Vigilate itaque,
quia nescitis diem, neque horam

Watch therefore, for you know
neither the day, nor the hour.

(Mt 25, 13)

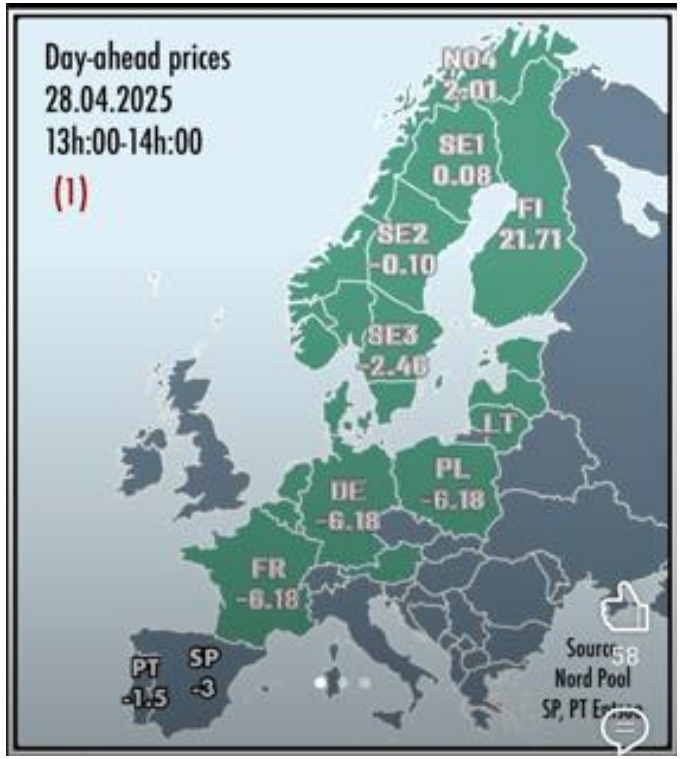
Luca Lo Schiavo

ERRA Regulatory Specialist

ERRA Energy Transition Committee meeting
March 17-18, 2026 | Vilnius, Lithuania

The First Blackout in the Era of Renewables

- *Traditionally Blackouts are associated with lack of adequacy*
- *Paradoxically, Spanish system had energy in abundance: **prices were negative,** not only in Spain.*
- *And it was Monday, not a low-load Sunday. However, something wrong happened somewhere*



- *Question for regulators: maybe due to **wrong rules?***
- *This seems the new reality: [managing abundance, not scarcity]*

(Oxford Energy Inst. 2025)

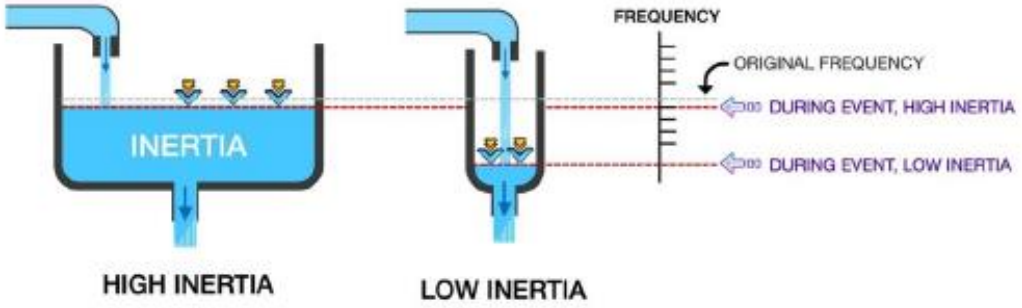
Critical Aspects of Power Systems (1/2)

- ***Frequency Control*** *and Reserves*
  Automatic Frequency Control Systems (primary, secondary)
- ***Voltage Control*** *and Reactive Power*
  Generator Excitation, Capacitors, Reactors,
- ***Role of Interconnections***
  Relative weakness of interconnections
  (Iberian grid separation in 2021)
- ***Grid Topology*** *and N-1 vs. N-2 Events*
  Grid operates to manage N-1.
  In N-2, load shedding is possible

Spain Interconnections
SP-PT: 4.5 GW, 400 kV
SP-FR: 1.4 GW (AC) + 1.4 GW (HVDC)
SP-MA: 1.3 GW (2 undersea cables AC)

Critical Aspects of Power Systems (2/2)

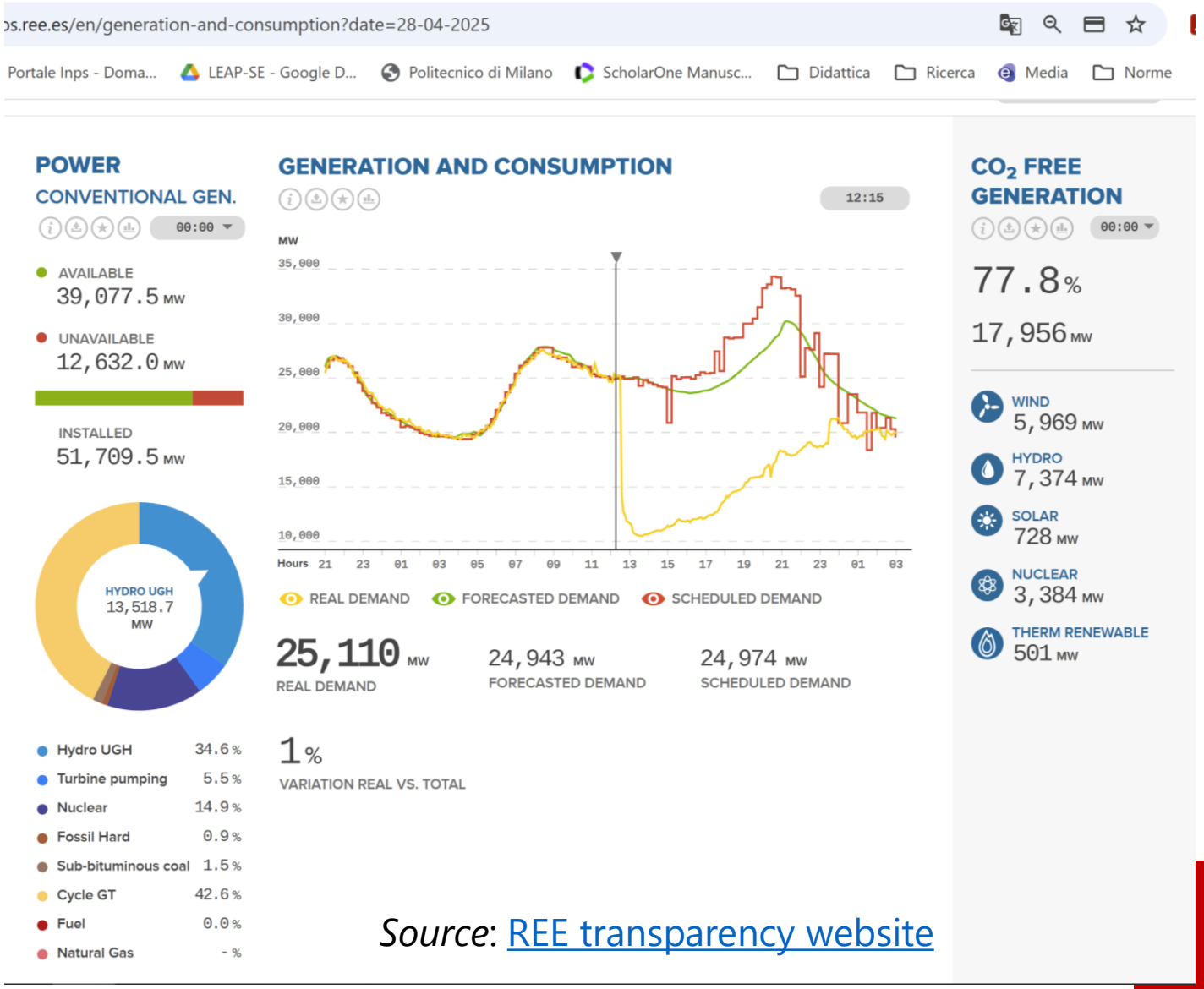
- ***System Inertia***
  Decreasing due to the increase in inverter-based RES
- ***Short-circuit currents***
  Limited contribution of sources connected via inverters, with possible instability and collapse phenomena
- ***Stability tools***
  Synchronous compensators, BESS, and renewable energy control are not yet widely integrated in EU power systems



