NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Iberian Peninsula Blackout

Contextual Comparison with North American BPS Reliability Safeguards

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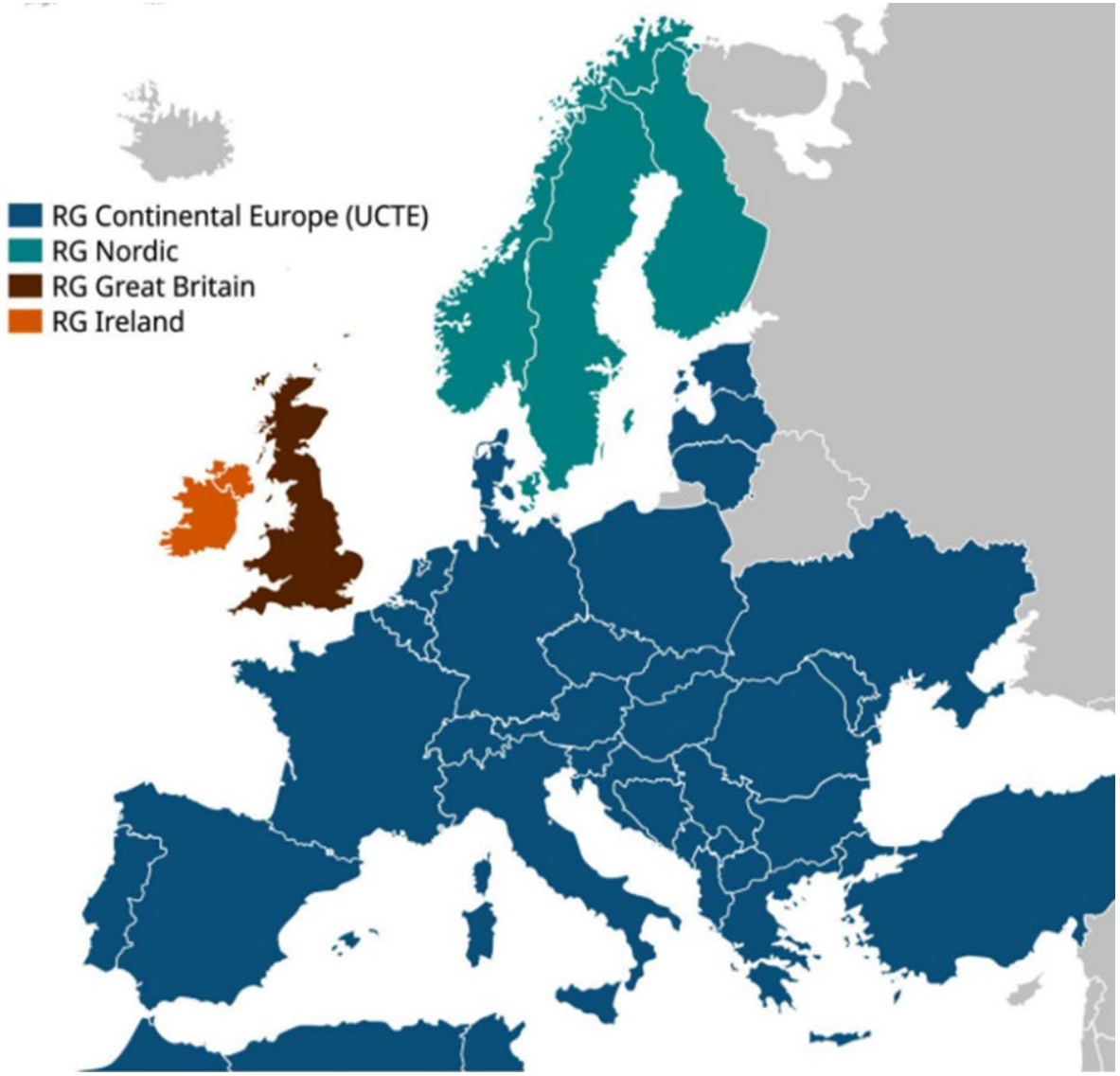
ENTSO-e Overview

