06-05-2026

BLACK-OUT:

ALS DE SPANNING WEG IS,
WORDT HET PAS ECHT SPANNEND

DUTCHPOWER

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TenneT TSO BV

Blok 1: Analyse & Learning – De Black-out in Spanje: Wat gebeurde er en wat leren we hieruit?

Expert Panel Final Report
28 April 2025 Blackout in Spain and Portugal

Dutchpower, Maurits Kazerne Ede, 6 mei 2026

Reliable Sustainable Connected

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1. Introduction

1.1 Purpose and scope of the Final Report

- The purpose of this report is to provide concrete technical analyses of the sequence of events leading to the blackout and the measures taken to restore its operation, in order to identify and understand its root causes.

- It aims to support transparency, learning and continuous improvement of the power system across Europe.

- The report provides recommendations to improve power system security, improve coordination and reinforce security of supply across the European power system, underlining the need for close cooperation among all relevant power system actors.

- This report is not intended to allocate or imply any liability or responsibility to any party, as this will be the responsibility of the competent authorities in the respective countries.

The report has been prepared and agreed by the Expert Panel established in accordance with the applicable legislation. The analyses, findings, and recommendations contained herein reflect the Expert Panel's technical assessment as at the date of issuance and are without prejudice to any investigation or supervisory action that may be undertaken by the competent authorities. The data presented in the report and in this PowerPoint are based on most reliable data made available to the Expert Panel. Given that the data originates from a wide range of providers, no representation or warranty, whether express or implied, is made as to the accuracy, completeness, fairness, or correctness of the information and opinions contained in this report and the accompanying PowerPoint presentation.

1.2 Expert Panel: role and composition

- The Expert Panel is a body legally mandated by the applicable legislation to investigate, from a technical perspective, any major grid incidents (Scale 2 and 3).
- The composition of the Expert Panel is determined in accordance with the applicable legislation.
- The Expert Panel for the 28 April 2025 incident is co-led by Klaus Kaschnitz (APG, Austria) and Richárd Balog (MAVIR, Hungary).

The Expert Panel includes **49 members** from:

Transmission System Operators (TSOs) and Regional Coordination Centres (RCCs) of:

Belgium
Denmark
France
Germany
Greece
Hungary
Ireland
Italy
Poland
Portugal
Romania
Spain
Switzerland

ENTSO-E

ACER

National Regulatory Authorities of:

Belgium
Czech Republic
France
Germany
Hungary
Italy
Poland
Portugal
Romania
Spain
Sweden
Switzerland

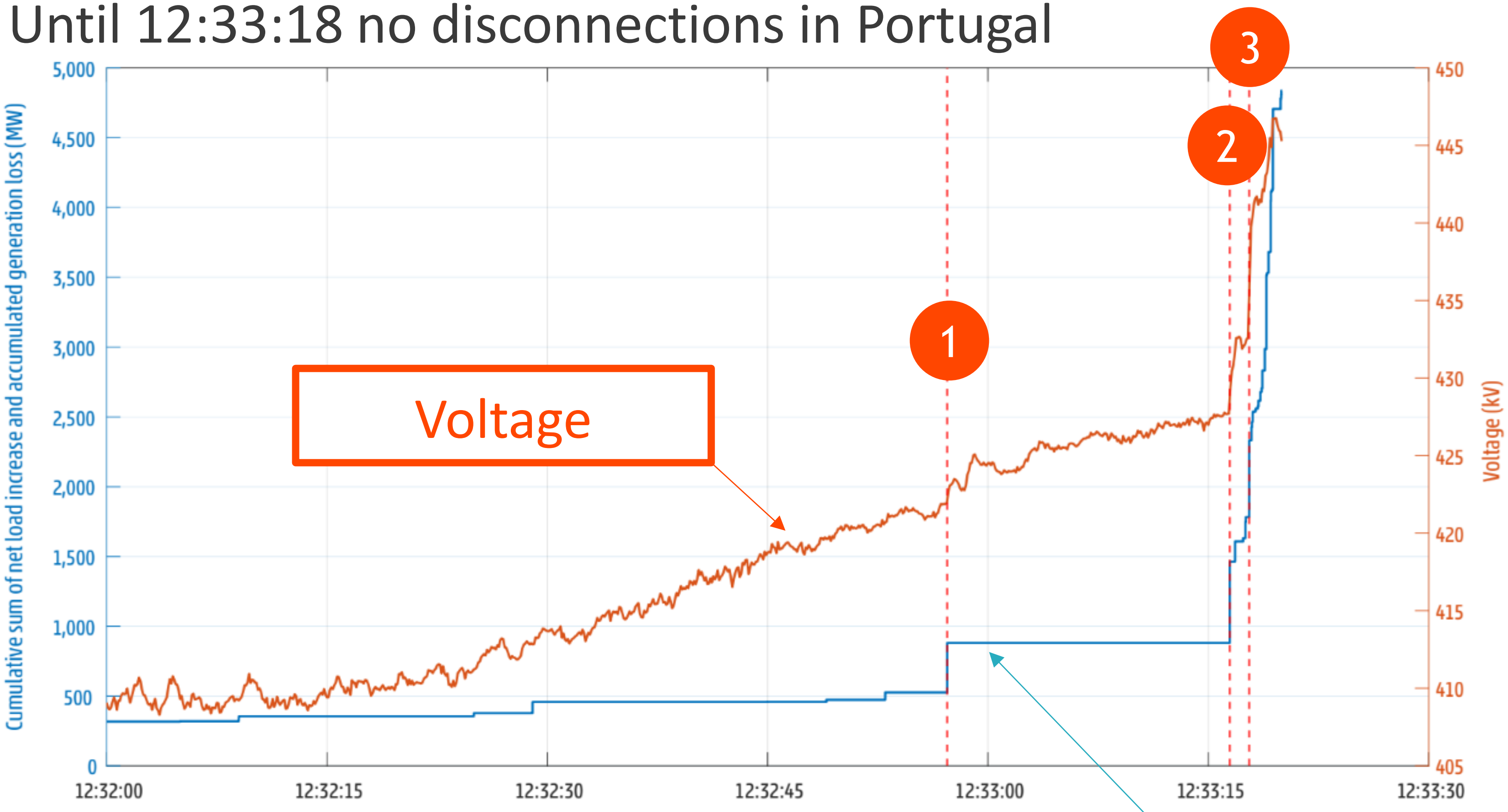
1.3 Significance of the incident

- On 28 April 2025, at 12:33 CEST, continental Spain and Portugal suffered a blackout.
- A small area in the South of France (at the border with Spain) was also affected during a very short period of time.
- The rest of the European power system did not experience any disturbance resulting from the incident.
- **This was the most severe blackout on the European power system in over 20 years, and the first ever of its kind (overvoltage)**.
- It had major repercussions for citizens and society.

2. Final sequence of the blackout

2.1 Three major tripping events in South-West Spain

Evolution of cascade of overvoltage disconnections of generators
Until 12:33:18 no disconnections in Portugal

