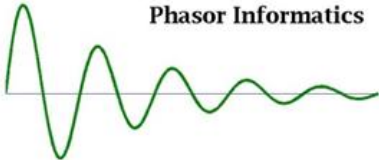


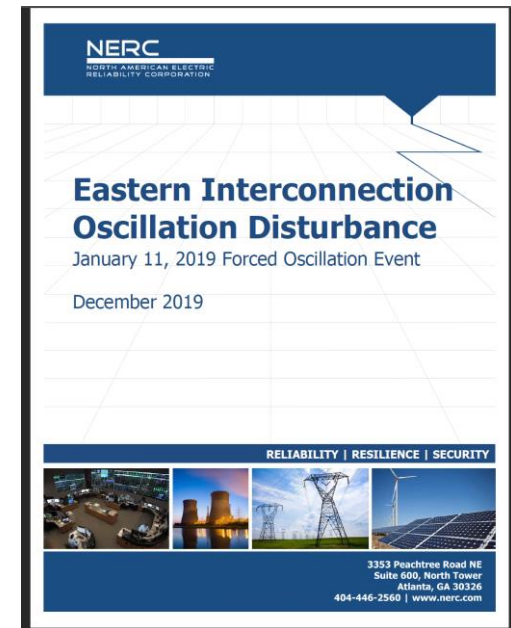
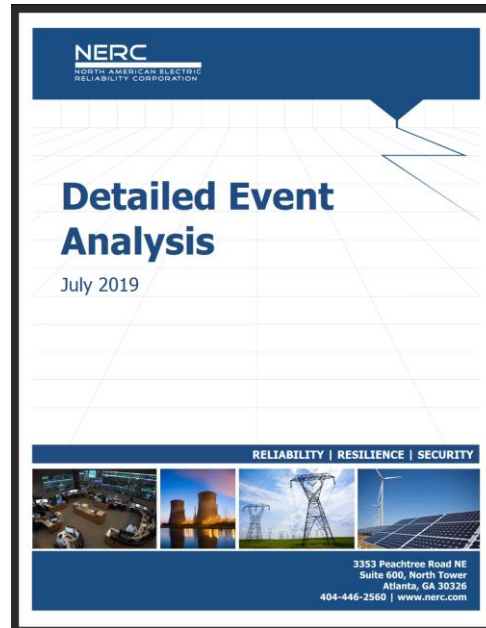
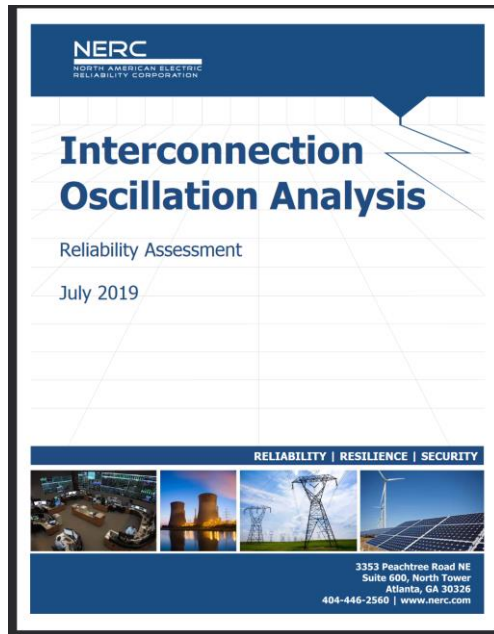
**MANTRA**  
Modal ANalysis  
and Oscillation  
TRacking

Mani V. Venkatasubramanian  
**Washington State University**  
**Pullman, USA**

**Phasor Informatics LLC**



# NERC Oscillation Analysis Reports



[https://www.nerc.com/comm/PC/SMSResourcesDocuments/Interconnection\\_Oscillation\\_Analysis.pdf](https://www.nerc.com/comm/PC/SMSResourcesDocuments/Interconnection_Oscillation_Analysis.pdf)

[https://www.nerc.com/comm/PC/SMSResourcesDocuments/Detailed\\_Event\\_Analysis.pdf](https://www.nerc.com/comm/PC/SMSResourcesDocuments/Detailed_Event_Analysis.pdf)

[https://www.nerc.com/pa/rrm/ea/Documents/January\\_11\\_Oscillation\\_Event\\_Report.pdf](https://www.nerc.com/pa/rrm/ea/Documents/January_11_Oscillation_Event_Report.pdf)



