As power systems grow more complex, real-time software and automated controls must evolve to manage scenarios with high renewable penetration, fast frequency drops, and constrained interconnection capacity.

The Iberian Peninsula Blackout of 2025

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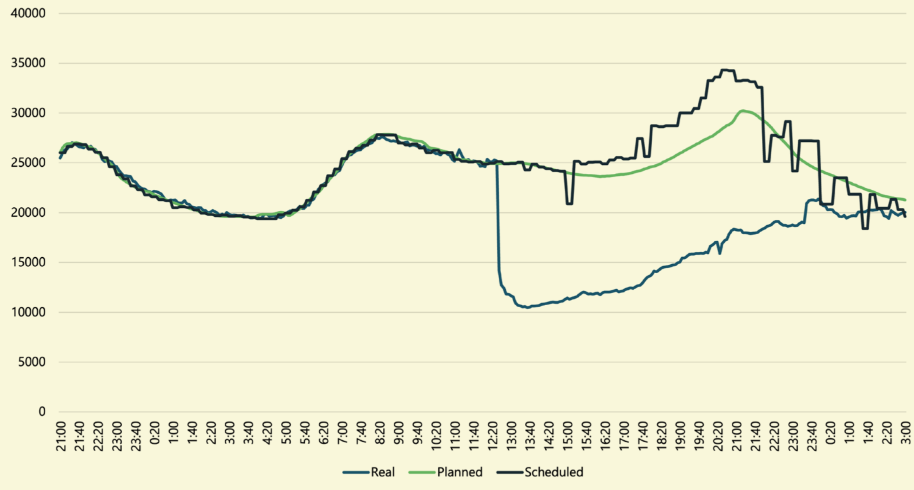
Introduction

On April 28, 2025, the Iberian Peninsula, encompassing Spain and Portugal, suffered a near-total blackout that lasted up to ten hours in many areas, impacting millions of lives and essential services. This massive power outage, triggered within seconds and cascading across two nations, exposed critical vulnerabilities in modern grid infrastructure and raised serious questions about the resilience of increasingly renewable-heavy energy systems.

Figure 1: Demand drop during the incident. Source: Red Eléctrica



Michael Sheppard has 20 years of market research experience designing numerous research practices from scratch while leading over 100 bespoke projects with Fortune-500 companies. In 2016 he co-founded Power Technology Research (PTR) and has since launched new research practices in solar, storage, battery, and e-mobility. In 2020, he co-founded Matos, an intelligence automation company focused on providing powerful AI-driven tools for the market research sector. In 2023, this business was acquired by PTR. Prior to founding PTR, he spent 8 years with iSuppli/IHS Markit in various analyst and consulting roles where he covered a broad range of sectors including mobile, renewable power and electricity transmission and distribution (T&D). In his last role, he led the power technology consulting group. He is an expert on the PV industry and has performed numerous competitive dynamics and opportunity assessment projects, covering upstream, downstream, and supply chain topics. In 2008, he obtained two Bachelor's of Science in both Financial Services and Corporate Finance from San Francisco State University.

Photo: AI generated

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Timeline and System Collapse

The blackout began at 12:33 CEST. Within moments, about 15 GW of generation, roughly 60% of the electricity in use, was lost across mainland Portugal and peninsular Spain. Some areas in France also experienced brief outages. Power was not fully restored in Portugal until after midnight and in Spain by 04:00 the next morning.

The sequence of failure was rapid. Spain and Portugal experienced two earlier periods of frequency oscillations in 30 minutes leading up to the incident that were mitigated by system operators. Just before the blackout, Spain was exporting power to France, Portugal, and Morocco. At 12:32:57 CEST, a series of generation trips occurred in southern Spain, reducing generation capacity by 2,200 MW in under 20 seconds. This triggered a frequency decline below 48.0 Hz, prompting automatic load shedding mechanisms.

By 12:33:21 CEST, the alternating current (AC) lines between France and Spain tripped, disconnecting the Iberian Peninsula from the continental grid. Three seconds later, the high-voltage direct current (HVDC) link also failed. The Iberian grid collapsed.

Restoration began promptly. By 12:44, one 400 kV AC line between Spain and France was re-energized. Moroccan-Spanish interconnection followed at 13:04. Spain's black-start-capable hydropower stations began restarting by 13:30, with AC lines progressively restored. Portugal lagged slightly behind, beginning black start at 16:11 and reconnecting tie-lines with Spain by late evening.[1]

Probable Causes

Though official investigations are ongoing, preliminary analysis identifies several contributing factors to the blackout. The incident likely began in southwestern Spain (Extremadura), where diverse generation types, including solar, are concentrated. Notably, Red Eléctrica data indicated a plunge in solar output from 18 GW to 8 GW[2] around the time of the blackout. The head of Red Eléctrica's operations noted that solar generation may have been involved in the initial generation trip.

