Willkommen zu den 47. Energy-Charts Talks

10 Jahre Energy-Charts

47. Energy-*Charts* Talks

Bruno Burger
- Stromerzeugung im April 2025

Leonhard Probst
- Blackout in Spanien und Portugal

Sönke Rogalla
- Grid Codes
- Netzbildende Wechselrichter

Montag, 05.05.2025, Live um 17 Uhr

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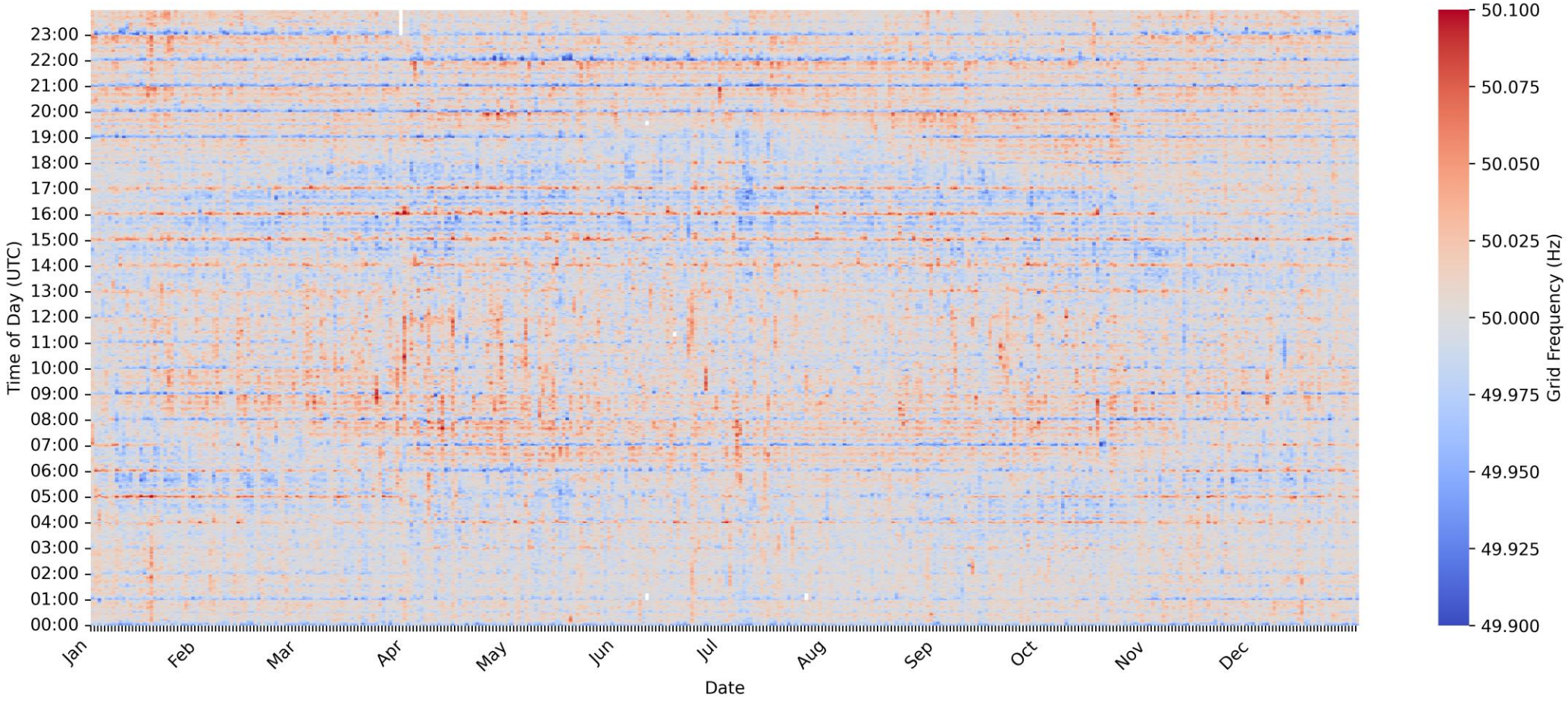
Grid frequency heatmap

2024



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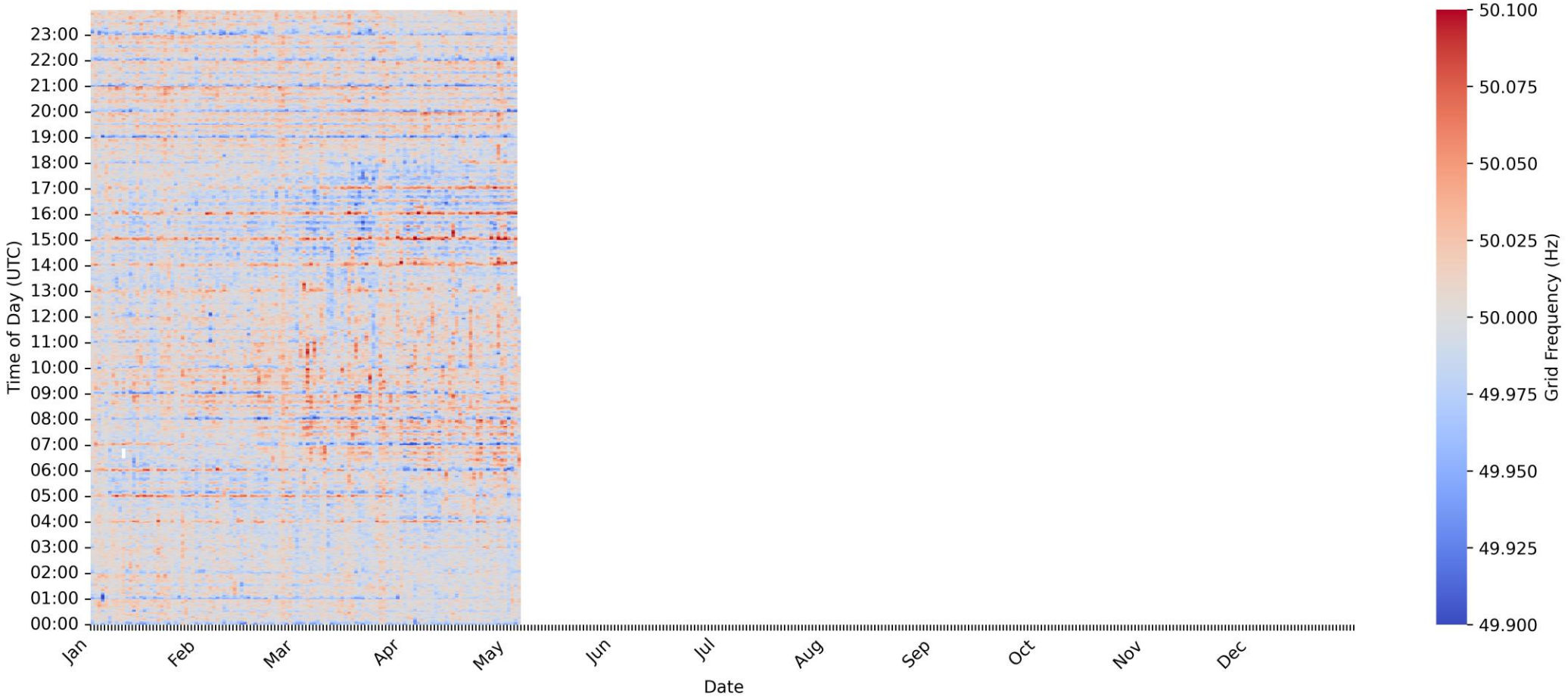
Grid frequency heatmap