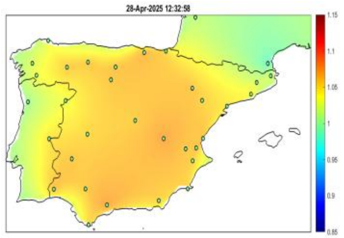


Disconnection of generators, reduction of infeed, increase of load

Loss of generation

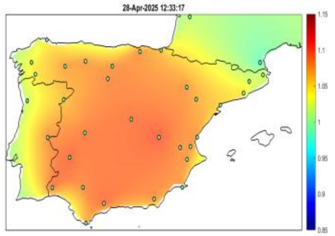
12:32:57 ①

355 MW in Granada (Wind, PV, Thermo-Solar)



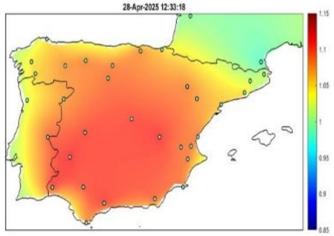
12:33:16 ②

727 MW in Badajoz (PV, Thermo-Solar)



12:33:17 ③

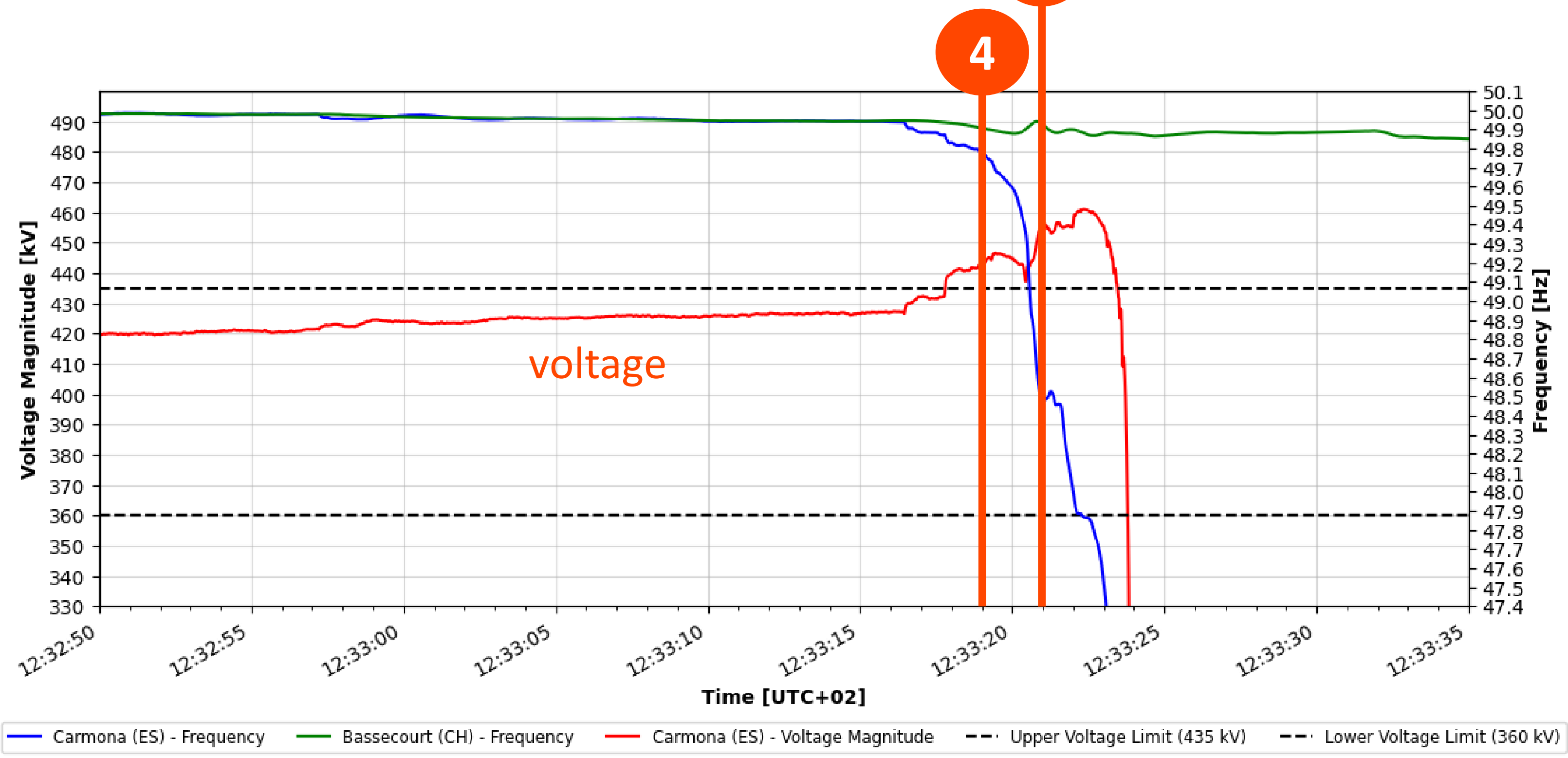
928 MW in Segovia, Huelva, Badajoz, Sevilla and Caceres (PV, Wind)



2.2 Voltage and frequency evolution during the incident

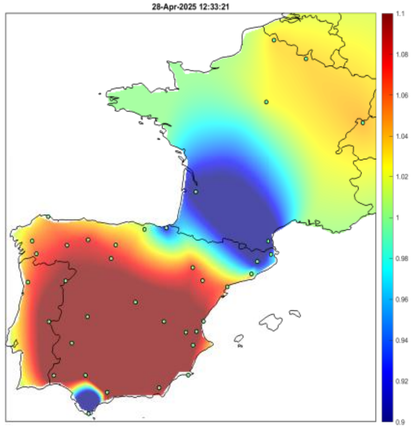
12:33:19 (4)

- Decrease of **frequency on Iberian Peninsula** and loss of synchronism with **rest of Continental Europe**
- System Defence Plans (automatic load shedding) were activated in Spain and Portugal but unable to stop the blackout due to its overvoltage nature



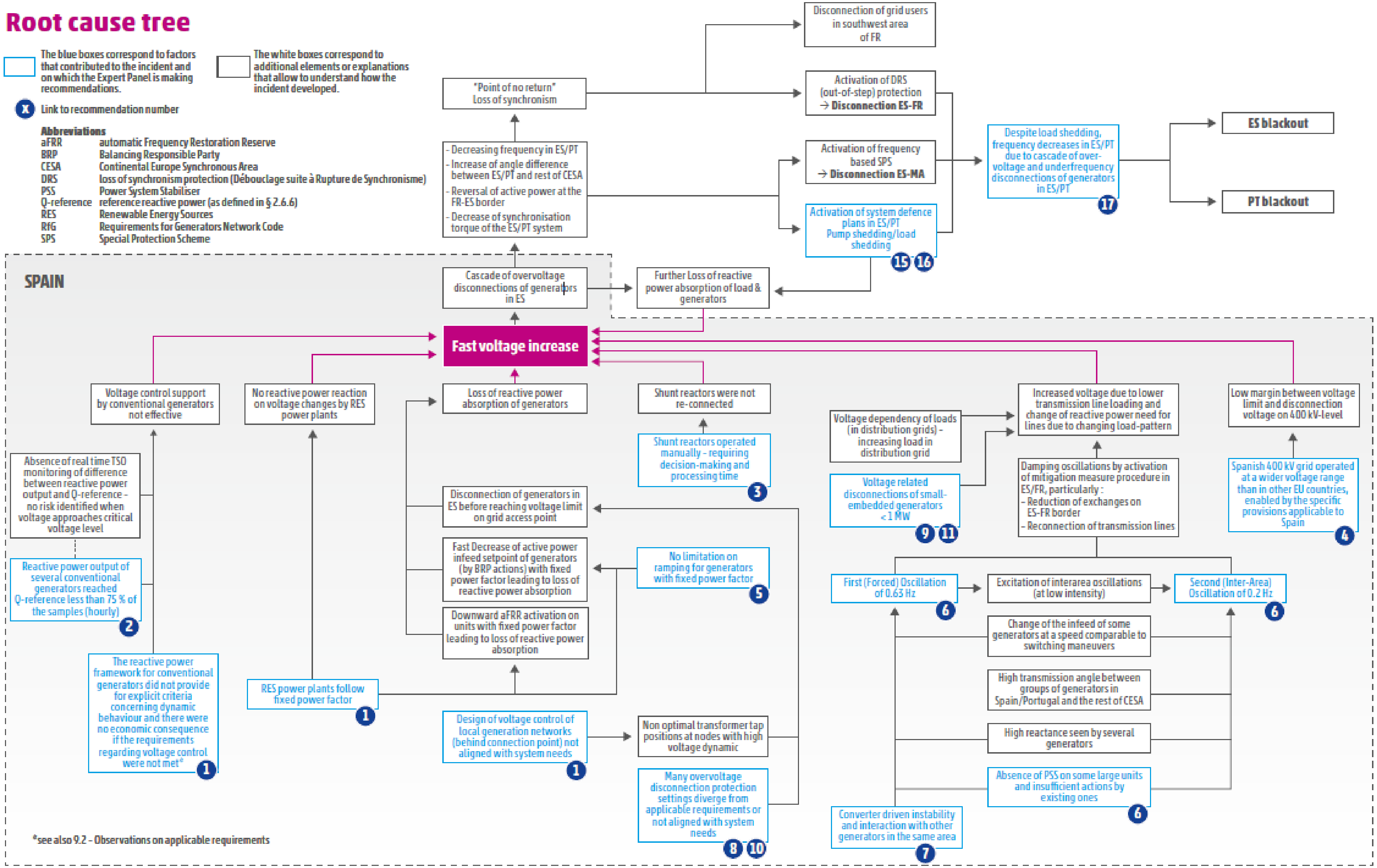
12:33:21 (5)

