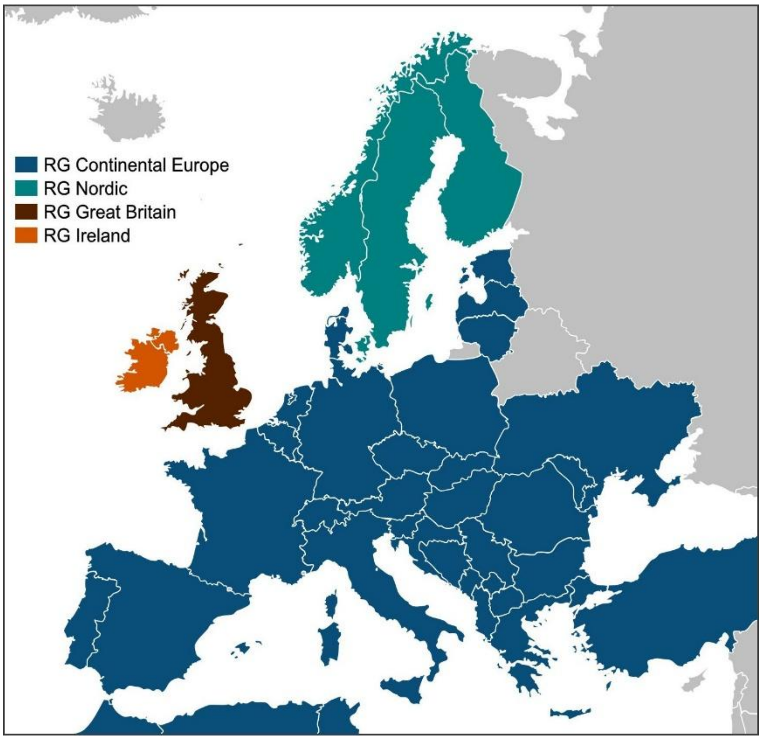

Fig. 1 - Source: Wikipedia

Continental Europe is the largest regional group (RG).

Traditionally, alternating current networks are supplied by rotating machines with a certain mechanical inertia. This inertia has so far ensured the stability of the system in the event of network faults.

There is a risk of oscillations in an alternating current network, especially if there are long distances and weak connections. Standing oscillations can develop into system collapse. Therefore, systems have been developed to detect and dampen oscillations in the network.

Low-frequency oscillations (< 1 Hz) have sometimes been observed between the Iberian Peninsula and Eastern Europe. This has not been taken very seriously so far.

Wind turbines are connected to the network using power electronics so that the speed can be optimized in relation to the wind. Therefore, the growth of wind and solar power has

[1] Grid Incident in Spain and Portugal on 28 April 2025 - Final Report - 20 March 2026 - https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/#Publications_&_Documents

reduced the rotating mass of the system and changed the dynamic properties of the system. This creates a need for continuous updating of the control systems and protections that must ensure stable operation.

Unclear conclusion

If you only read chapter 9.1 ("Summary"), you will not understand the causes of the incident. The text leaves the impression that the incident is the result of a coincidence of unfortunate circumstances. I think the ineffective voltage control in Spain should be highlighted in the summary. In Europe, we like to wrap up criticism nicely. I've seen a number of similar reports from the US, and here they are more direct. The idea is to learn something in a limited amount of time

An unusual voltage collapse

After 12:32:00, the voltages at numerous nodes rose, as shown in the Figure 1-6.

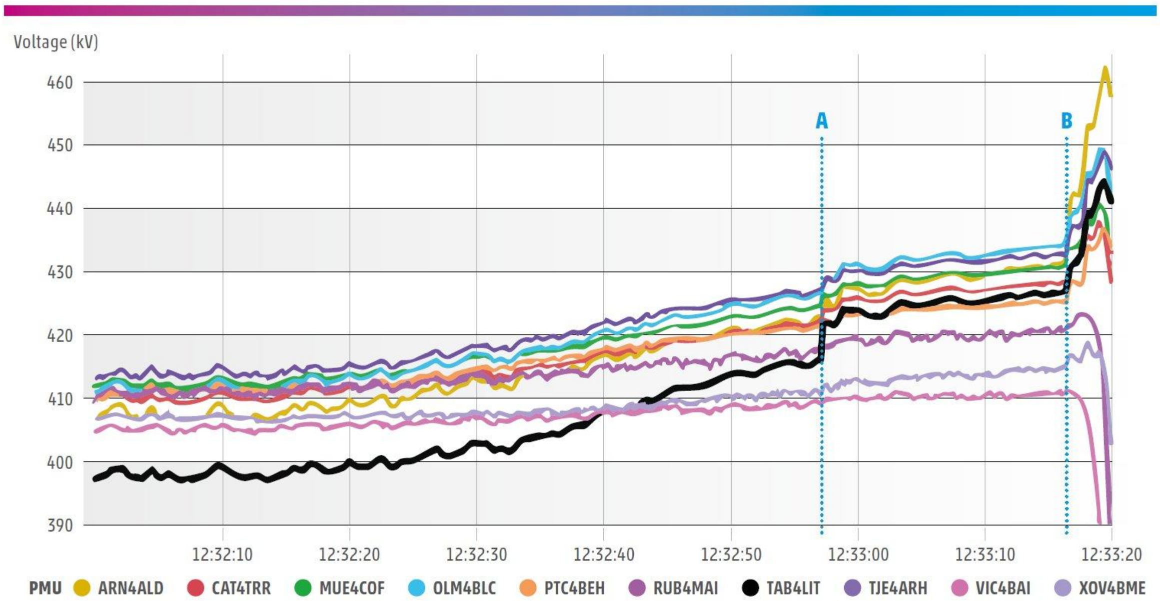

Figure 1-6 : Voltage (positive symmetrical component) evolution in the Spanish power system after 12:32:00 (PMU data). Phase asymmetry (not visible in this chart) was observed in some nodes.

