

Wide Area Monitoring WAM

Asja Derviskadic
Head of Network Modelling & Analysis

Lausanne, 26 May 2025

Outlook

Context and Motivation

Wide Area Monitoring Systems

Oscillatory Stability Analysis

Swissgrid WAM

Events in 2024 in Continental Europe

Takeaways

Outlook

Context and Motivation

Wide Area Monitoring Systems

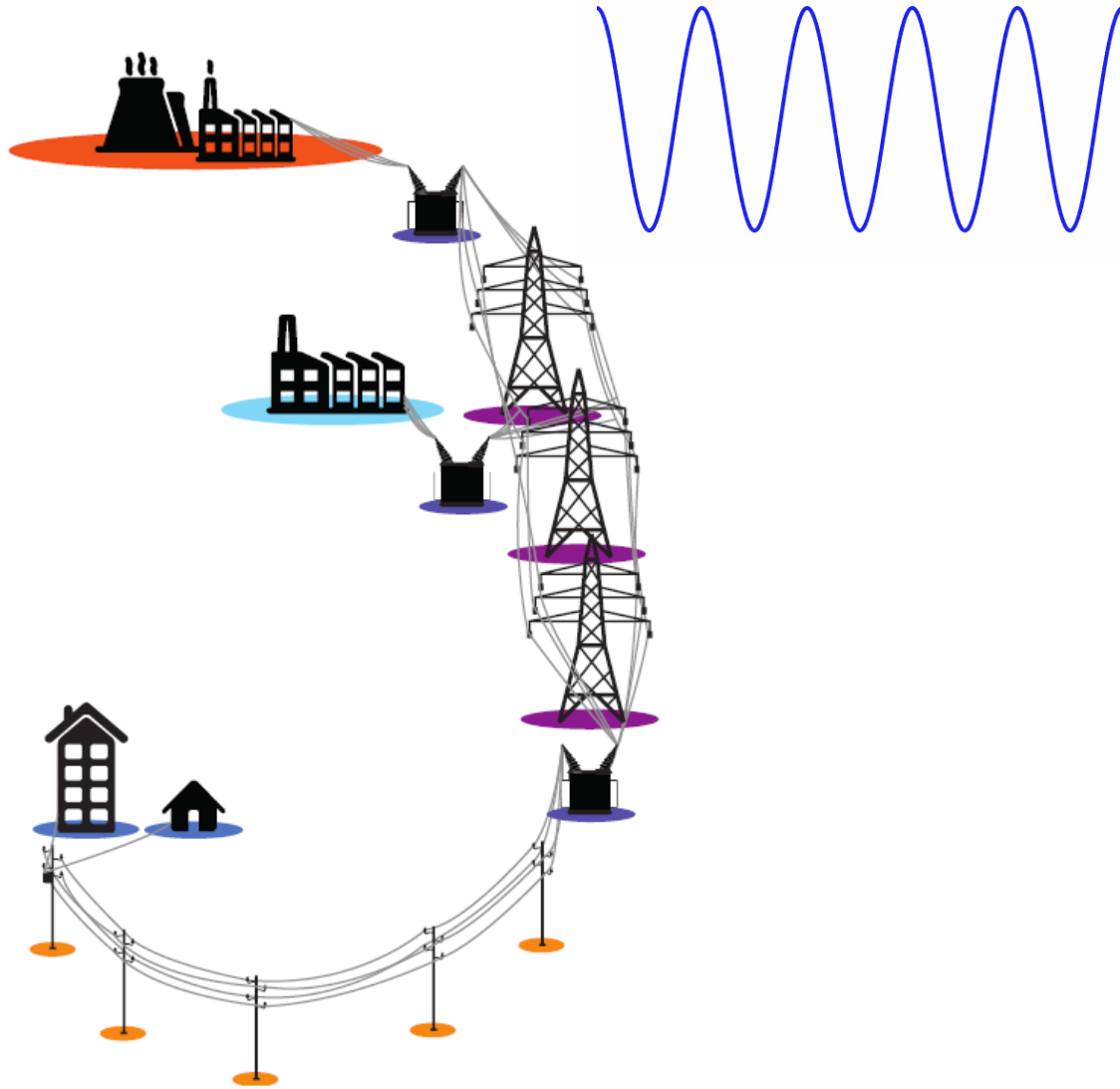
Oscillatory Stability Analysis

Swissgrid WAM

Events in 2024 in Continental Europe

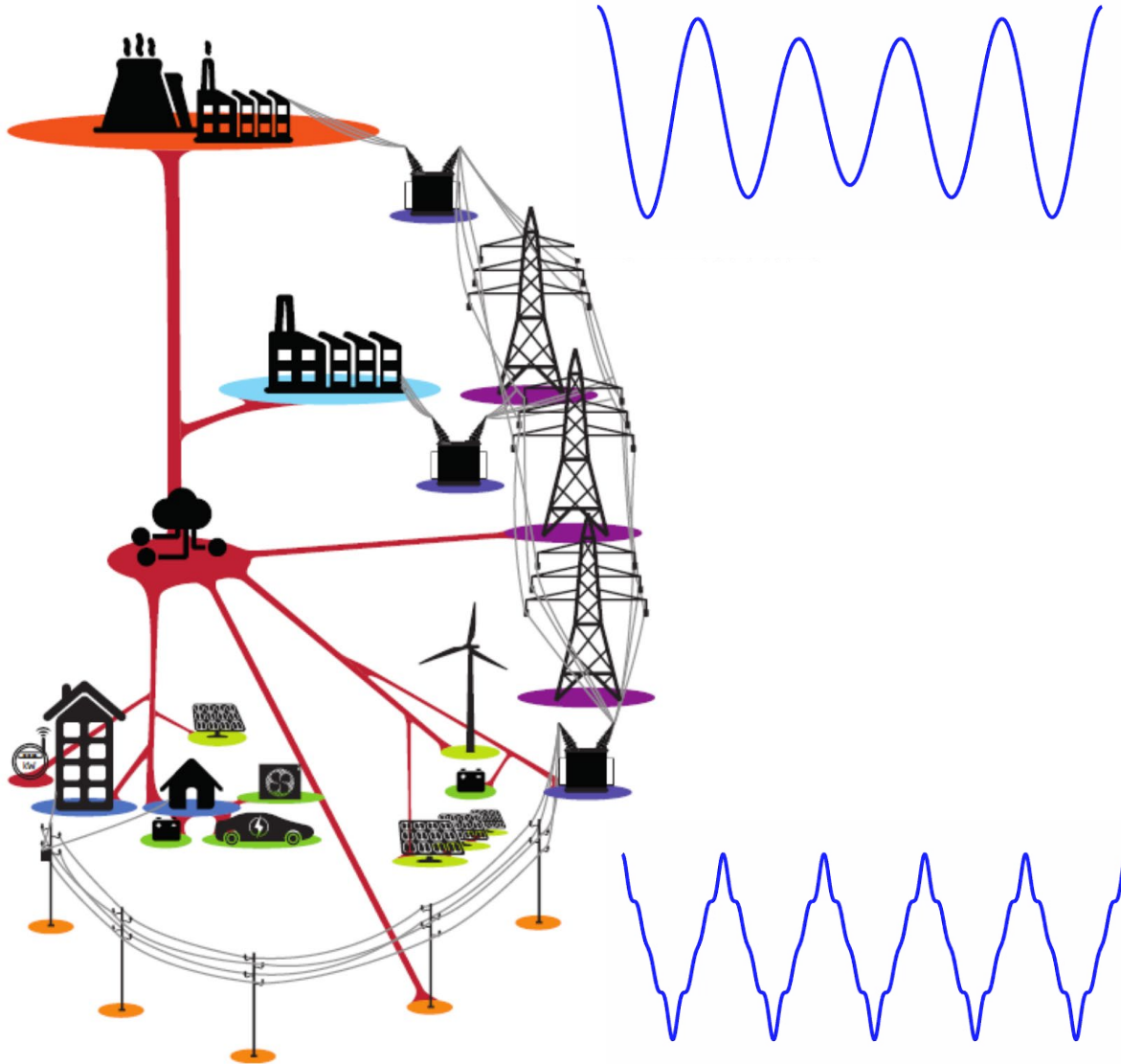
Takeaways

Context and Motivation



- **Traditional power system paradigm:**
- Centralized generation
- Unidirectional power flows
- Synchronous generators → Inertia
- **Steady state**

Context and Motivation



- **Traditional power system paradigm:**

- Centralized generation
- Unidirectional power flows
- Synchronous generators → Inertia
- Steady state

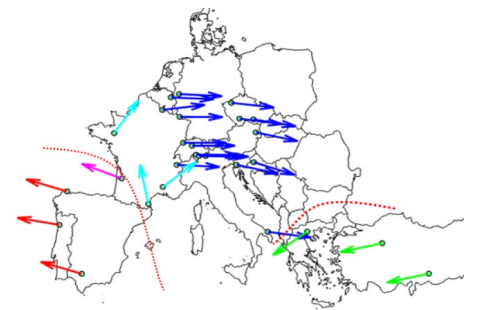
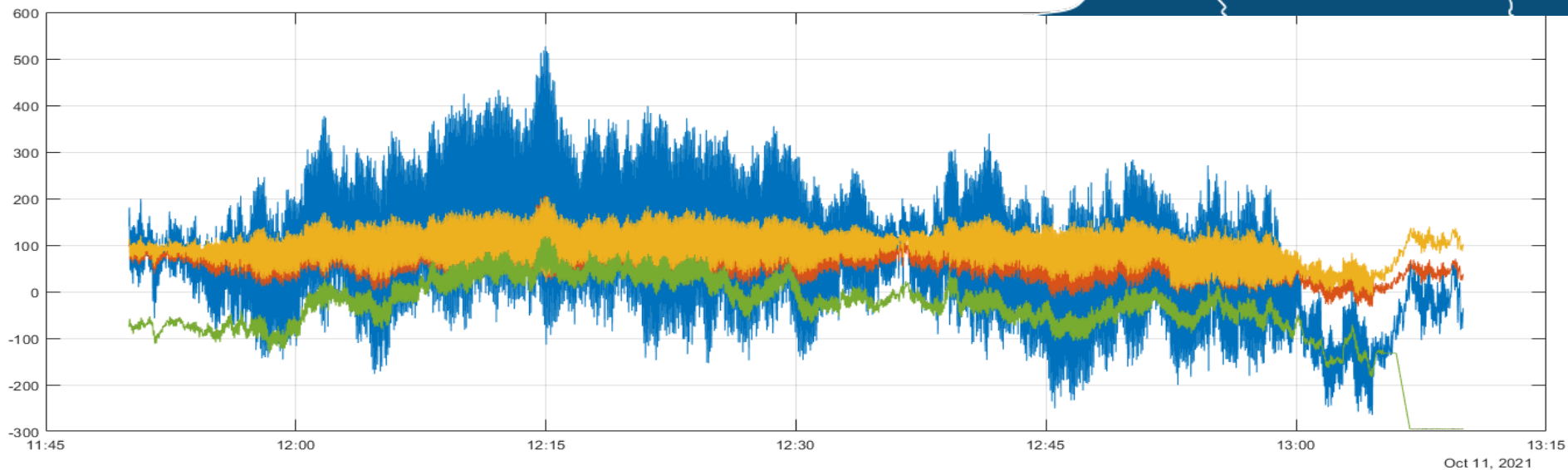
- **Modern power system paradigm:**