- Disconnection of all AC-lines from Spain to Morocco and France



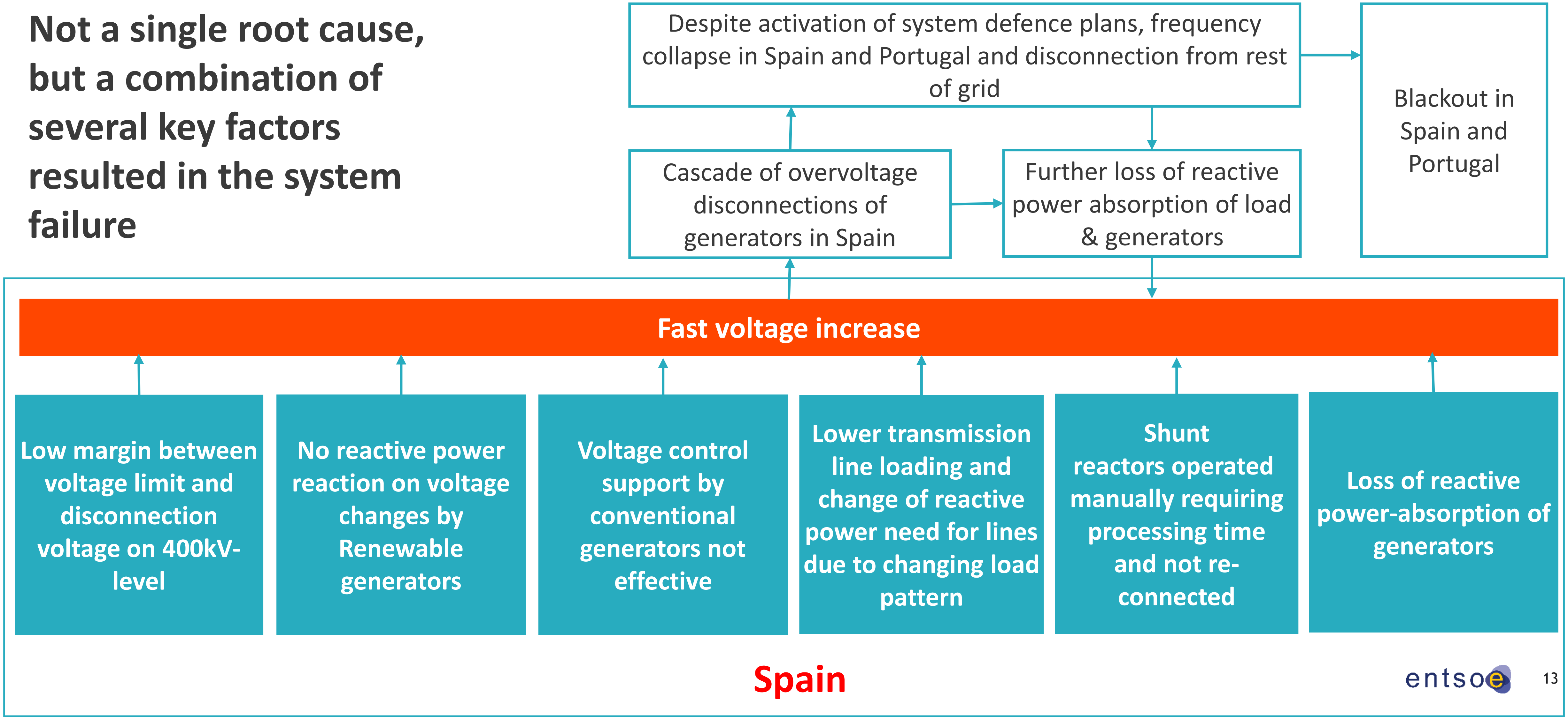
3. Analysis of factors that caused the blackout

3.1 Full Root Cause Tree



3.2 Simplified Root Cause Tree

Not a single root cause, but a combination of several key factors resulted in the system failure