Fig. 2 - Spain allows voltages up to 440 kV - Most other countries allow a maximum of 420 kV.

System operators must both balance production with consumption and maintain the system's voltage. The two balances are controlled by regulating active and reactive power, respectively. This requires sufficient controllable resources of both.

Lack of reserves of reactive resources has previously led to interesting blackouts. This is the case, for example, when most of France went dark on December 19, 1978. The same was the case in southern Sweden and on Zealand on September 23, 2003.

The grid's own generation of reactive power increases with the square of the voltage. If the voltage drops for some reason, the grid generates less reactive power, and then the voltage drops a little more. This creates a vicious circle that can only end in collapse if there is nothing to counter it.

In the current case, it was just the opposite. An increased voltage results in more generation of reactive voltage in the grid, and then the voltage rises a little more. And so the carousel goes on. Fig. 2 shows that the voltage collapse took approximately 70 seconds. This did not allow time for manual intervention, and the automatic sources for reactive power regulation were insufficient.

Therefore, the explanation of the management of reactive resources is central. The report mentions these factors (in no particular order):

- Coupling with reactive components (e.g. shunt reactors) is done manually and takes time.
- RE production is operated with a fixed phase angle and thus a constant MW/MVar ratio and therefore cannot respond automatically to voltage variations.
- The conventional synchronous power plants did not contribute their full reactive capacities according to the data provided.
- The current Procedure 7.4 on reactive power from synchronous generators does not include the specification of dynamic response, and there are no economic consequences if the current requirements are not met.
- The voltage control for producers in local networks is not designed to the needs of the system.
- When Spain allows a higher 400 kV voltage than the rest of Europe, the margin between this limit and the limit for automatic disconnection of production becomes very small or non-existent.

To put it politely, there is quite a lot to fix here.

The last point is incredible. See Fig. 2. Normally you only fill a glass to the brim to avoid spilling.

The synchronous generators must regulate the reactive power according to the voltage. They can absorb reactive power, but they have a stability limit that you want to keep a safe distance from. This may be the reason why the traditional power plants did not contribute as much to voltage regulation as they should have.

Determining how much reactive power you should have is a question of experience and risk appetite. In practice, there should be criteria for dimensioning and rules for manual intervention. In 1978 in France, there was an overload of the grid, and you had about half an hour in which you hoped that the crisis would pass by itself. It did not. In 2003 in Zealand, after an incident in Sweden, you only had 92 seconds, which did not allow for manual intervention.

The generally low interest in reactive power is understandable. Usually things go well, but not always.

Other studies

The European expert group behind the report also examined the oscillations observed before the grid collapse, the exchanges between Transmission System Operators (TSO) and Distribution System Operators (DSO) and the automatic low frequency demand disconnection (LFDD).

Selected conclusions:

- The analysis of the impact of inertia indicates that, even with significantly higher inertia values, the loss of system synchronism would not have been avoided.
- The analyses of voltage stability clearly indicate that the key phenomenon in the incident was the non-effectiveness of voltage control within the Spanish power system. Simulations show that increased reactive power margins could have prevented system collapse, enabling it to operate at lower voltage levels and maintain overall system stability.

Overview of the Expert Group's Recommendations

Voltage Control:

- Analysis of the possibility of detecting reduced voltage stability (Priority: low)
- Guidelines for good practice for voltage support measures and for voltage stability studies. (Priority: high)
- Units in voltage control mode (Priority: high)
- Visibility and adequacy of reactive power assets (Priority: medium)
- Automatic activation of reactive resources (Priority: medium)
- Voltage, permissible operating range (Priority: high)
- Ensure appropriate rapid adaptation of active and reactive power as long as RE plants use constant phase angle. (Priority: medium)

Oscillations:

- Framework for improving the damping of oscillations between areas in the European synchronous area (Priority: high)
- Improved dynamic monitoring and operational detection of oscillations in the grid (Priority: high)

Outages:

- Approved generator protection settings for units connected to TSO and DSO (Priority: medium).
- Defined voltage profile that class A units must be able to handle (fault-ride-through-capability) (Priority: high)
- Regular monitoring of grid users' assessment of grid robustness (voltage variations, RoCoF) (Priority: medium)
- Investigation of local generators outside central monitoring (Priority: medium)

There is nothing surprising in this list. One finds almost identical recommendations after the wave of blackouts in the US and Europe in 2003. Therefore, much of it should have been implemented in Spain long ago.

This also dismisses the suspicion that the incident in Spain is due to the growth in wind and solar power or the reduced rotating mass.

System monitoring, system control and system protection must be updated at all times in relation to current system changes. Some updates are self-evident. Others must be discovered by studying incidents in one's own or foreign networks. This is why clear incident reports are so useful.