K4K Food4Thought:

Reflections on the Iberian blackout of 28 April 2025

At 12:33 PM on 28 April 2025, much of Spain, Portugal and Andorra went dark. By nightfall, most power supply had been restored across the affected regions, though some areas waited longer to come back online—and not before nearly 60 million people had experienced one of Europe's most significant grid collapses in decades. In our latest K4K "Food for Thought" piece, we reflect on what happened and explore what it tells us about the modern power system. We explain how single faults can trigger cascading failures, why "grid-forming" inverters matter, and what makes restarting a large-scale system so delicate. Blackouts aren't random or mysterious. They're usually the result of a chain reaction—and while they can often be prevented if we pay attention to the warning signs, no system can ever be 100% immune.

Author's Note: Although I'm not an electrical engineer, I've worked as an economist and energy consultant since 1997, with a focus on electricity markets and infrastructure. I studied electricity in high school and have learned a great deal over the years by listening to engineers. This note isn't intended as a technical paper, but rather a reasoned reflection on how modern power systems behave—and sometimes fail. Any simplifications are mine, so please be understanding if I don't get every technical detail exactly right. 😇

Why Power Outages Happen: Unpacking the Layers

Major blackouts rarely occur because of a single isolated incident. Instead, they are typically the result of a chain reaction involving three interrelated layers:

1. **Primary Triggers**—the immediate event that initiates the crisis. This could be a severe storm, extreme temperatures, an equipment failure, a cyberattack, or even human error.

2. **Structural Vulnerabilities**—weaknesses built into the system over time. These include aging infrastructure, lack of investment in maintenance, insufficient redundancy, poor planning for rare events, and in some cases, over-reliance on a single fuel source or technology.

3. **Operational or Regulatory Failures**—shortcomings in how the system is managed or governed. For example, market designs that discourage resilience, lack of enforced standards, miscommunication during emergencies, or failures in automated protection systems.

When a trigger occurs, it sets off a cascade. What starts as a manageable fault escalates quickly if underlying vulnerabilities and policy gaps allow it to spread. This is why many blackouts look sudden and total from the outside—but they may expose problems that had been building for years.

Why Conspiracy Theories Miss the Point

Because the final collapse often happens abruptly and affects millions, it can seem like a coordinated attack or secret plan—fertile ground for conspiracy theories. But the truth is more grounded and more troubling: these events are predictable failures of systems we neglect or mismanage, not evidence of hidden agendas. Understanding blackouts through this layered lens—trigger, vulnerability, governance—not only helps explain the past, it also shows where future resilience must be built.

One must remember that no electricity system is infallible. There will be failures. System operators use a range of tools and criteria to keep frequency and voltage levels within safe bounds. They try to anticipate problems and have backup plans for all sorts of contingencies. But sometimes, everything goes sideways. When that happens, they apply measures to isolate the issue. Most of the time that works—you might just notice the lights flicker for a second. It's rare, but problems can escalate and cascade across the grid.

These failures do not discriminate by income level: power supply disruptions can affect low-, middle-, and high-income economies alike. Table 1 below presents a curated record of major blackouts worldwide since 2020, with emphasis on their technical causes, populations affected, and structural system weaknesses. By distinguishing between immediate triggers and deeper failures—whether structural or regulatory—the analysis highlights how complex and interconnected modern electricity disruptions have become, and why resilience planning must go beyond weather-related risks.

Table 1: Recent Major Power Outages: Global Incidents, Technical Causes, and Systemic Vulnerabilities

Date	Location	Duration	People Affected	Estimated Peak Demand	Outage Type	Root Cause Category	Technical Cause
28 Apr 25	Spain, Portugal, Andorra	~11h	~58 mn	~55 GW	Total blackout	Infrastructure Failure	Grid frequency instability; transmission fault
25 Feb 25	Chile (national)	~1 day	~18.6 mn	~10–12 GW	Total blackout	Infrastructure Failure	Malfunction in electronic/software protection; 500 kV transmission line trip caused system collapse
05 Aug 24	Oman	3-6h	~4 mn	~7-8 GW	Partial blackout	Extreme Weather	Transmission fault; reserve shortfall
15 Jul 24	Nigeria (National Grid)	~24h	~200 mn	~14-16 GW	Total blackout	Multiple Factors	Gas supply constraints, aging infrastructure, poor maintenance, vandalism, and operational disruptions due to labour actions
08 Dec 23	Mumbai, India	~10h	~20 mn	~3-4 GW	Localized blackout	Cyber/Grid Instability	Grid instability; transmission trip
08 Sep 23	Libya	~12h	~6 mn	~5 GW	Partial blackout	Extreme Weather	Grid frequency collapse; technical fault
23 Jan 23	Pakistan	~12h	~230 mn	~25 GW	Total blackout	Grid Management	Frequency drop; grid failure
20 Dec 22	Jordan (Partial)	~6h	~2 mn	~3 GW	Partial blackout	Infrastructure Failure	Technical fault, high demand
24 Nov 22	Ukraine (Partial)	Hours-days	~10 mn	~5 GW	Partial blackout	Infrastructure Failure	Missile strikes on energy infrastructure