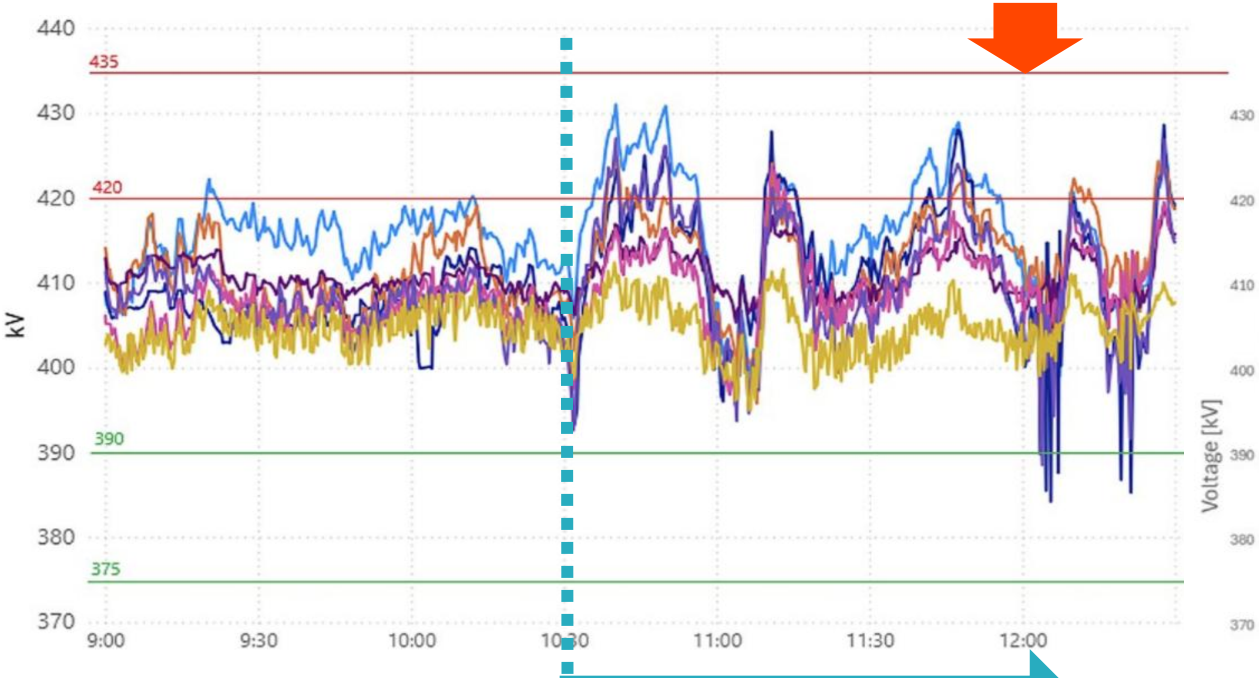


3.3 Low margin between voltage limit and disconnection voltage on 400 kV level in Spain

Spain

10:30

Upper voltage limit in Spain: **435 kV***

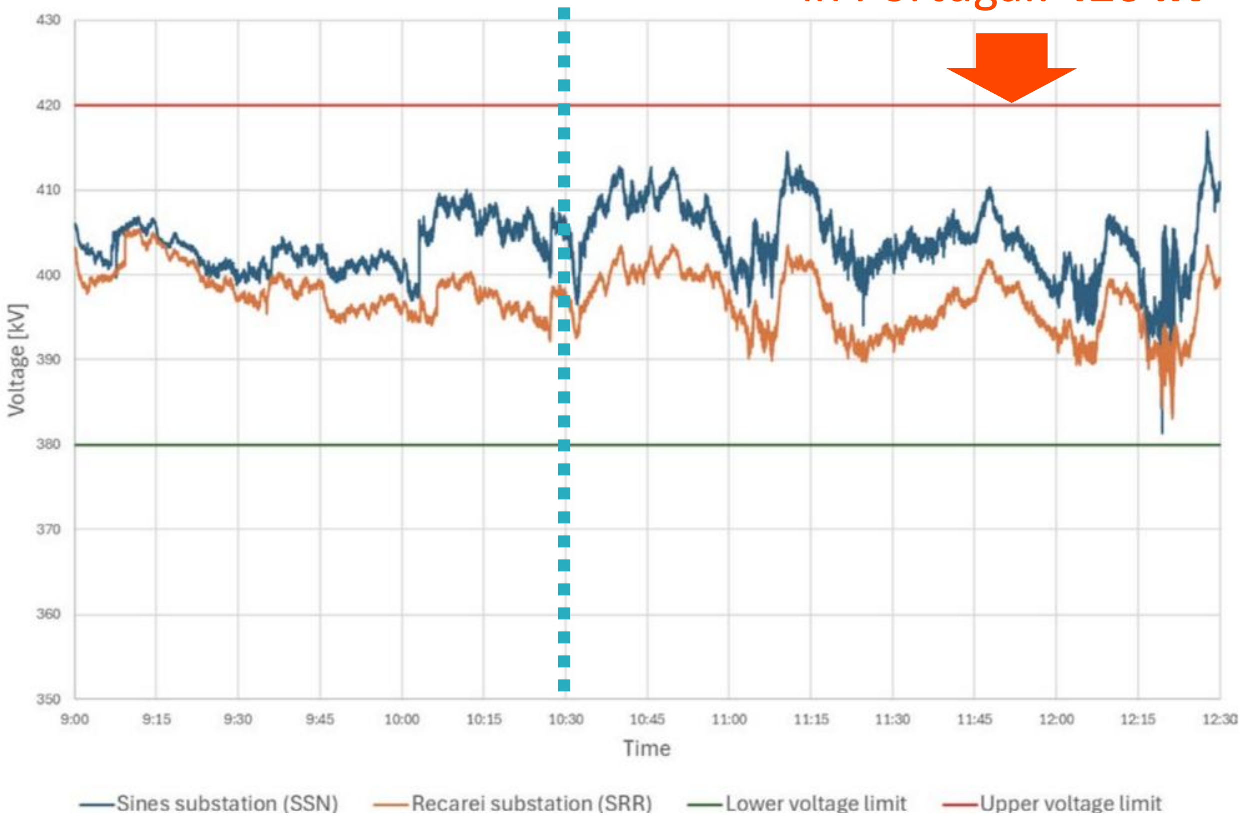


First significant variations of the voltage from 10:30

Portugal

10:30

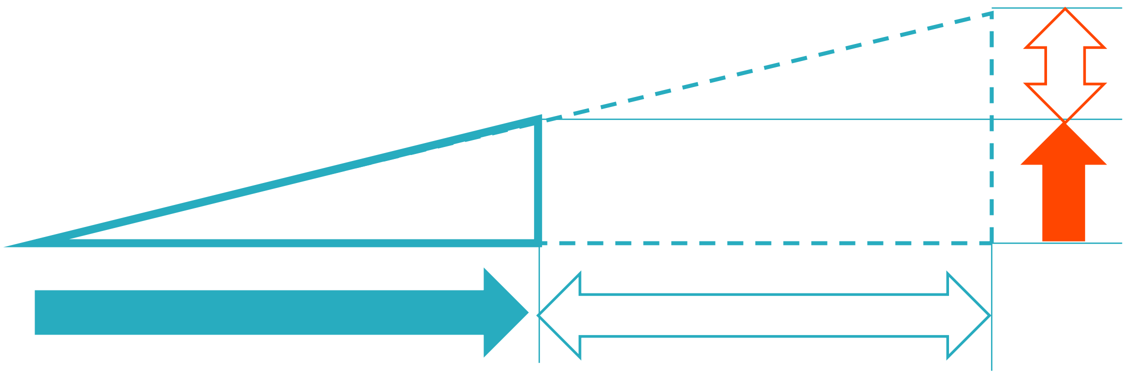
Upper voltage limit in Portugal: **420 kV**



* These values may occur on occasion at the 400 kV level (confirmed by CNMC, Spanish regulator)

3.4 No reactive power reaction on voltage changes by Renewable generators in Spain

Renewables with fixed power factor:
P and Q are always in the same ratio to each other

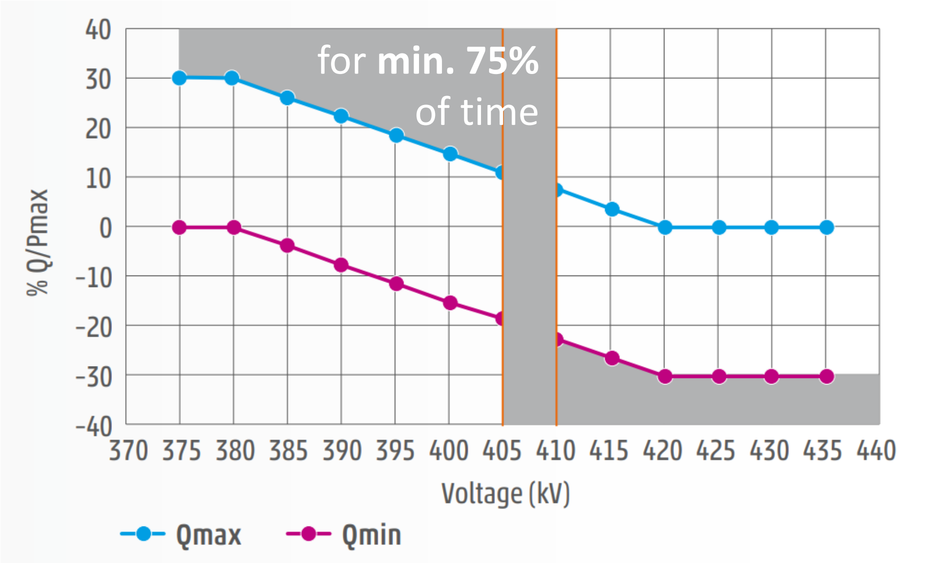


Changes of P result in proportional **changes of Q**

No dynamic voltage control by Renewables with fixed power factor, as Q absorption is dependent on P, but not voltage