- Large interconnected systems (Wide Area)
- Decentralized generation
- Bi-directional power flows
- Renewables → **Low inertia**
- **Dynamic state** & harmonic components

Context and Motivation: Inter-Area Oscillations

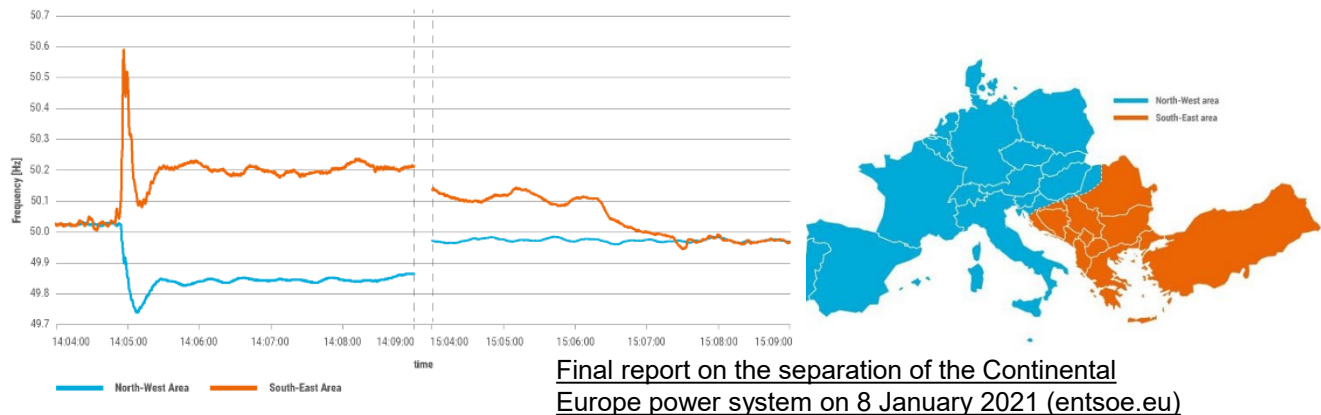
- North-South mode ~ 0.25 Hz
- East-West mode ~ 0.15 Hz
- East-Center-West ~ 0.18 Hz
- Swissgrid is obligated by the ENTSO-E Network Codes (SO GL Article 38 and 39) to continuously monitor power oscillations within its own grid and across the entire Continental European synchronous area.

