School of Engineering

The Continental European Power System: Overview, Challenges, and Opportunities

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Is possible to avoid blackouts in power systems?

No, it is not possible…

- The electrical power system is the most complex human-made system

- A failure in the electrical power system is as likely as in any other system due to malfunctioning, lack of service, weather conditions, etc.

Europe at night from Space

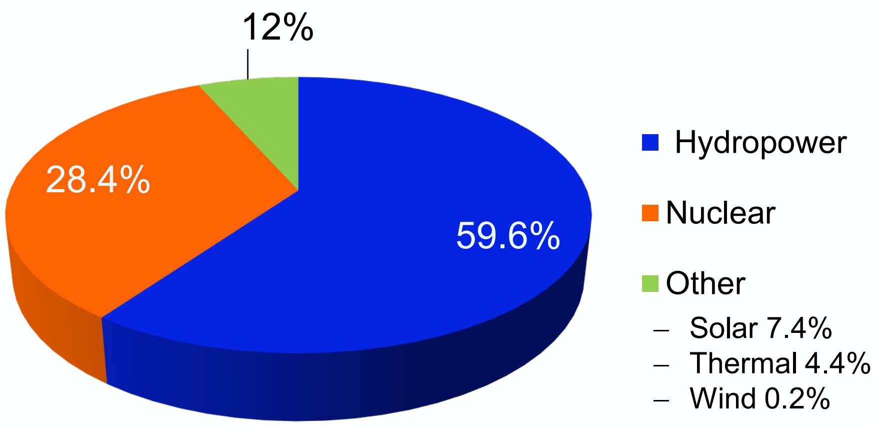
Agenda

1. Overview of the Swiss and European power system
2. Close-up on the blackout in the Iberian Peninsula
3. Challenges and Opportunities

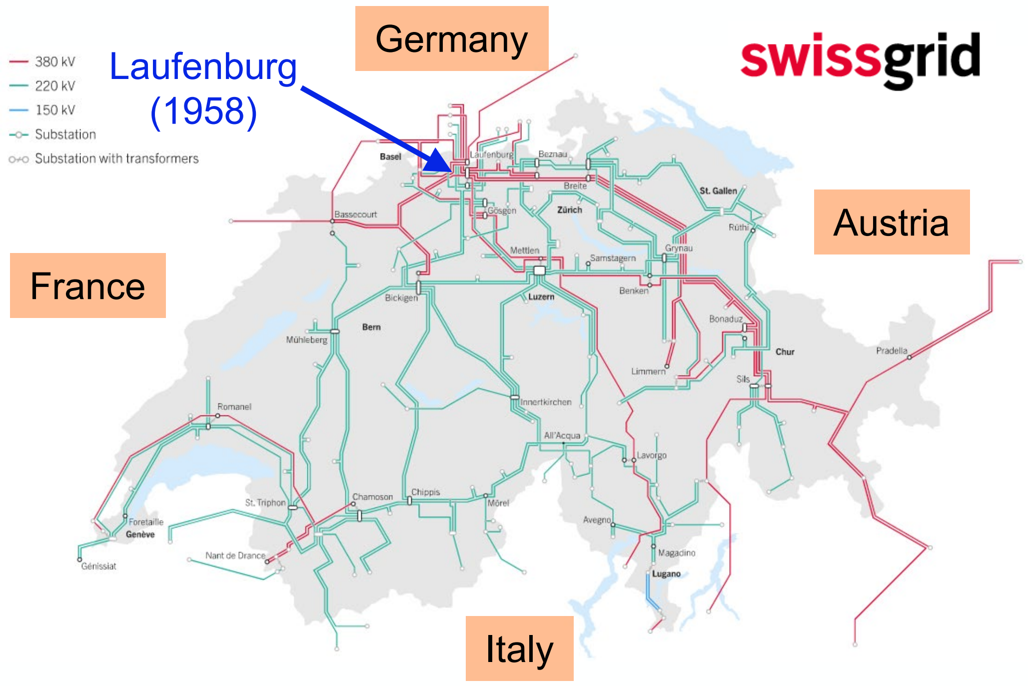
1. Overview of the Swiss and European power system

The electrical power system of Switzerland

Switzerland produced
57.5 TWh of Energy in 2024



Source: SFOE press release



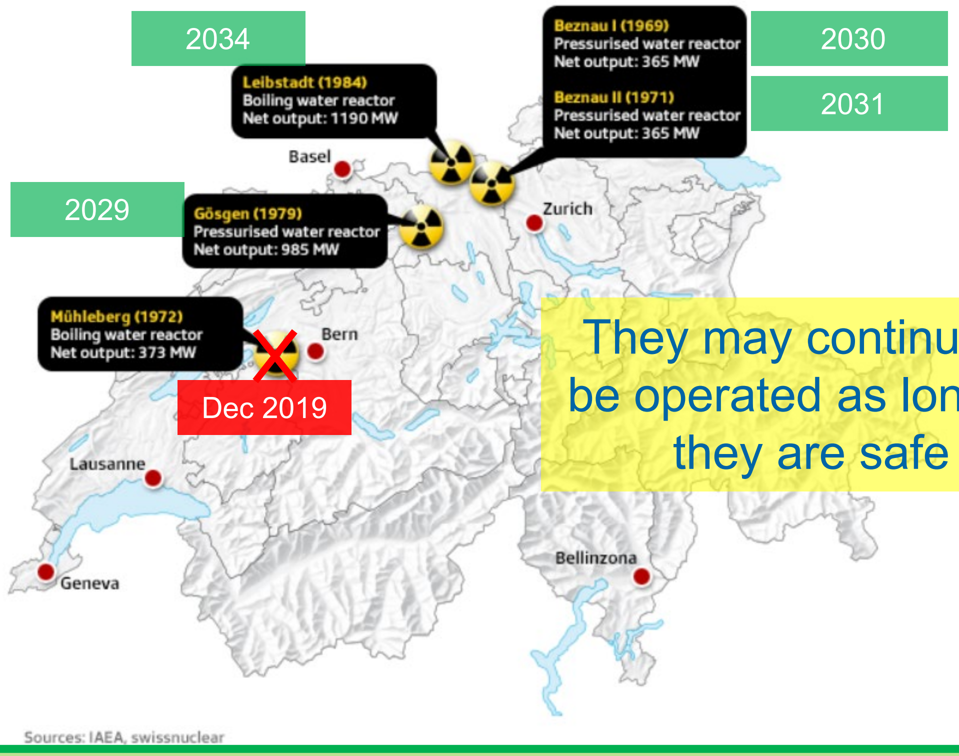
Source: Swissgrid grid data production

- Major contribution is Hydropower
- Nuclear still playing an important role
- Renewables are growing compared to 10 years ago, but they need to increase even more.