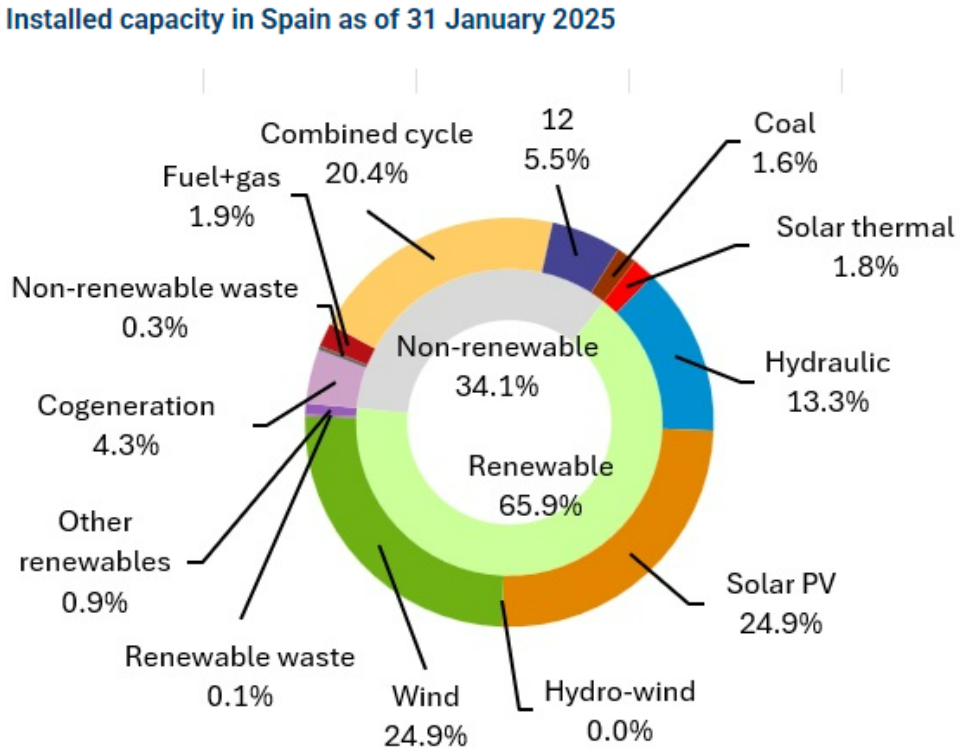


- European Network of Transmission System Operators for Electricity
  - 40 Transmission System Operations (TSOs)
  - 36 countries across Europe, beyond EU borders
  - + 500 millions people served
  - Nearly 300K miles of transmission lines
  - + 1TW net generation capacity
  - Consumption of 3,600 TWh

Source: https://annualreport2017.entsoe.eu/about-entso-e/

Spanish System Overview

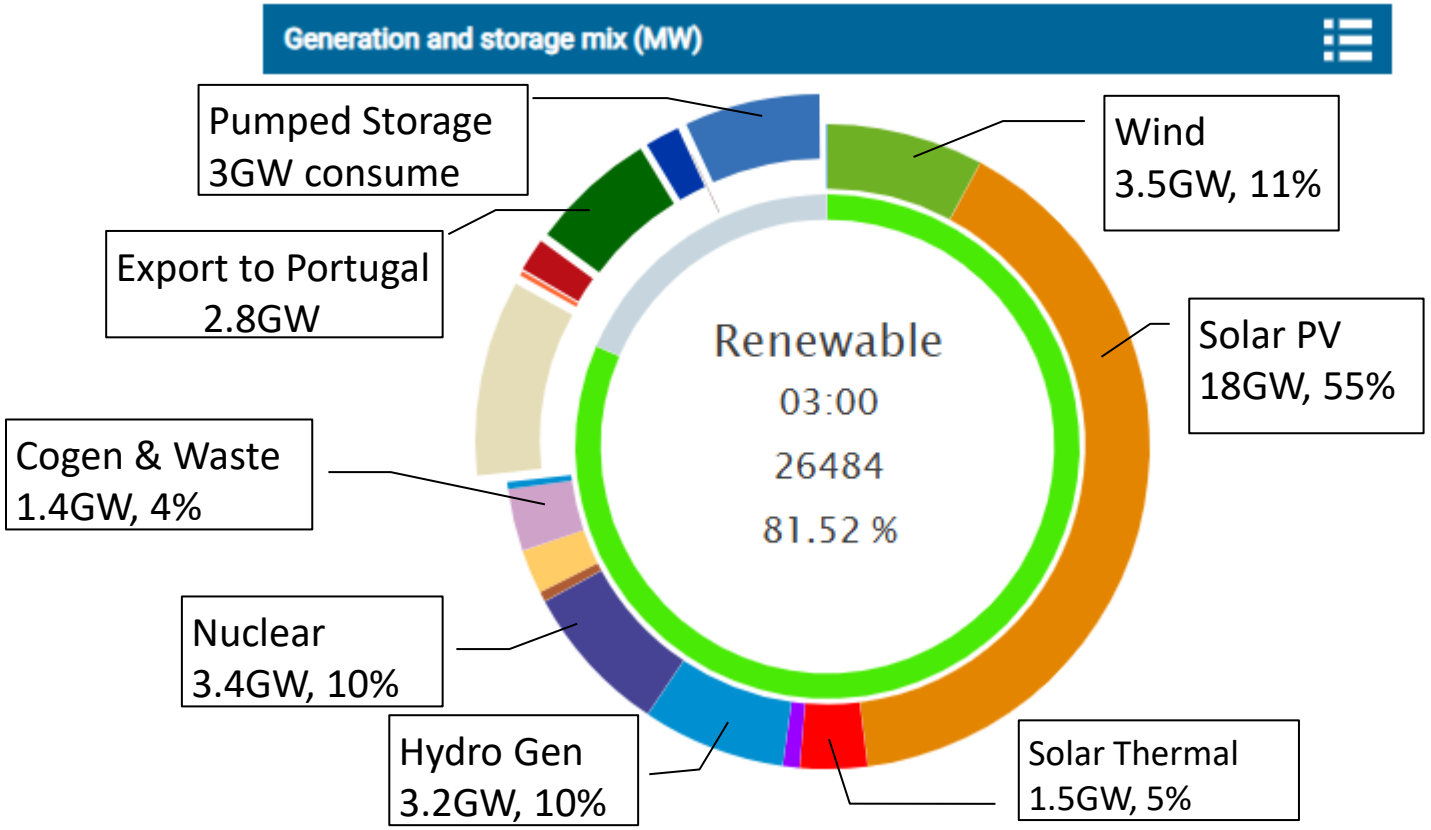
- Total Installed Capacity: 123 GW (66% renewable, 50% IBR)**
- Total Installed Storage: 3.3 GW (mostly pumped hydro; < 50MW BESS)**
- Total rooftop PV for self-consumption: ~ 8.5 GW***
- Data Center load: ~ 1 GW ****