2025



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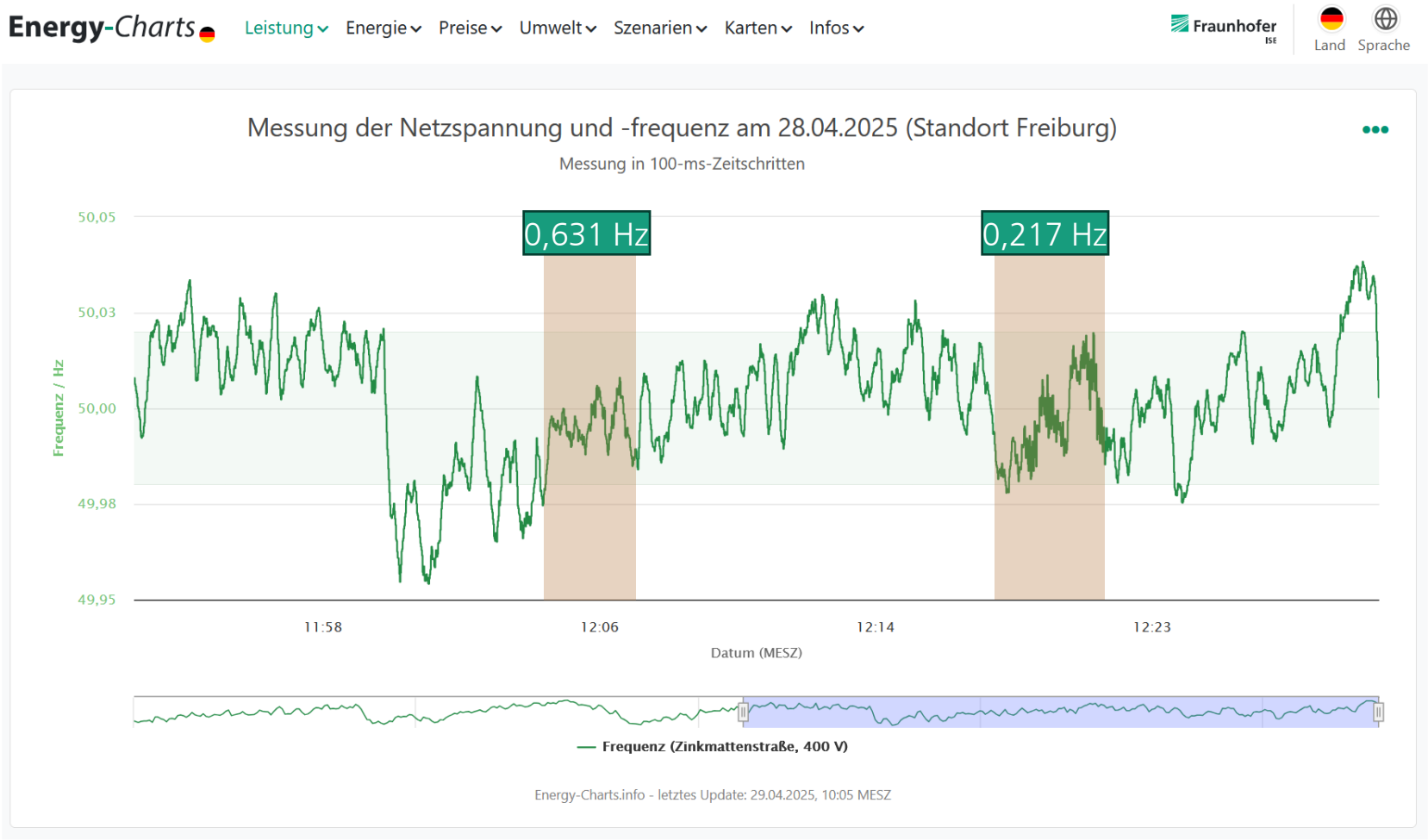
Frequenzmessung im Vorfeld des Blackouts in Spanien/Portugal



https://energy-charts.info/charts/frequency/chart.htm?l=de&c=DE&timeslider=1&hour=10&datetimepicker=28.04.2025

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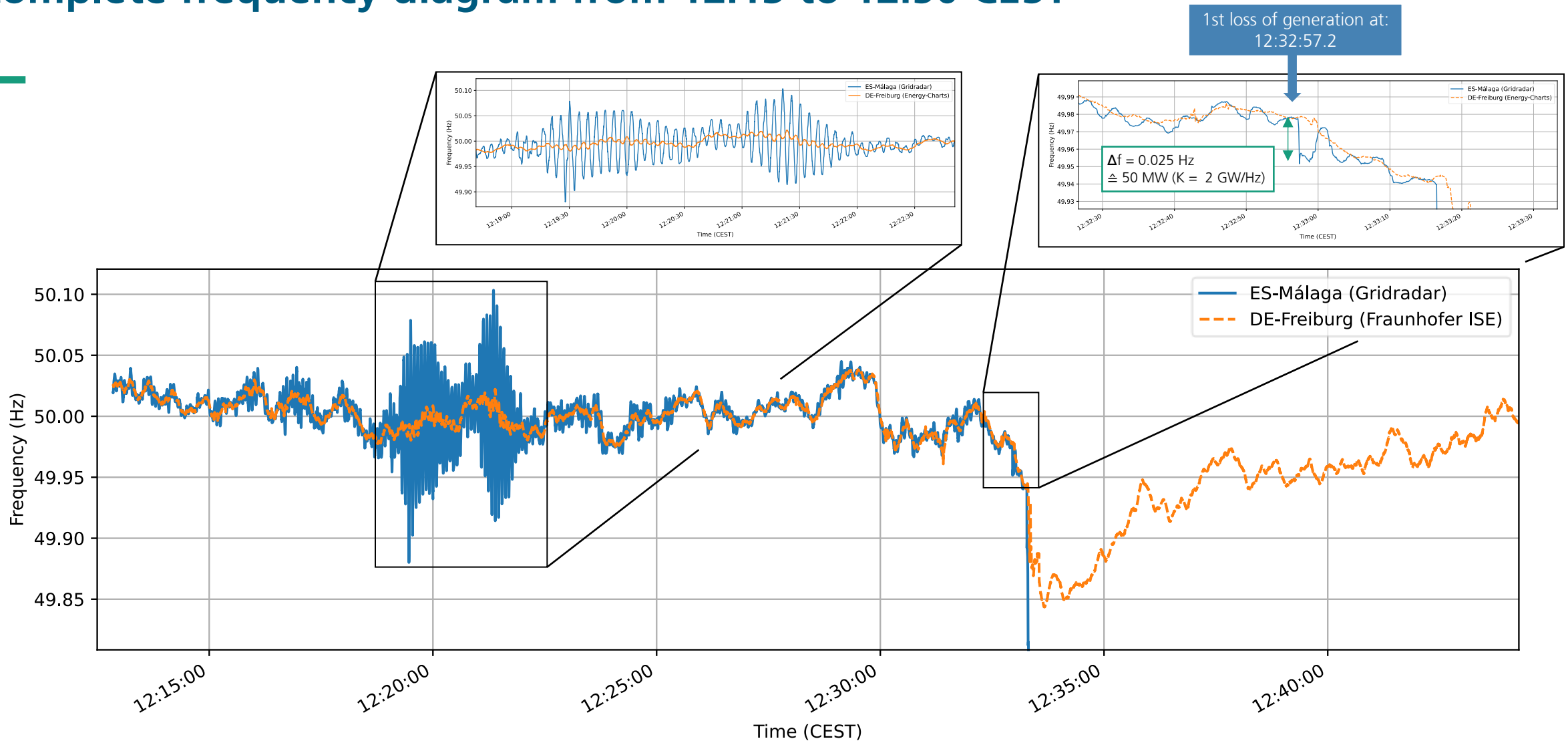
Complete frequency diagram from 12:13 to 12:50 CEST