- Voltage of 380 and 220 kilovolts
- 6,700 kilometres long, 12,000 pylons
- 141 substations
- **41 cross-border lines**
- **1958 GER-FRA-CH connected together at 220 kV for the first time**

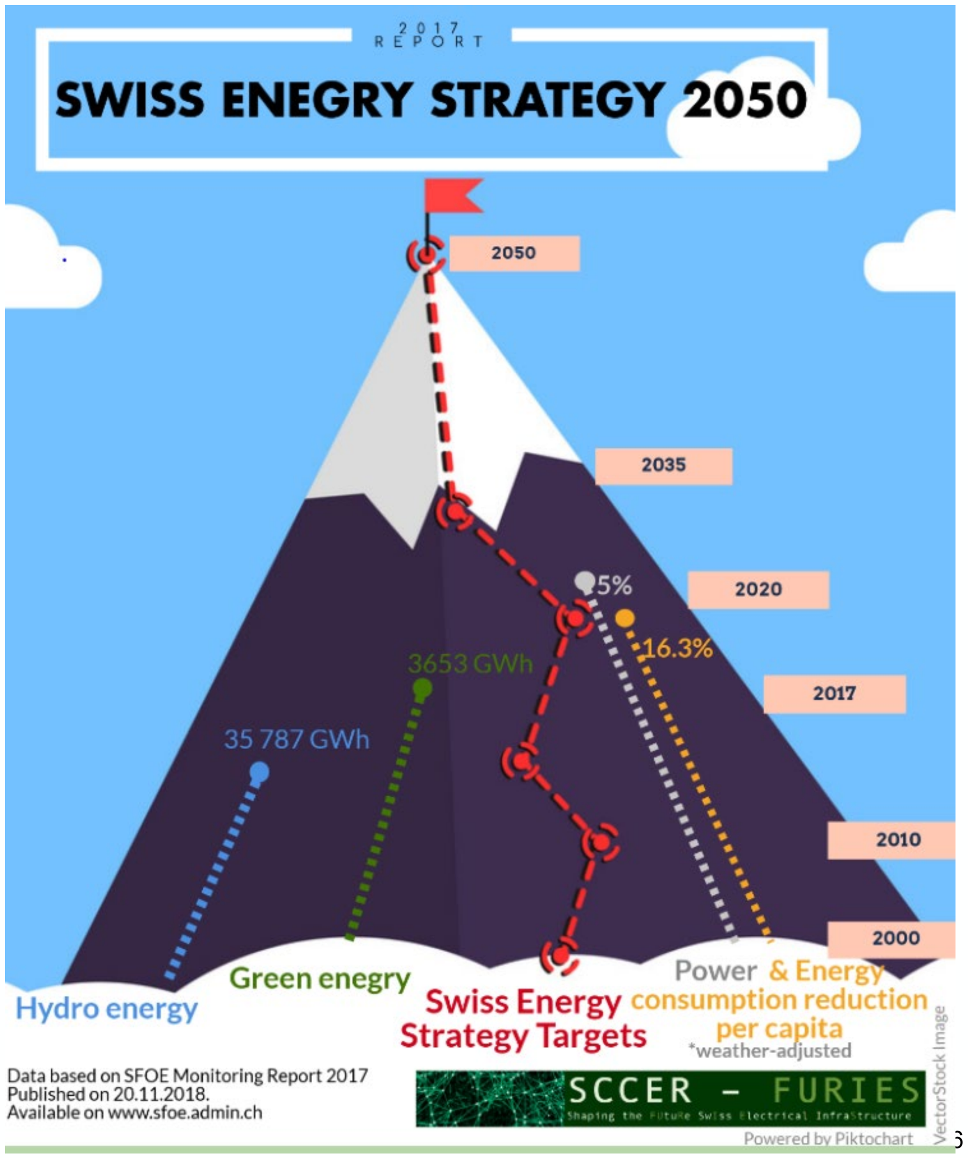
Energy Strategy 2050

The five nuclear reactors in CH and their expected decommissioning date



They may continue to be operated as long as they are safe

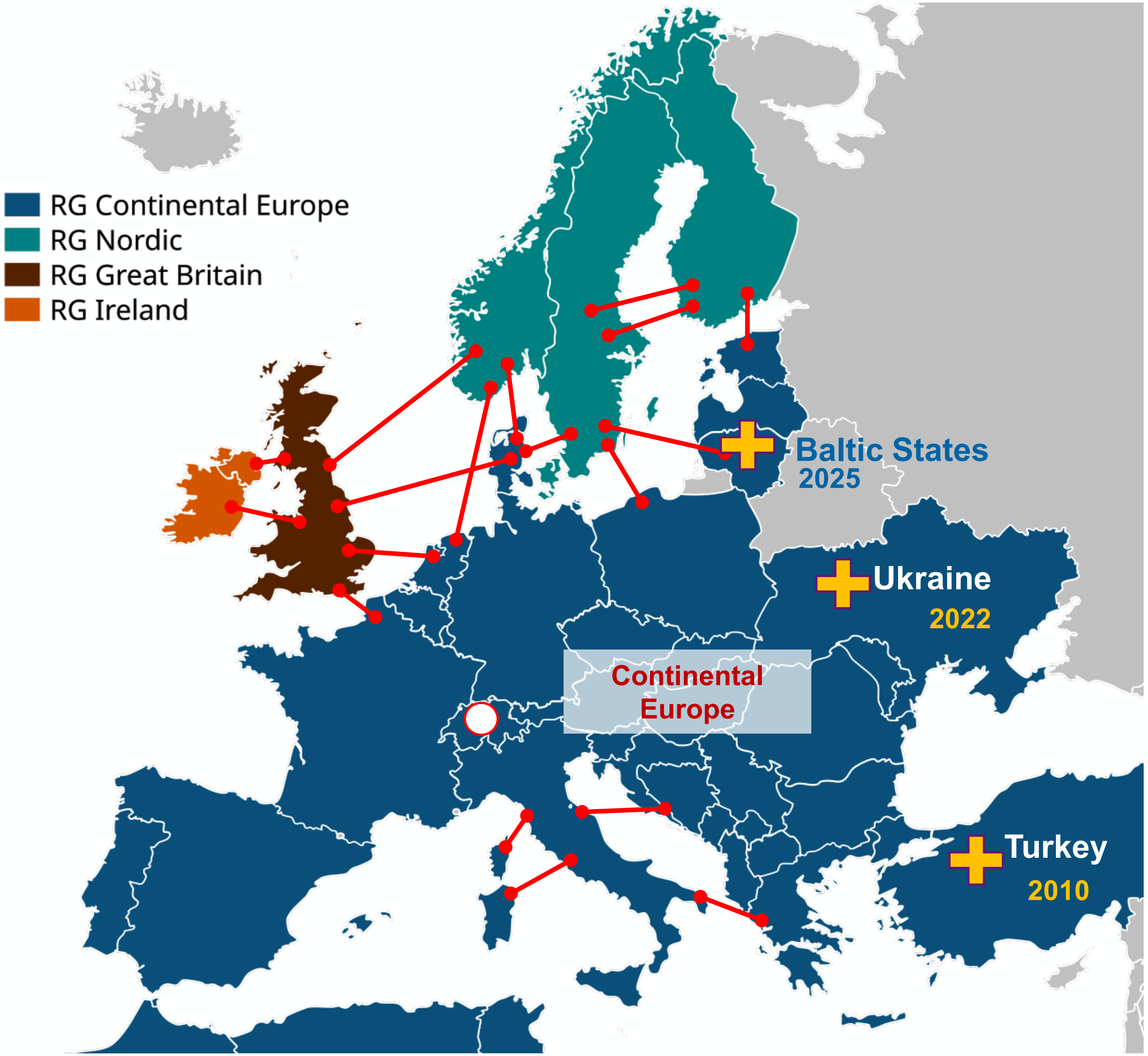
By **2050** it should be possible to meet **20%** (**12.5 TWh**) of the current level of electricity demand through the use of **photovoltaic systems**



The European Power System

- 4 Asynchronous Areas
  - **Continental Europe (blue)**
  - Nordic (green)
  - GB model (brown)
  - Ireland (orange)

- Interconnection through HVDC
- In September 2010, Turkey was synchronized with Continental Europe
- In March 2022, Ukraine was synchronized
- In February 2025, three Baltic States (Estonia, Latvia and Lithuania) were synchronized



Similarly, energy transitions across EU

The European countries have a common objective for a carbon-neutral power grid by 2050 at the latest