October 11th, 2021 11h55

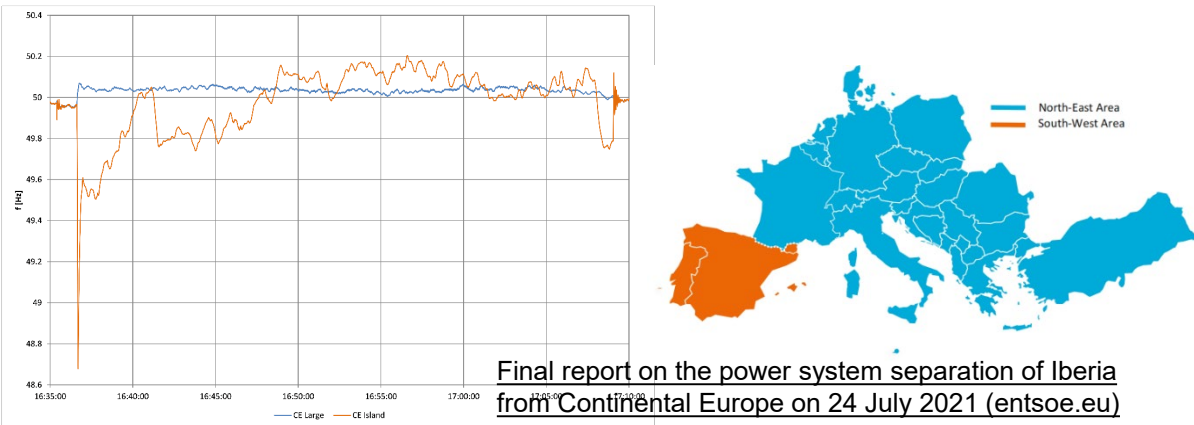


Context and Motivation: Major Incidents in Continental Europe 2021-2025

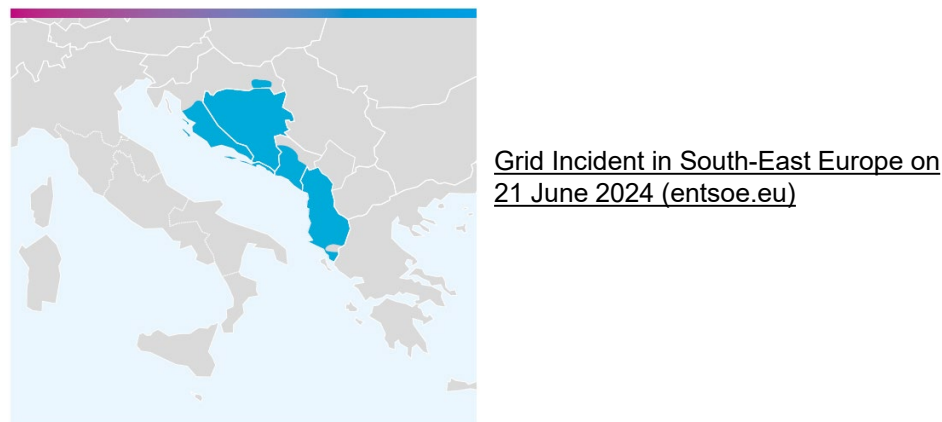
System Split January 8, 2021 14h05



System Split July 24, 2021 16h35



Blackout June 21, 2024 12h20



Blackout April 28, 2025 12h33



Outlook

Context and Motivation

Wide Area Monitoring Systems

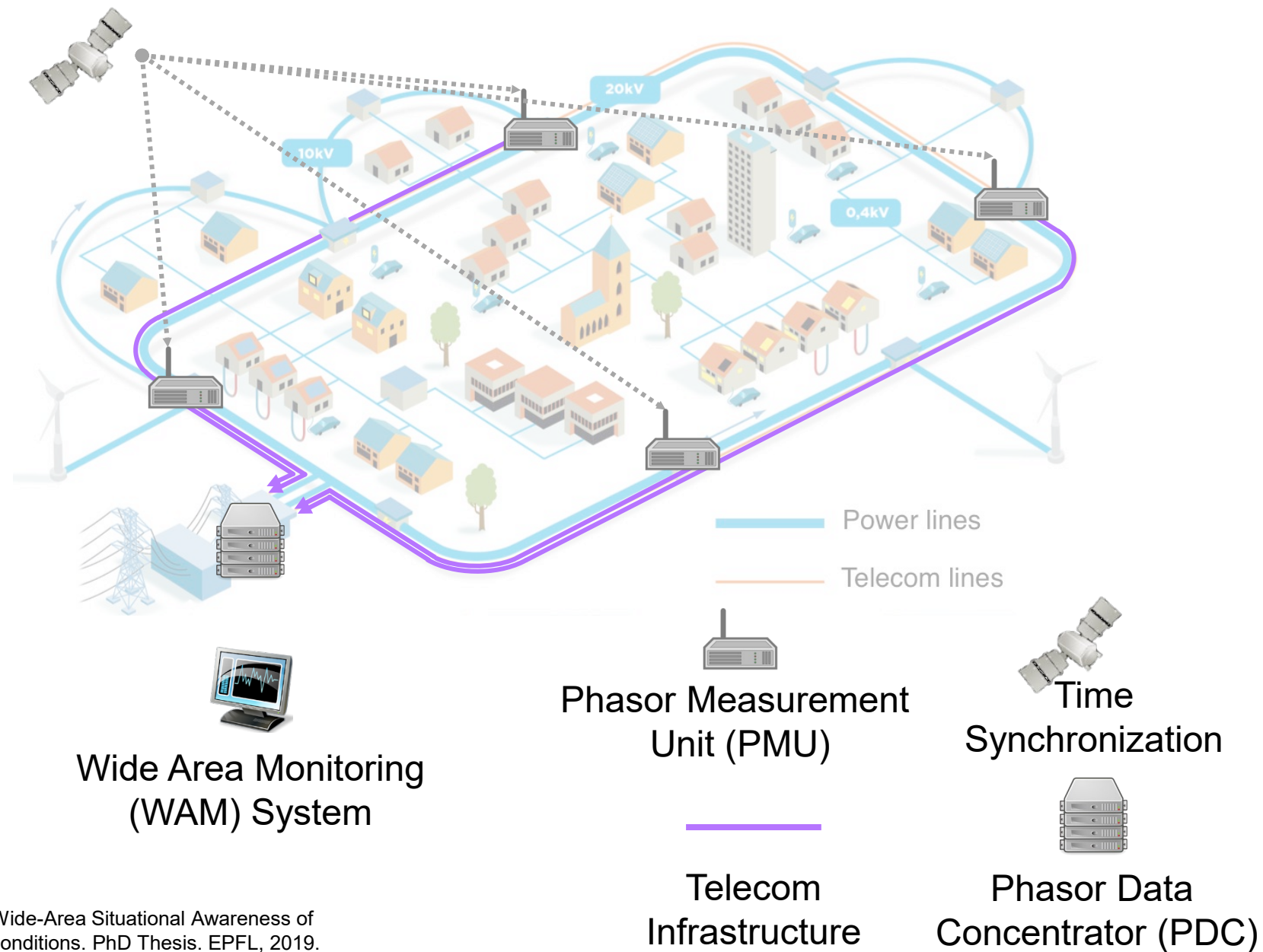
Oscillatory Stability Analysis

Swissgrid WAM

Events in 2024 in Continental Europe

Takeaways

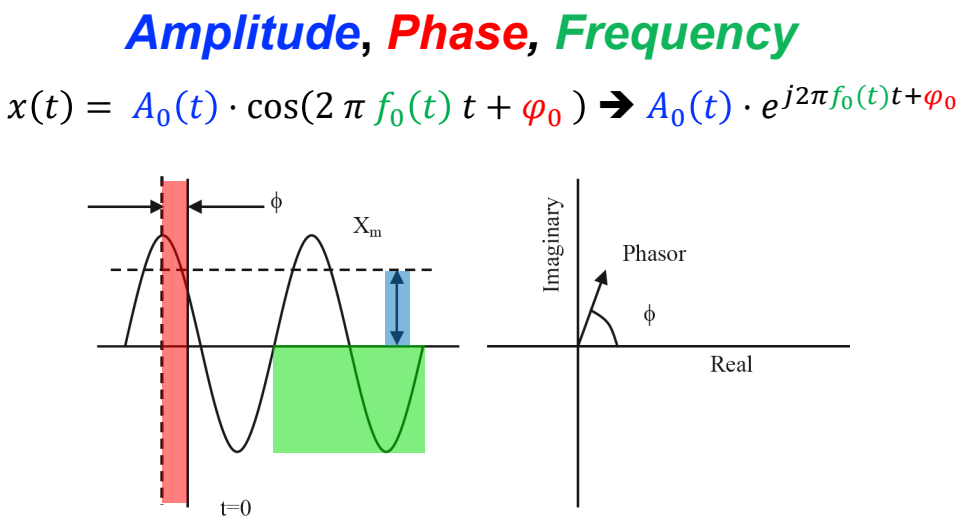
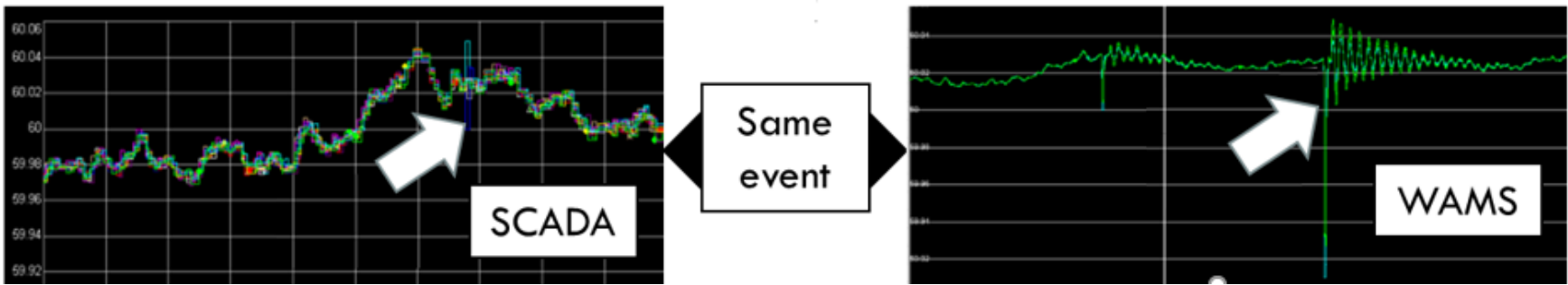
Wide Area Monitoring (WAM) via Phasor Measurement Units (PMU)



Derviskadic, Asja. Synchronized Sensing for Wide-Area Situational Awareness of Electrical Grids in Non-Stationary Operating Conditions. PhD Thesis. EPFL, 2019.

Phasor Measurement Units (PMU)

	RTU SCADA Remote Terminal Unit	PMU WAM
Reporting Rate	1-10 s	20 ms (50 fps)
Observation Interval	1-10 s	60-100 ms
Time Sync	NO	YES
Standardization		IEEE Std. C37.118

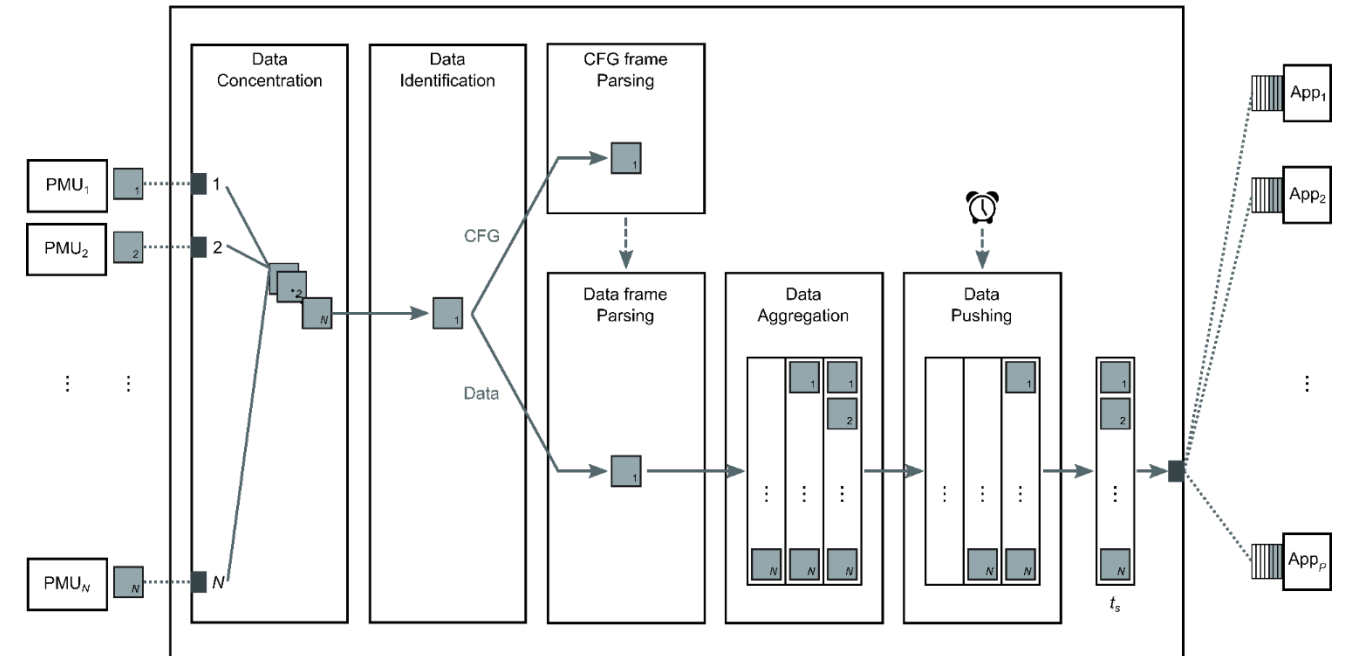
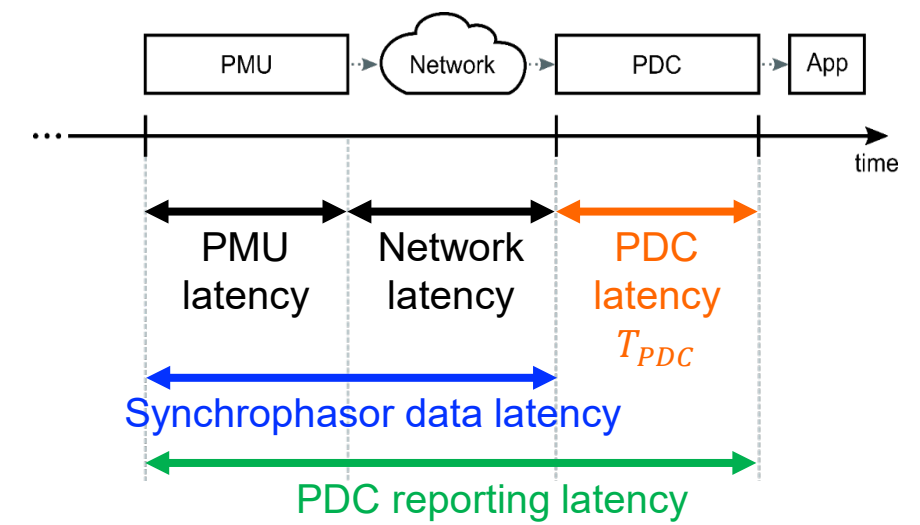


Phasor Data Concentrator (PDC)