# Wide-area Measurement Based Online Oscillation Alarming System at RTE

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**Paris, France**

IEEE SmartGridComm  
Sep 19, 2024



# Continental Europe Synchronous Area / RTE



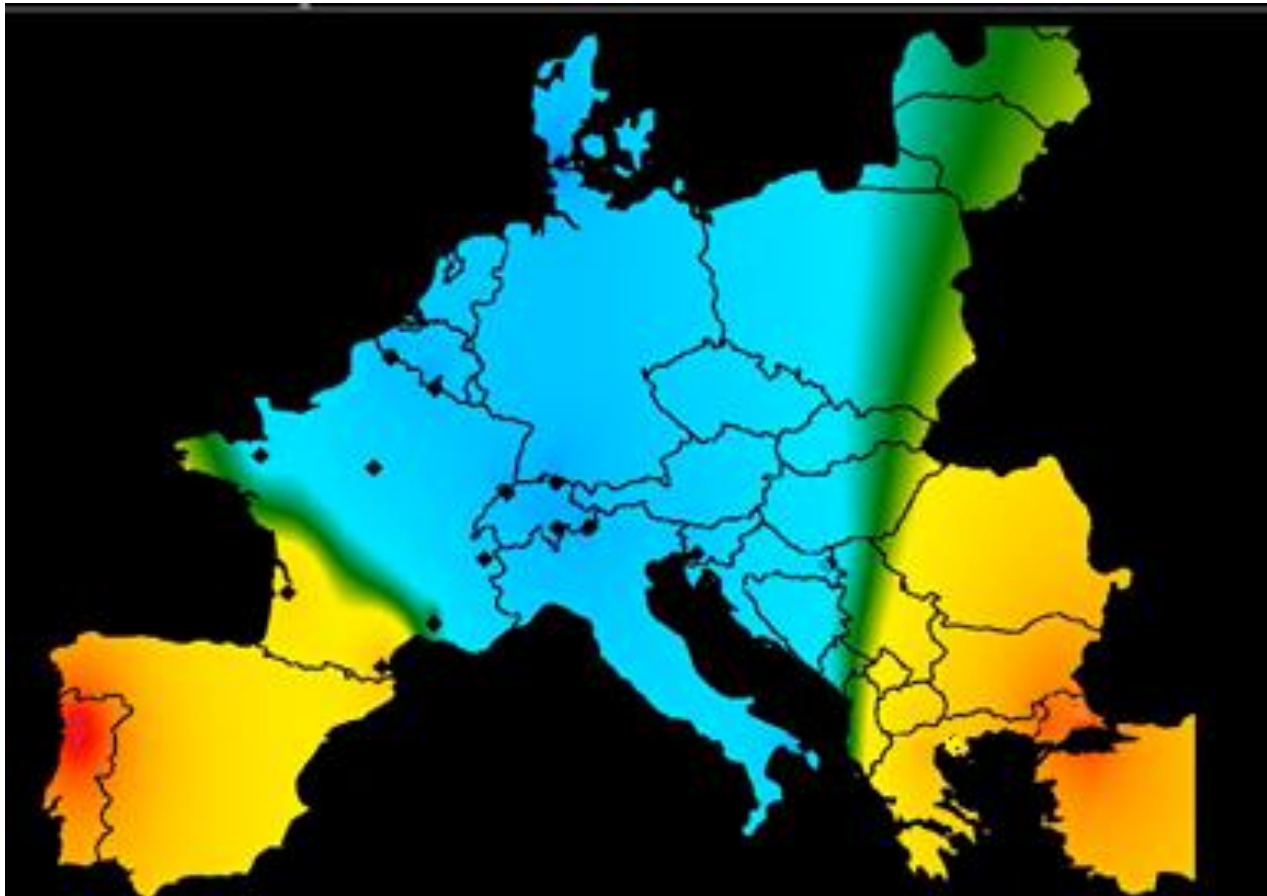
## Continental Europe

- ❖ Installed Generation ~970 GW
- ❖ Annual load ~3000 TWh
- ❖ Peak load ~ 500 GW