Source: Oxford Energy Institute, Inertia Paper (2023)

Spanish system at the moment of incident

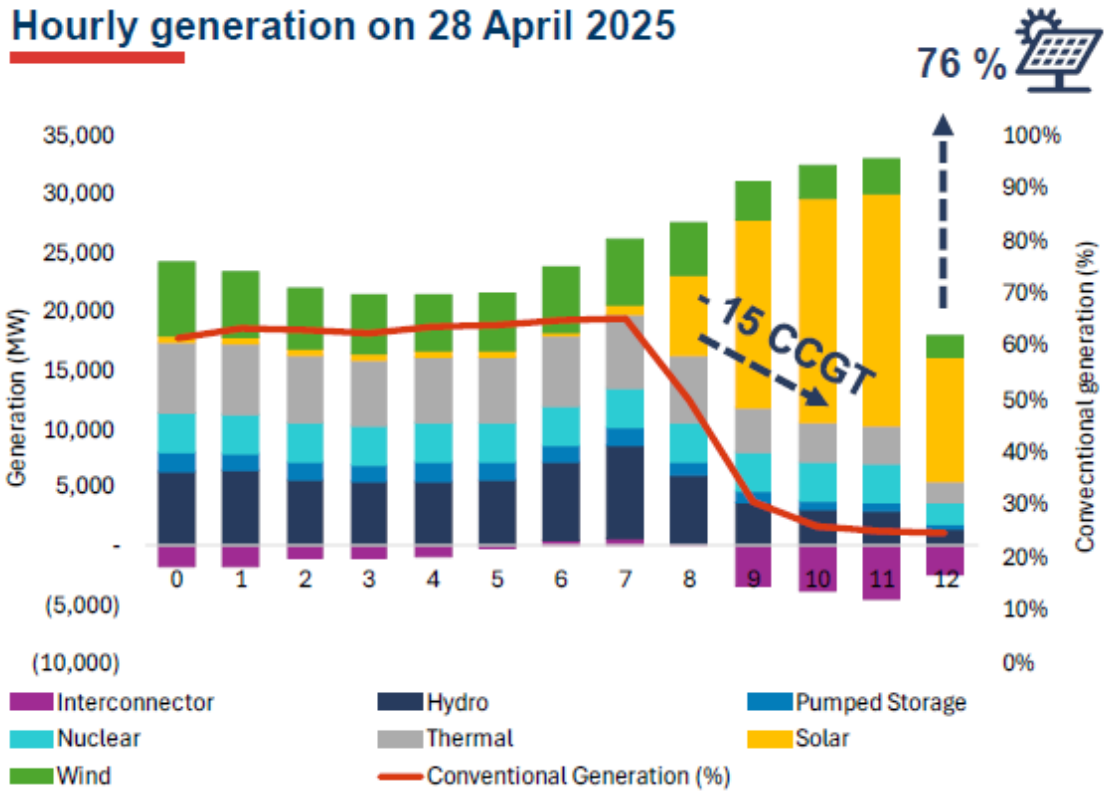
- *Demand:* **25 GW**
- *Generation Availability:* **39 GW**
- *Renewables* **77.8%** *at blackout instant*
- **67%** *inverter-based generation*
- *Inertia:* **118 GW·s** *(Entso-e, Sept.2nd), still within acceptable limit*



Source: [REE transparency website]

When Rules Don't Follow the Pace of Reality

- *Voltage control gap after day-ahead market > "technical restrictions" decided by REE*
- *Lowest conventional capacity for voltage regulation in the year (11 units only, REE decision according to P.O. 7.4)*
- *The Spanish system was technically compliant with all existing regulations.*
- *The problem wasn't rule-breaking: it was rules designed for a different world.*

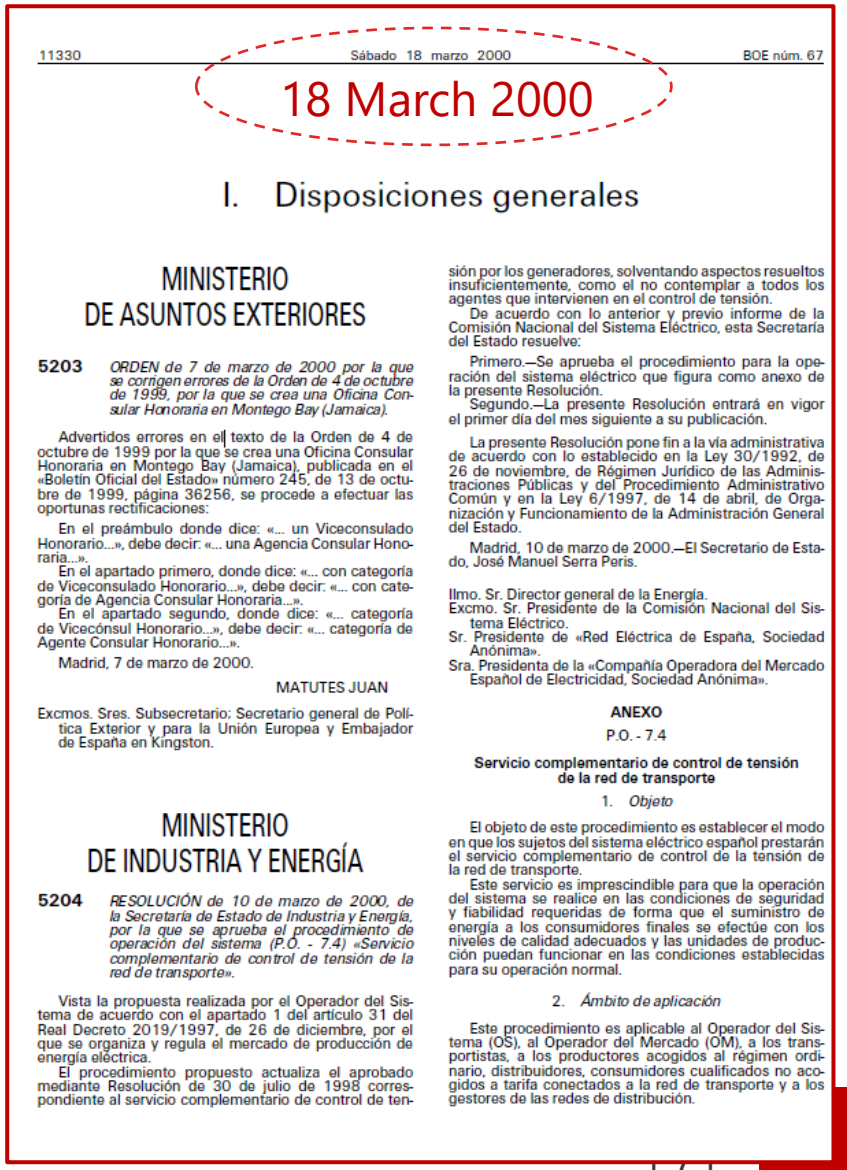


Source: CompassLexecon, INESCTEC

The Hidden Fragilities

- ***Insufficient reactive power absorption*** *capacity in some areas, notwithstanding largely available generation (including termo-solar)*
- ***Fixed power factor*** *renewables: no dynamic adaptation of reactive*
- ***P.O. 7.4 rules from 2000*** *pre-renewables era!*
- ***Old P.O. 7.4****: Sync generators only (>30 MW) – only 11 units coupled on 28.04*

If you're interested in the full story of P.O. 74:
Lo Schiavo – Delfanti paper
(available in English on LinkedIn)



11330 Sábado 18 marzo 2000 BOE núm. 67

18 March 2000

I. Disposiciones generales

MINISTERIO DE ASUNTOS EXTERIORES

5203 *ORDEN de 7 de marzo de 2000 por la que se corrigen errores de la Orden de 4 de octubre de 1999, por la que se crea una Oficina Consular Honoraria en Montego Bay (Jamaica).*

Advertidos errores en el texto de la Orden de 4 de octubre de 1999 por la que se crea una Oficina Consular Honoraria en Montego Bay (Jamaica), publicada en el «Boletín Oficial del Estado» número 245, de 13 de octubre de 1999, página 36256, se procede a efectuar las oportunas rectificaciones:

En el preámbulo donde dice: «... un Viceconsulado Honorario...», debe decir: «... una Agencia Consular Honoraria...».