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Oscillation event on December 1st, 2016

[1]

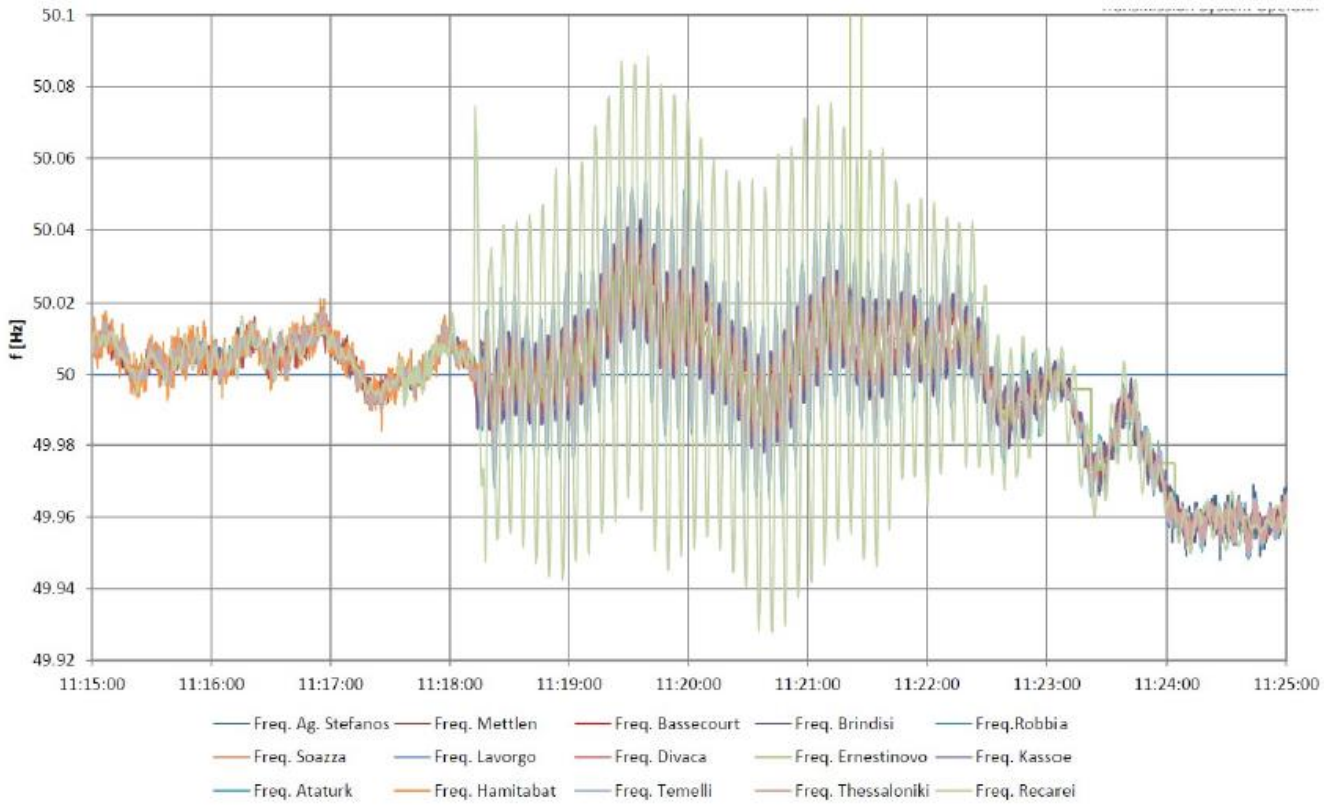

Figure 7: Frequency recordings in different locations of CE (Swissgrid).

- Oscillation frequency: 0.15 Hz
- North south mode: 0.25 Hz
- East west mode: 0.15 Hz (was 0.2 – 0.3 Hz before coupling of Turkey)
- Last coupling events:
  - Ukraine: 16th March, 2022
  - Baltics: 9th February, 2025

[1]

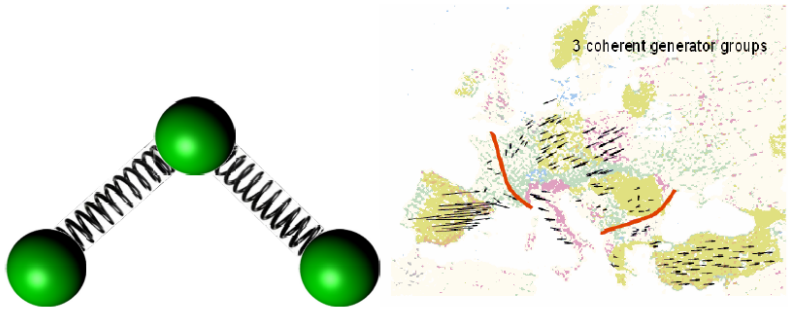

Figure 1. East-Centre-West mode. Mechanical analogy and mode shape (E. Grebe et al.)

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[1] https://www.entsoe.eu/Documents/SOC%20documents/Regional_Groups_Continental_Europe/2017/CE_inter-area_oscillations_Dec_1st_2016_PUBLIC_V7.pdf