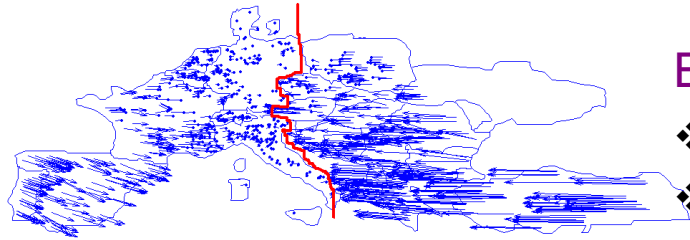
## RTE

- ❖ 100,000 km of lines
- ❖ Nominal voltages 63-400 kV
- ❖ 8500 employees

# 0.25 Hz East-Center-West Oscillation Mode



# 3 Main Inter-area Modes



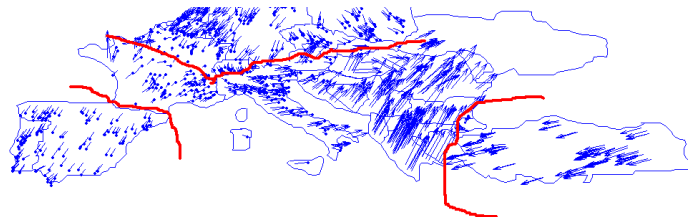
## East-West mode

- ❖ Frequency ~ 0.15 Hz
- ❖ Damping : good



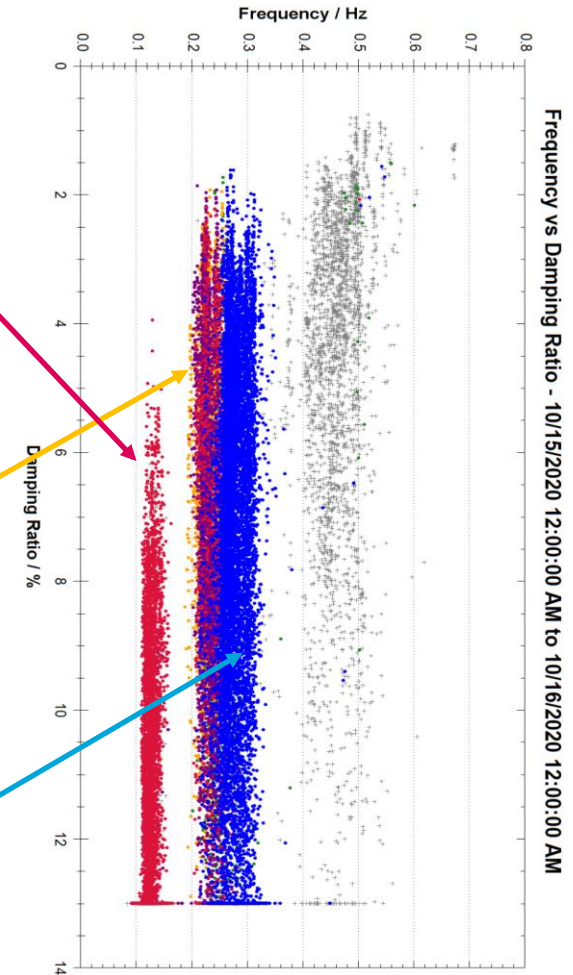
## East-Center-West mode

- ❖ Frequency ~ 0.22 Hz
- ❖ Damping : can be low



## North-South mode

- ❖ Frequency ~ 0.3 Hz
- ❖ Damping : can be low



## 2 Recent Events

### East-Center-West mode

❖ 01 December 2016

❖ Ref : *ENTSOE – Analysis of CE inter-area oscillations of 1<sup>st</sup> December 2016*

[https://eepublicdownloads.azureedge.net/clean-documents/SOC%20documents/Regional Groups Continental Europe/2017/CE\\_inter-area\\_oscillations\\_Dec\\_1st\\_2016\\_PUBLIC\\_V7.pdf](https://eepublicdownloads.azureedge.net/clean-documents/SOC%20documents/Regional Groups Continental Europe/2017/CE_inter-area_oscillations_Dec_1st_2016_PUBLIC_V7.pdf)