En el apartado primero, donde dice: «... con categoría de Viceconsulado Honorario...», debe decir: «... con categoría de Agencia Consular Honoraria...».

En el apartado segundo, donde dice: «... categoría de Vicecónsul Honorario...», debe decir: «... categoría de Agente Consular Honorario...».

Madrid, 7 de marzo de 2000.

MATUTES JUAN

Excmos. Sres. Subsecretario; Secretario general de Política Exterior y para la Unión Europea y Embajador de España en Kingston.

MINISTERIO DE INDUSTRIA Y ENERGÍA

5204 *RESOLUCIÓN de 10 de marzo de 2000, de la Secretaría de Estado de Industria y Energía, por la que se aprueba el procedimiento de operación del sistema (P.O. - 7.4) «Servicio complementario de control de tensión de la red de transporte».*

Vista la propuesta realizada por el Operador del Sistema de acuerdo con el apartado 1 del artículo 31 del Real Decreto 2019/1997, de 26 de diciembre, por el que se organiza y regula el mercado de producción de energía eléctrica.

El procedimiento propuesto actualiza el aprobado mediante Resolución de 30 de julio de 1998 correspondiente al servicio complementario de control de tensión por los generadores, solventando aspectos resueltos insuficientemente, como el no contemplar a todos los agentes que intervienen en el control de tensión.

De acuerdo con lo anterior y previo informe de la Comisión Nacional del Sistema Eléctrico, esta Secretaría del Estado resuelve:

Primero.—Se aprueba el procedimiento para la operación del sistema eléctrico que figura como anexo de la presente Resolución.

Segundo.—La presente Resolución entrará en vigor el primer día del mes siguiente a su publicación.

La presente Resolución pone fin a la vía administrativa de acuerdo con lo establecido en la Ley 30/1992, de 26 de noviembre, de Régimen Jurídico de las Administraciones Públicas y del Procedimiento Administrativo Común y en la Ley 6/1997, de 14 de abril, de Organización y Funcionamiento de la Administración General del Estado.

Madrid, 10 de marzo de 2000.—El Secretario de Estado, José Manuel Serra Peris.

Ilmo. Sr. Director general de la Energía.
Excmo. Sr. Presidente de la Comisión Nacional del Sistema Eléctrico.
Sr. Presidente de «Red Eléctrica de España, Sociedad Anónima».
Sra. Presidenta de la «Compañía Operadora del Mercado Español de Electricidad, Sociedad Anónima».

ANEXO

P.O. - 7.4

Servicio complementario de control de tensión de la red de transporte

1. *Objeto*

El objeto de este procedimiento es establecer el modo en que los sujetos del sistema eléctrico español prestarán el servicio complementario de control de la tensión de la red de transporte.

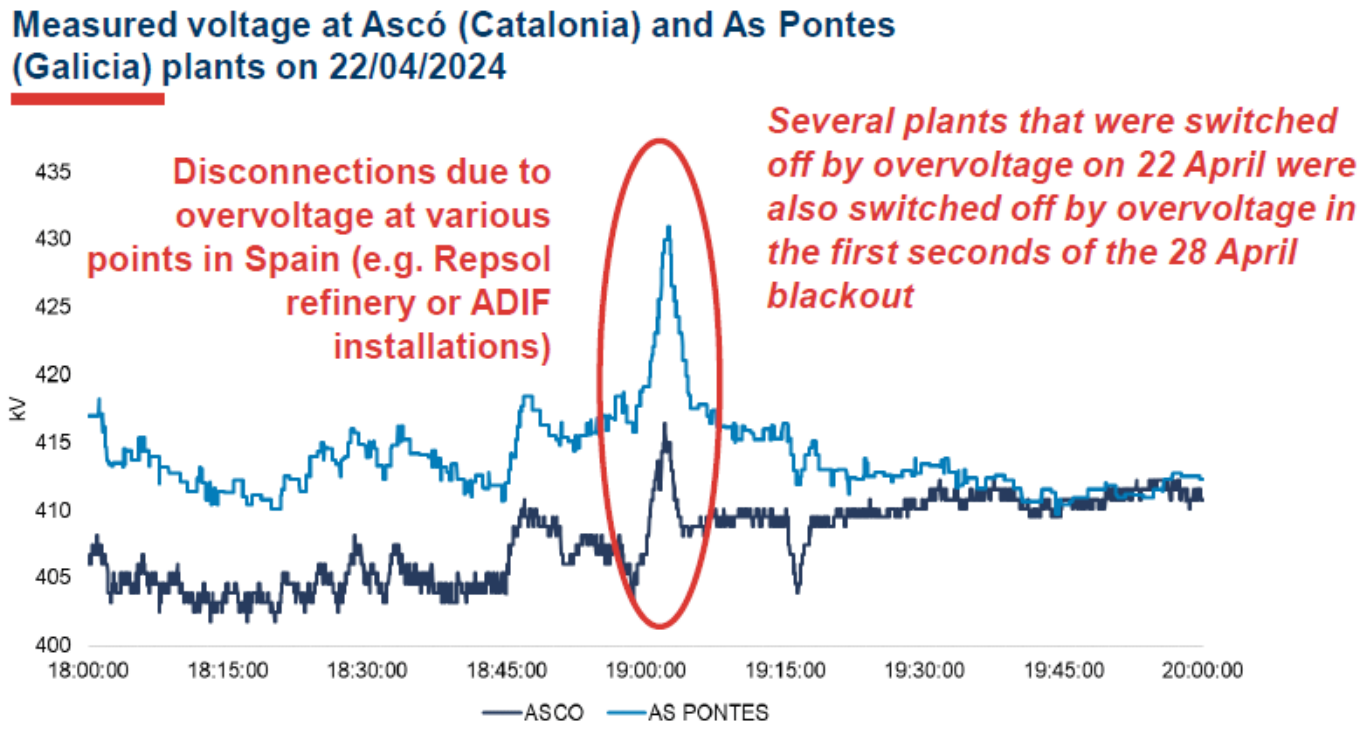
Este servicio es imprescindible para que la operación del sistema se realice en las condiciones de seguridad y fiabilidad requeridas de forma que el suministro de energía a los consumidores finales se efectúe con los niveles de calidad adecuados y las unidades de producción puedan funcionar en las condiciones establecidas para su operación normal.

2. *Ámbito de aplicación*

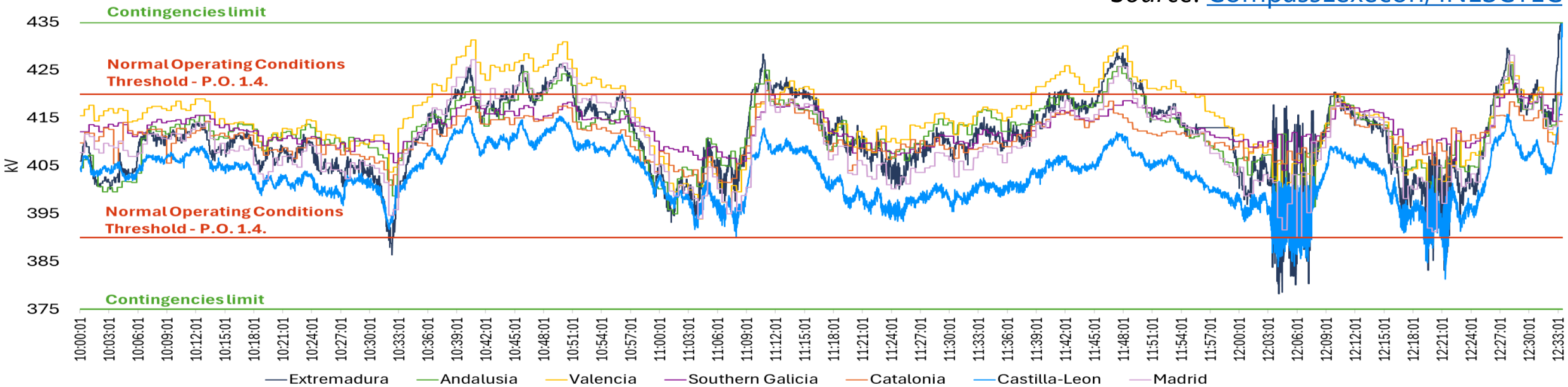
Este procedimiento es aplicable al Operador del Sistema (OS), al Operador del Mercado (OM), a los transportistas, a los productores acogidos al régimen ordinario, distribuidores, consumidores cualificados no acogidos a tarifa conectados a la red de transporte y a los gestores de las redes de distribución.