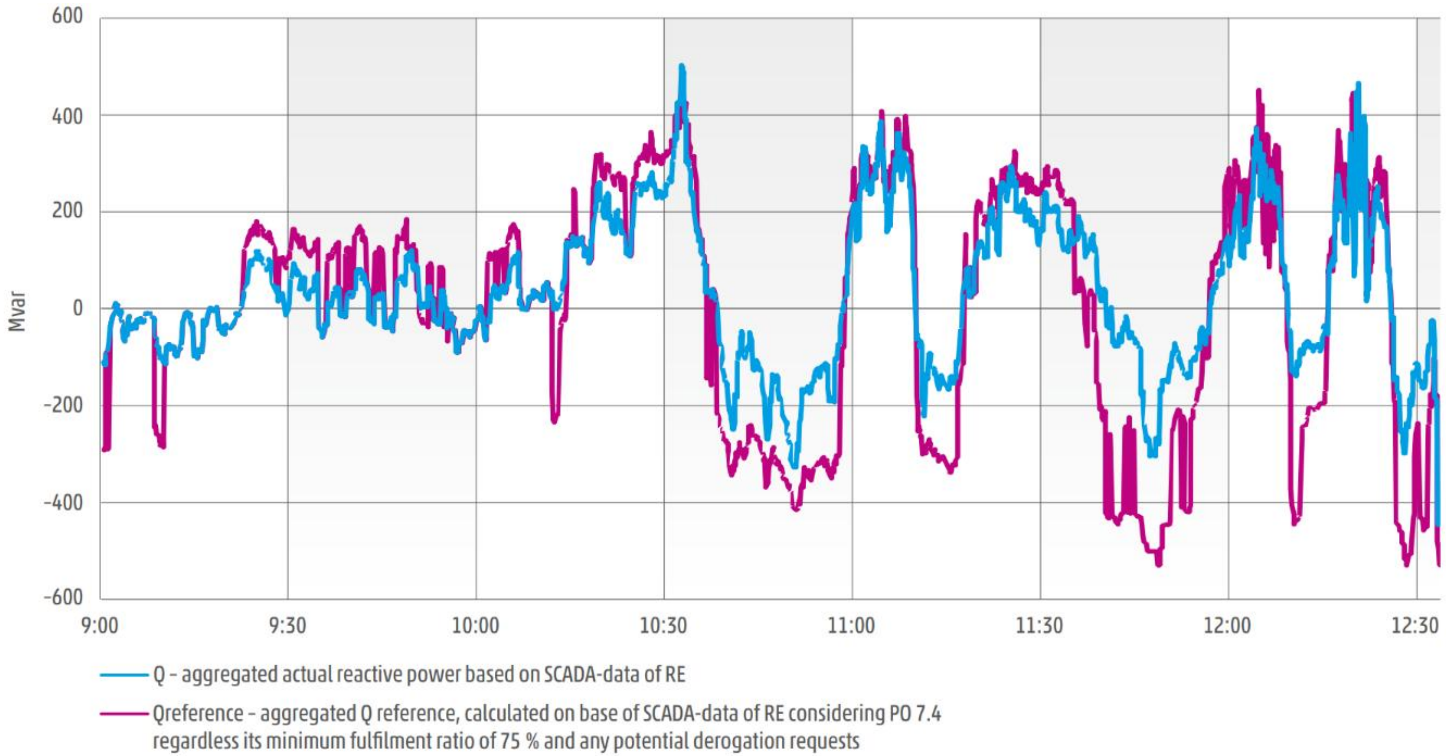
3.5 Voltage control support by conventional generators not effective in Spain

Q-area defined by PO 7.4



The **requirements** applicable to the conventional generators' Q output **do not include specifications for dynamic behaviour** and there is **no economic consequence** if Q output is not aligned with the 75% rule

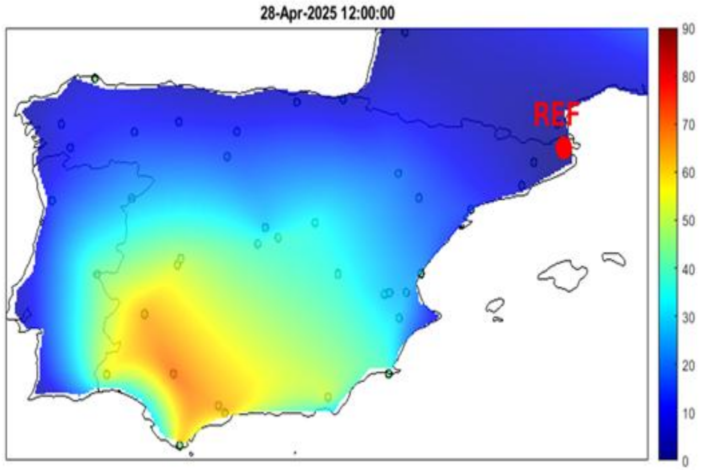
Some generators diverged from the applicable requirements for 75% alignment of actual Q with Q reference, **without prejudice to any potential derogations** from these requirements

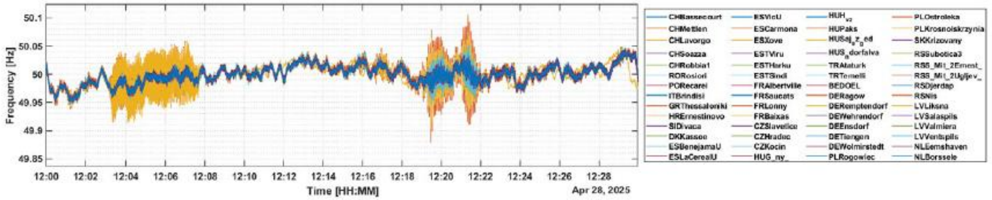


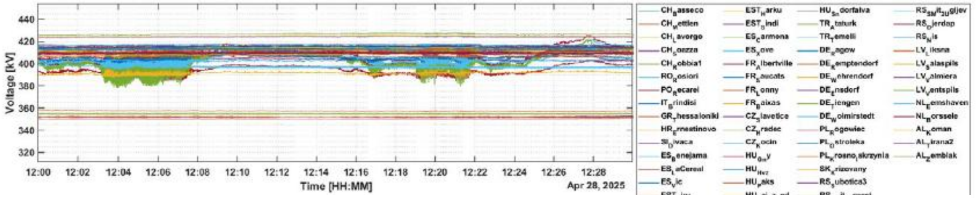
3.6 Lower transmission line loading after mitigating oscillations

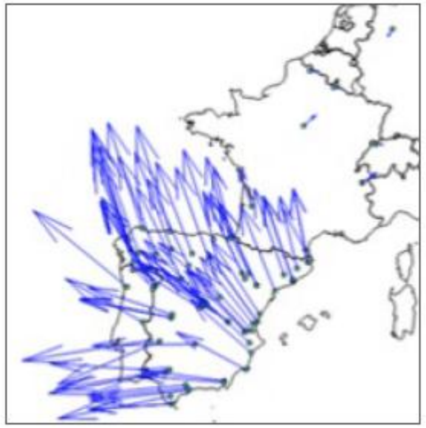
High Renewables infeed in Southwest of Spain