### North South mode

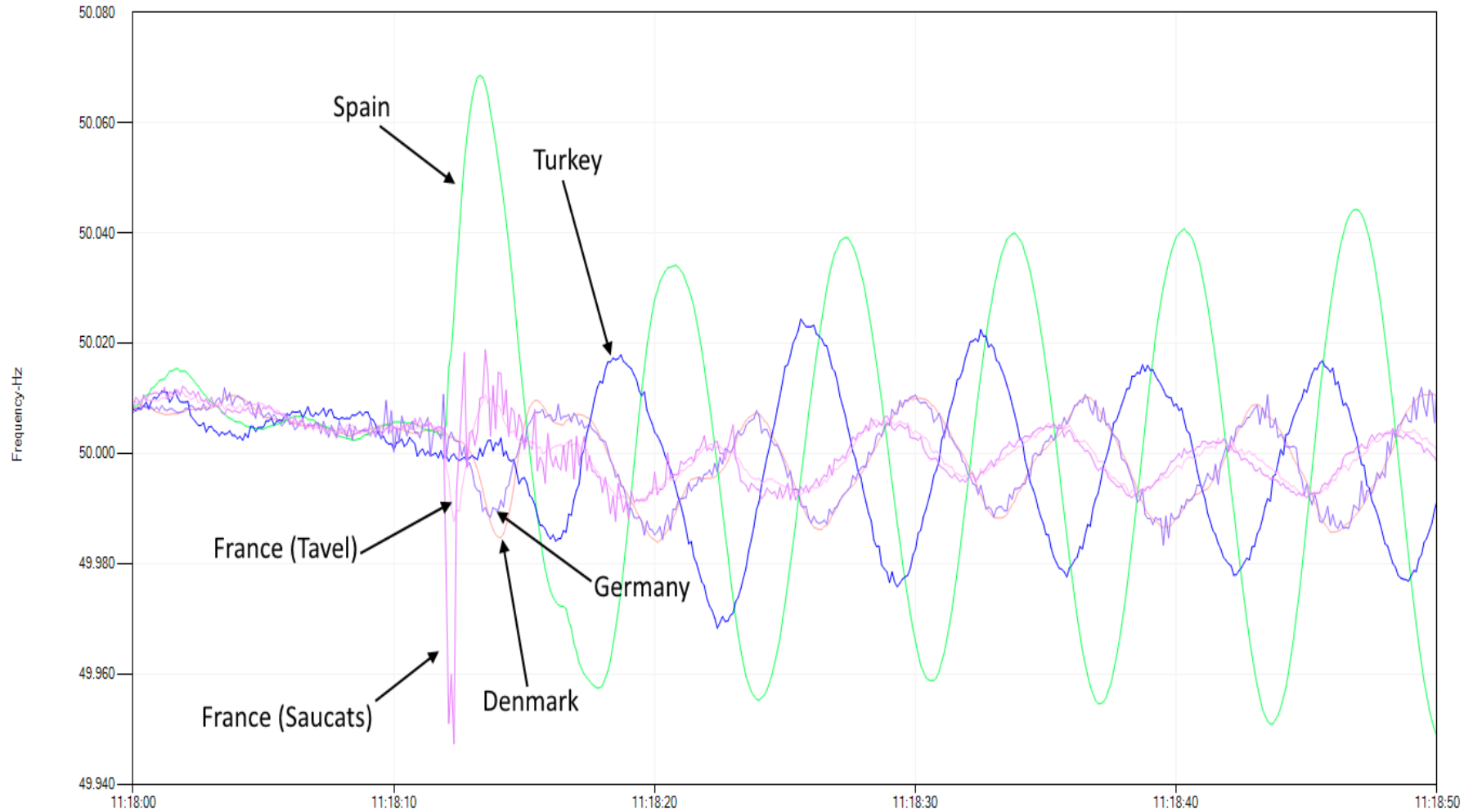
❖ 03 December 2017

❖ Ref : *ENTSOE - Oscillation Event 03.12.2017*

[https://eepublicdownloads.azureedge.net/clean-documents/SOC%20documents/Regional Groups Continental Europe/OSCILLATION REPORT\\_SPD.pdf](https://eepublicdownloads.azureedge.net/clean-documents/SOC%20documents/Regional Groups Continental Europe/OSCILLATION_REPORT_SPD.pdf)



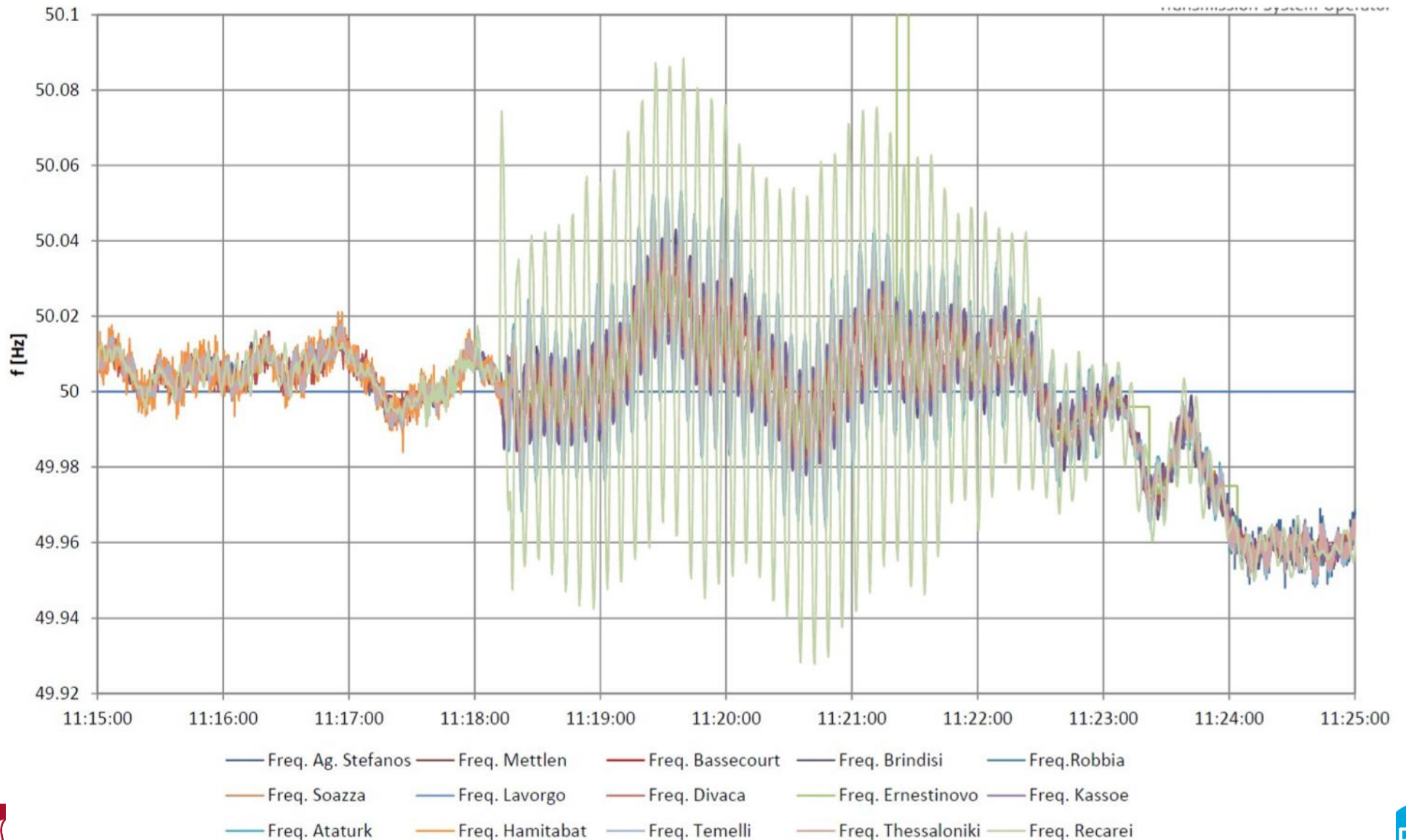
# Oscillations Event on December 1, 2016