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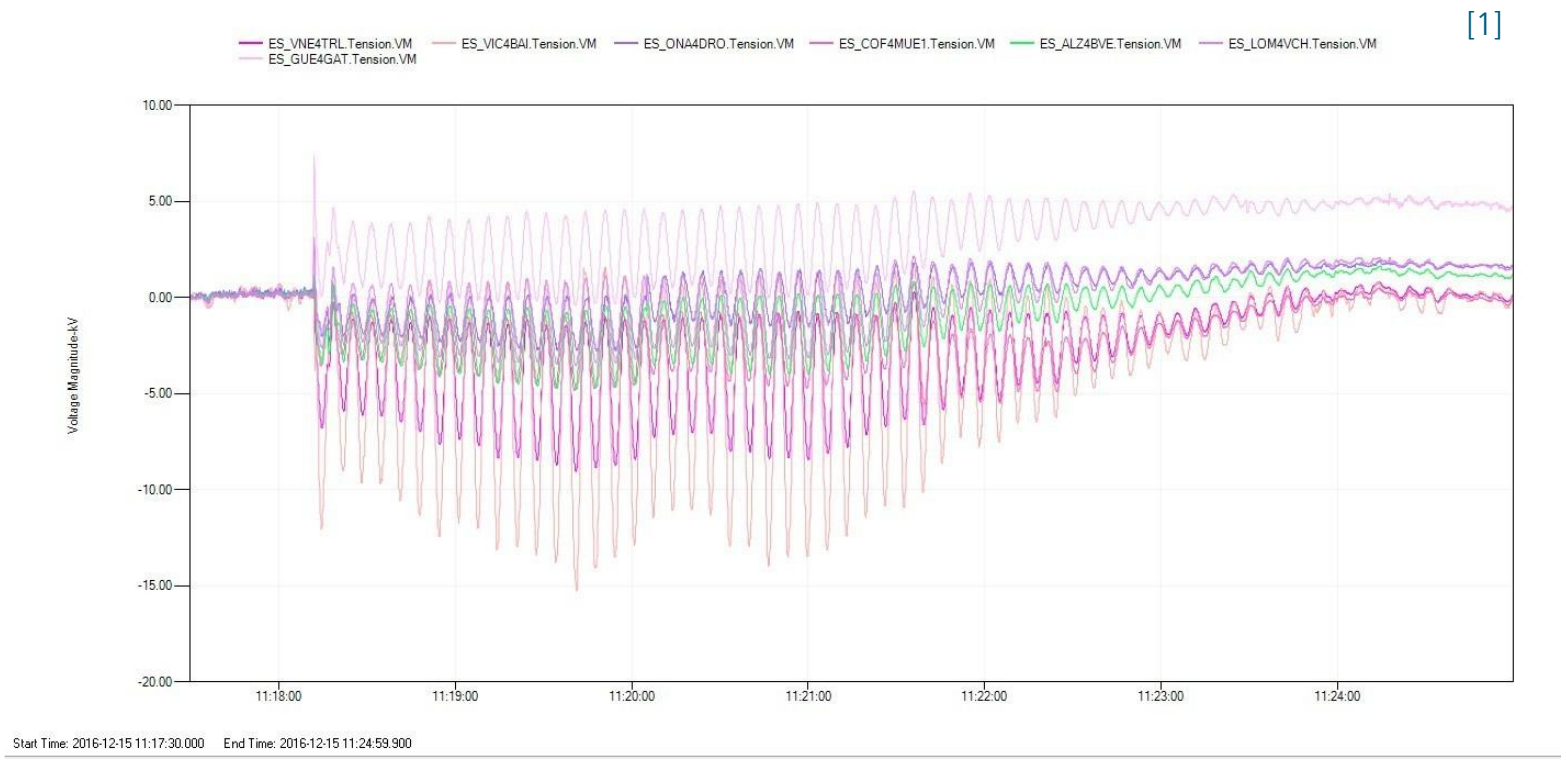
Oscillations are also observed in the voltage measurements



- Screenshots from social media indicate, that there were very high voltage oscillations appearing on the Iberian peninsula on 28th of April
- Frequency oscillations could be just secondary effects
- Generators need to operate according to grid codes and be capable for LVRT and HVRT (low and high voltage ride through)
- However, if limits are exceeded, grid codes require disconnection

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[1] https://www.entsoe.eu/Documents/SOC%20documents/Regional_Groups_Continental_Europe/2017/CE_inter-area_oscillations_Dec_1st_2016_PUBLIC_V7.pdf

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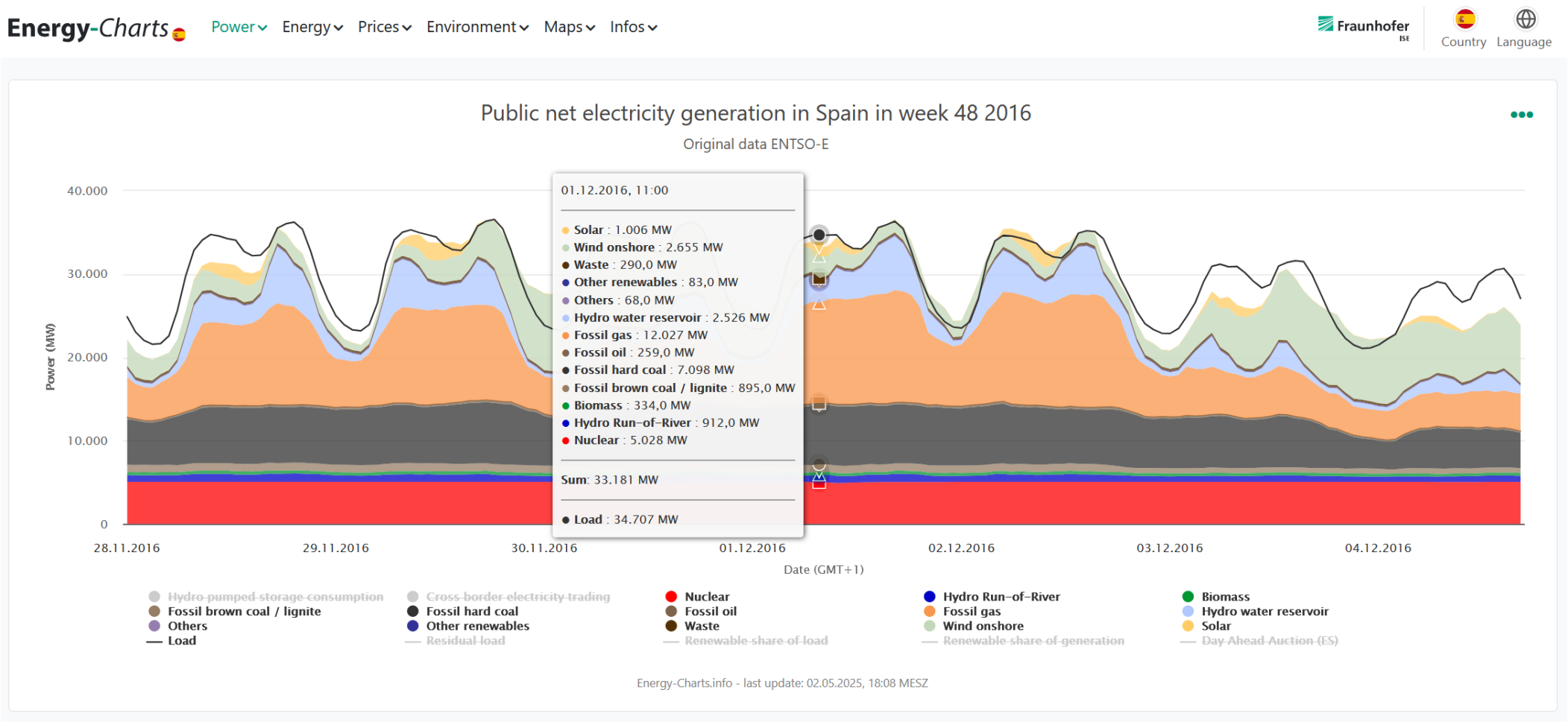
Public net electricity generation in Spain in week 48, 2016