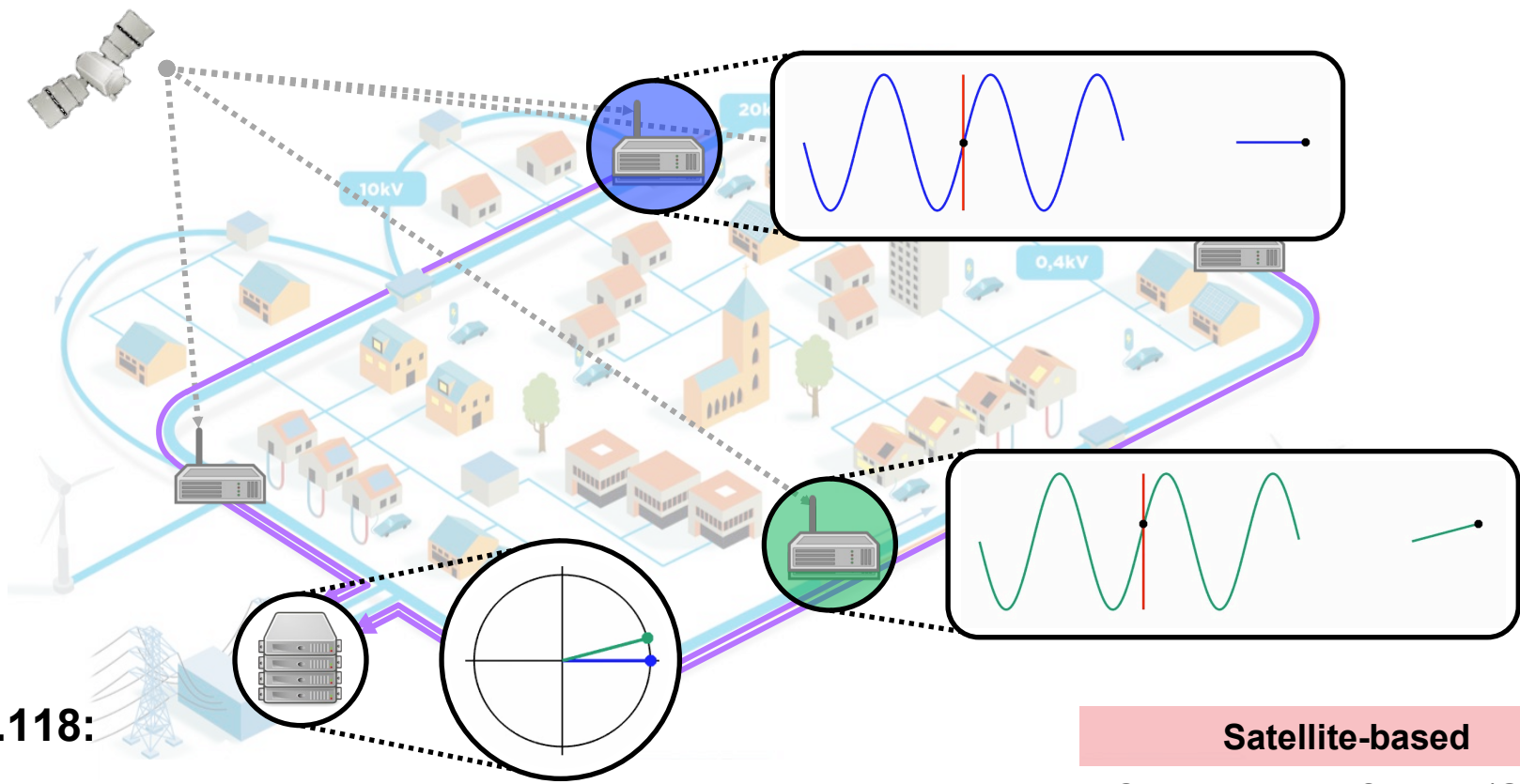
- Functions of a PDC [IEEE Guide C37.244]:
- **Data aggregation** → Time-alignment of multiple PMU data
- **Data pushing** → Forward time-aligned datasets to applications
- *Mitigate latency variations introduced by the components of the synchrophasor network*
- PDC reporting latency: one of the main design parameters of synchrophasor networks
- Hard real-time applications → **tens/hundreds of ms**
- Soft real-time applications → **tens of s**

Telecom infrastructure:

- Crucial role of **reliable**, **secure** and **low latency** telecommunication
- Efficient use only by wide system data exchange
- **IEEE Std. C37.118.2**: Clear rules and **standards for data exchange** including separation of market sensitive information data exchange



PMU Time Synchronization



- IEEE Std. C37.118:
- **Accurate: 1 μ s**
- **Reliable: 24/7**
- Available: urban area
- **Secure: timing attacks**
- Common practice: GPS ± 100 ns \rightarrow 31 μ rad @ 50 Hz

	Satellite-based	Network-based
	Global Position System (GPS)	Precision Time Protocol (PTP)
Uncertainty	100 ns	1 μ s
Features	<ul style="list-style-type: none">▪ Low installation cost▪ Widely used	<ul style="list-style-type: none">▪ Time dissemination on the same Ethernet physical layer as PMU data transfer▪ Standard profile for power systems
Limitations	<ul style="list-style-type: none">▪ Accessibility▪ Security	<ul style="list-style-type: none">▪ Accuracy▪ Fiber physical layer

Outlook

Context and Motivation

Wide Area Monitoring Systems

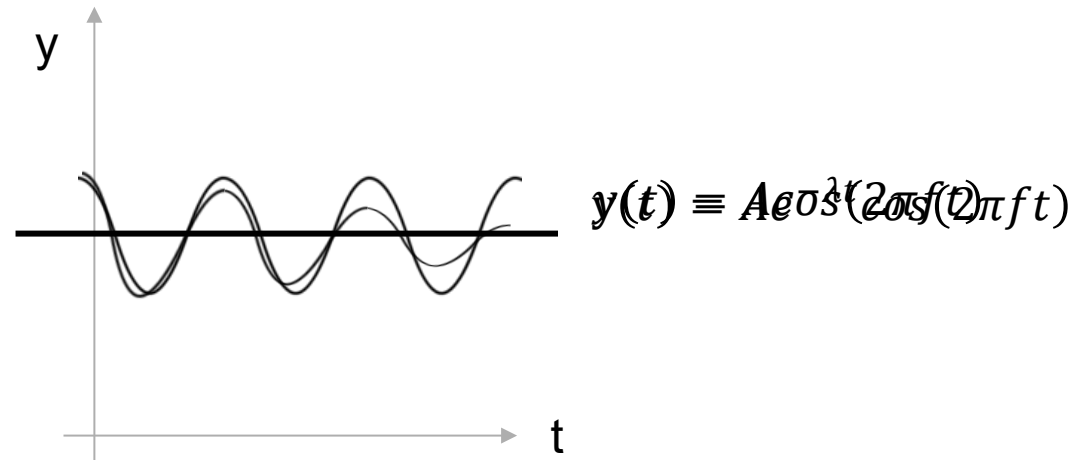
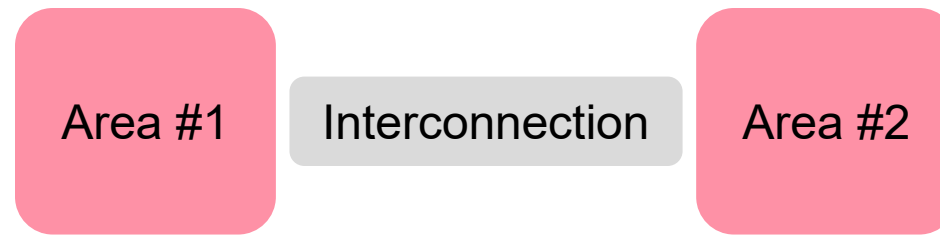
Oscillatory Stability Analysis

Swissgrid WAM

Events in 2024 in Continental Europe

Takeaways

Inter-Area Oscillations in Power Systems



Oscillation parameters:

- A amplitude
- f frequency \rightarrow angular frequency $\omega = 2\pi f$
- λ decay rate \rightarrow damping ratio $\zeta \approx \lambda/\omega \approx \lambda/2\pi f$