Figure 2: Generation mix before the event. Source: Red Eléctrica

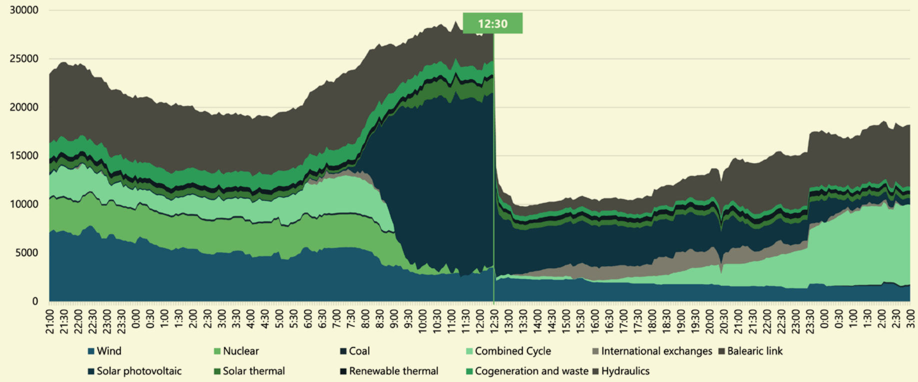
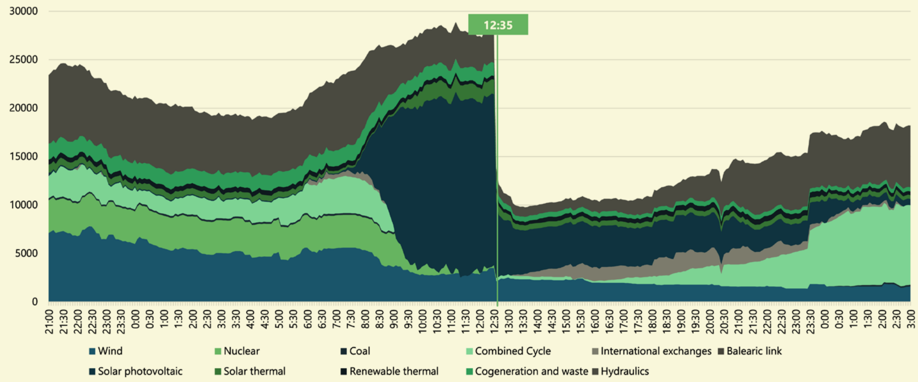


Figure 3: Generation mix after the event. Source: Red Eléctrica



Energy policy must embrace a holistic approach that integrates the goals of decarbonization with the fundamental need to maintain grid stability and resilience. Simply increasing renewable energy capacity is not sufficient without concurrently addressing the systemic impacts on the grid infrastructure.

Generation Structure (MW) – 28th April 2025		
Hour	12:30	12:35
Wind	3499	2142
Nuclear	3387	0
Coal	229	0
Combined Cycle	982	326
International exchanges	-4196	0
Balearic link	-102	0
Solar photovoltaic	17657	7844
Solar thermal	1498	1058
Renewable Thermal	377	376
Cogeneration and Waste	1356	835
Hydraulics	3172	1232

Table 1: Generation Structure (MW) before and after event. Source: Red Eléctrica

Two prior episodes of frequency oscillation suggest the system was already stressed. The Iberian grid may have been operating close to its stability margins, leaving it vulnerable to cascading failure after the initial shock.

A key factor was the high share of renewable energy, solar and wind contributed around 78%[3] of electricity just before the event. While vital for decarbonization, renewable sources like solar and wind do not inherently provide rotational inertia, a stabilizing force offered by traditional synchronous generators (e.g., gas, coal, or nuclear). Lower system inertia means frequency can drop more quickly during disruptions, reducing the time available for mitigation and heightening risk of collapse. Importantly, the issue is not with renewables per se, but with how they are integrated. Inverter-based technologies, when equipped with advanced grid-forming controls, can help stabilize voltage and frequency. However, most systems today still depend heavily on traditional inertia.

Another factor was the limited interconnection capacity between the Iberian Peninsula and the rest of Europe which was only about 6%[4]. Once the AC lines to France tripped, the Iberian system was effectively islanded and unable to draw power from the wider grid, limiting its ability to compensate for the generation loss.

Additionally, the economic underutilization of conventional power plants might have left the system more fragile. Low or negative electricity prices, driven by high renewable output, reportedly forced some base-load plants, including nuclear units, to idle at reduced capacity. With fewer conventional plants online, the grid may have lacked crucial stability services like inertia and frequency regulation at a critical moment.

Furthermore, grid control systems may also have been insufficiently equipped to handle this sequence of events. As power systems grow more complex, real-time software and automated controls must evolve to manage scenarios with high renewable penetration, fast frequency drops, and constrained interconnection capacity.