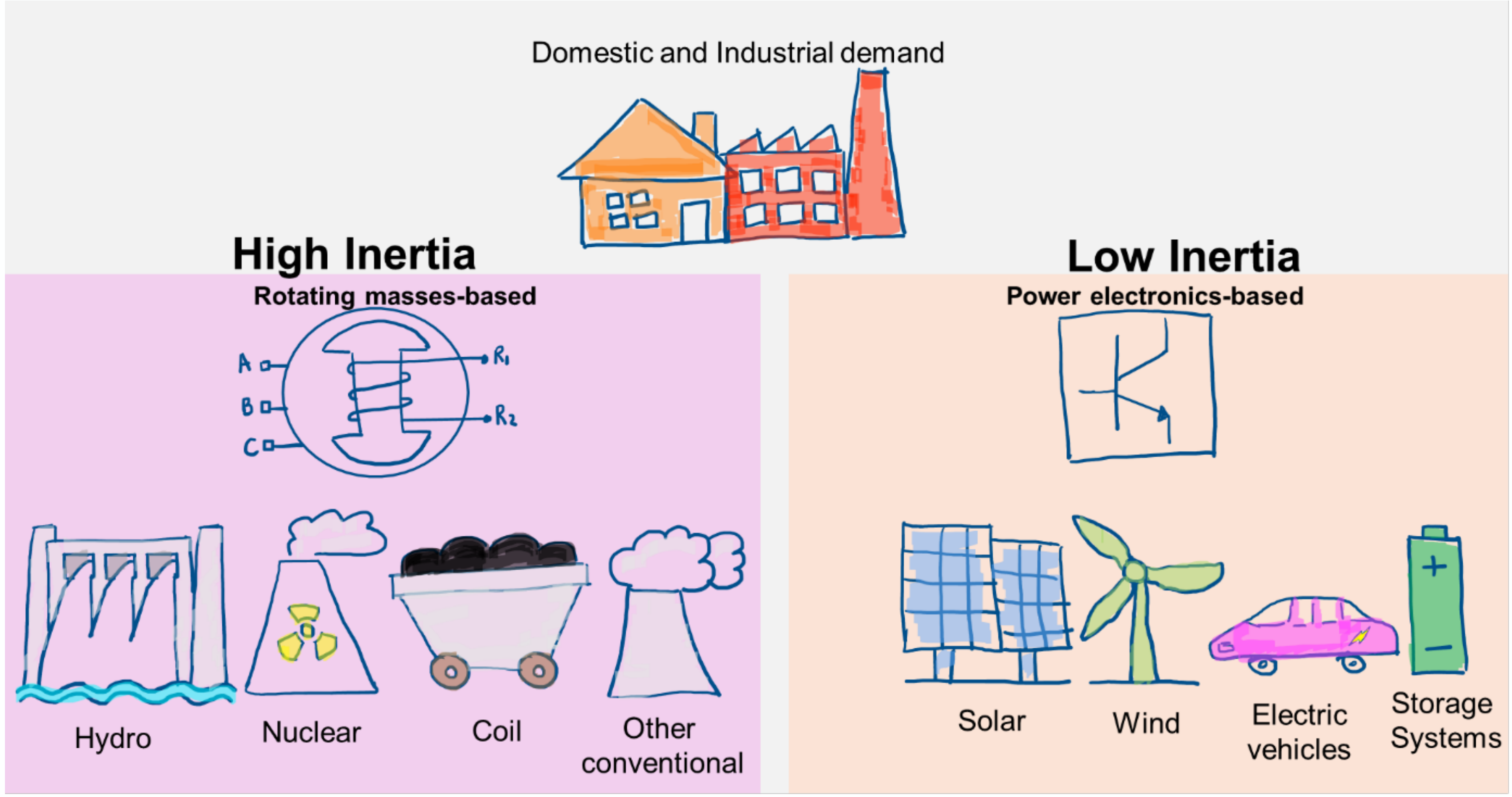
- Integration of massive amounts of renewable generation (wind, solar)
- Energy Storage Systems
- Digitalization of power systems
- Market design (electricity cost)
- Large investment in system infrastructure

Why should we care about all these changes?

The topology (structure) of the power system is changing

Technology developed to operate more than 100 years ago

The first AC transmission systems emerged in the late 19th century



Massive amounts installed in the last few years and even more to come in the upcoming years

Very large PV power plants like Witznitz (650 MW) in Germany and Francisco Pizarro (590 MW), in Spain, operating since 2024 and 2022, respectively.

Major events in CE in the last 15 years

2

Interarea Oscillations
(Iberian Peninsula vs CE system)
of f=0.15 Hz

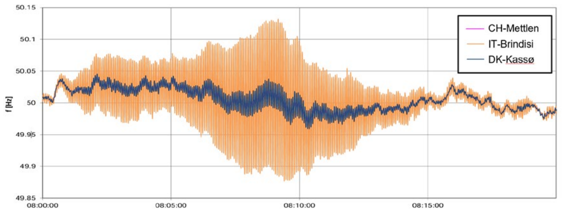
18 Sep 2010
The Turkish Power System is Synchronized with the interconnected CE power system

2003 **2010** **2011** **2012** **2013** **2014** **2015** **2016** **2017**

Italian Blackout

1

Interarea Oscillations
(North vs South)
of f=0.29 Hz



Interarea Oscillations
(North vs South)
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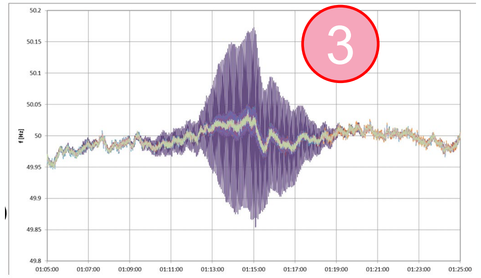