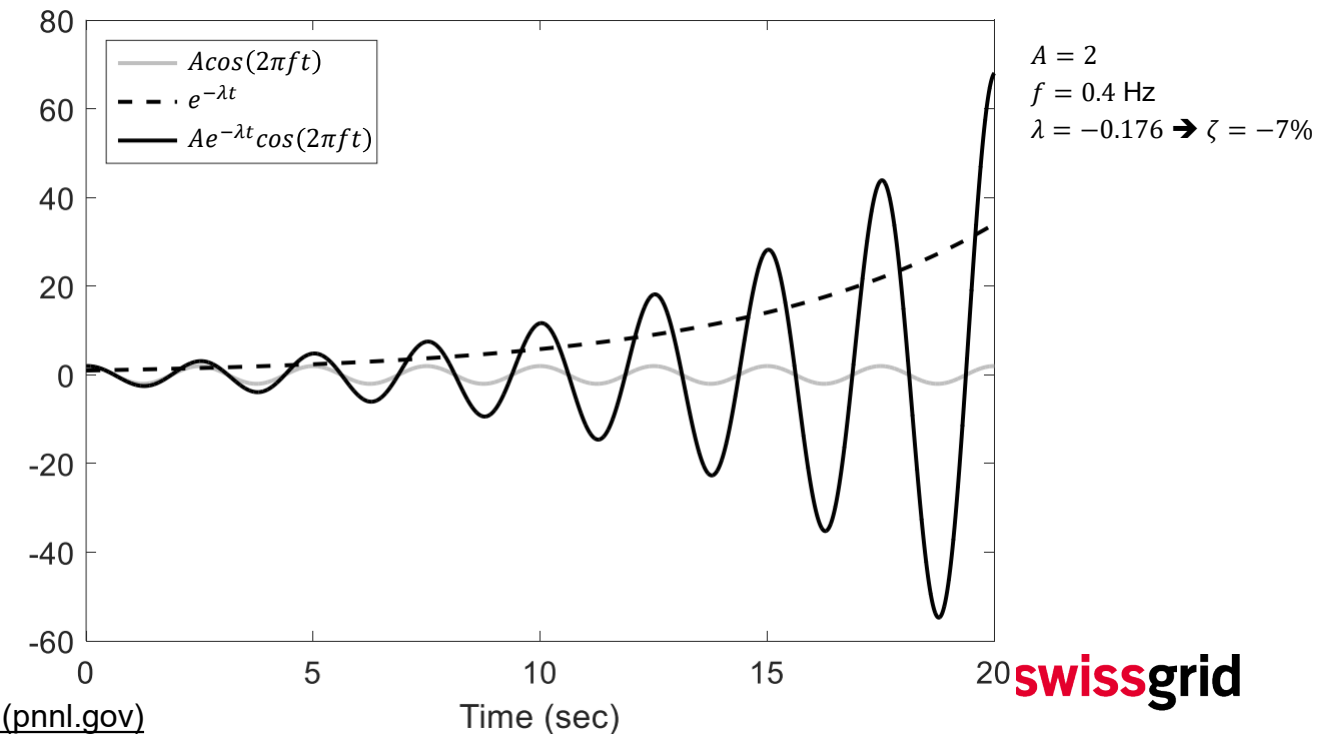
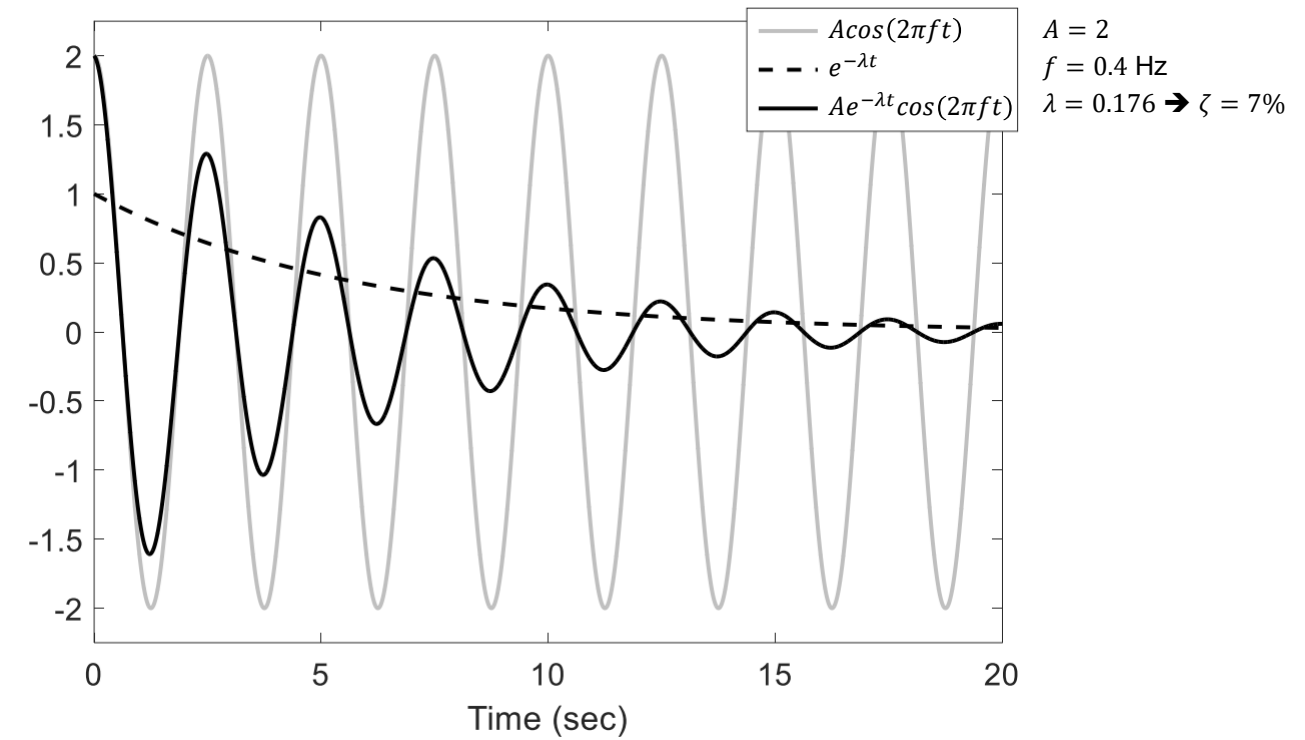
Inter-area oscillations in power grids:

- A amplitude \rightarrow The smaller the better!
- f frequency \rightarrow 0.1 ~ 1 Hz (Electromechanical oscillations)
- λ decay rate \rightarrow The higher the better!

Inter-Area Oscillations in Power Systems

Oscillation classification and relative effects:

- **Damped oscillations ($\lambda > 0$)** → the amplitude of the oscillation gradually decreases, or the oscillation can be suppressed by appropriate measures
 - **System stable**
- **Moderately damped oscillations ($\lambda = 0$)** → the amplitude of the oscillation is constant
 - **System unstable**
 - Unexpected trips
- **Undamped oscillations ($\lambda < 0$)** → the amplitude of the oscillation increases continuously
 - **System unstable**
 - Unexpected trips



Inter-Area Oscillations in Power Systems

Inherent causes:

- Incorrect setting/malfunction of generator controllers:
 - **Power System Stabilizers (PSS)**
 - Governor
 - Excitation system

Negatively influencing and triggering conditions:

- **Loss of major generator or load**
- Increase of impedance seen by the generators (e.g., **planned/unplanned trip of a line**)
- **Low demand** → decreasing the natural damping contribution by the loads
- Low inertia
- Large voltage phase angle variations (typical of high level of export from the periphery to the centre of the system)
- Generators operating in under excitation → machines in weaker operating points

Wide area monitoring systems – Support for control room applications | eCIGRE (e-cigre.org) (2018)

Wide Area Monitoring Protection and Control Systems – Decision Support for System Operators | eCIGRE (e-cigre.org) (2023)

Outlook

Context and Motivation

Wide Area Monitoring Systems

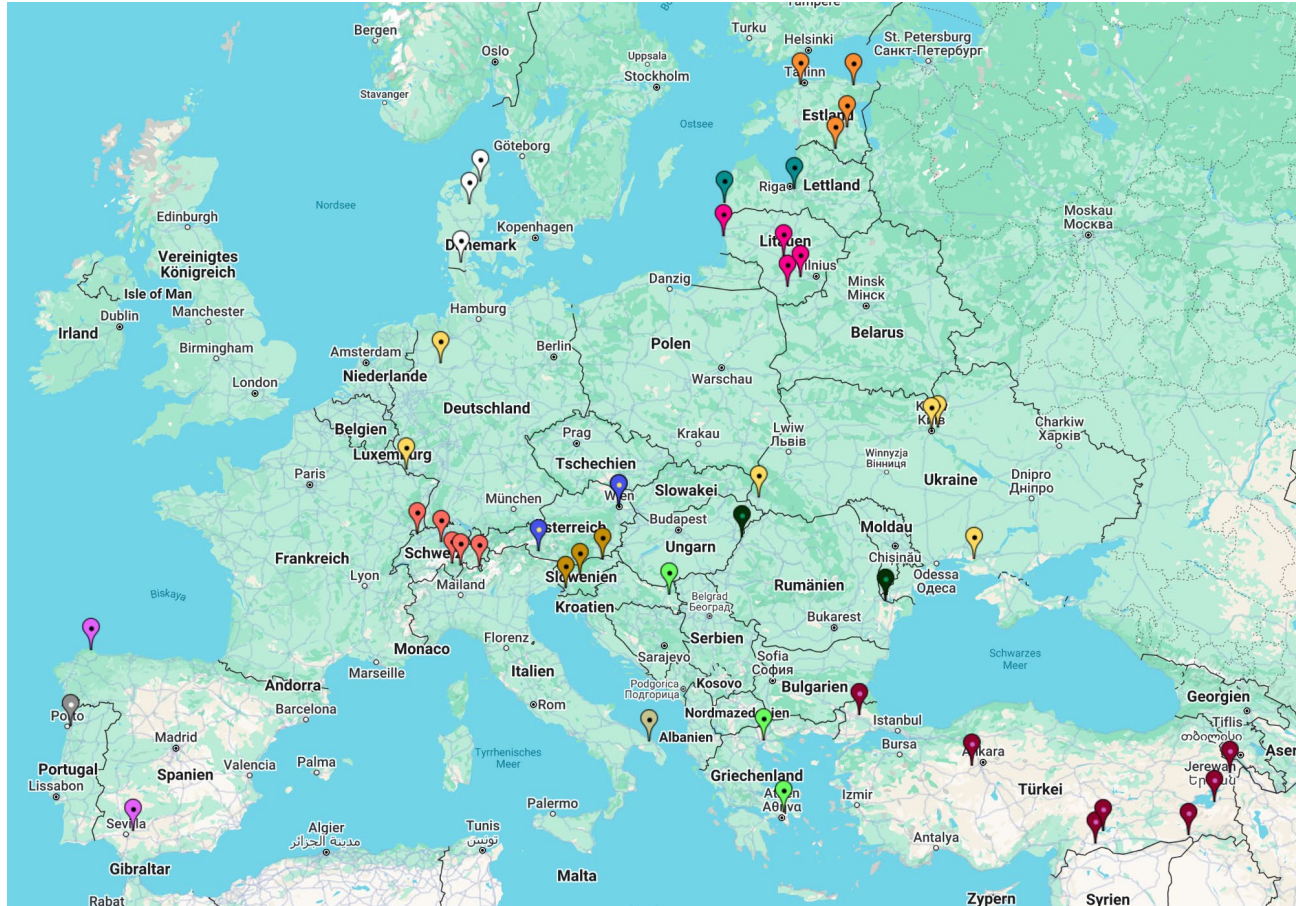
Oscillatory Stability Analysis

Swissgrid WAM

Events in 2024 in Continental Europe

Takeaways

Swissgrid WAM System



45+ Phasor Measurement Units (PMU):

- 6 in CH
- 42 PMUs over Continental Europe (16 different countries)
- Accurate time-stamped high resolution (100 ms) measurements