Early Warnings

- *April 22nd overvoltages in distribution networks*
- *April 28th in the morning several overvoltages and atypical voltage variability*

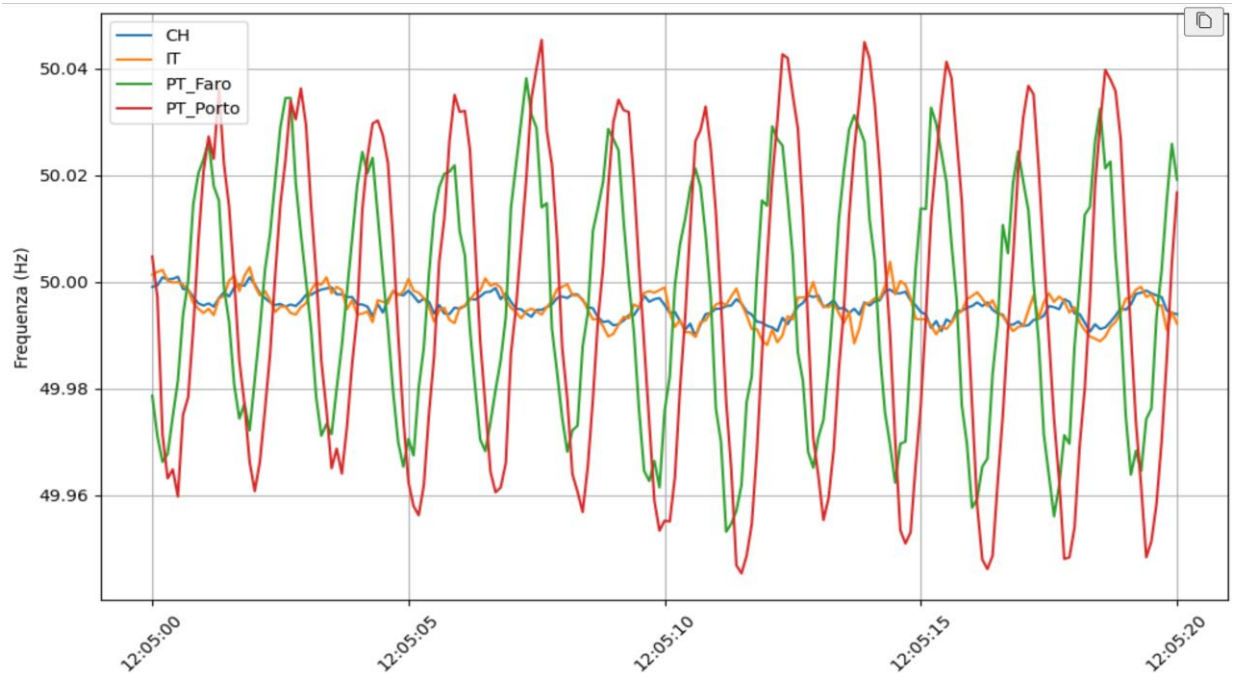


Source: CompassLexecon, INESCTEC



Interarea oscillations

- ***Interarea and local oscillations***, *either in frequency and/or in power flows, may happen as a* ***warning*** *of system instability*
- ***April 28th morning*** *hours: anomalous frequency oscillations*
  - ***12:03****: First major interarea oscillation (0.6 Hz, 4 min.)*
  - ***12:19****: Second interarea oscillation (0.2 Hz, 5 min.)*



Interconnection Management

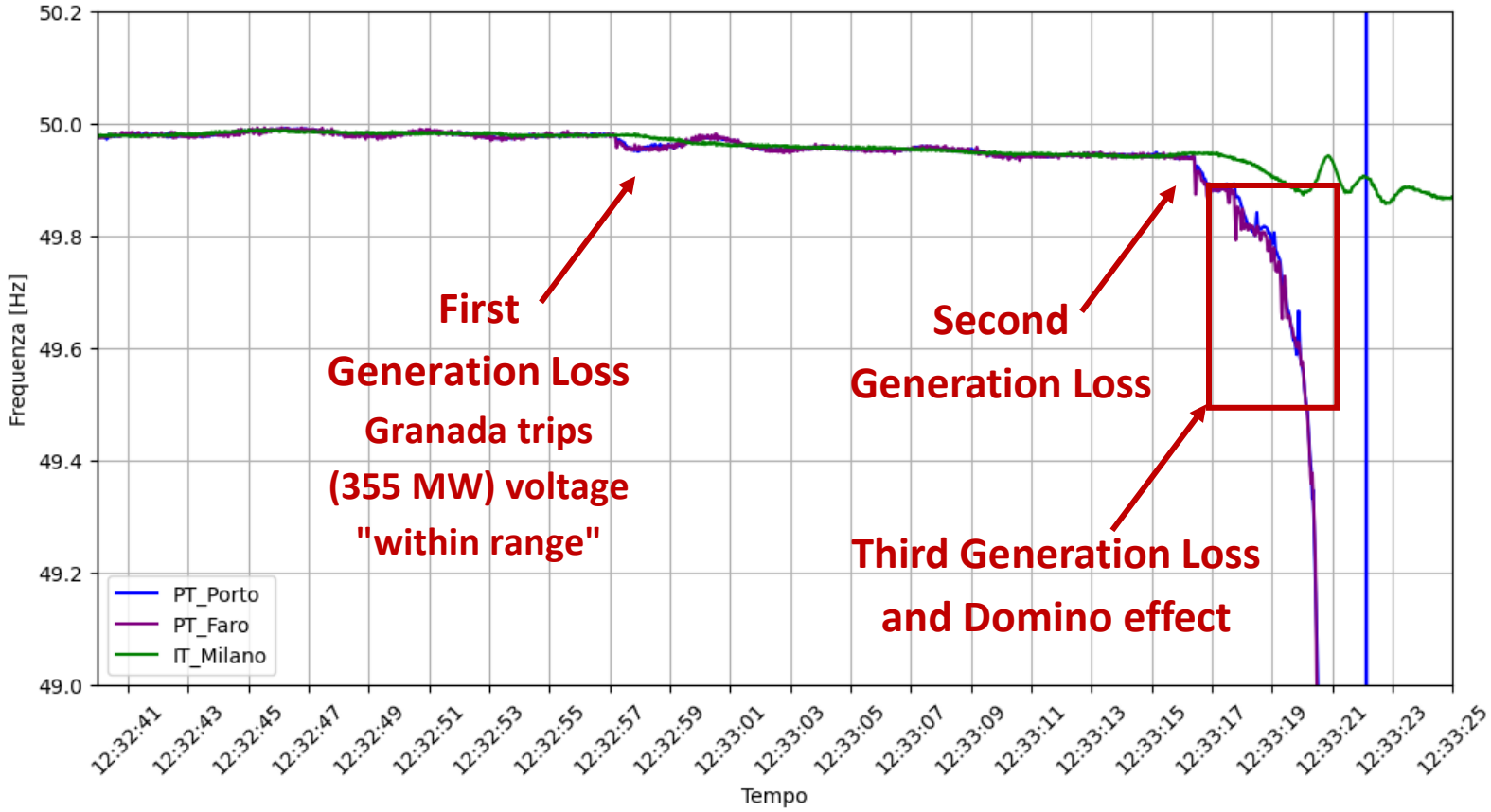
- ***Spain-Portugal**: Single synchronous zone (4.5 GW interconnect.)*
- ***Spain-France**: AC+HVDC links (1.4 + 1.4 GW capacity)*

  HVDC can work in two different modalities:

  AC-like or "constant DC power"

- ***Protective disconnection** saves neighboring systems; but only "AC-like" mode adapts power if frequency reduces (as on 24.07.21 separation from France, without any major event)*
- ***Minutes before the blackout**, to damp inter-area oscillations, REE switches the HVDC interconnection with France to "Constant DC power" mode reducing export*