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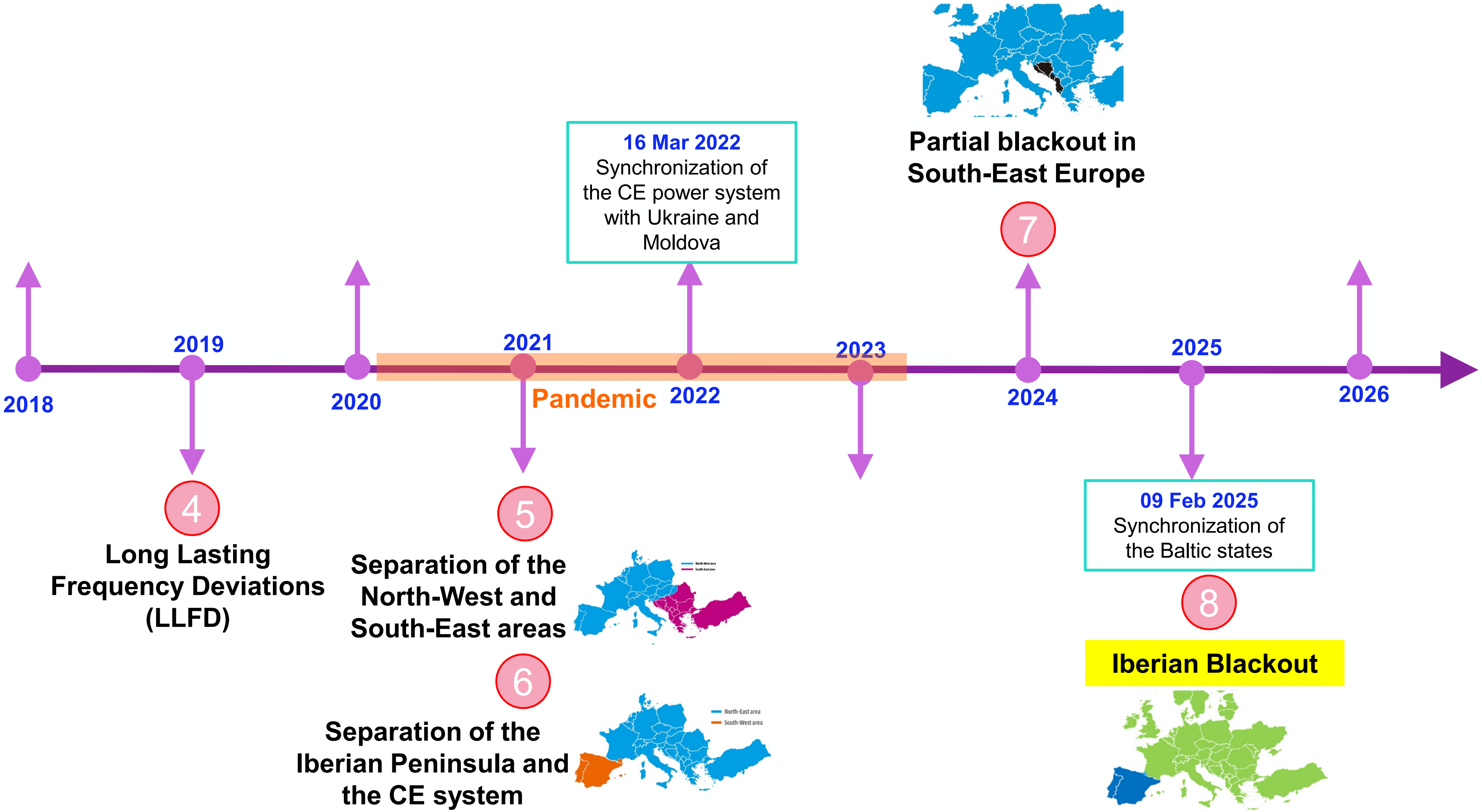
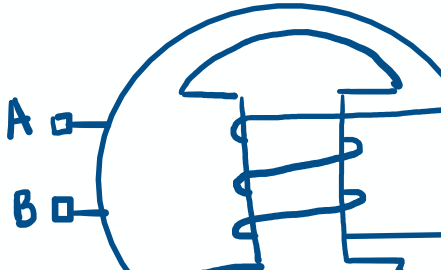
Major events in CE in the last 15 years



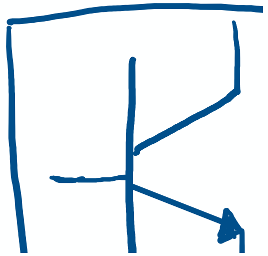
What has happened in the last years?

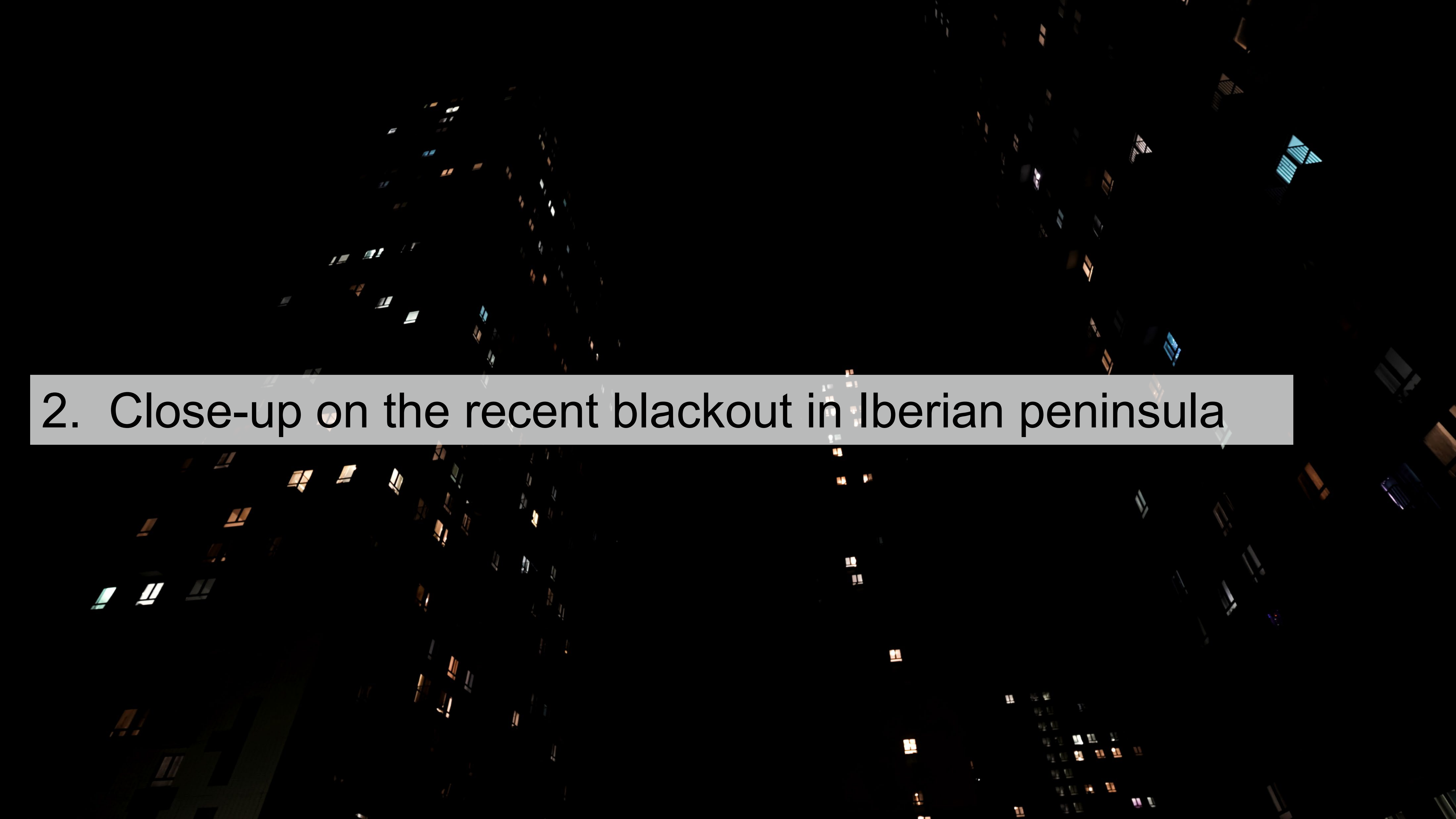
- The **power system has grown** in the past two decades (Turkey, Ukraine/Moldova, Baltic states)
- The amount of **converter-interfaced renewable generation has significantly increased** all over Europe
  (in Spain during the blackout about 70%)
- The power system has become **more complex and challenging to operate**
- The frequency and severity of **incidents has gradually increased**
  (**in particular, in the last 5 years**)