Start Time: 2017-03-10 11:18:00.000 End Time: 2017-03-10 11:18:50.000

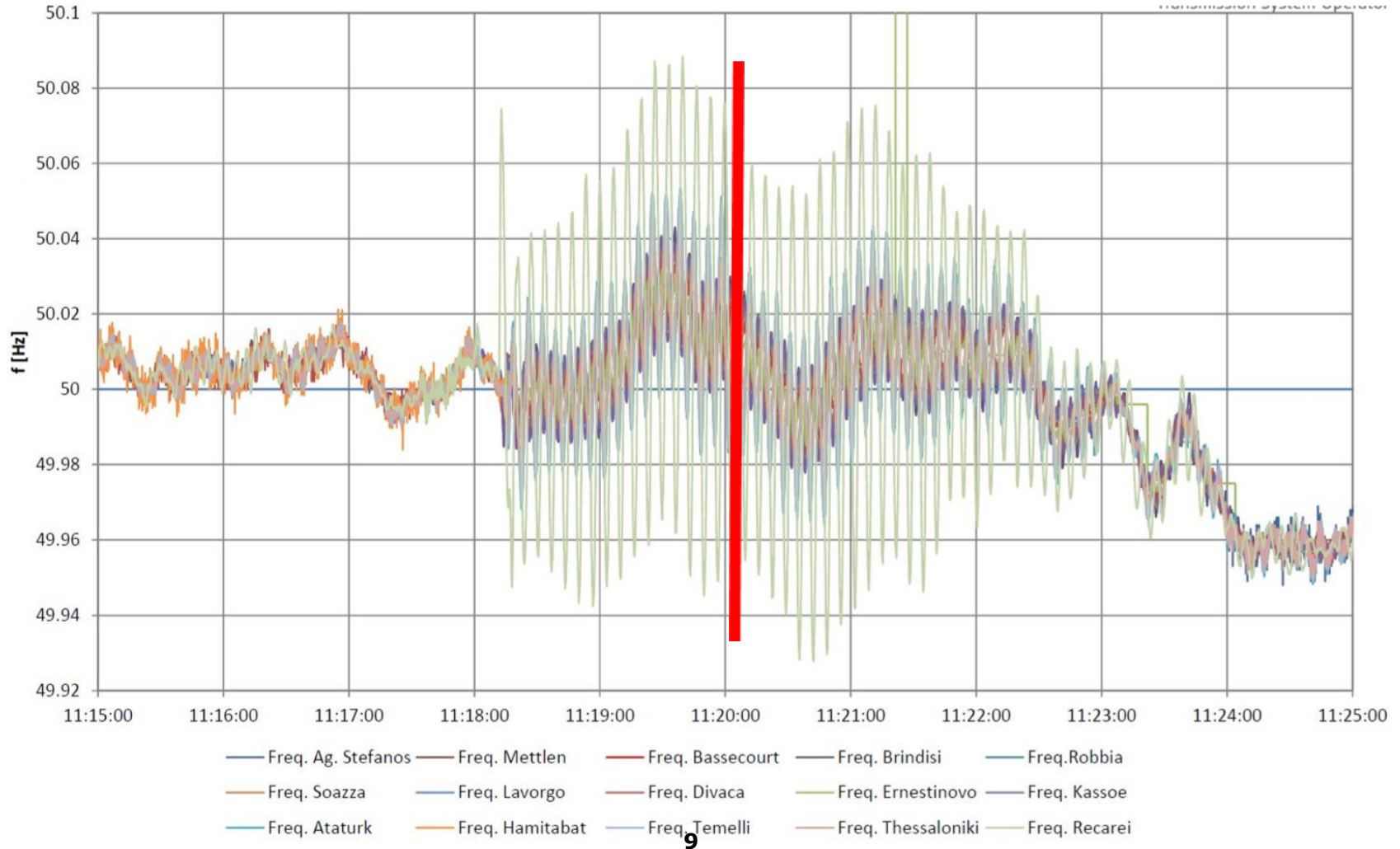


# Oscillations on the European Network...

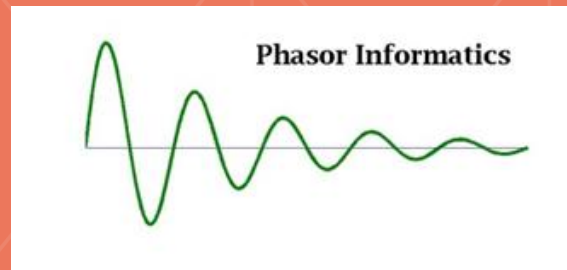


# RTE Dispatchers Action

11h21 : reduction of the Spain to France schedule from 2250 MW to 1000 MW to restore N-1 security