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Date	Location	Duration	People Affected	Estimated Peak Demand	Outage Type	Root Cause Category	Technical Cause
04 Oct 22	Bangladesh	~7h	~140 mn	~13-14 GW	Total blackout	Infrastructure Failure	Grid failure; transmission trip
13 Jul 21	Cuba	~12h	~11 mn	~3 GW	Total blackout	Grid Management	Fire at substation; aging failure
14 Feb 21	Texas, USA	Hours-days	~12 mn	~75 GW	Rolling blackouts	Multiple Factors	Extreme winter weather, inadequate infrastructure winterization, and regulatory shortcomings
07 Jan 21	Kazakhstan	~6h	~16 mn	~9-10 GW	Partial blackout	Infrastructure Failure	Grid imbalance; coal plant trip
20 Oct 20	Taiwan	~6h	~2 mn	~35 GW	Partial blackout	Infrastructure Failure	Generator tripping event

Source: ChatGPT, DeepSeek, Wikipedia, K4K research.

The exact cause of the Iberian blackout will become clear in time. But early indications suggest that two major generators in southwest Spain tripped in quick succession. Red Eléctrica de España ("REE"), the Spanish system operator, was able to manage the first event, but didn't have enough fast-response capacity to stabilize the system after the second. Other hypotheses have also been raised—for example, an unexplained drop in the demand signal may have led REE to shut down a large portion of generation unnecessarily. In both cases, the result would be the same: a sudden drop in grid frequency, which occurs when real demand exceeds available supply. As frequency fell, thermal power plants began entering self-protection mode, disconnecting to avoid equipment damage—much like a household circuit breaker ("los plomos saltan") during a short circuit. With each disconnection, the frequency dropped further, triggering more shutdowns in a cascading chain. The result? Puff. Lights out across Iberia.

This didn't spread to the rest of Europe because the Spanish grid was automatically disconnected at the Pyrenees. That might sound drastic, but it's exactly what's supposed to happen—contain the problem, then carefully re-energize once it's resolved.

What can we do about it?

A few key aspects deserve close attention. One is the growing importance of grid-forming inverters compared to grid-following inverters, and synchronous condensers. We will likely need more of the former. Grid-forming inverters enable PV plants and batteries to provide synthetic inertia—a substitute for the mechanical inertia traditionally supplied by spinning thermal power plants. Synchronous condensers—large rotating machines that remain connected to the grid—can also play a role in certain situations, especially where mechanical inertia or short-circuit strength is needed.

Today, mechanical inertia comes from the heavy rotating masses of conventional power stations: steam turbines driven by boilers or gas turbines (essentially industrial jet engines). These spin at 50 cycles per second (50 Hz) and are difficult to speed up or slow down, making them natural frequency stabilizers simply by keeping on spinning.

Photovoltaic panels and batteries, of course, don't rotate. Wind turbines rotate, but they are lighter than the huge turbines of nuclear, combined cycle gas plants, etc. so their contribution to physical inertia is limited. But with the right hardware and software, renewables can emulate this effect: synthetic inertia. Blaming renewables for grid problems is nonsense. The energy transition is not just about introducing renewables into the grid with control systems developed in the 20th century. The energy transition will require changes to grids and adaptation of control systems. Failures from time to time can be expected as part of this evolution.

Why did it take so long to restart the grid?

REE responded competently under pressure. Not all plants can help restart a system from scratch—many need external power just to boot up! Even hydro plants require powered control rooms to open sluice gates. Restarting the grid is tricky: everything must stay in perfect balance, or the whole thing trips again making black start procedures a delicate and high-risk task.

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Madrid, 30 April 2025.