Conventional Synchronous Machine



Power Electronic Converter





2. Close-up on the recent blackout in Iberian peninsula

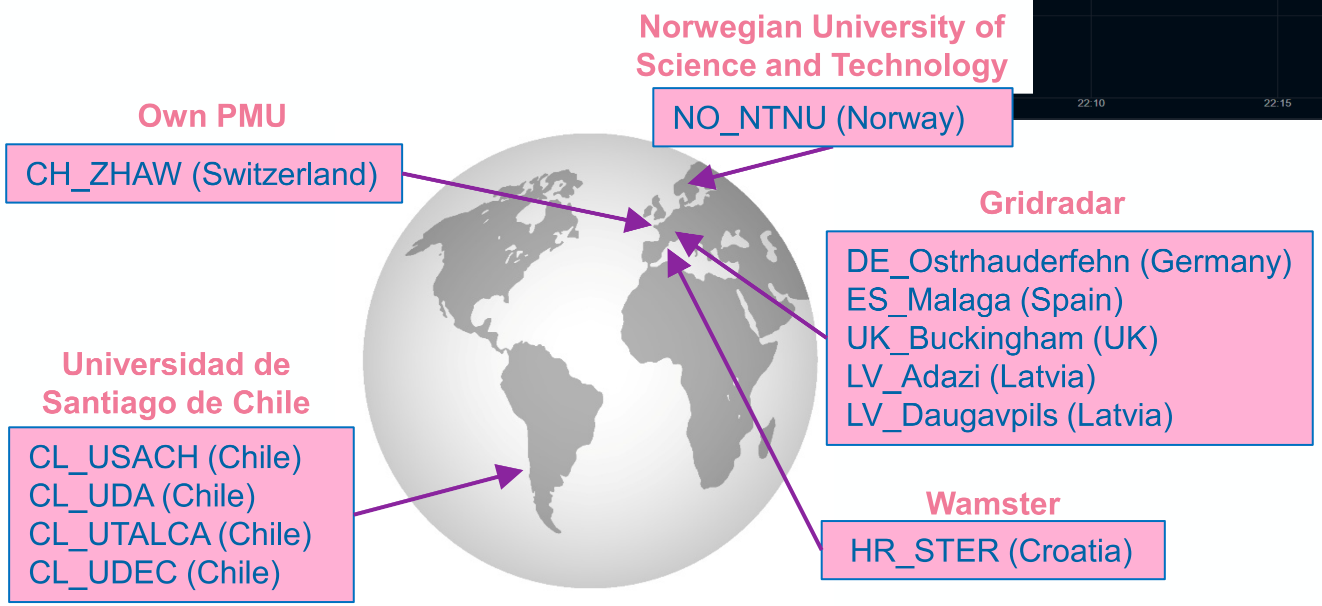
ZHAW Monitoring System

Installation:
In the context of an ERA-NET project "CloudGrid" in 2015

PMU: National Instruments

PDC: SEL-5073

Visualization Tool:
SEL-5703 Synchrowave Monitoring



Fast Data Collection:
50 samples/sec

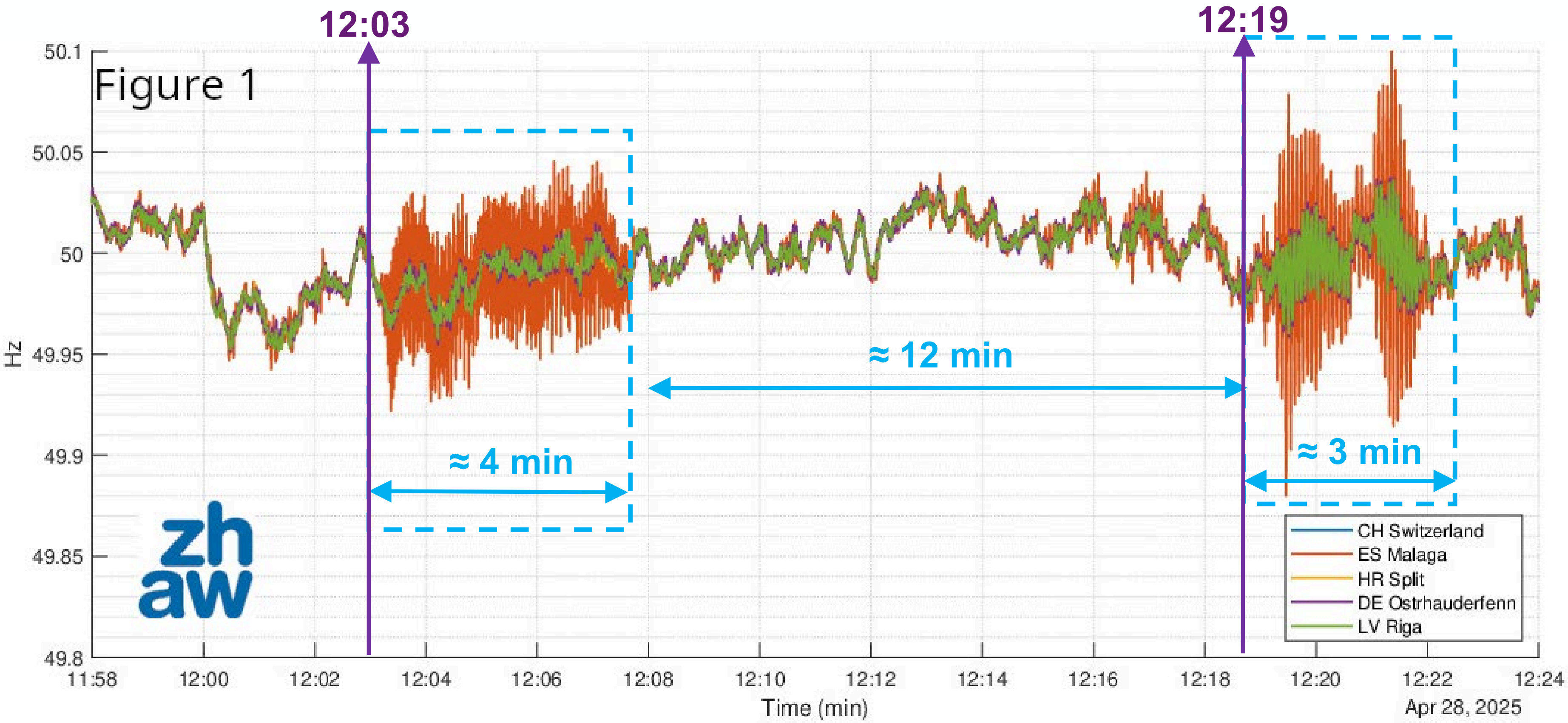
Storage Required:
250 MB/h, 150 GB/month