# Modal ANalysis and oscillation TRACKing (MANTRA) tool framework



MANTRA: <https://phasorinformatics.com/products/mantra>



# MANTRA Modal Analysis Algorithms

## Ringdown Analysis Algorithms

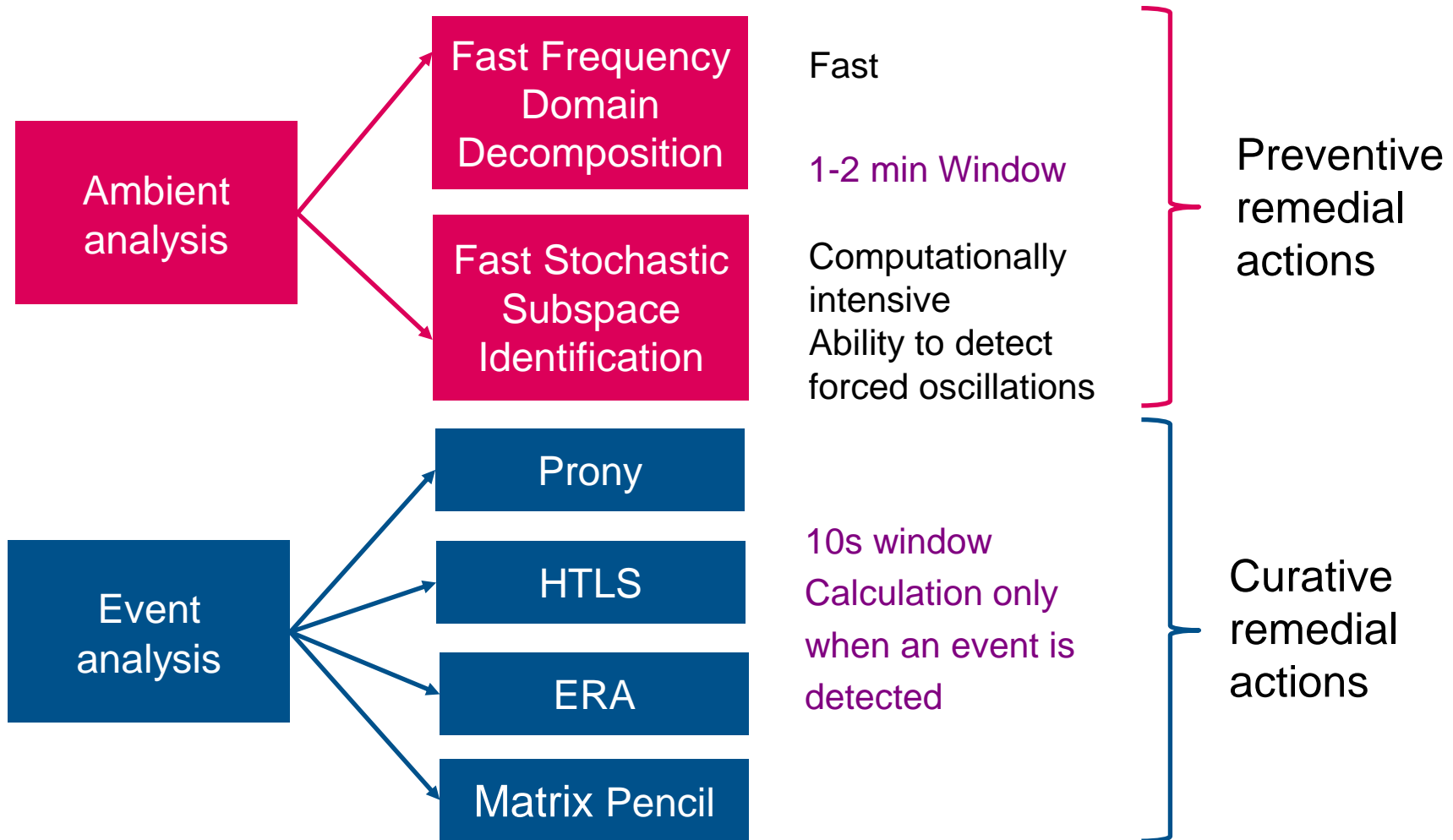
- Use disturbance data for modal estimation
  1. Prony
  2. Matrix Pencil
  3. Eigensystem Realization Algorithm (ERA)
  4. Hankel Total Least Squares (HTLS)