Source: Red Electrica

Pre-event Resource Mix

- **System Strength**: Weak grid conditions - higher voltage sensitivity to network changes
- **Total load pre-event**: 27 GW
- **Export pre-event:** 1 GW to France, 2.8GW to Portugal, 800MW to Morocco



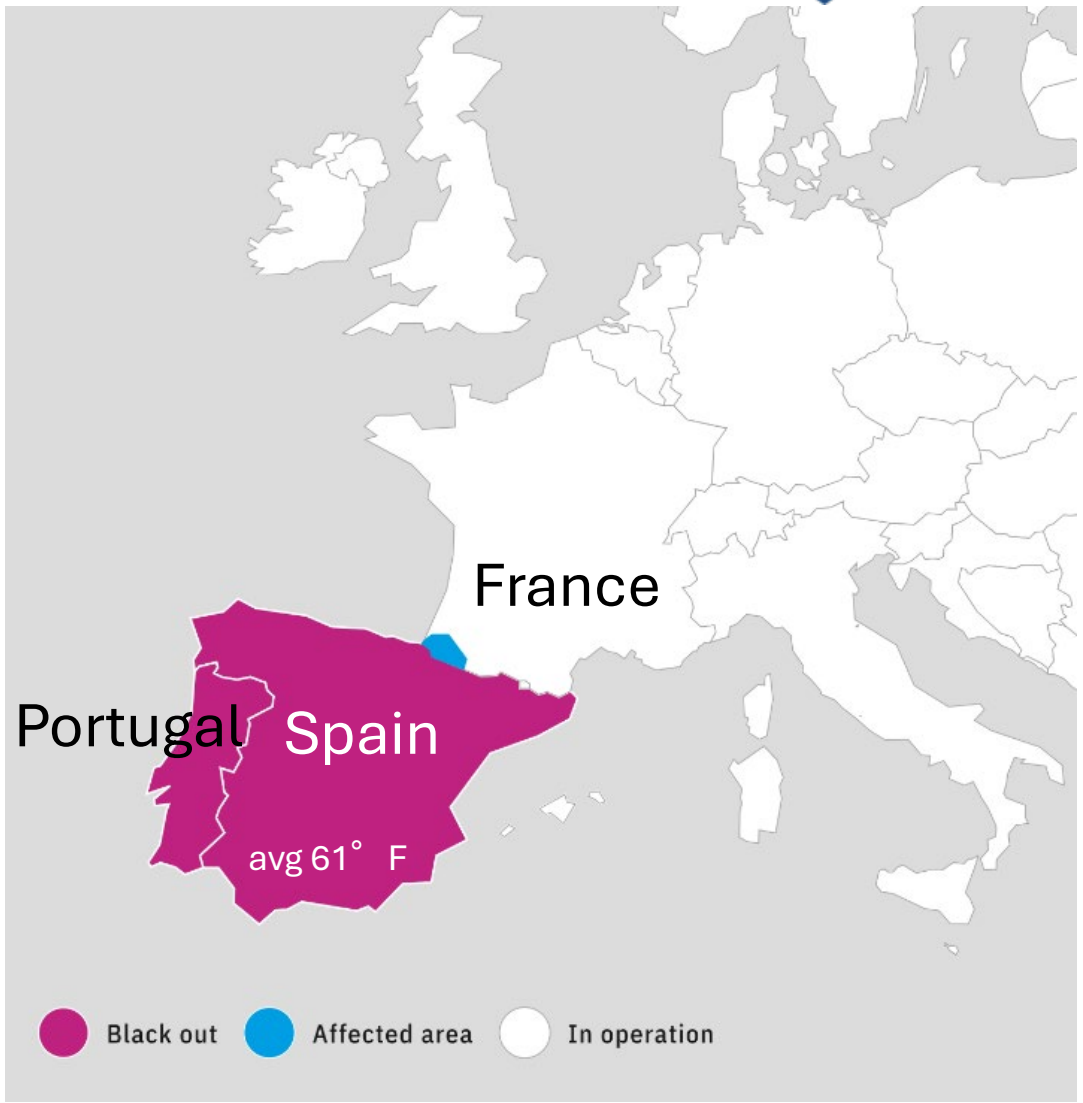
* Source: REE, Generation Dashboard, April 28 2025