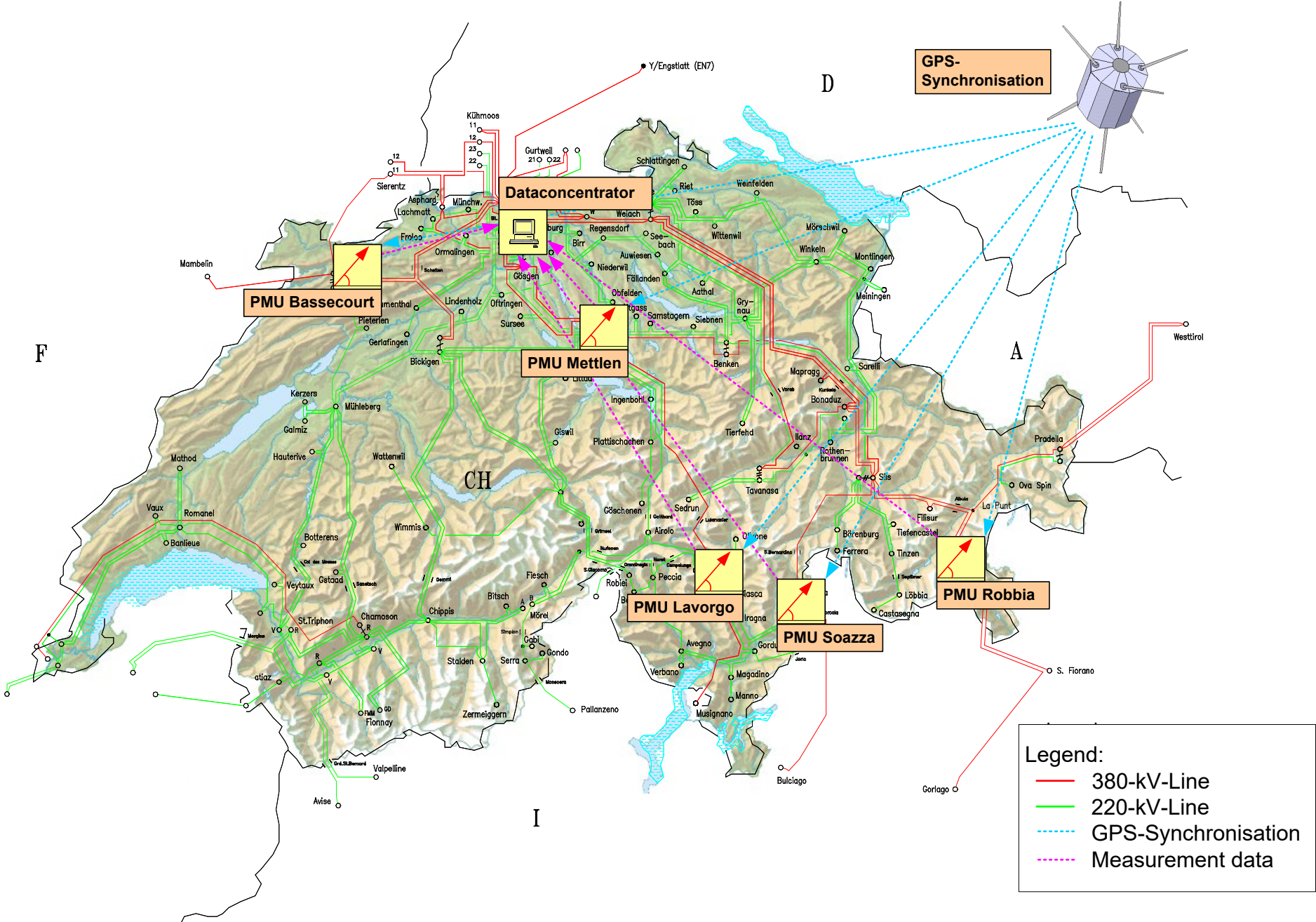
On-line:

- **Oscillatory Stability Monitoring** (*Netzpendelungsalarm*)
- Voltage phase angle differences monitoring

Off-line:

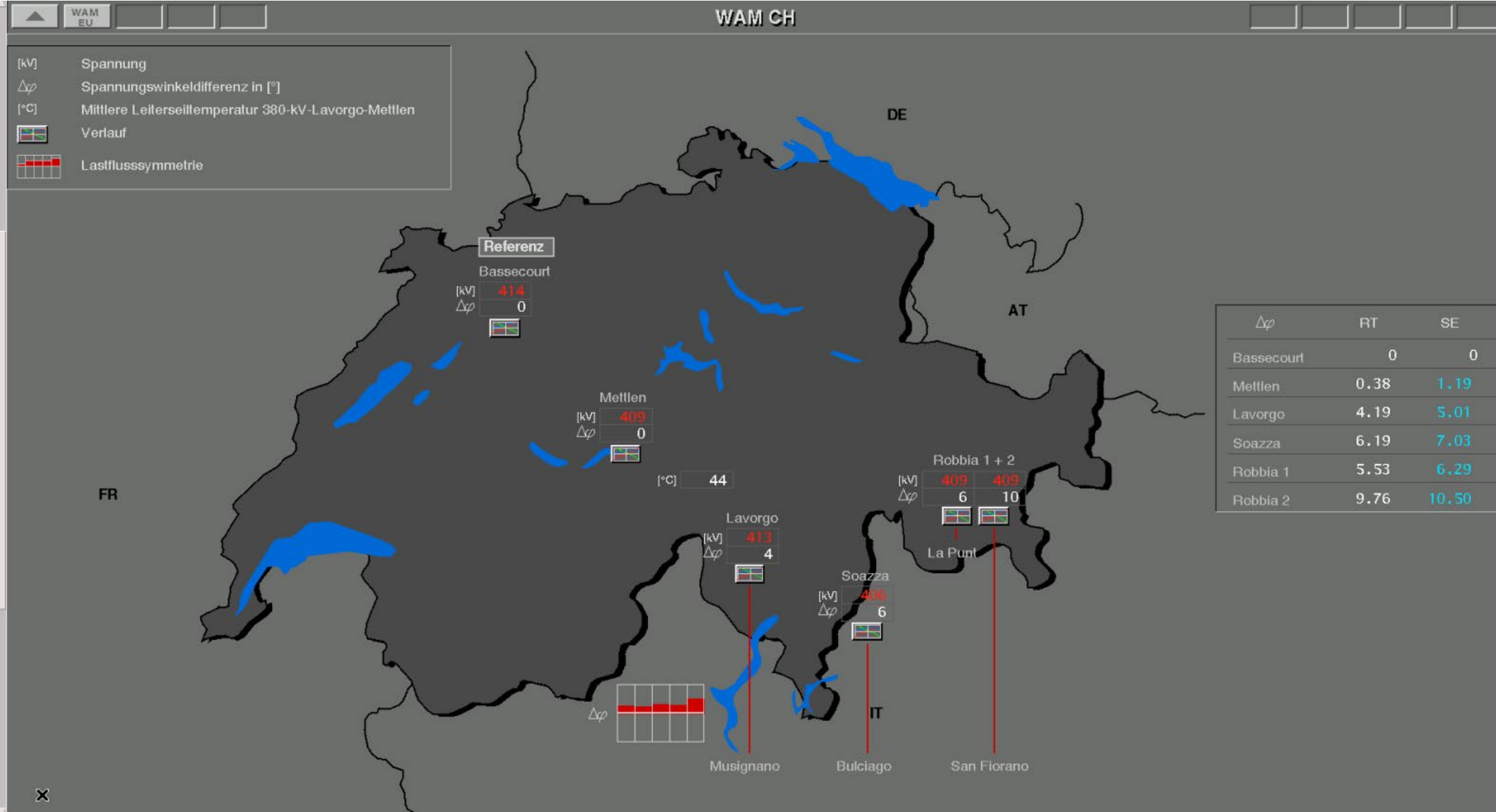
- Post-event analysis of specific dynamic events
- Dynamic model calibration