https://energy-charts.info/charts/power/chart.htm?l=en&c=ES&year=2016&week=48

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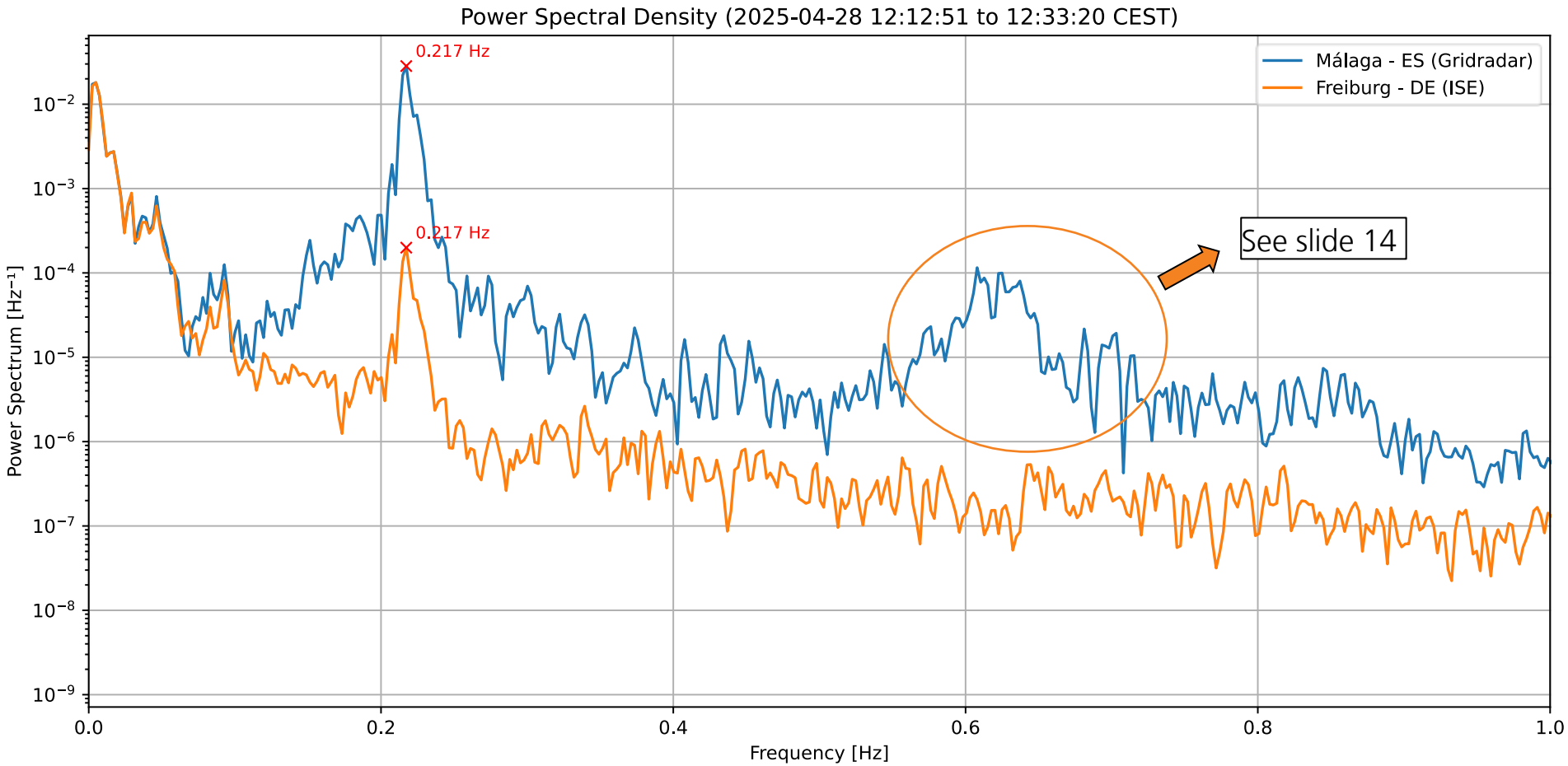
Spectral analysis of osciallations prior to blackout



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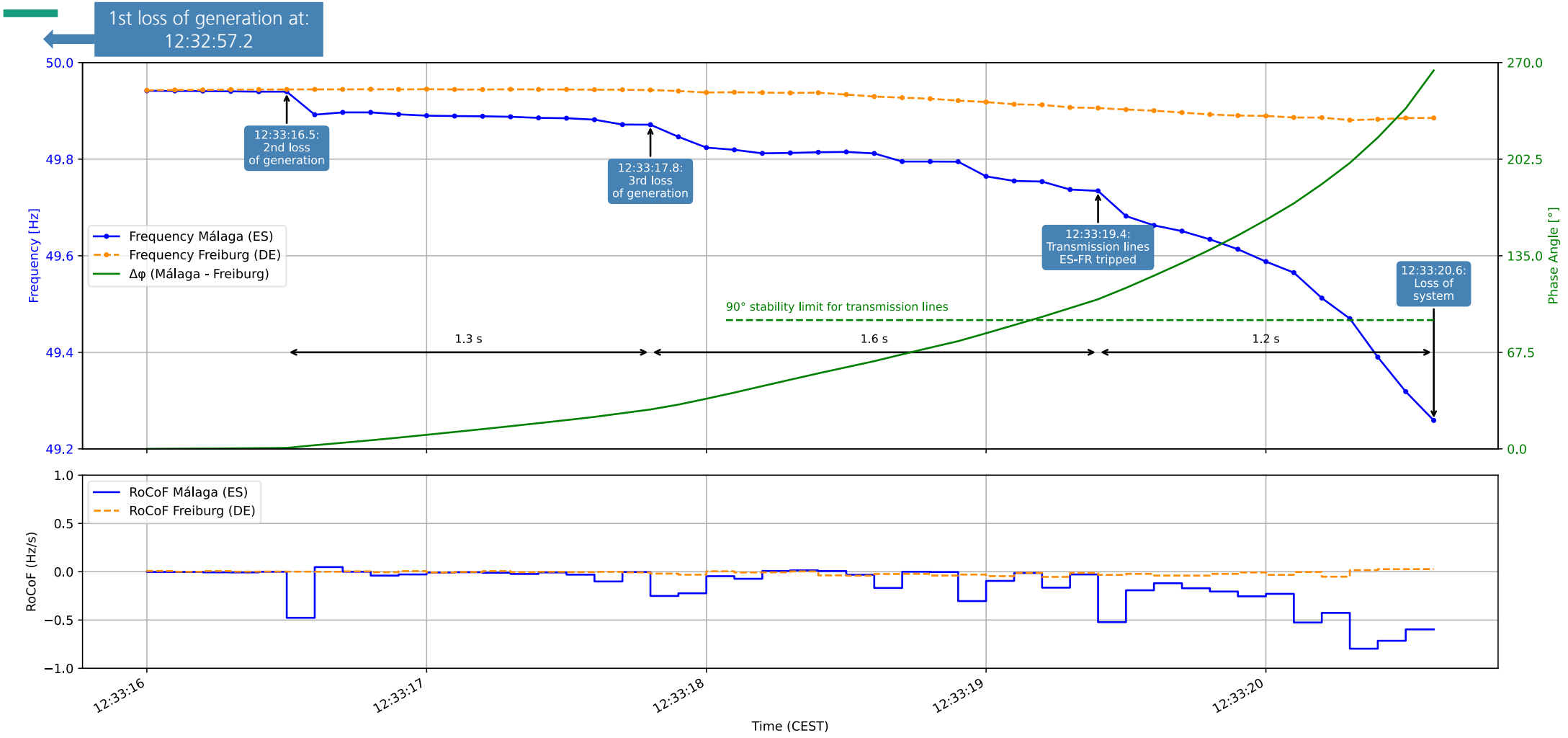
Timeline of system break starting at 12:33:16.5 CEST