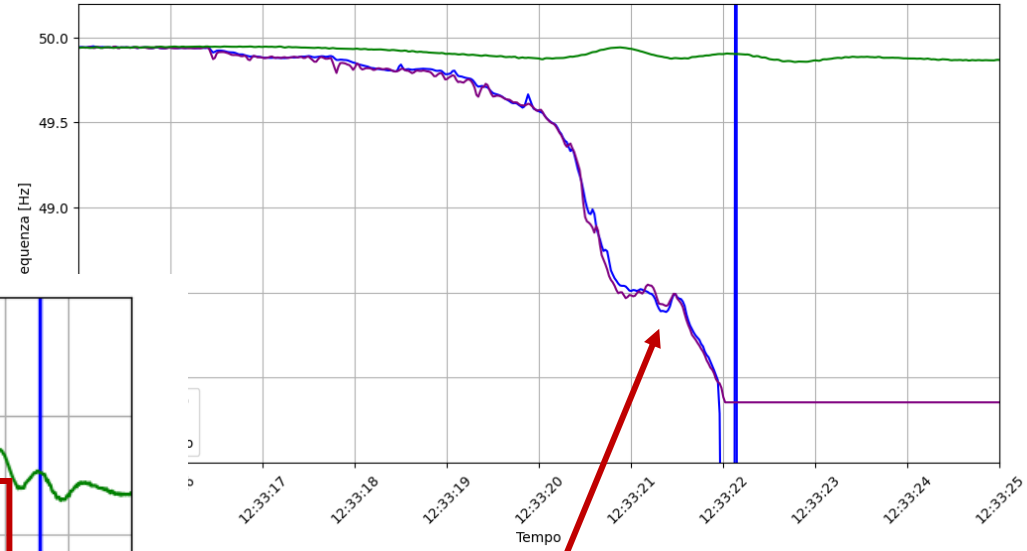
The Event: Frequency Collapse



First Generation Loss Granada trips (355 MW) voltage "within range"

Second Generation Loss

Third Generation Loss and Domino effect



Defense System not designed to face such an effect (no storage)

Source: Politecnico di Milano

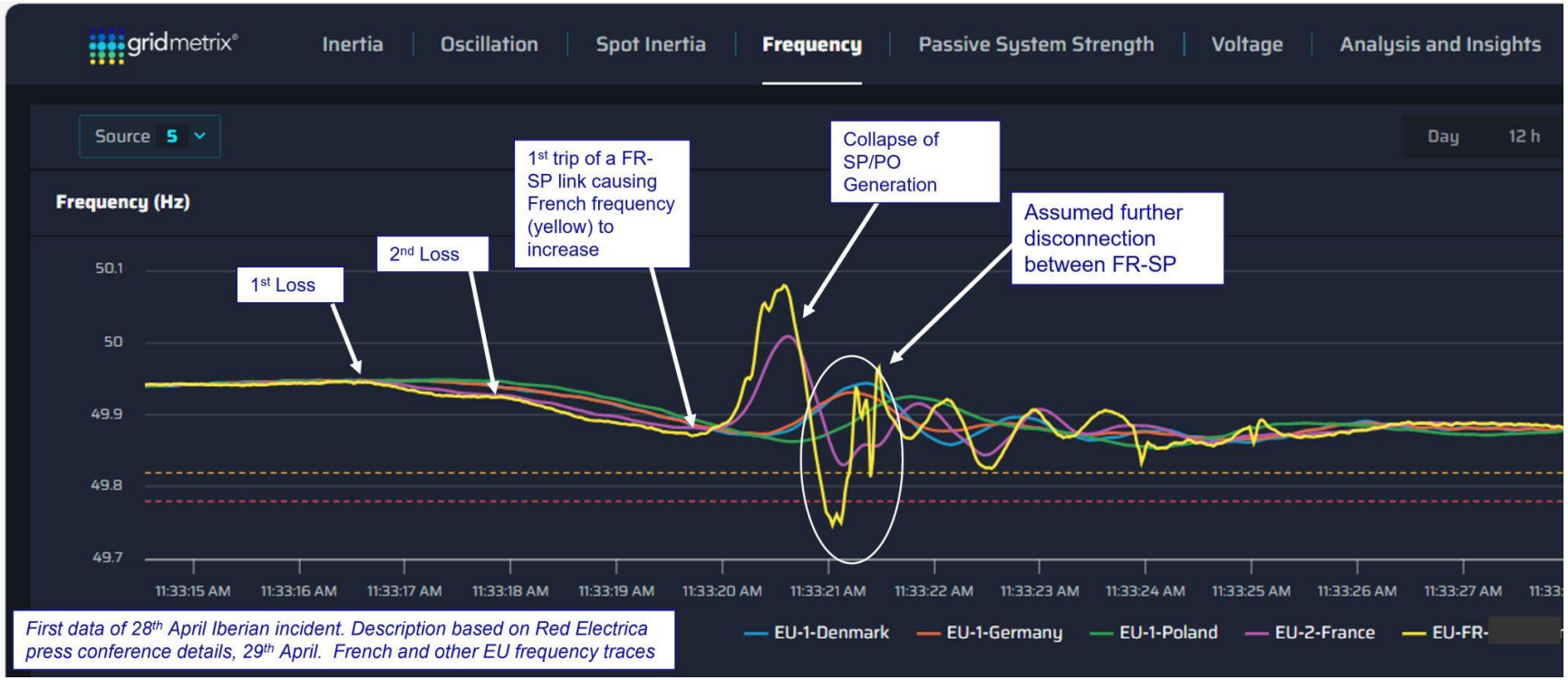
47M people: In the dark for hours

Source

Life in the Neighbouring Countries

- ***Spain and Portugal were isolated*** *at 12:33:21 CEST*

- ***France***
  yellow and violet lines
- ***Germany***
  orange line
- ***Poland***
  green line



Source: GridMetrix

«Are Physics Laws Different in Spain?»

Lost generation → voltage increases

- ***Voltage control is a "local" issue**: has it been misregarded by frequency focus, that is a "global" issue?*
- ***Vicious cycle**: Each generation trip worsens overvoltages*

Next question

«Why wasn't the Domino Effect Timely Selected and "Confined"?»

- *Answer is the connection requirements*
- *Voltage domain largely unmonitored in real-time*

Connection Requirements

- *TED 749/2020: **1-second trip** threshold (>1.1 p.u.)*
- *distributed generation (connected at MV/LV)*

2.1.2 Módulos de generación de electricidad B y C conectados en red de distribución radial. En el caso de módulos de generación de electricidad de tipo B o C conectados en red de distribución radial a tensión inferior a 110 kV, las condiciones y ajustes para la desconexión de dichos módulos serán las recogidas en la tabla 5.

Tabla 5. Condiciones y ajustes para desconexión automática de módulos de generación de electricidad tipo B o C conectados en red de distribución radial a tensión inferior a 110 kV