Heatmap of angular displacement at 12:00

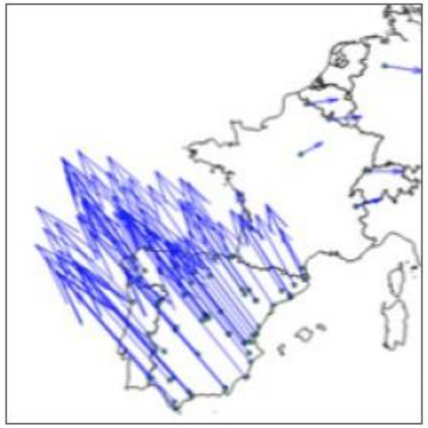








Local oscillation by 0.63 Hz

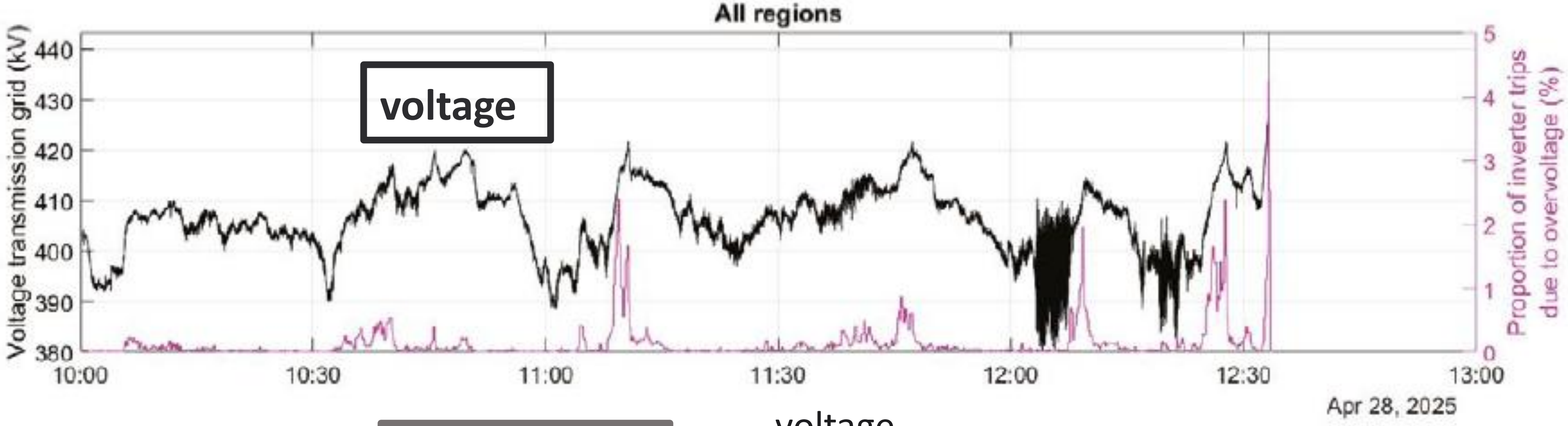


Inter-area oscillation by 0.2 Hz

Mitigation measures according to common protocol of French and Spanish TSOs

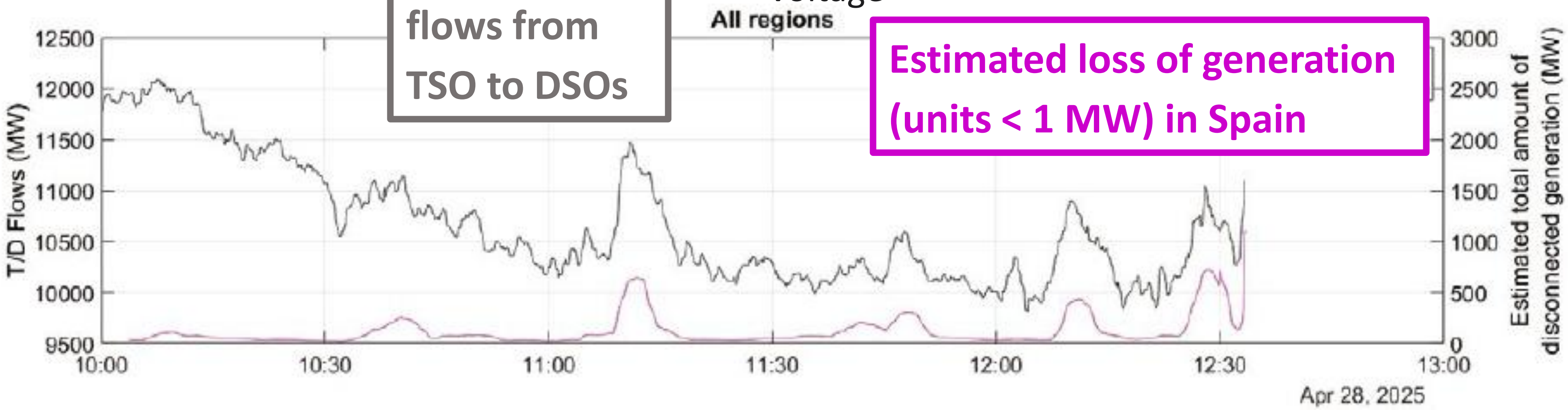
- **successful in damping** the oscillations
- naturally leading to **voltage increase** (still within operational range)

3.7 Loss of small embedded generators and increase of flow from TSO to DSO grids in Spain



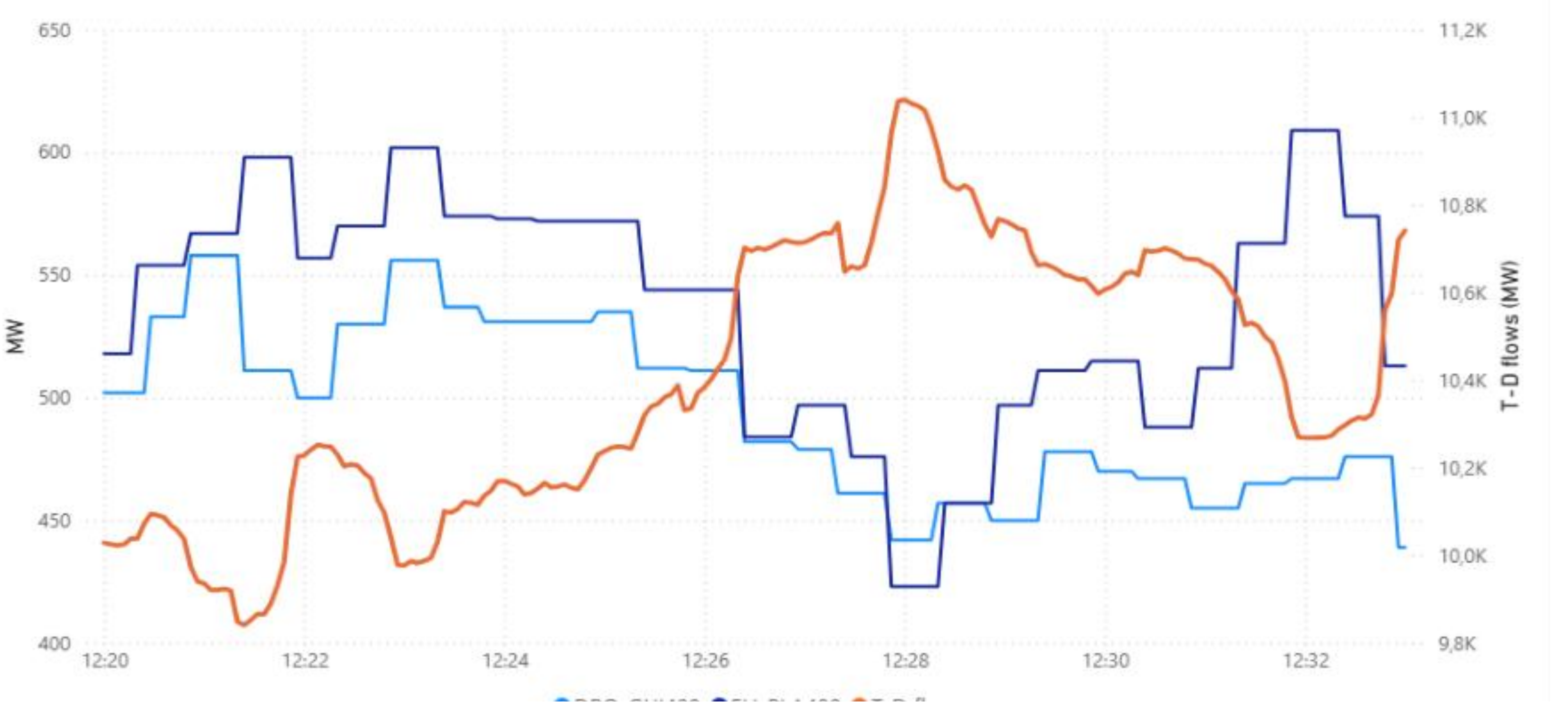
Tripping of small embedded generators < 1 MW (e.g. PV-household) reported by one inverter company