Blackout Event Overview

- Affected: Portugal & Spain
  - Small part of south France

- April 28, 2025
- 12:33 CET – Black Out
- 12:35 CET – Black-Start began
- 13:04 CET – Morocco-Spain interconnector reenergized
- 13:35 CET – Eastern France-Spain interconnector re-energized
- 18:36 CET – Tie-line between Portugal and Spain re-energized
- 21:35 CET – 400kV tie-line Portugal and Spain re-energized

- April 29
- 00:22 CET – Portugal transmission system restored
- 04:00 CET – Spain transmission system restored



Sequence of Event

- 12:03 – 12:07 — Local oscillation between Spanish and Portuguese systems (0.6 Hz)
- 12:16 – 12:22 — Inter-area oscillation (0.2 Hz), followed by rising voltage due to DER tripping

16 mins ↓

- 12:32:57 — Generation loss in Spain (355 MW, unknown type)
  - Collector substation tripped due to overvoltage
  - Some generators responsible for voltage regulation failed to perform

19 sec ↓

- 12:33:**16** — Generation loss in Spain (727 MW, 1 PV, 1 unknown type)

1 sec ↓

- 12:33:**17** — Generation loss in Spain (834 MW, 4 wind farms, 4 PV)

= total 2GW generation loss

27 sec

Sharp voltage increase, triggering a cascade of additional generation losses

2 sec ↓

- 12:33:**19** — Import from France reached 4,609 MW through AC ties. Iberian Peninsular system began to lose synchronism with the European system. Automatic load shedding began.