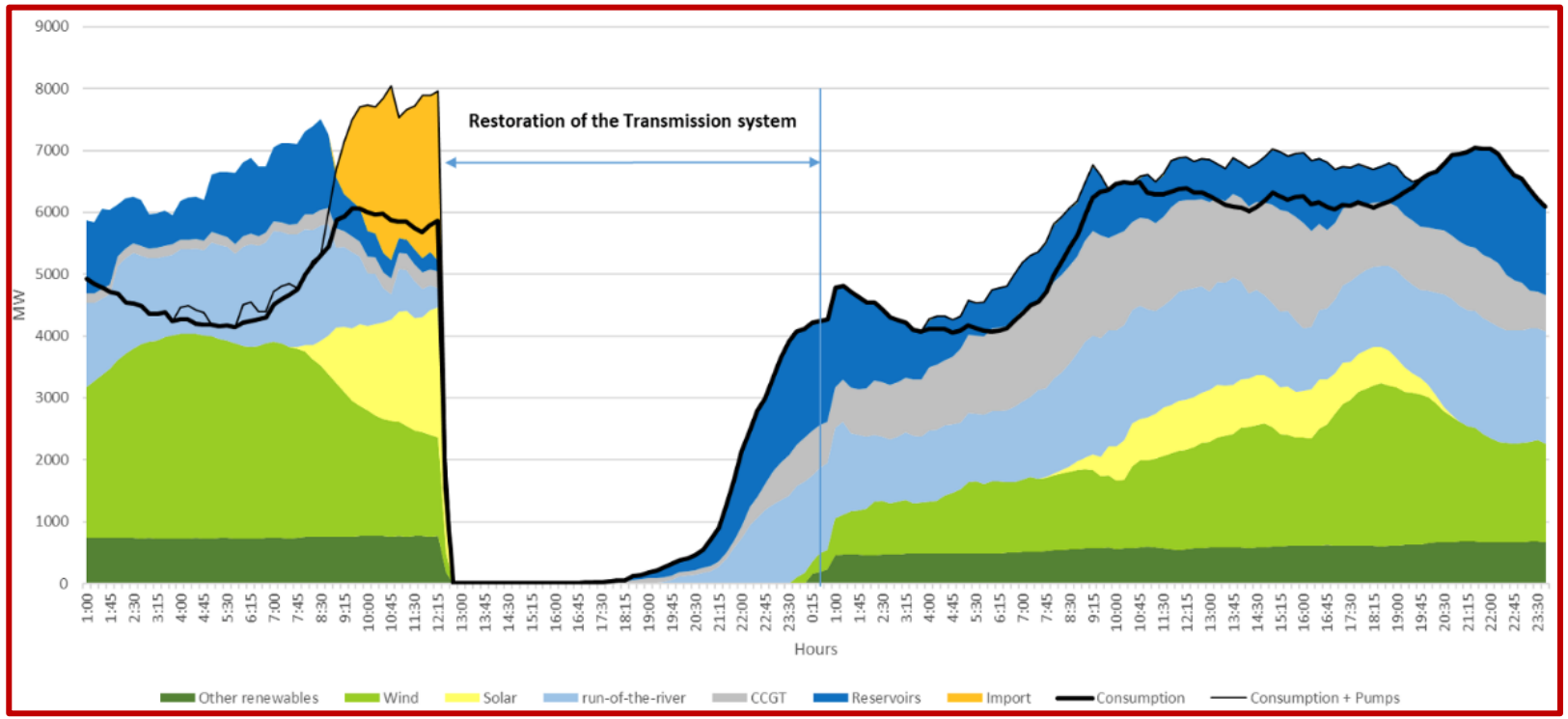
Umbral de tensión	Tiempo de desconexión
<0,85 pu	1,5 segundos
1,10-1,15 pu	1 segundo
>1,15 pu	0,2 segundos

- *Thousands of PV plants disconnect simultaneously*
- *When thousands of distributed generators follow the same protection logic **simultaneously**, you get a system-wide **cascade***

The Long Road Back

***Portugal black-start**. Source: ENTSO-e*

- *France & Morocco remain energized*
- ***Black start** from hydro plants*
- ***Gradual reconnection** of conventional generation plants (including nuclear)*
- *Distributed renewables last to reconnect*



*If you're interested in «**Apagão**», the Portuguese perspective of Iberian blackout (i.e., the Spanish Apagón seen by an innocent victim!), look at this easy-written report of PT Regulator: ERSExplica*

Multiple Investigations, Competing Explanations

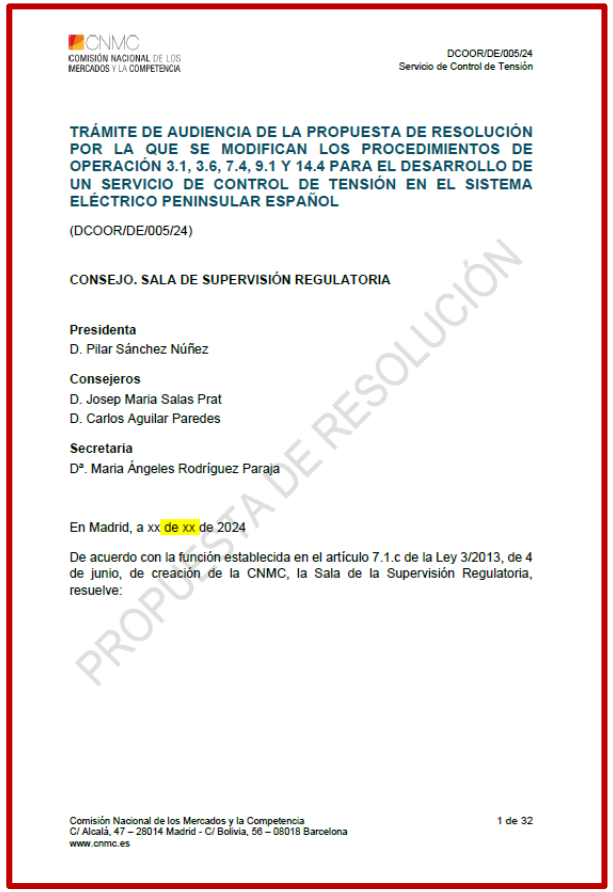
- *Initial narrative: "Too many renewables"*
- *Luis Badesa (Univ.Politecnica Madrid): "Overvoltages visible all morning"*

*«Red Eléctrica tenía **un problema como un elefante** ese día y contaba con **una hormiga para resolverlo**. Y eso es una realidad. Y no se trata de cuantos megavatios salieron o cuantos megavatios perdimos o qué centrales disparò primera o segunda. La **falta de previsiòn** también es un incumplimiento» (AELEC, Senado 18 Sept.)*

	Overvoltage in previous years	Voltage fluctuations in previous days	D-1 generation schedule	Voltage fluctuations between 10:00-12:00	Manoeuvres to dampen oscillations	Conventional generation voltage control	Reason for the tripping of the first plants	Operation in subsequent days
	1	2	3	4	5	6	7	8
GOBIERNO DE ESPAÑA	Not analysed	There were significant fluctuations	Lowest number of coupled thermal power groups of the year	There were significant fluctuations	The change of interconnection to constant DC mode aggravated the situation	Failed to comply with regulations	Vicious circle of overvoltage and some incorrect tripping	Not analysed
RED ELÉCTRICA DE ESPAÑA	Not analysed	Not analysed	It was adequate	The situation was stable	The change of interconnection to constant DC mode did NOT aggravate the situation	Failed to comply with regulations	Incorrect tripping	Not analysed
COMPASS LEXECON / INESCTEC	They have increased in recent years	There were significant fluctuations	The lowest capacity to control voltage in the year, lowest in the south	There were significant fluctuations	Pending analysis	There was not enough conventional generation to control voltage	Simultaneous failures without a systemic cause seem unlikely	Decrease in fluctuations

Regulatory lessons
1/ When technical urgency meets bureaucracy

- ***March 13, 2024***:
  REE submits new P.O. 7.4
- *Months of delays:*
  Consultations, hearings, revisions
- ***April 28, 2025****: Blackout strikes*
- ***June 12, 2025****: Finally approved*
  (post-disaster)
- *The proposal was technically ready*
  for over a year.
- *The delay wasn't technical but procedural:*
  a luxury that high-RES penetration systems cannot afford.



CNMC
COMISIÓN NACIONAL DE LOS MERCADOS Y LA COMPETENCIA

DCOOR/DE/005/24
Servicio de Control de Tensión

TRÁMITE DE AUDIENCIA DE LA PROPUESTA DE RESOLUCIÓN POR LA QUE SE MODIFICAN LOS PROCEDIMIENTOS DE OPERACIÓN 3.1, 3.6, 7.4, 9.1 Y 14.4 PARA EL DESARROLLO DE UN SERVICIO DE CONTROL DE TENSIÓN EN EL SISTEMA ELÉCTRICO PENINSULAR ESPAÑOL

(DCOOR/DE/005/24)

CONSEJO. SALA DE SUPERVISIÓN REGULATORIA

Presidenta
D. Pilar Sánchez Núñez

Consejeros
D. Josep Maria Salas Prat
D. Carlos Aguilar Paredes

Secretaria
Dª. María Ángeles Rodríguez Paraja

En Madrid, a xx de xx de 2024

De acuerdo con la función establecida en el artículo 7.1.c de la Ley 3/2013, de 4 de junio, de creación de la CNMC, la Sala de la Supervisión Regulatoria, resuelve:

PROPUESTA DE RESOLUCIÓN

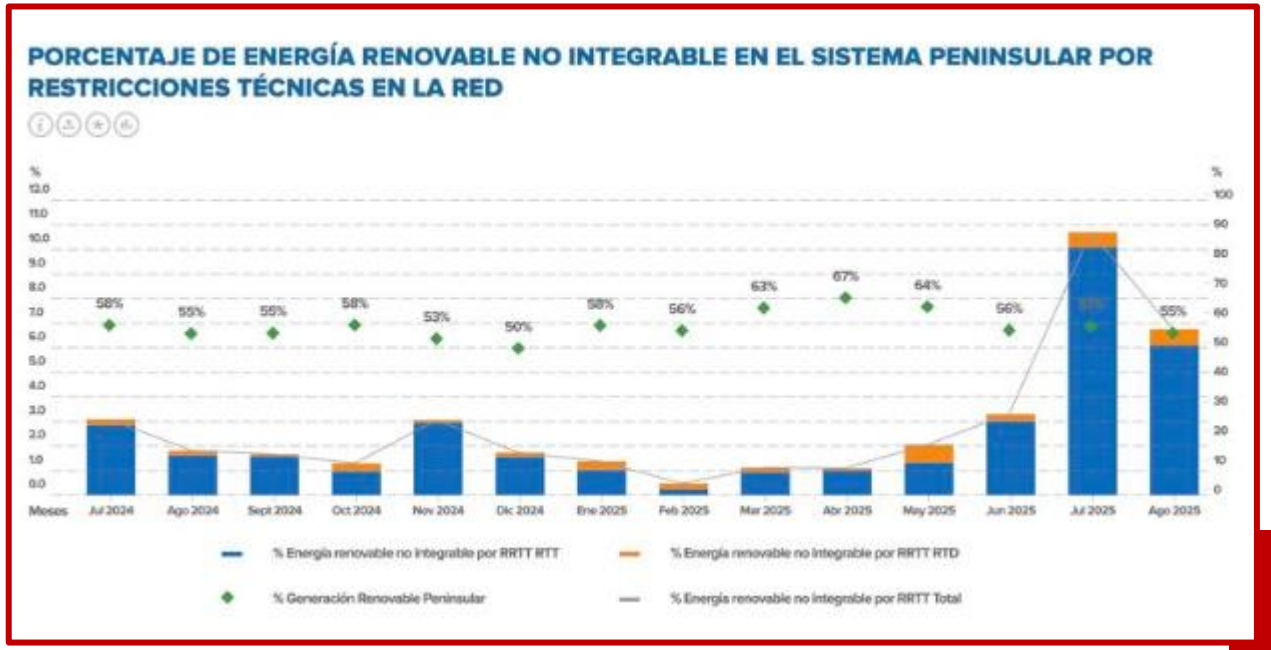
Comisión Nacional de los Mercados y la Competencia
C/ Alcalá, 47 – 28014 Madrid - C/ Bolivia, 56 – 08018 Barcelona
www.cnmc.es

1 de 32

Regulatory Lessons
2/ Ambition vs Prudence?

- *Green ambition: RES targets*
- *Technical prudence: **Voltage stability** concerns*
- *Political pressure: "Move fast, break things"*
- ***Reality check**: Some things can't be broken*

*After the blackout, REE increased significantly the "technical restrictions", i.e. the **generators coupled for voltage control** and the **RES curtailment***



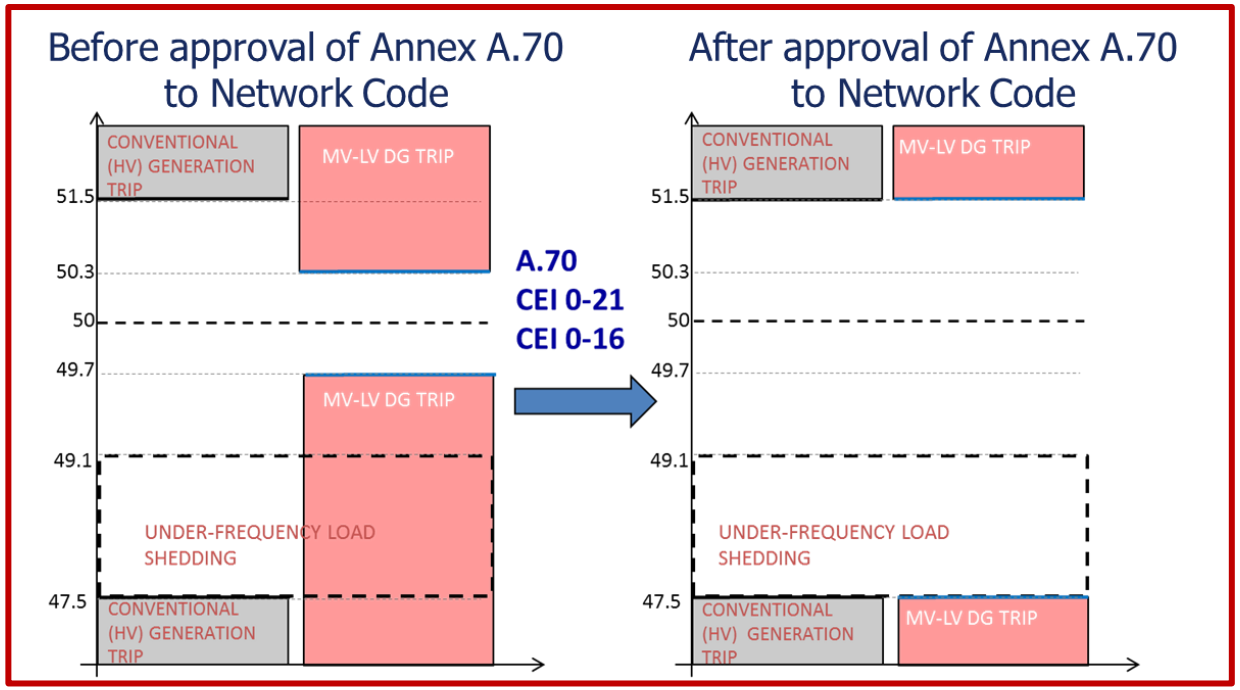
Regulatory Lessons
3/ New Resources for High-VRE Systems

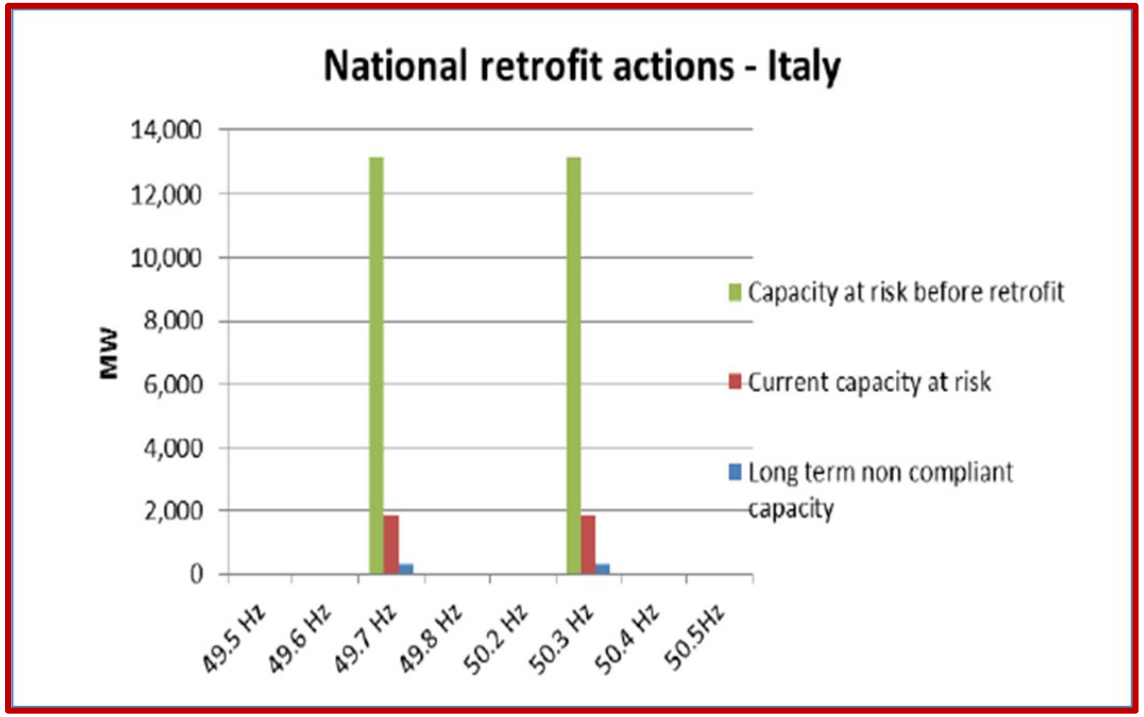
- *The **new P.O. 7.4 Revolution***
- *From Command&Control to Market-Based*
- *All technologies: RES, storage, hybrid, conventional*
- *Dynamic response: Real-time voltage orders*
- ***Market mechanisms**: Competitive reactive power*
- *Economic incentives: Performance-based payments*
- ***Tests** and **penalties** in case of unproper reactive power behaviour*

Finally, that's regulation!