Max. RoCoF for Málaga: -0.8 Hz/s



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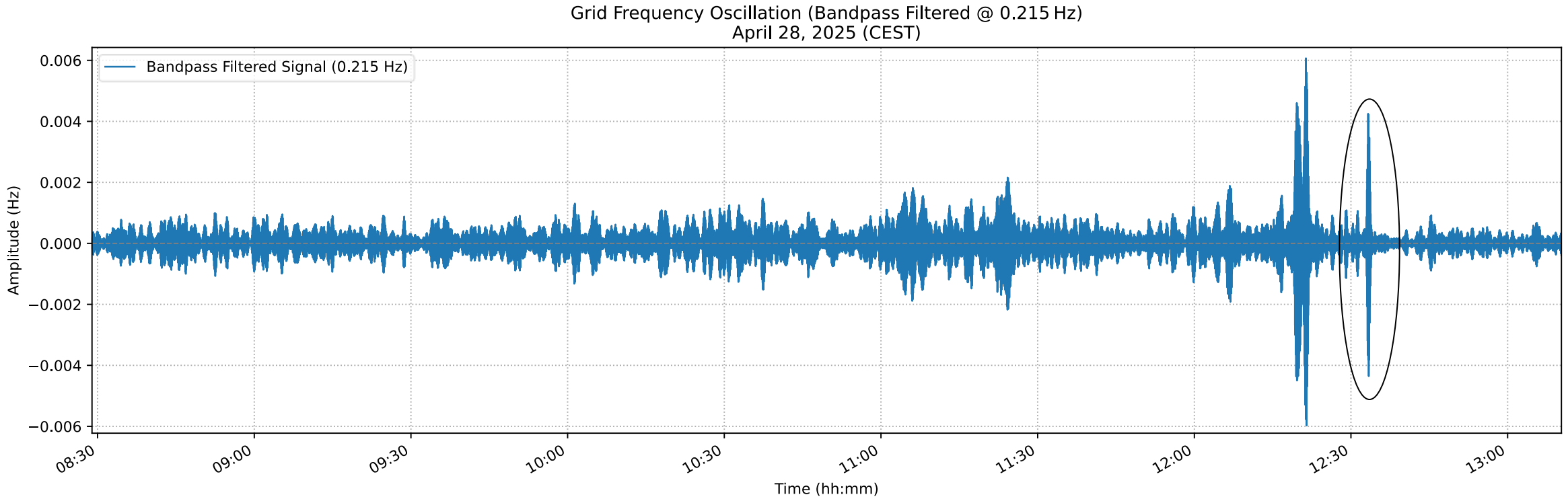
Bandpass filtering of frequency signal

Measurement location: DE-Freiburg (Energy-Charts)



- 0.217 Hz oscillation also measured in Freiburg just before system split (12:33 CEST)

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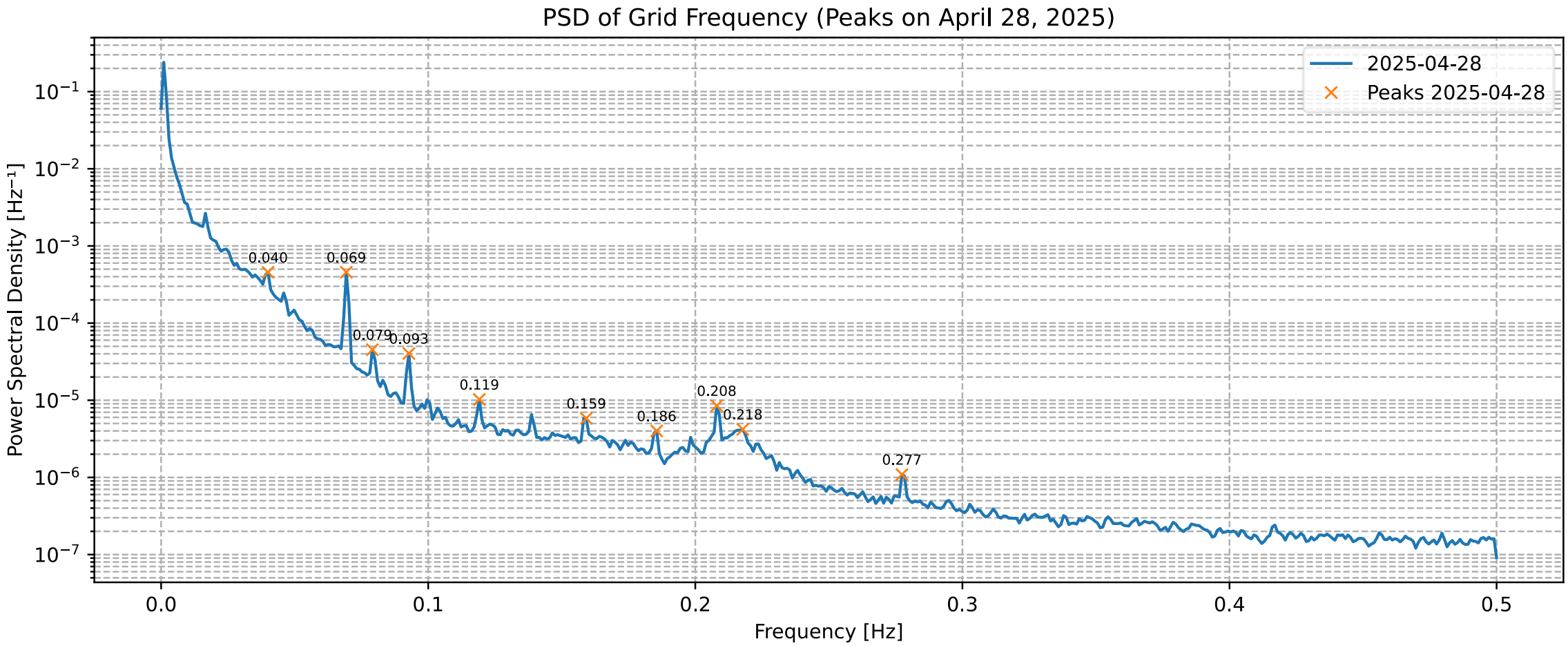
Power spectral density for April 28th, 2025

Measurement location: DE-Freiburg (Energy-Charts)