## Ambient Analysis Algorithms

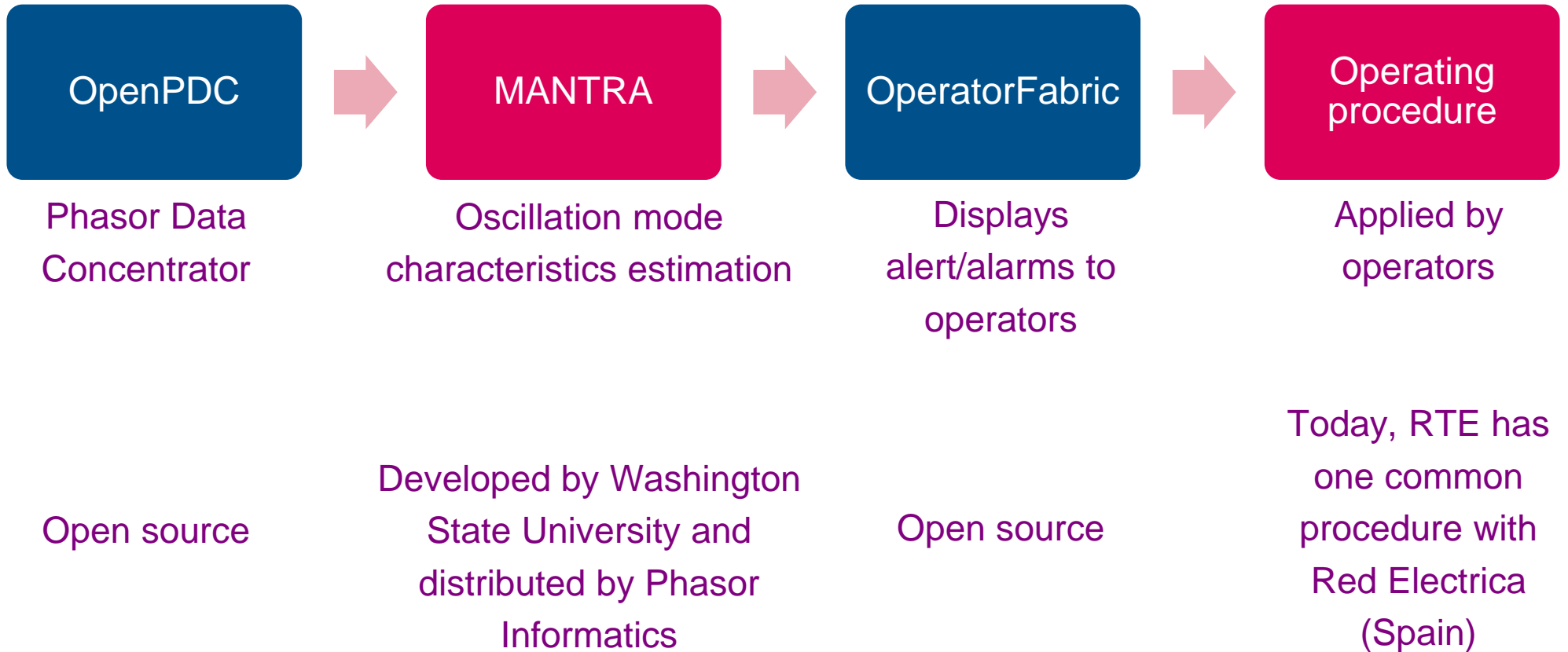
- Use ambient data for modal estimation
  1. Fast Frequency Domain Decomposition (FFDD)
    - Frequency domain method
    - Requires a comparatively shorter window of data
  2. Fast Stochastic Subspace Identification (FSSI)
    - Time domain method
    - Can distinguish forced oscillations from natural oscillations