THE BLACKOUT OF APRIL 28th IN THE IBERIAN PENINSULA

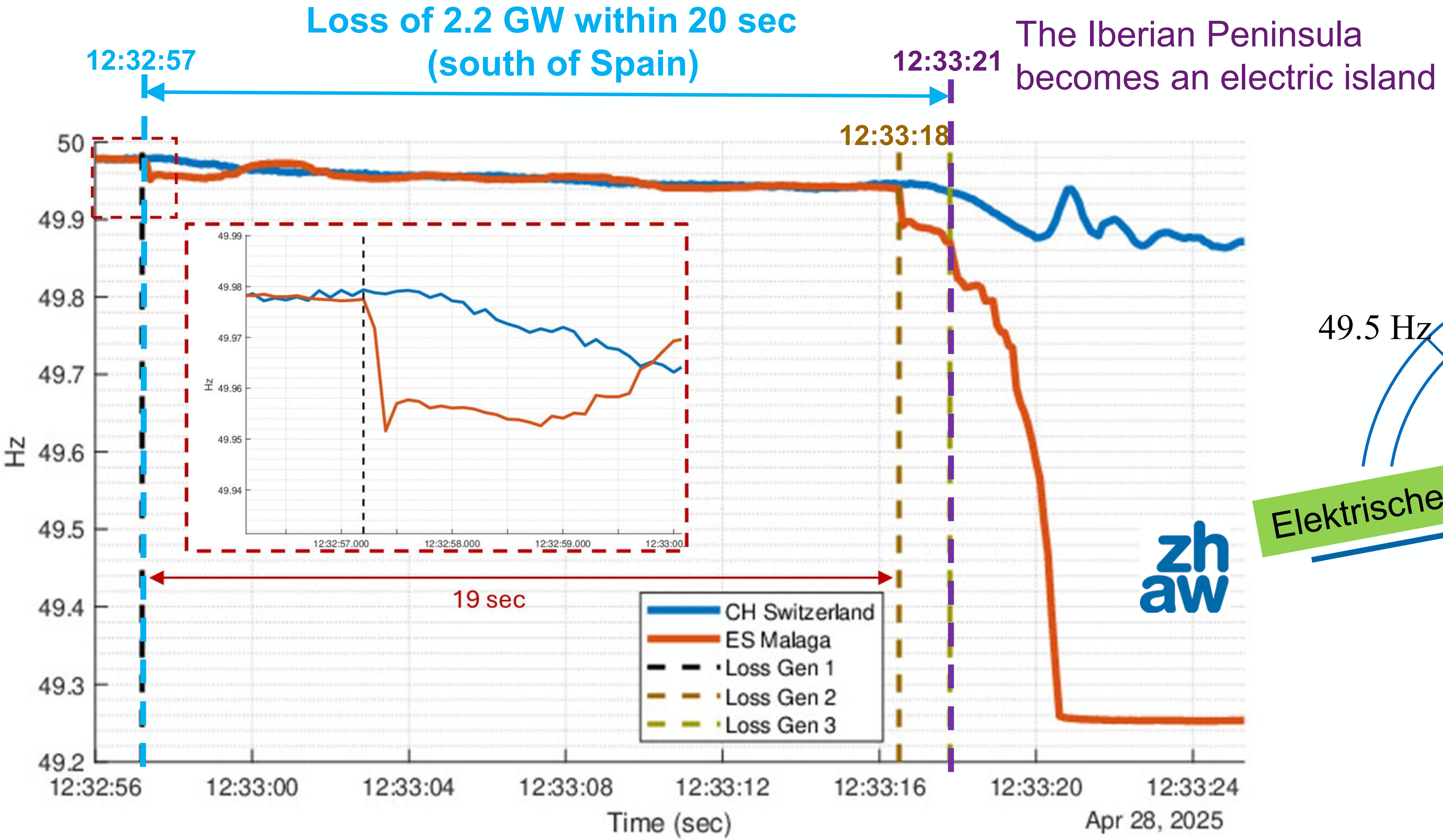
12:33:24

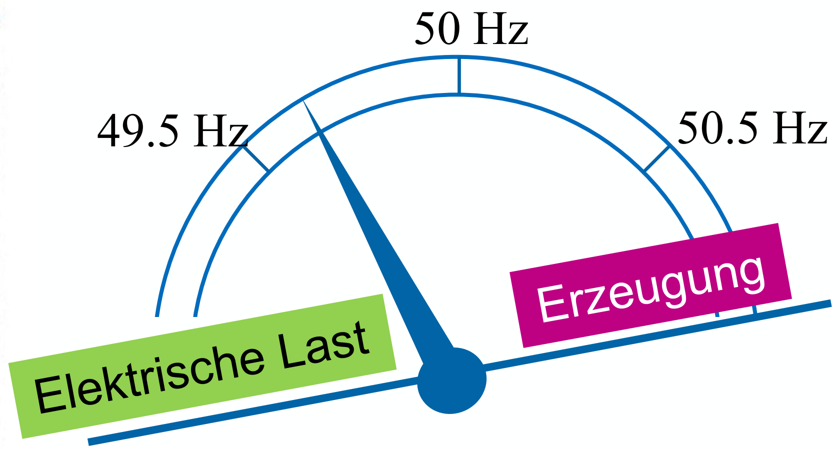
30 minutes prior the incident

- At approximately 12:03, large oscillations were also observed, which disappeared after about 4 minutes.
- Twelve minutes later, at around 12:19, significant oscillations were triggered again, lasting for about 3 minutes.



Last 20 sec prior blackout





First ENTSO-E Official Response (11 days after incident)

NEWS

ENTSO-E expert panel initiates the investigation into the causes of Iberian blackout

9 May 2025

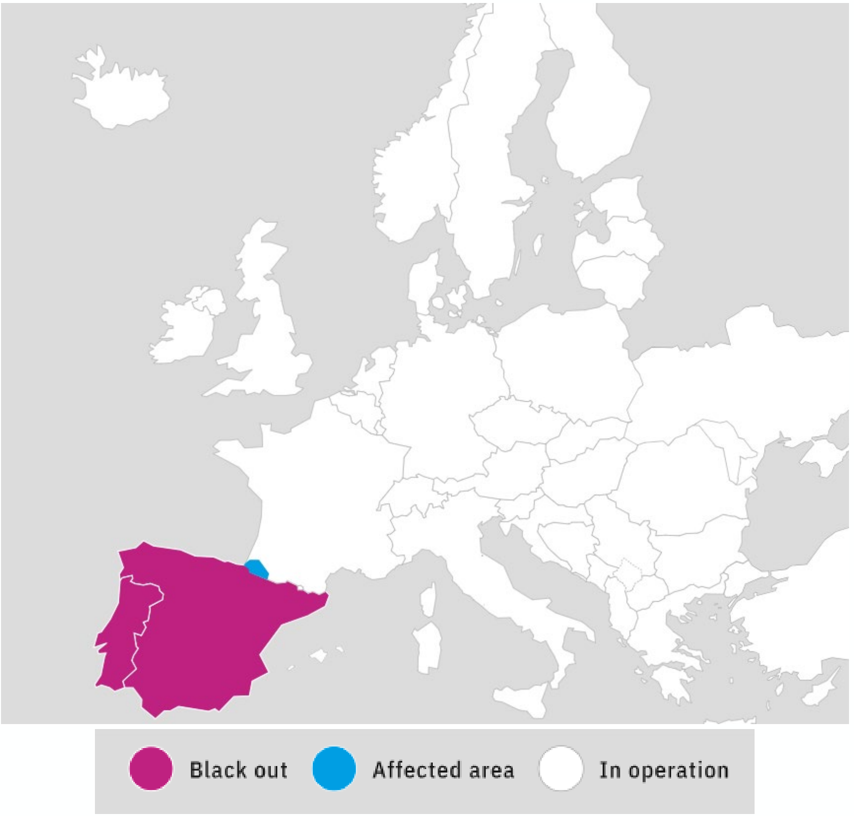
Data so far, have yielded the following sequence of events during the incident:

1. Starting at 12:32:57 CET and within 20 seconds afterwards, presumably a series of different generation trips were registered in the south of Spain, accounting to an initially estimated total of 2200 MW. No generation trips were observed in Portugal and France. As a result of these events the frequency decreased and a voltage increase is observed in Spain and Portugal.

2. Between12:33:18 and 12:33:21 CET, the frequency of the Iberian Peninsula power system continued decreasing and reached 48,0 Hz. The automatic load shedding defence plans of Spain and Portugal were activated.

3. At 12:33:21 CET, the AC overhead lines between France and Spain were disconnected by protection devices against loss of synchronism.

4. At 12:33:24 CET, the Iberian electricity system collapsed completely and the HVDC lines between France and Spain stopped transmitting power.