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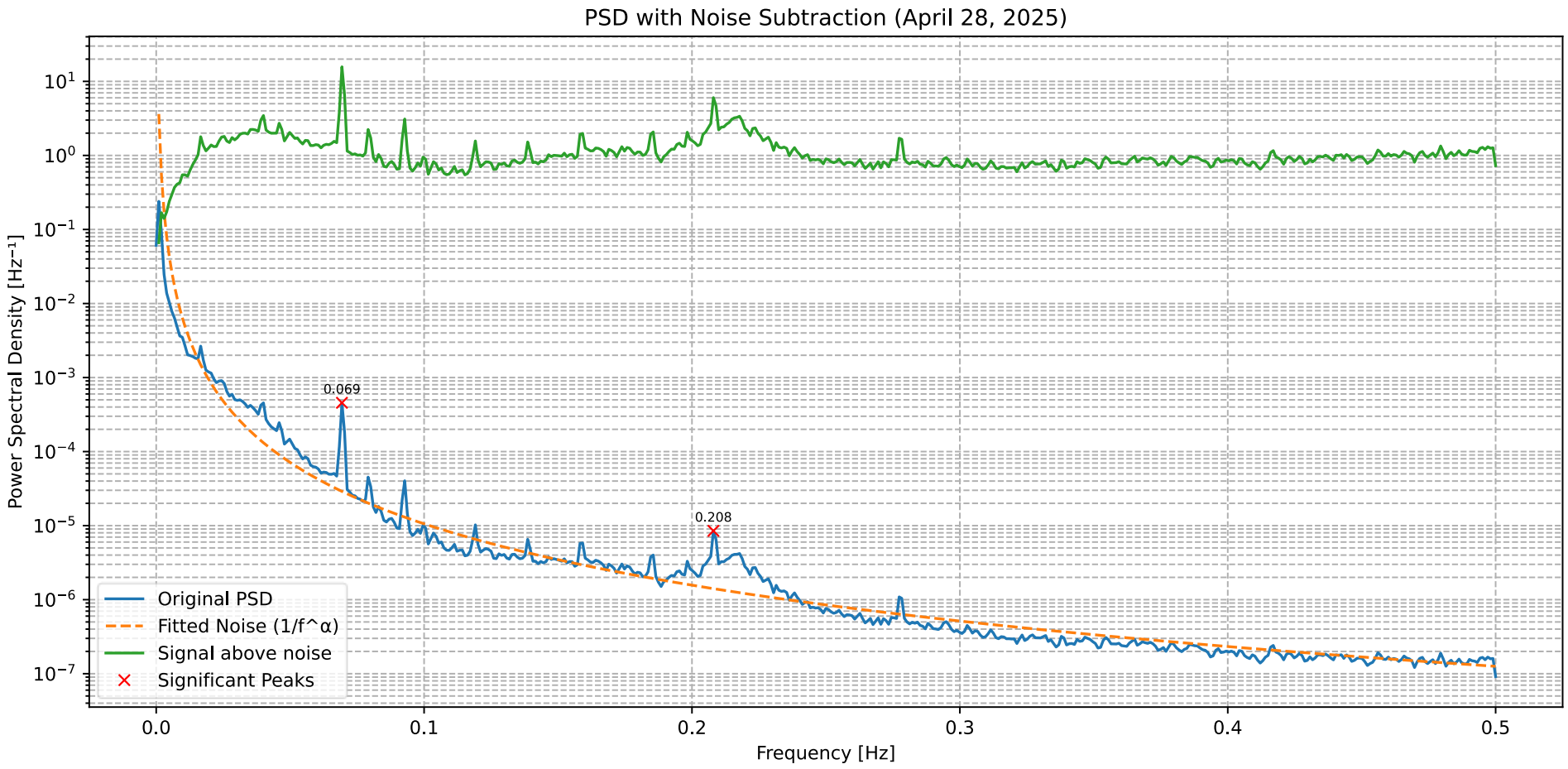
Power spectral density for April 28th, 2025

Noise substraction model



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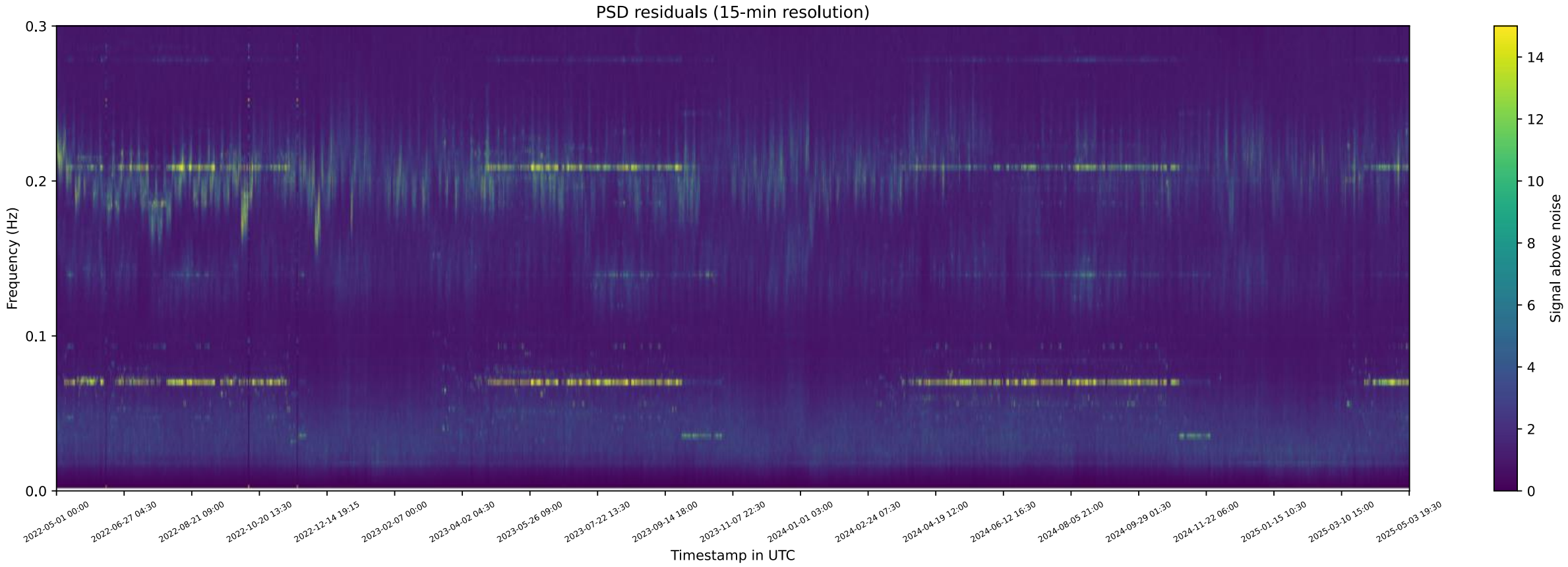
Sesonal behavior of oscillation modes



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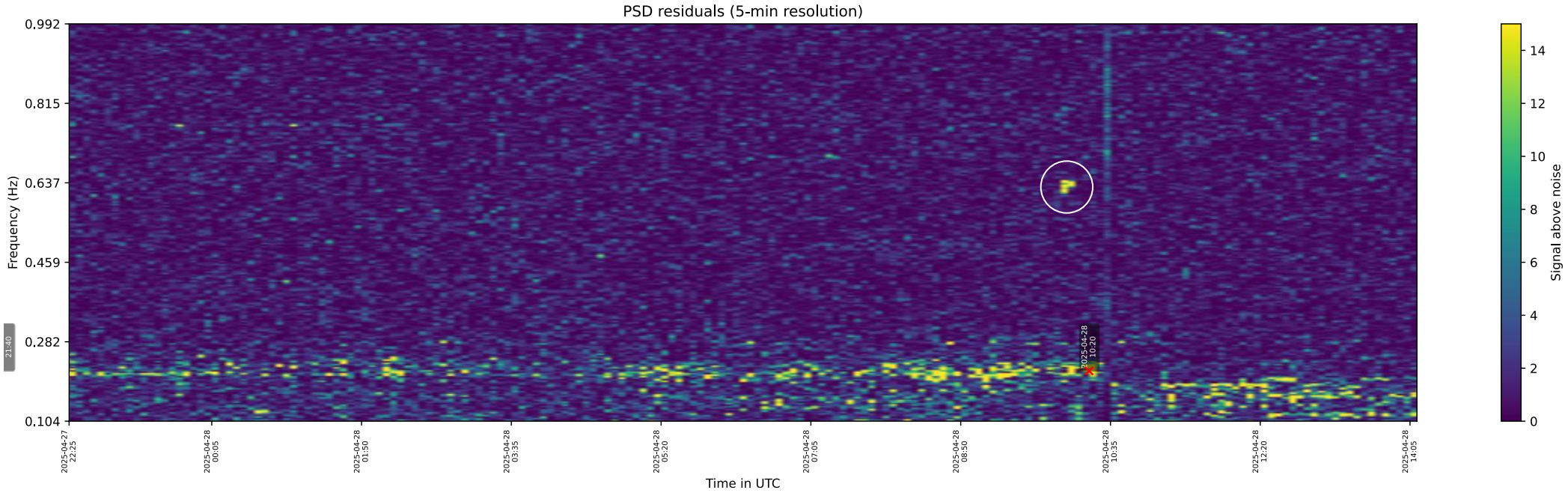
PSD residuals