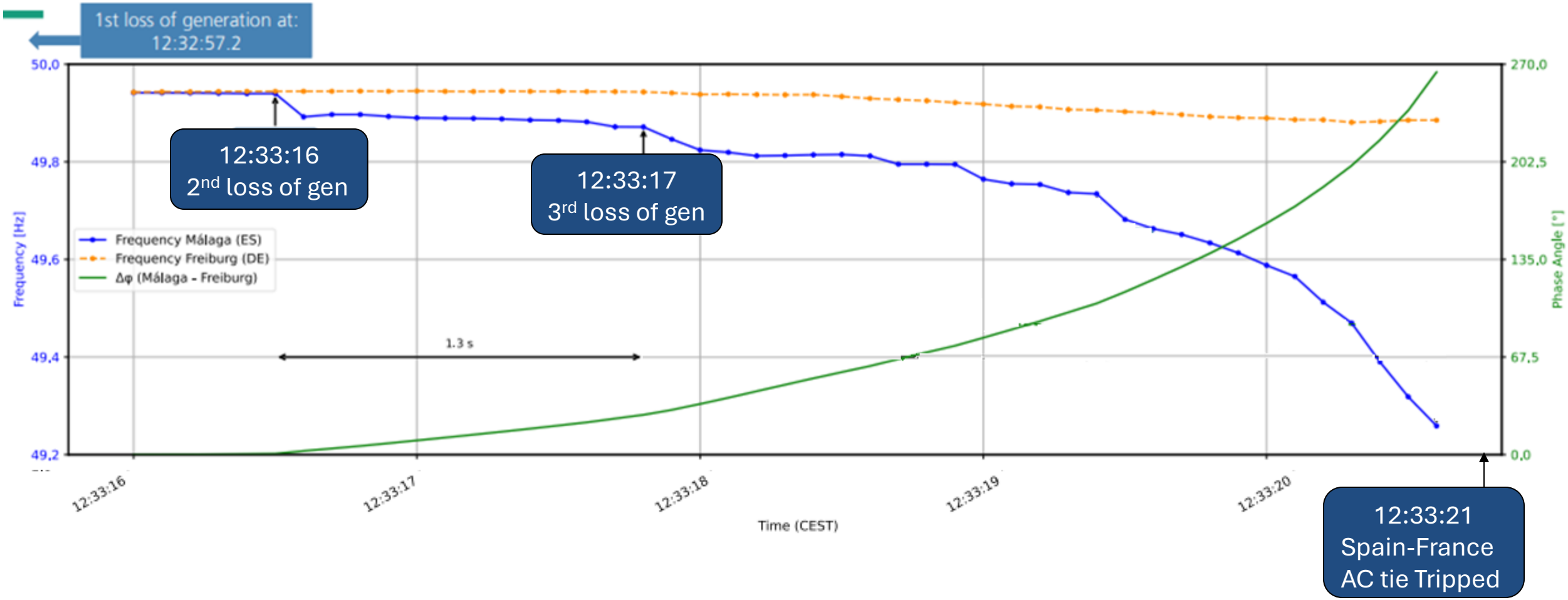
2 sec ↓

- 12:33:**21** — AC lines between France and Spain were disconnected by loss of synchronism protection

3 sec ↓

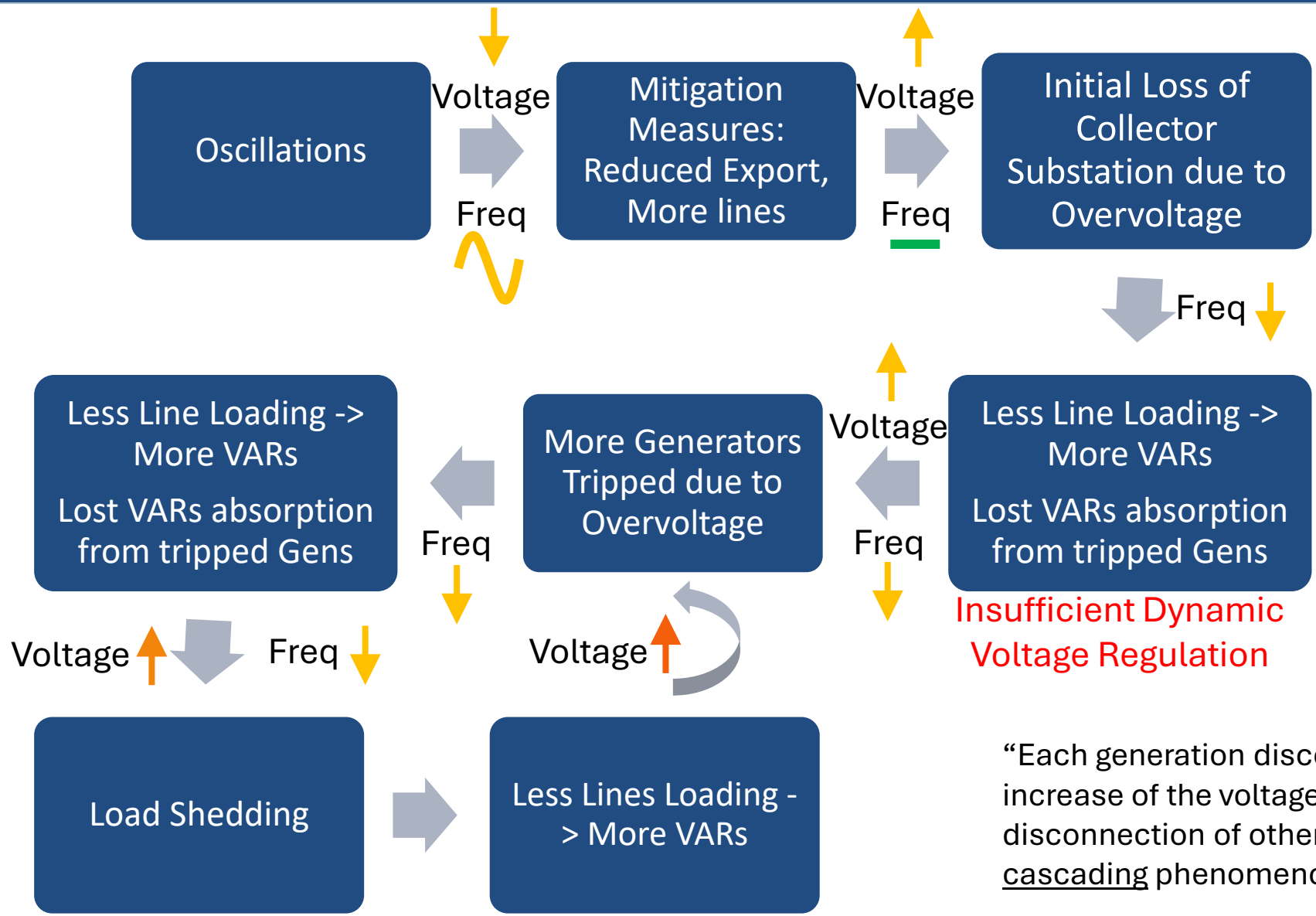
- 12:33:**24** — Spanish and Portuguese systems collapsed. HVDC lines stopped.