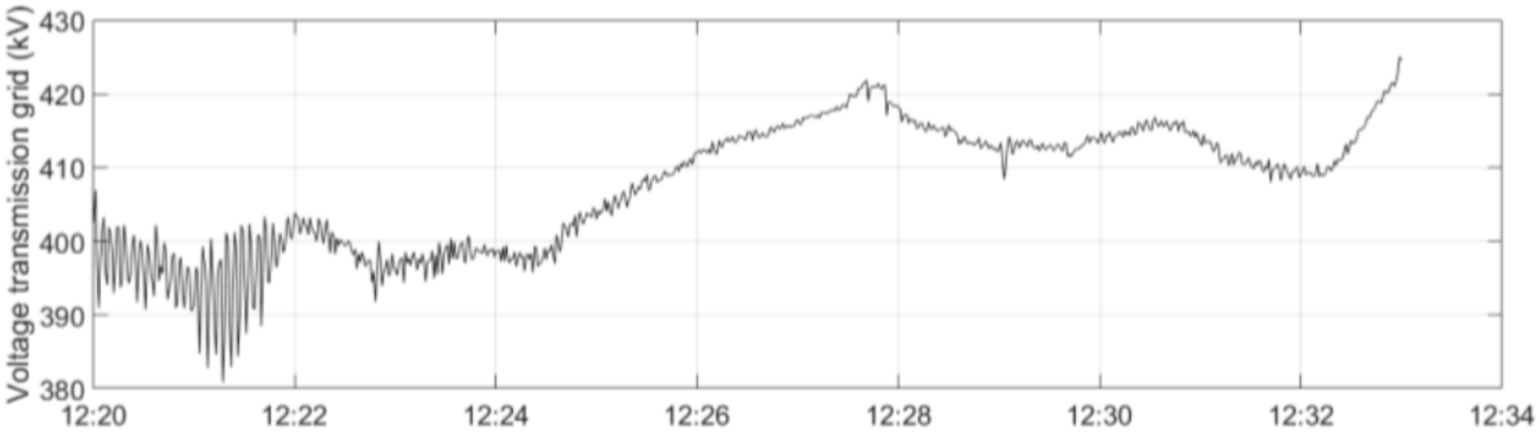
voltage



Estimated loss of generation (units < 1 MW) in Spain

3.8 Lower transmission line loading due to increase of flow from TSO to DSO grids in Spain





Loss of active power infeed plus increase of load due to higher voltage leads to **higher flows from TSO to DSOs**

This results in **lower line loading** in some parts of the grid

Lower line loading results in **voltage increase**

3.9 Shunt reactors operated manually - requiring processing time - and not re-connected

Low voltage during oscillation episodes required **shunt reactor disconnection**

Shunt reactors and capacitors are used for **static voltage control in Spain**, (dis-) connected **manually**

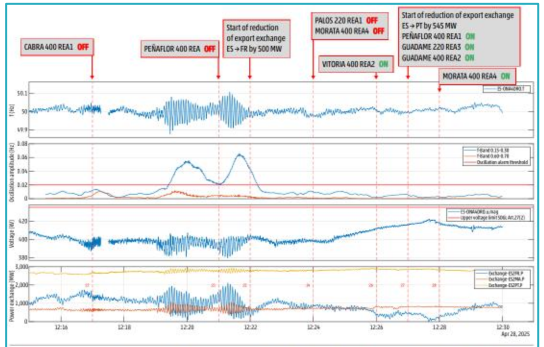
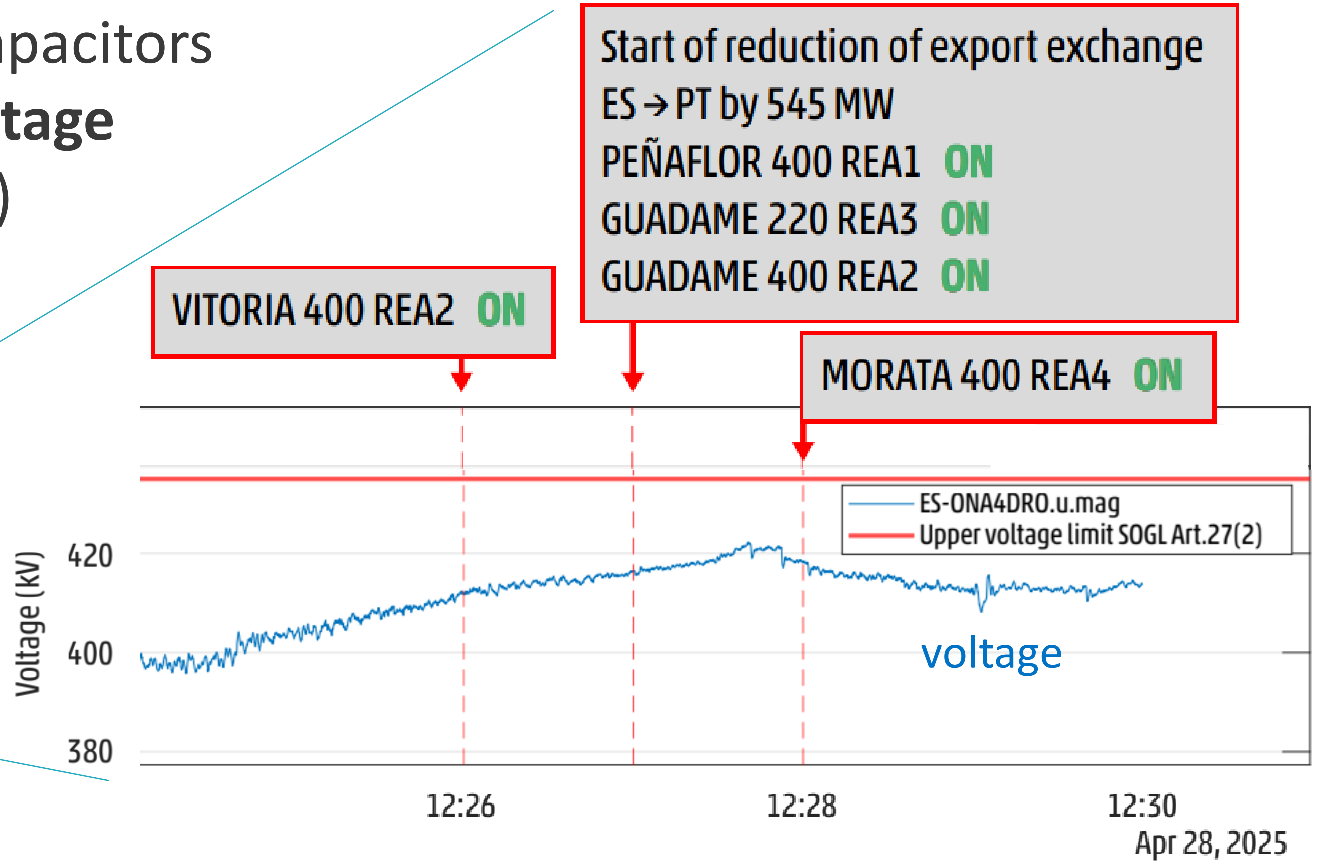


Figure 2-62: Characteristics data of the second oscillations and increasing voltage (source: WAMS 100 ms sampling rate at the 400 kV Carmona substation) and countermeasures

Connecting shunt reactors contributed to **voltage stabilisation until 12:32**



At 12:32 about **58% of reactive power capacity** of Spanish shunt reactors were **connected**

Remaining capacities could **not** be **connected** in time due to **needed processing time** for manual switching

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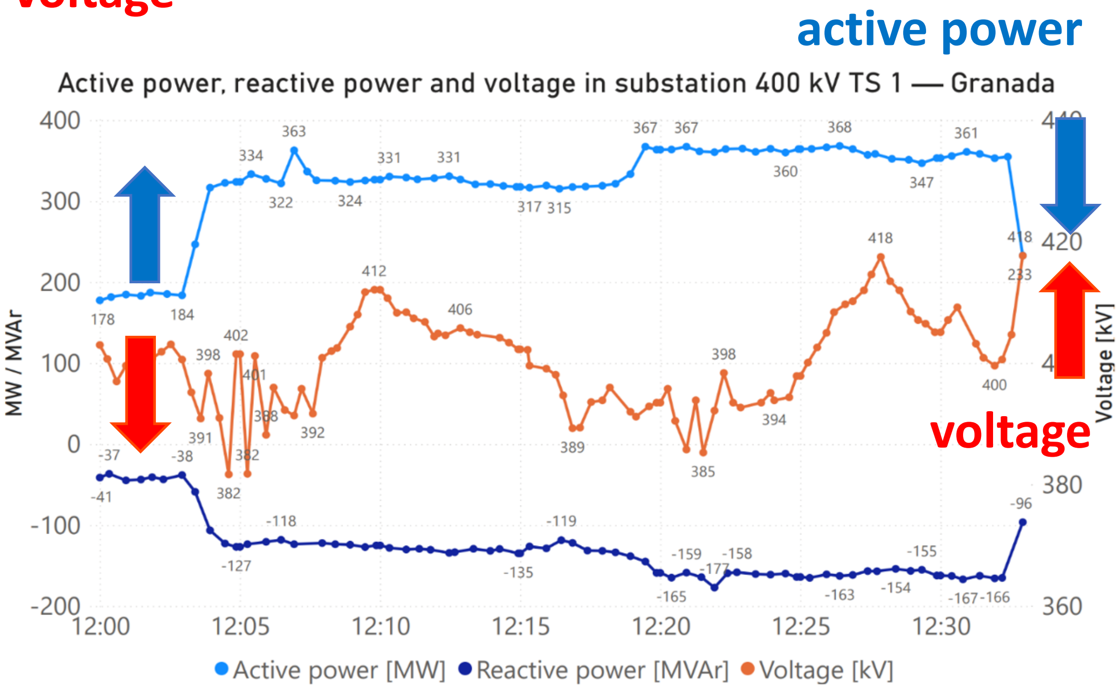
3.10 Loss of reactive power absorption of generators in Spain