28th of April, 2025



- 0.631 Hz oscillation measured in Freiburg starting at 12:03 CEST, prior to oscillations on slide 5
- Very unique frequency, not measured before
- Also visible on psd of measurement in Málaga starting at 12:13 CEST

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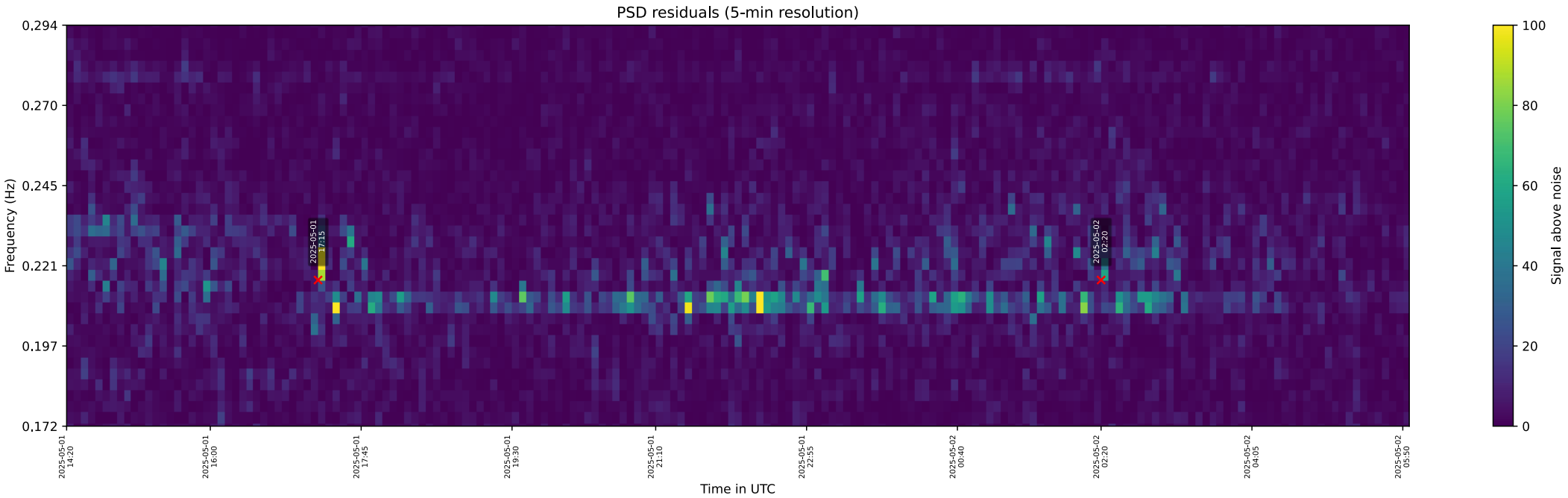
PSD residuals

1st of May, 2025



- Oscillation mode with 0.217 Hz is still measurable
- Most significant event starting at 1st of May at 19:15 CEST

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Momentanreserve

Rotierende Masse ≠ Momentanreserve

- Momentanreserve ist für stabilen Betrieb der Stromnetze notwendig, damit die ausreichende Trägheit gewährleistet ist, bis Kraftwerke Ausfälle durch ihre Regelung kompensieren können (Regelenergie)
- Momentanreserve in Europa: etwa 300 GWs (Spanien etwa 45 GWs)

Netztrennung Spanien 28.04.2025

$$\omega_1 := 2 \cdot \pi \cdot 49.94 \cdot Hz \qquad \omega_2 := 2 \cdot \pi \cdot 49.26 \cdot Hz$$

$$\Delta W_rel := \frac{\frac{1}{2} \cdot J \cdot \left(\omega_1^{\,2} - \omega_2^{\,2}\right)}{\frac{1}{2} \cdot J \cdot \omega_1^{\,2}} = 0.027$$

- Vorgang auf Folie 10:
  $\Delta T = 4{,}1$ s, $f_1 = 49{,}94$ Hz, f2 = 49,36 Hz
- Weiterer Frequenzabfall könnte aufgetreten sein, aber dafür liegen aktuell keine Daten vor
- Kraftwerke gaben während des Ausfalls in Spanien nur 2,7% der gespeicherten Rotationsenergie ab
- 1,215 GWs (mittlere Leistung: 296 MW)

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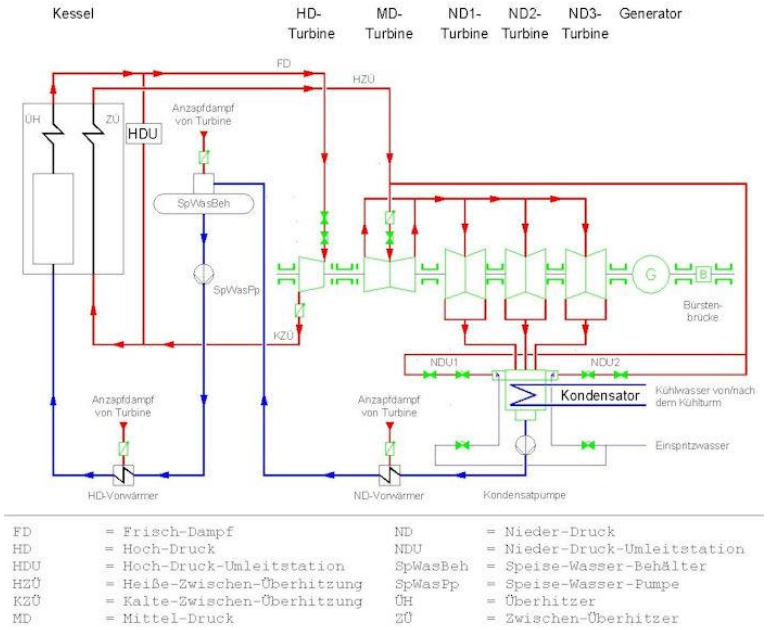
Beispiele für Momentanreserve von Kraftwerken

- Klassisches Dampfkraftwerk: 9 MWs (472 MW Nettoleistung)
- Blackhillock Battery Storage[1]: 370 MWs (200 MW / 400 MWh)

- Momentanreserve wird auch in zukünftigen Energiesystemen benötigt
- Dafür stehen bereits heute moderne und effiziente Technologien bereit
- Dafür notwendig: **Netzbildende Wechselrichter**

Grün: Trägheitsmoment des Generators



Schaltbild eines süddeutschen Dampfkraftwerks

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[1] https://www.sma.de/en/newsroom/news-details/sma-solution-secures-grid-stability-in-europes-largest-battery-system

Contact

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