Swissgrid WAM System

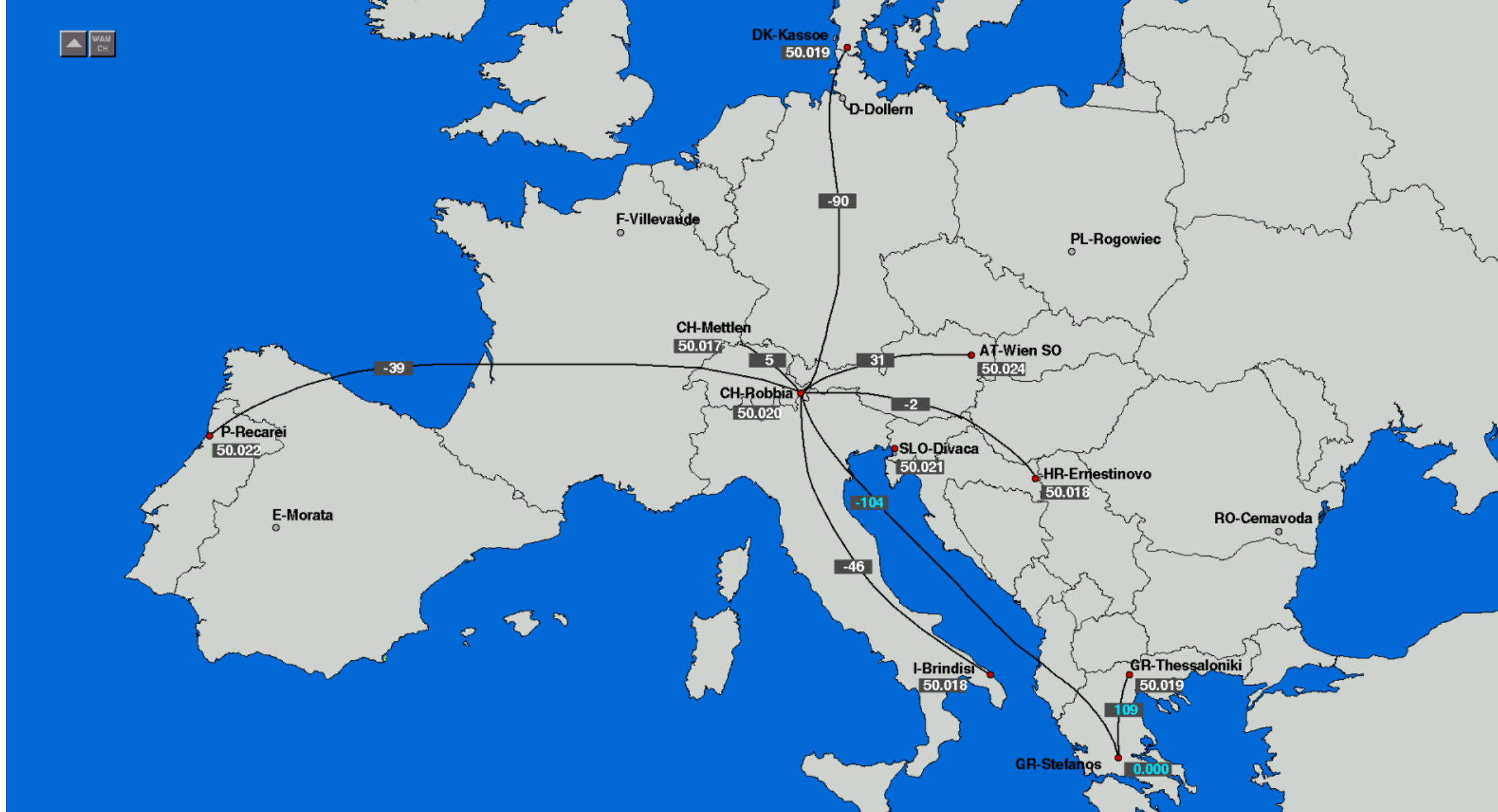


- In use **since 2003**
- PDC replacement ongoing

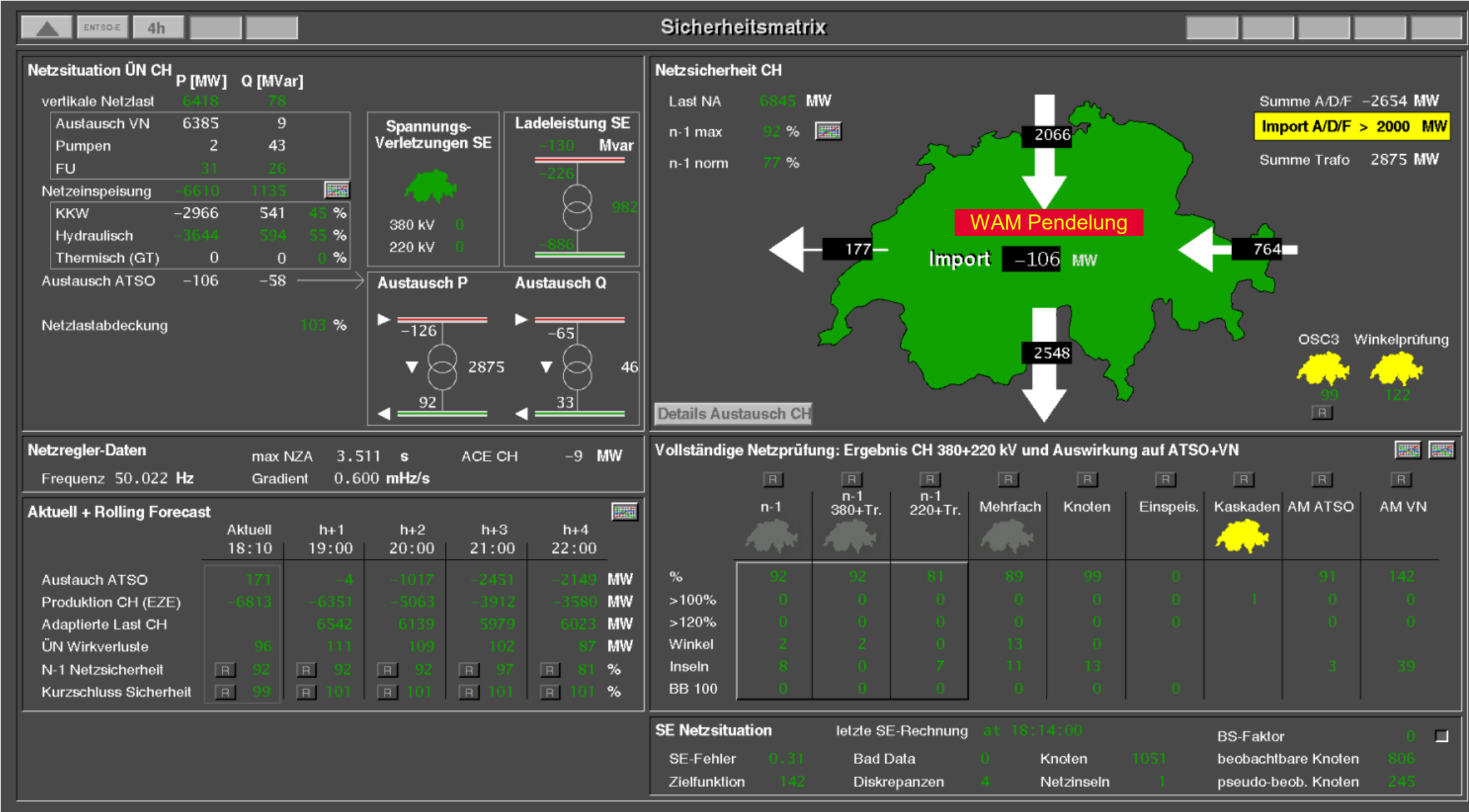
Swissgrid WAM System – Situational Awareness in the Control Room



Swissgrid WAM System – Situational Awareness in the Control Room



Swissgrid WAM System – Situational Awareness in the Control Room



Swissgrid WAM System – Oscillatory Stability Monitoring

- **North-South mode ~0.25 Hz**

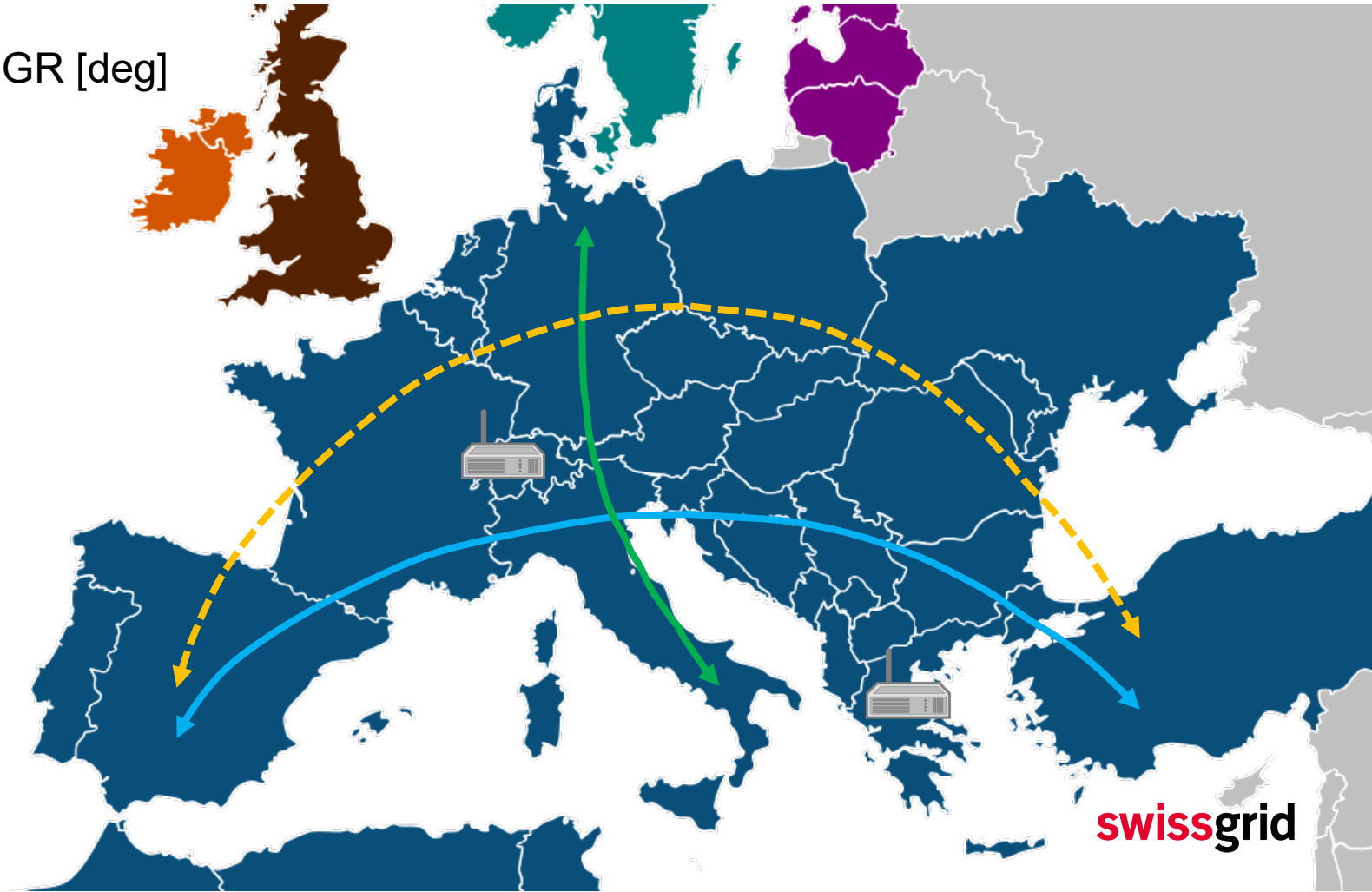
- Active power from CH to IT [MW] → PMU Robbia, line 380 kV Robbia-Gorlago