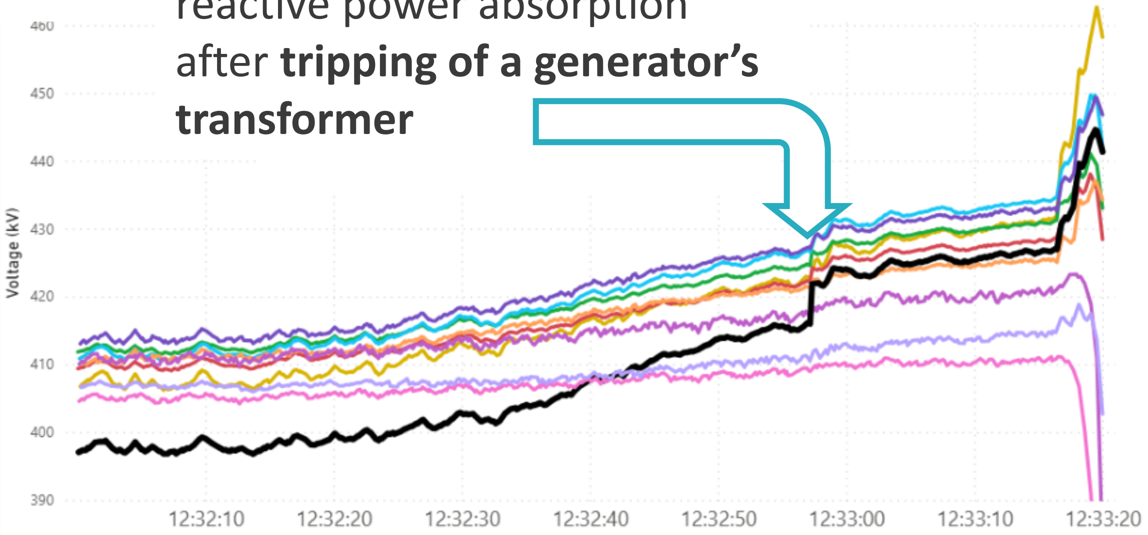
Fast changes of infeed setpoints of generators with fixed power factor result in **fast changes of voltage**



Rate of infeed change sometimes (in case of generators without ramping limitations) comparable with switching events

12:32:57

Voltage increase due to loss of reactive power absorption after **tripping of a generator's transformer**



Many **protection settings** diverged from applicable requirements or were **not aligned with system needs**

Design of voltage control of some local generation networks (behind connection point) **not aligned with system needs**

4. Key recommendations and observations

4. Key recommendations and observations

1

Voltage Control

Voltage range, control mode and behavior of generators, dynamic voltage control capabilities

2

Oscillations

Damping, modelling, monitoring and detection.

3

Disconnections

Protection settings (generators, evacuation grids, embedded units)

4

System Defense Plan

Modernization to integrate fast voltage variations

5

Restoration

Black start capability, testing, communication, reconnection

Observation on Regulatory Frameworks

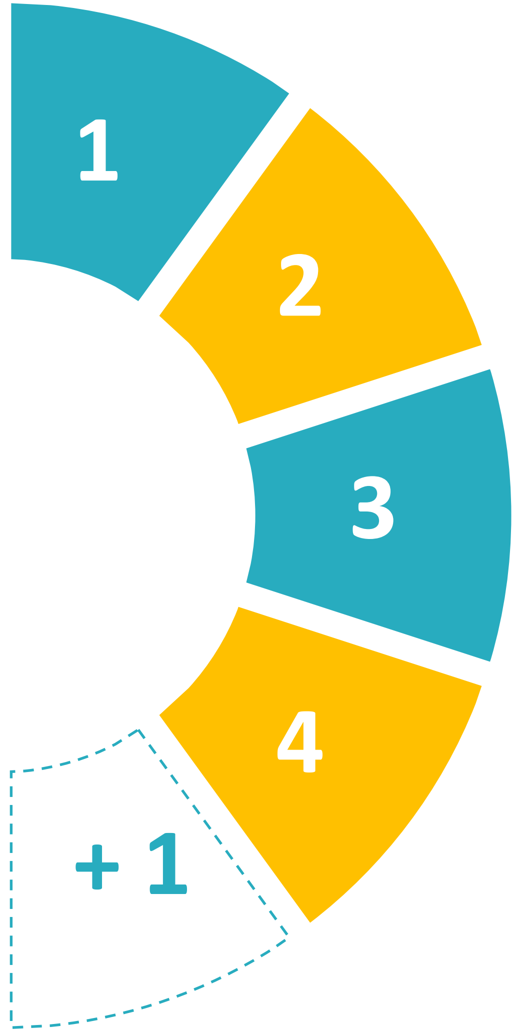
The investigation shows the need for regulatory frameworks to adapt to implement these recommendations in line with the evolving nature of the power system.

Maatregelen die we versneld moeten voltooien in Nederland

Maatregelen	Wanneer
Ontwikkel en implementeer een sector-brede visie, strategie en roadmap voor de beheersing van spanning en blindvermogen	2027-2030
Compenseer nu het blindvermogen uit de onderliggende netten door inkoop van blindvermogen, tenzij het plaatsen van spoelen nu een optie is	2026
Introduceer oscillatie-management tools en procedures voor bedrijfsvoering	2026
Actualiseer en automatiseer spanningsregelingen: implementeer hiërarchische spanningsregeling, handhaaf primaire spanningsregeling, stuur de levering van blindvermogen aan via EMS	2026
Zorg voor voldoende synchrone opwekking voor stabiliteit en spanningshandhaving	Doorlopend
Bouw meer bedrijfsmiddelen die zorgen voor een sterk net met een stabiele spanning: spoelen, condensatoren, SynCons, STATCOM's	2026-2030
Zorg dat opwekking met omvormers voldoende dynamische ondersteuning voor spanning en demping levert	2026
Zorg dat bedrijfsvoering beter zicht op het net krijgt: uiteindelijk moet elke TenneT-connectie, alle (E)HV stations en alle koppelpunten tussen TenneT en de DSB's PMU's hebben	2026-2030
Verbeter zich op opwekking in de MV en LV netten en verbeter de uitwisseling van data tussen de DSB's en TenneT	2026-2030
Zorg voor een strikte naleving van de eisen uit de systeemcode en monitor deze doorlopend	2026-2027
Verbeter berekeningen, prognoses en tools voor bedrijfsvoering en netplanning	2026-2027
Actualiseer beschermings- en herstelplannen	2026-2029

5. Concluding remarks

5.1 Key Takeaways from the blackout



1 **A first-of-its-kind blackout**
With valuable learnings to prevent similar incidents in the future.

2 **No single cause, clear recommendations**
Multiple interacting factors, with solutions already technically feasible.

3 **Complex interactions between active system participants**
Need to strengthen coordination between all Generators, DSOs and TSOs.

4 **A local issue that escalated very quickly**
Knowledge and action at both Local and European levels are essential.

The Power System is governed by Physics
The fundamental physical limits must be considered for all market mechanisms, regulatory frameworks and energy policies.

Q&A