Frequency in Spain



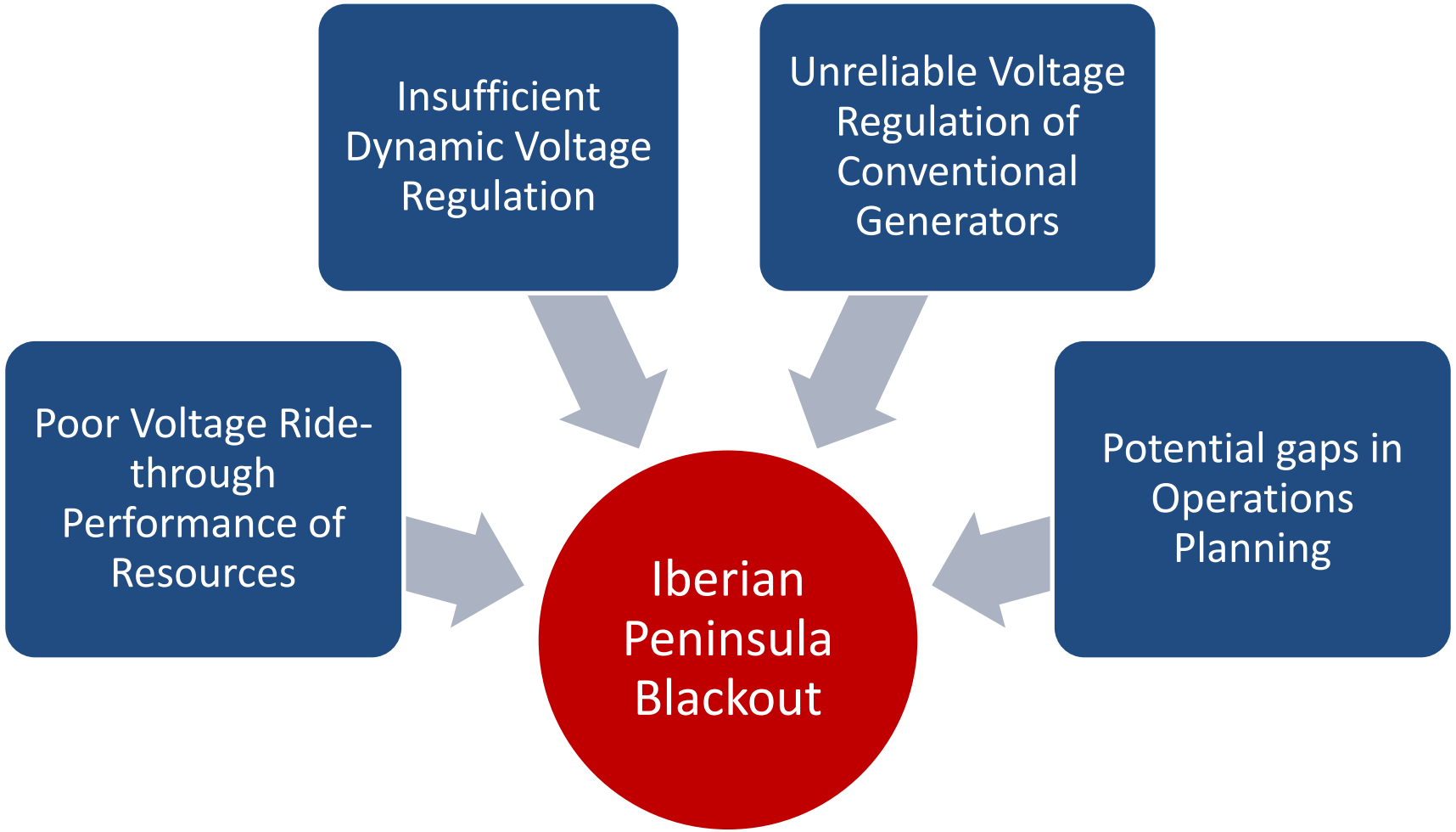
Graph Source: Leonhard Probst, Scientist at the Fraunhofer Institute for Solar Energy Systems ISE