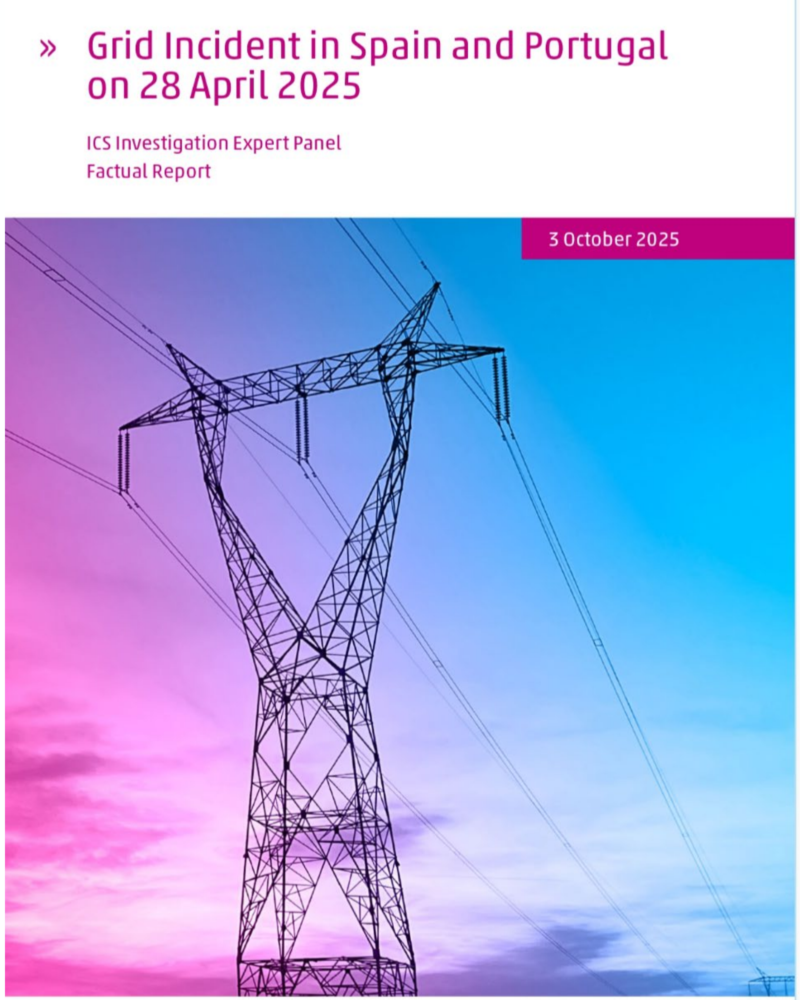
Link to official document

Incident Classification Scale

Scale 3 Major incident / 1TSO	
Priority-Short definition (Criterion short code)	
#1	Blackout (OB3)

ENTSO-E Factual and Final Reports

- **Factual Report**: 3 October 2025 (5 months after the incident).
- **Final Report**: 20 March 2026 (10 months after the incident).

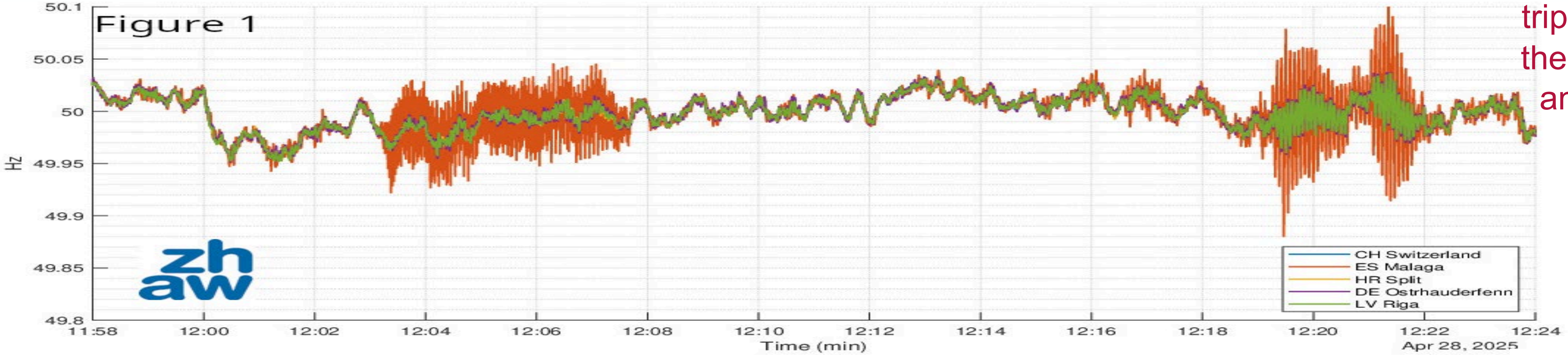


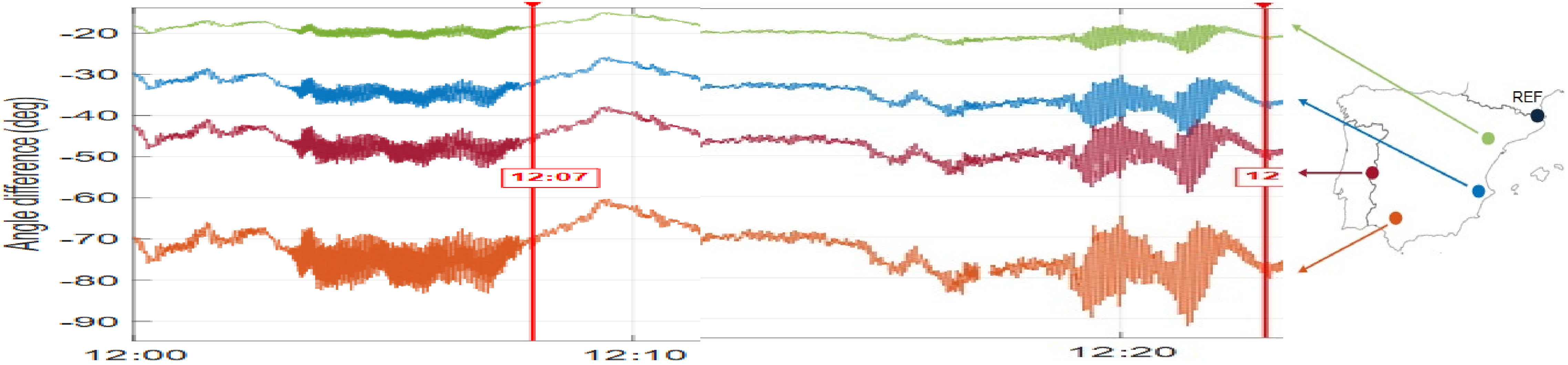
Official response

- It has been reported that "*the operators conducted the correct actions to mitigate the problem known as interarea-oscillations, however, these actions cause an increase in Voltage, leading to a system collapse (Blackout)*".