Regulatory Lessons
4/ Cooperation with Standardization Bodies

- *ARERA/CEI (2005>) cooperation*
- *Not only new generation units, also retrofit*
- *Not only frequency, also voltage requirements*





Source: ENTSO-e «Dispersed Generation Impact on Continental Europe Region» position paper, 15 Nov.2014

Post Scriptum /1

On Oct. 3rd ENTSO-e presented its Factual Report (260+ pages)

This presentation was prepared before the Entso-e Factual Report was issued

Analysis Confirmed

✓ System conditions: All key metrics accurate (demand 25 GW, renewables 77.8%, 67% Inverter based Generation)

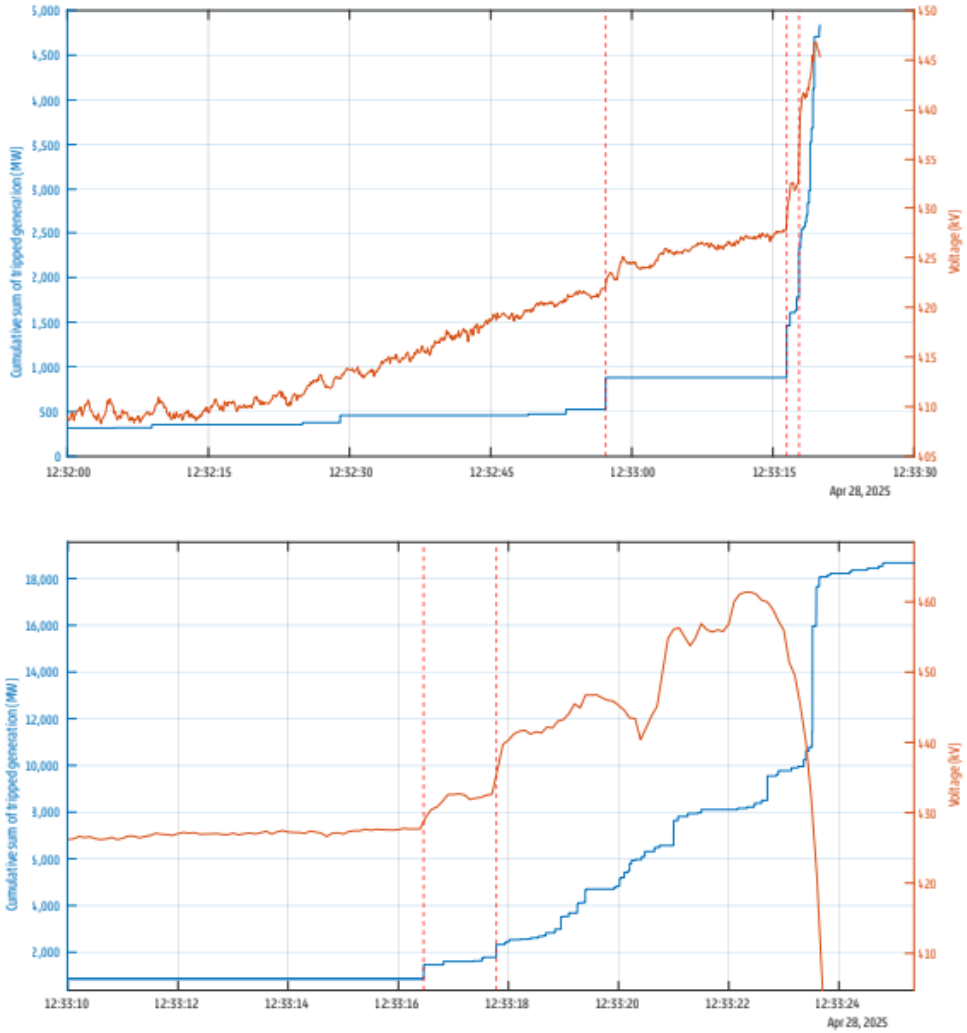
✓ Inertia refined: **119.5 GW·s** (vs. cited 118 GW·s) small difference, within acceptable limits

✓ Oscillations timeline: 12:03 (0.63 Hz) and 12:19 (0.21 Hz) – confirmed

✓ Cascade mechanism: Generation loss → voltage rise → more trips → faster collapse

The Vicious Cycle Visualized

✓ Fig. 3-7 Accumulated generation losses (SP+PT) vs 400 kV max Voltage. Dotted lines are the three main events (below enlarged scale)



For experts only: «forensic» analysis of the Report

Post Scriptum /2

On Oct. 5th Comillas Univ. published its Report (commissioned by gener.)

IIT Research Centre of Universidad Pontificia de Comillas issued a Report on 28.04 Iberian Blackout that was commissioned by Spanish generators

National vs Regional Values of Inertia

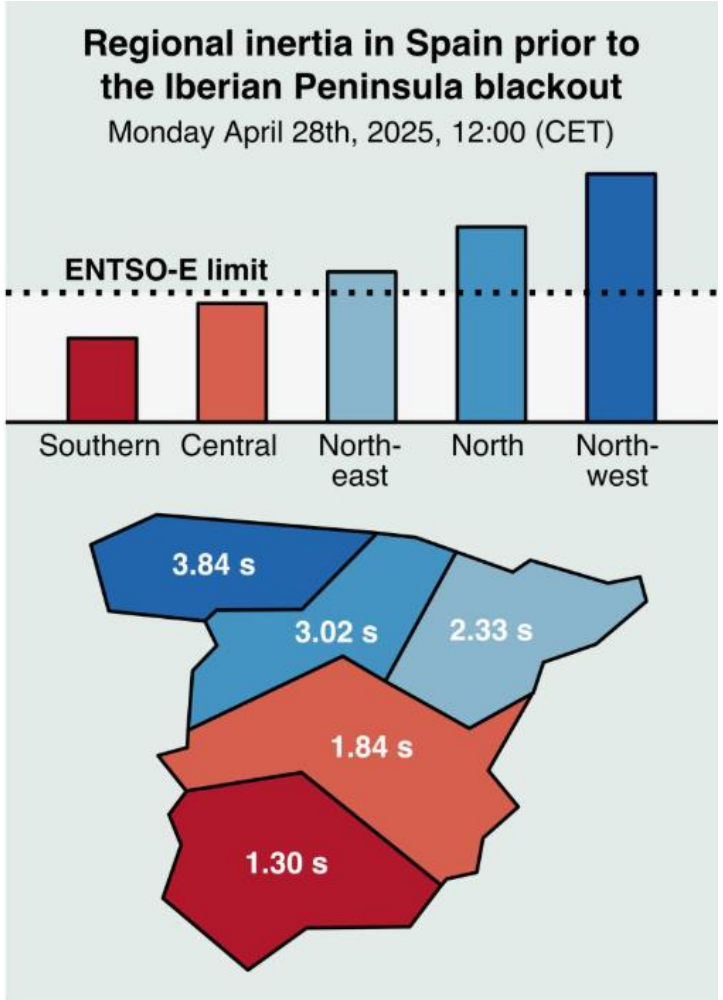
✓ Entso-e published only national levels

- **Spain total**: 97.590 GW·s (H = 2.17-2.67 s)
- **Portugal total**: 21.884 GW·s (H = 2.45-2.95 s)
- **Iberian Peninsula total**: 119.474 GW·s (H = 2.21-2.71 s)

✓ Comillas published macro-area levels for Spain

- **South Spain** largely critical (due to lack or rotating gen.)
- **Central Spain** moderately critical, just below the limit
- **North Spain** in line with requirements or above the limit

✓ Comillas methodology very robust although REE refused to provide state estimator data (citing confidentiality), so values are approximations based on market data



Inertia: KE [GW·s] = H [seconds] × S_{base} [GW]

THANK YOU FOR YOUR ATTENTION!

Luca Lo Schiavo
luca.loschiavo@erranet.org

If you're interested in a short but excellent synthesis of all aspects of the Iberian Apagón, I suggest you to download and read:
Blackout: Is Spain Far Away?
RSE Energy Notes (Appunti di Energia)
by E. Ciapessoni and D. Cirio, RSE Italy