How It Happened



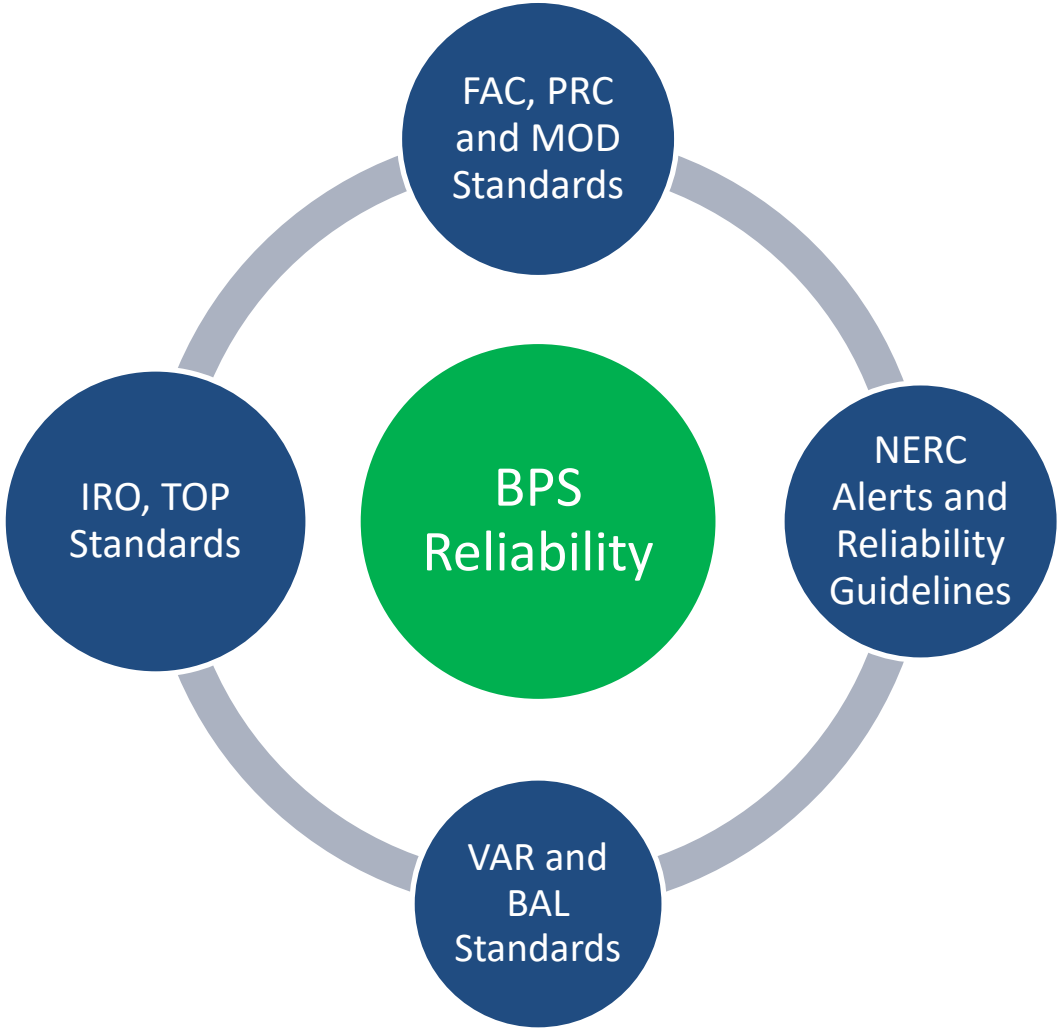
"Each generation disconnection causes a slight increase of the voltage, which in turn causes the disconnection of other generators, producing a cascading phenomenon." - REE

Primary Contributing Factors



Lesson Learned for North America: If resource tripping is caused by overvoltage and results in underfrequency condition, UFLS will result in higher voltage in the absence of sufficient voltage regulation.