A vicious circle occurred

tripping power plants caused the reduction of power flows and consequently voltage increase



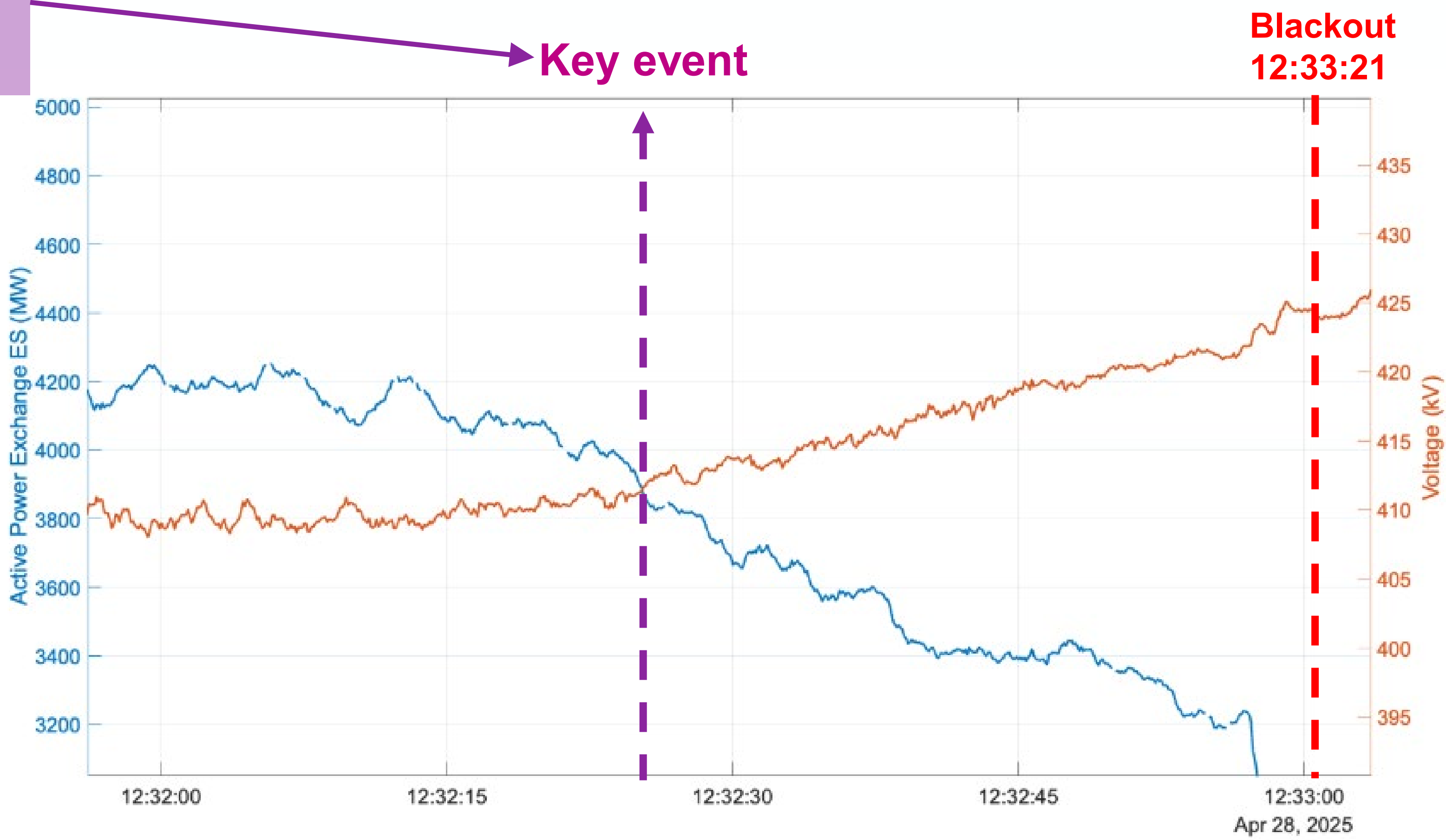


Official response

- **Key event**: When the active power began to decrease, the voltage started to increase.

- **Cause**: loss of more than 500 MW of wind and solar generation units connected to the distribution networks in Spain.

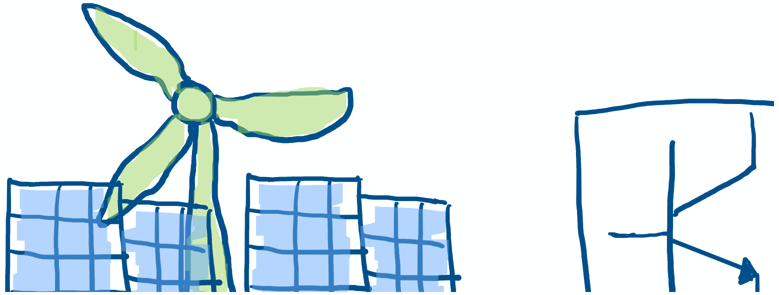
- **Why?**: Remains unknown.



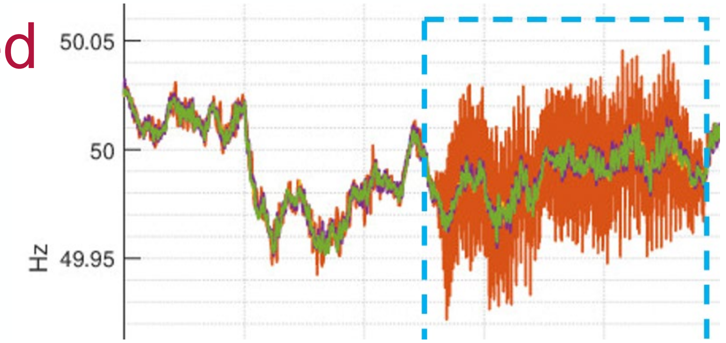
[link to official Blackout website]

3. Current Challenges and Opportunities

Challenges and Opportunities



- Open issues with the use of IBRs components
  - Voltage and Frequency support
  - Restoration capabilities
  - Legal framework and regulations
- Current methods for tuning damping controllers depend primarily on operator expertise, highlighting the need for more innovative and automated approaches



- Additional sources of virtual inertia, such as synchronous condensers equipped with flywheels, are required to enhance system stability.
- Monitoring systems are established but improved online and offline operational support tools are necessary.

Final thoughts

How close are we to the next blackout?

As long as we have a hybrid-electrical system (conventional-renewable based) and no significant improvements are done in terms of regulations and operational experience, **the next blackout in continental Europe may be closer than we expect (personal opinion)**

- **Why?**
  The **learning curve in the managing of a hybrid-electrical system**. Electrical power systems are an extremely conservative field, reluctant to use technology as it becomes available, e.g. the use of AI. Moreover, development of key transmission infrastructure (new transmission lines) is close to impossible.

- **Can we still achieve a net-zero power system?**
  Yes, we will reach a sustainable power grid. These events are only **bumps in the road** and are necessary to fix and improve the way of operating this hybrid systems.

Invitation to join DynPOWER 2026

Rafael Segundo • You
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The workshop features an outstanding lineup of international experts, the key
📍 Venue: Casinotheater Winterthur, Switzerland
📅 Date: Monday, 7 September 2026
🌐 Hybrid Event: Attend onsite (limited availavility) or online
💲 Participation is free of charge,

🔗 Workshop detailed program and registration instructions:
https://lnkd.in/eS2ZzTEk

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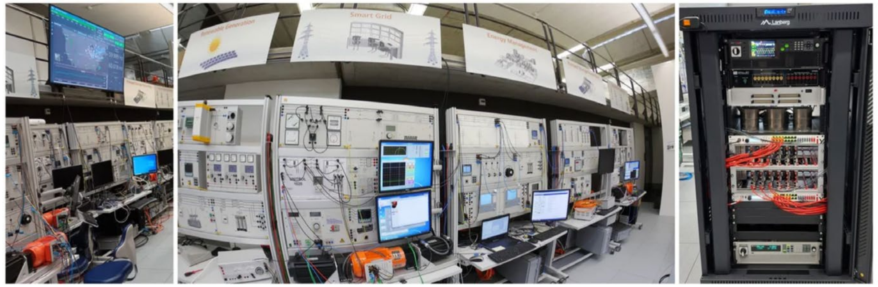
ZHAW Electric Power System Group

Head: Prof. Petr Korba

For more technical details on the discussed topic visit:

https://www.zhaw.ch/en/engineering/institutes-centres/iefe/energy-storage-and-grids/electric-power-systems-and-smart-grids

Electric Power Systems and Smart Grids



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