Solutions and Recommendations

The blackout highlights the urgent need for systemic improvements across several dimensions to ensure a resilient, low-carbon power future. The following strategic actions are critical next steps that Spain and Portugal must prioritize and fast-track.

1. Scale up smart grid investment
   This is essential to improving situational awareness and operational response during disturbances. Smart grids allow for real-time fault detection, automatic isolation, and faster recovery which are all crucial during cascading failures. Both countries are moving in the right direction but must maintain momentum. Spain's CNMC and Portugal's ERSE should identify and prioritize critical nodes for advanced monitoring and control upgrades, especially in high-renewables zones with documented curtailments.

2. Expand and strategically deploy energy storage
   Large-scale energy storage can help stabilize renewable-heavy systems by providing fast-response capacity and absorbing shocks. Such systems, when properly located, offer grid balancing and can act as synthetic inertia. It is critical to accelerate permitting for storage assets at both transmission and distribution levels and integrate storage planning into local congestion mitigation strategies.

3. Deploy and fast track black start capable and grid-forming inverter technologies
   Grid restoration and stability

increasingly depend on modern technologies beyond conventional generation. Spain and Portugal should prioritize inverter-based resources with both black-start and grid-forming capabilities. While these technologies have been successfully deployed in smaller, isolated systems, their widespread application in large, interconnected grids is still undergoing testing and development. Grid-forming inverters can emulate the stabilizing behavior of synchronous machines, actively regulating voltage and frequency—a function critical in high-renewables environments. These systems can also support grid restoration after major outages. Germany's Netzbooster project[5] and Australia's Hornsdale Power Reserve[6] demonstrate how inverter-based assets can contribute synthetic inertia and support grid restart. Iberian TSOs should integrate such technologies at strategic nodes to reduce restart times, stabilize frequency, and prevent cascading failures during disturbances.

4. Strengthen cross-border interconnection capacity
   Spain's planned Bay of Biscay interconnector is a step in this direction. The EU's 15% interconnection target by 2030[7] should be fast-tracked for vulnerable regions like the Iberian Peninsula.

5. Market reforms and policy alignment
   Market designs should focus on valuing grid services like inertia, frequency control, and black-start capability. Policymakers must reform markets to better incentivize reliability-oriented services and ensure dispatchable resources remain financially viable. Capacity mechanisms and reserve markets should include criteria for stability contributions, not just energy output. This includes not only dispatchable thermal assets but also inverter-based resources that provide synthetic inertia or fast frequency response.
   The UK has launched targeted markets like Dynamic Containment (DC) and Enhanced Frequency Response (EFR) to pay for fast-acting stability services from technologies such as batteries. The UK Capacity Market now includes criteria for black-start readiness and system support, not just energy supply.[8] Similarly, Australia's Fast Frequency Response market rewards providers that react within 2 seconds to frequency drops. AEMO is also piloting procurement of system strength services from inverter-based assets to address low-inertia challenges.[9]

Lessons Learned

The Iberian Peninsula blackout of 2025 has provided several lessons for managing power grids undergoing a transition towards higher levels of renewable energy. Maintaining adequate grid inertia in systems with a significant share of wind and solar power is essential for ensuring frequency stability during disturbances. Robust frequency regulation mechanisms and sufficient fast-response generation capacity, including energy storage, are important for quickly addressing imbalances between supply and demand. Furthermore, the reliability of protection systems to prevent localized faults from escalating into widespread system collapses is critical, as demonstrated by the rapid cascade of events following the initial generation trips. Moreover, diversified energy portfolios that include dispatchable generation sources and sufficient "black start" capable power plants are necessary for ensuring a secure and resilient energy system.

The blackout also yielded important policy implications. Energy policy must embrace a holistic approach that integrates the goals of decarbonization with the fundamental need to maintain grid stability and resilience. Simply increasing renewable energy capacity is not sufficient without concurrently addressing the systemic impacts on the grid infrastructure.

The energy transition is not just about increasing clean generation—it's about rethinking how we operate and safeguard the grid.

Significant and sustained investment in modernizing grid infrastructure, including the deployment of smart grid technologies and energy storage solutions, is essential to support the energy transition and prevent future widespread blackouts. Moreover, strengthening cross-border energy cooperation and increasing interconnection capacity are crucial for enhancing regional grid resilience and providing mutual support during energy emergencies.

In conclusion, the 2025 Iberian Peninsula blackout was a wake-up call: the energy transition is not just about increasing clean generation—it's about rethinking how we operate and safeguard the grid. The event revealed that high renewable penetration, while necessary, can become a liability without proper planning, technology integration, and policy alignment. To build a resilient and decarbonized power system, Europe, and the world should invest in smarter grids, better interconnections, more advanced control systems, and supportive market frameworks.

References

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