Relevant Measures in North American BPS



Post-Event Recommendations by REE vs. North American BPS

Mandate all generation units, including IBRs capable of voltage regulation perform such control	• We already do this! • NERC VAR-002-4 and FERC Order No. 827
Review of overvoltage protection settings	• NERC Level 2 and Level 3 Alerts on IBR Performance Issues and Modeling Deficiencies
Enhancement of voltage control resources	• Synchronous condensers and SVC/STATCOMs are already leveraged in North American BPS.
Define minimum monitoring requirements for incident analysis	• New PRC-028: Disturbance Monitoring

Source: “Blackout in Spanish Peninsular Electrical System the 28th of April 2025” by the Spanish Transmission System Operator (TSO), Red Eléctrica

Recommendations in Spanish Government Report

- Strengthen oversight and verification of regulatory compliance
- Improve voltage control capabilities and oscillation damping
- Increase interconnection with the European system
- Review of services framework
- Update system restoration procedures
- Analyze and update operating procedures
- Boost demand
- Increase strength and flexibility

Source: "Report from the Committee for the analysis of the electricity crisis of April 28th 2025", published by the Spanish government

Relevant On-going NERC Activities

- FERC Order 901 Milestone 3 and 4 standard development projects
- NERC work plan priority to develop a comprehensive framework to identify risks resulting from the transforming grid (e.g., inverter-based resources, large loads, essential reliability services)
- Relevant essential reliability services include
  - Inertia,
  - Rate of Change of Frequency (RoCof),
  - Frequency Response Measurement – ERO-wide performance assessment of BAL-003,
  - Reactive Capability,
  - Voltage Performance,
  - System Strength (sensitivity to voltage magnitude and phase)

Questions and Answers

Relevant Measures in North American BPS

Insufficient Voltage Regulation	• NERC VAR-001-5: Voltage and Reactive Control • NERC VAR-002-4 requires ALL generators to operate in automatic voltage control mode (unless otherwise instructed by TOP) • FERC Order No. 827: Mandatory Automatic Voltage regulation • NERC Level 2 Alert IBR Performance Issues, Recommendation 6 • NERC Level 3 Alert, Essential Action #4 (for GOs)
Unreliable Voltage Regulation	• PRC-019-2: Coordination of Generating Unit or Plant Capabilities, Voltage Regulating Controls and Protection • MOD-026: Periodic model verification against plant performance • NERC Level 3 Alert, Essential Action #3 (for TOs, TPs, PCs), #4 (for GOs)

Relevant Measures in North American BPS

Poor Voltage Ride-through Performance of IBRs	• PRC-024-4: Synchronous machine voltage and frequence trip settings • PRC-029-1: IBR Ride-through performance • PRC-030-1: Unexpected IBR Event Mitigation • FAC-008-5: Facility ratings • NERC Level 2 Alert IBR Performance Issues, Recommendation 1, 2, 3, 4 • NERC Level 3 Alert Essential Actions #1
Active Power Frequency Control	• Primary Frequency Response (FERC Order No. 842) • Fast Frequency Response (in select region) • BAL-002-3: Identify and have reserve for most severe single contingency • BAL-003-2: Maintain Interconnection frequency within predefined bounds • NERC Level 3 Alert Essential Actions #1

Relevant Measures in North American BPS

Reliability Operations	• FAC-011-4: System Operating Limits Methodology for Operations Horizon • IRO-008-3: Reliability Coordinator Operational Analyses and Real-time Assessment • IRO-009-2: RC Actions to operate within Interconnection Reliability Operating Limit
Operations Planning	• TOP-002: Analysis to identify and avoid unstable operating conditions • TOP-003: Maintain situation awareness for real-time operation • TOP-010 and IRO-018: Quality of analysis for real-time assessment • FERC Order No. 901 – Directive to study more variety of contingencies and operating conditions

Relevant Measures in North American BPS

System Restoration	• EOP-005-3: System Restoration from Blackstart Resources • EOP-006-3: System Restoration Coordination
Effective UFLS Operation	• PRC-006-5: Automatic UFLS • PRC-008-0: UFLS Equipment Maintenance Programs • PRC-012-2 & PRC-017-1: Remedial Action Scheme