- **East-West mode ~0.15 Hz**

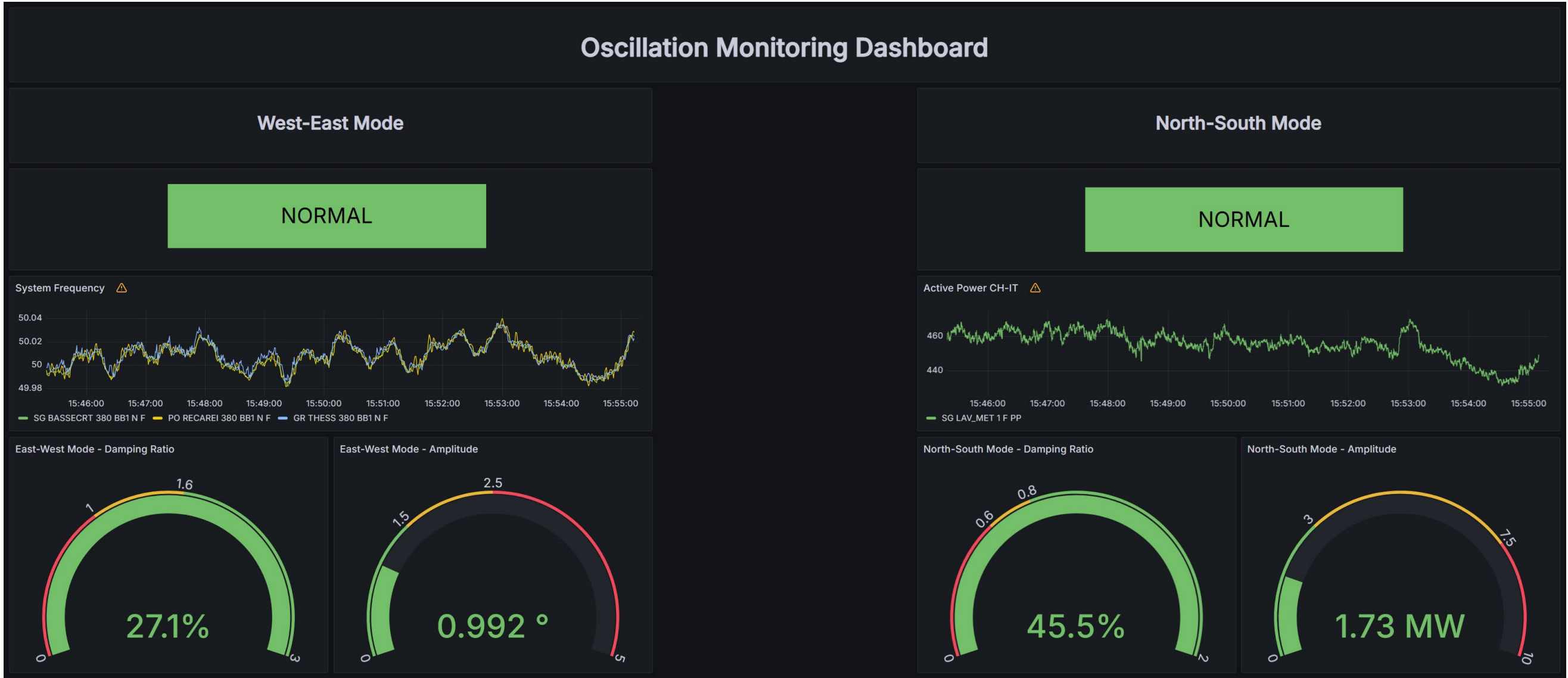
- Voltage phase angle difference between CH and GR [deg]
→ PMU Bassecourt vs PMU Thessaloniki

- **East-Center-West ~0.18 Hz**

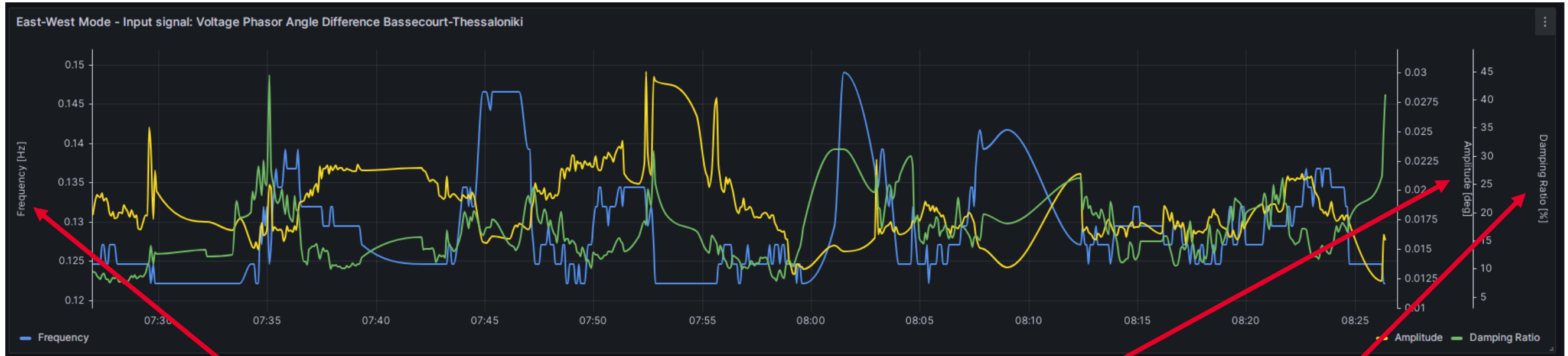
- Tuning in progress



Swissgrid WAM System – Oscillatory Stability Monitoring



Swissgrid WAM System – Oscillatory Stability Monitoring



$$y(t) = Ae^{-\lambda t} \cos(2\pi f t)$$

Oscillation parameters:

- **A amplitude**
- **f frequency** → angular frequency $\omega = 2\pi f$
- λ decay rate → **damping ratio** $\zeta \approx \lambda/\omega \approx \lambda/2\pi f$

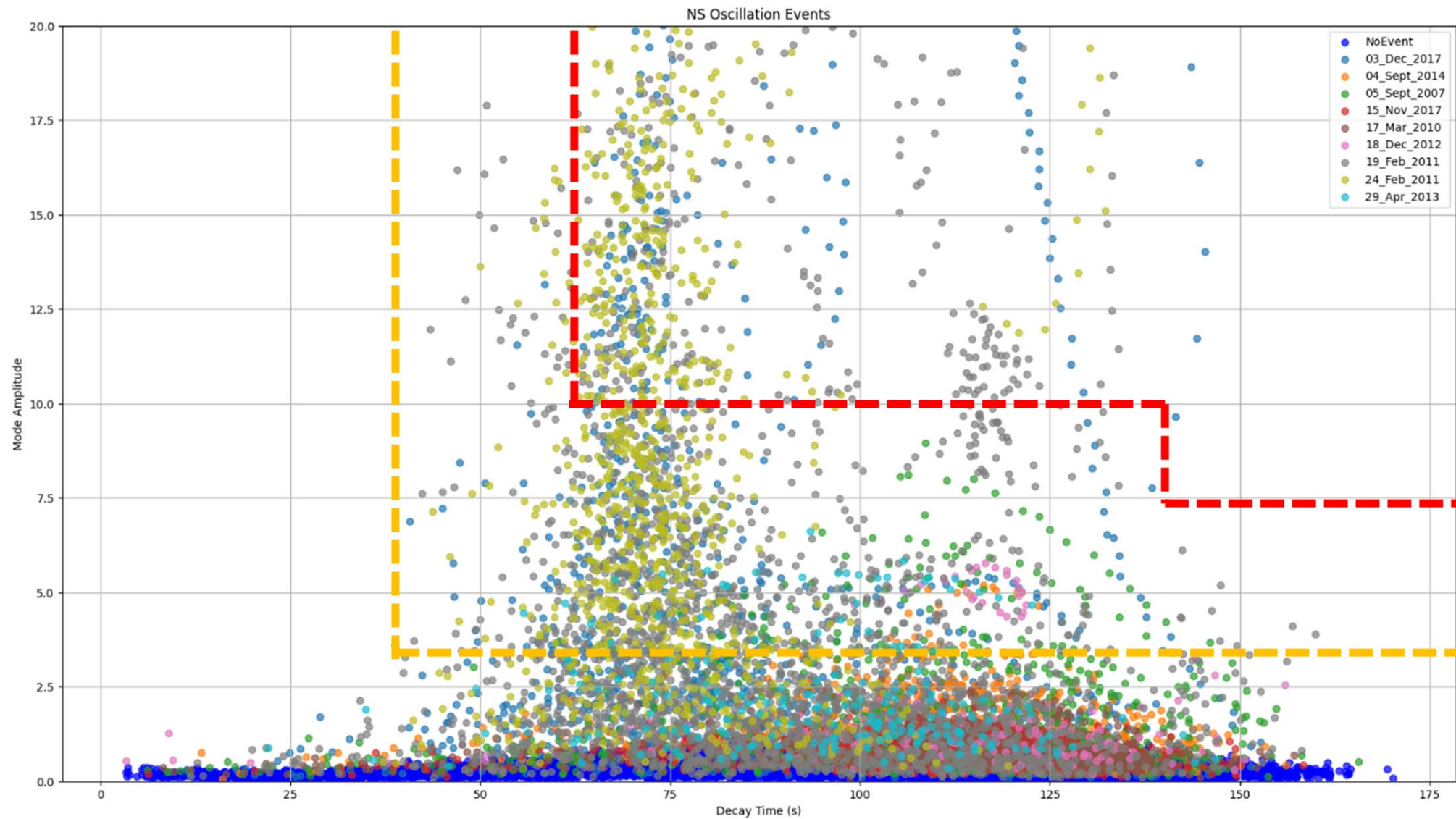


Select time range

Frequency trend over time

East-West

North-South



Outlook

Context and Motivation

Wide Area Monitoring Systems

Oscillatory Stability Analysis

Swissgrid WAM

Events in 2024 in Continental Europe

Takeaways

Outlook

Context and Motivation

Wide Area Monitoring Systems

Oscillatory Stability Analysis

Swissgrid WAM

Events in 2024 in Continental Europe

Takeaways

Takeaways

- Depending on the power system state, situational awareness in the control room can be achieved using **steady state (SCADA)** or **dynamic state (WAM)** tools
- At Swissgrid we have a **Wide Area Monitoring (WAM)** system that we use:
 - **On-line:** Oscillatory Stability Monitoring and **Netzpendelungsalarm** in SP4 (SCADA) and SGC (Control Room)
 - *Power oscillation monitoring*
 - *Voltage phase angle differences monitoring*
 - **Off-line:** **post-event analysis** of specific dynamic events
 - *Dynamic model calibration*
 - *Analysis of dynamic behavior of future configurations*
 - *Definition of operational limits for secure system operation*
- Swissgrid **Phasor Data Concentrator (PDC)** collects PMU data from 16 countries across Continental Europe. With a resolution of **100 ms**, we monitor **frequency**, **voltage magnitue** and **phase angle**

Students @ Swissgrid

- Students (swissgrid.ch)
- **Thesis:** Bachelor- & Masterthesis Job Details | Swissgrid
- **Talent Pool quiz:** Quiz (swissgrid.ch)
- **Contact:** Corina Wieland, Talent Acquisition, hr@swissgrid.ch
- **Graduate program:** (nominations already closed for this year!)

Nous vous remercions de votre intérêt

Swissgrid Ltd
Bleichemattstrasse 31
P.O. Box
5001 Aarau
Switzerland

Swissgrid Icons

La couleur peut être modifiée via le menu «Graphique»