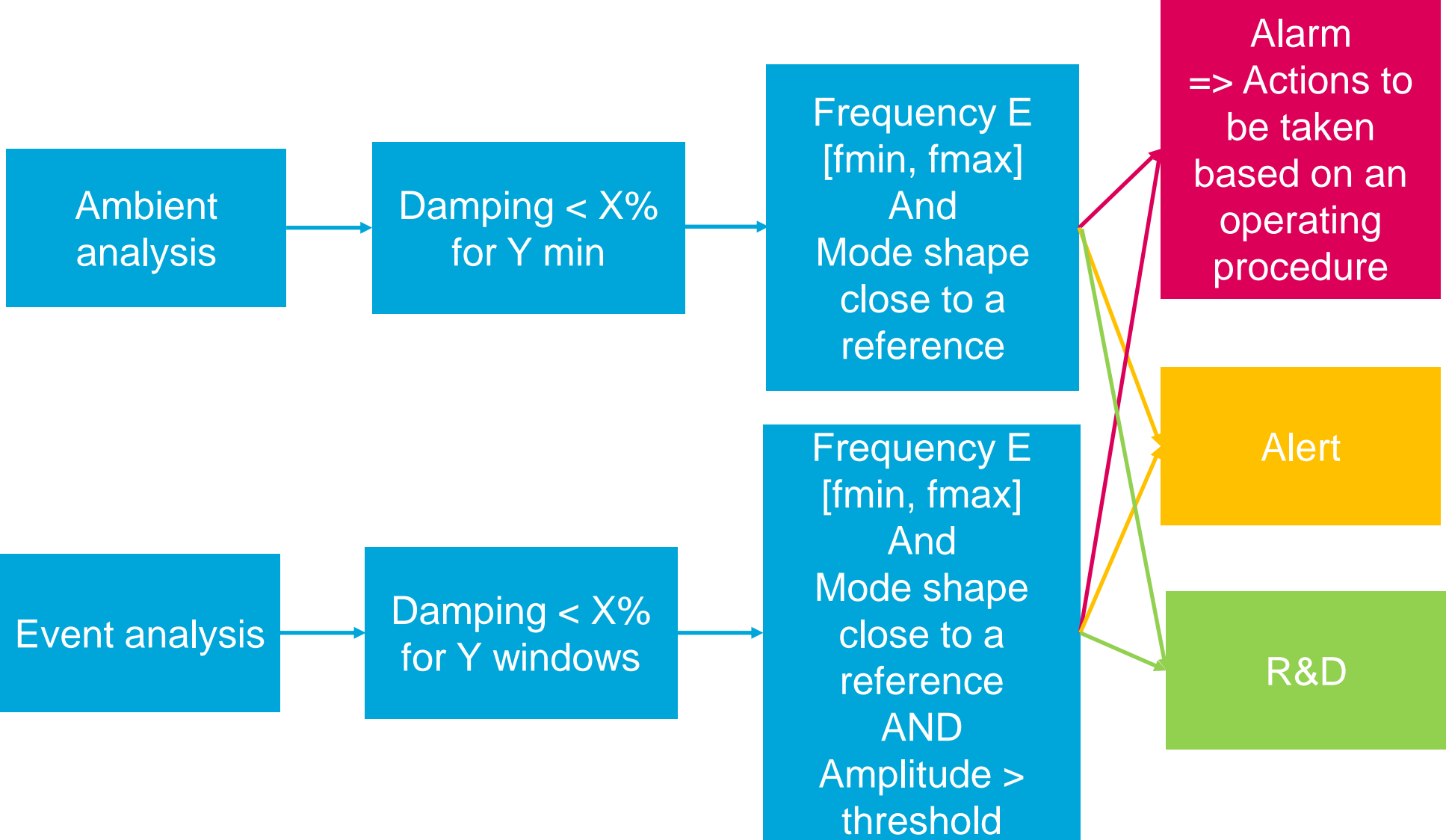
# Oscillation Monitoring Principle



# Oscillation Monitoring in RTE

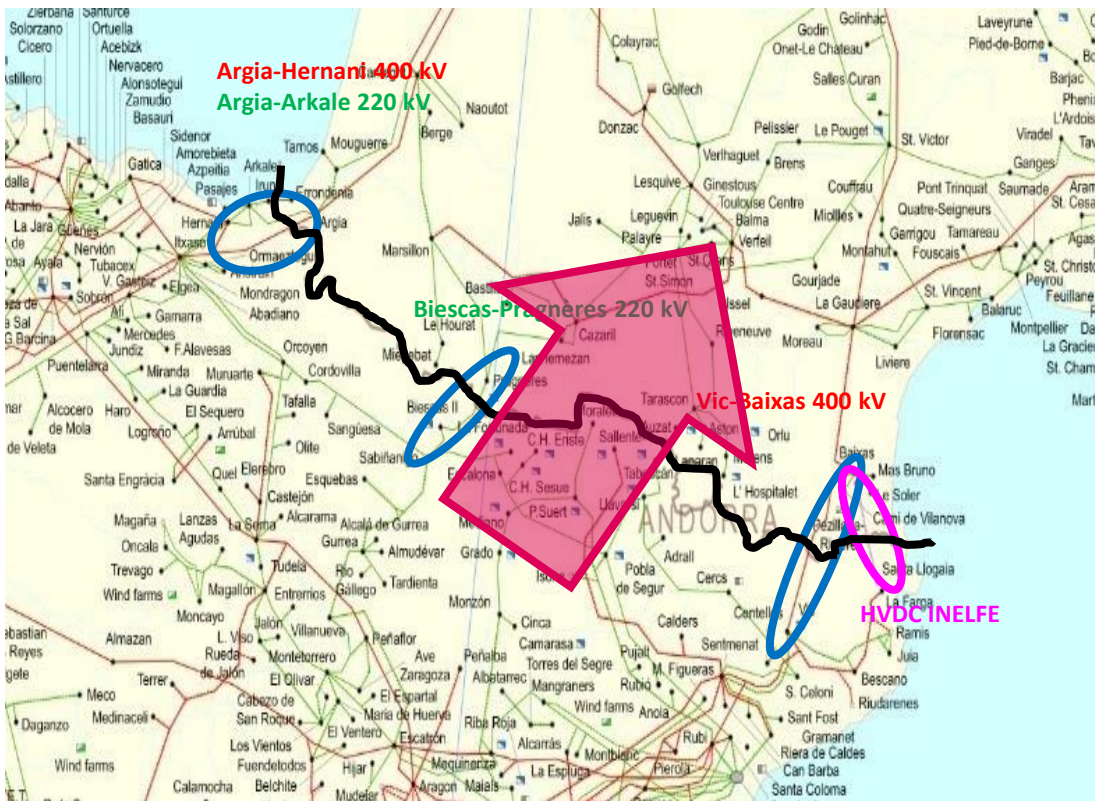


# Alarming Principle





# Operating Procedure on East-Center-West mode



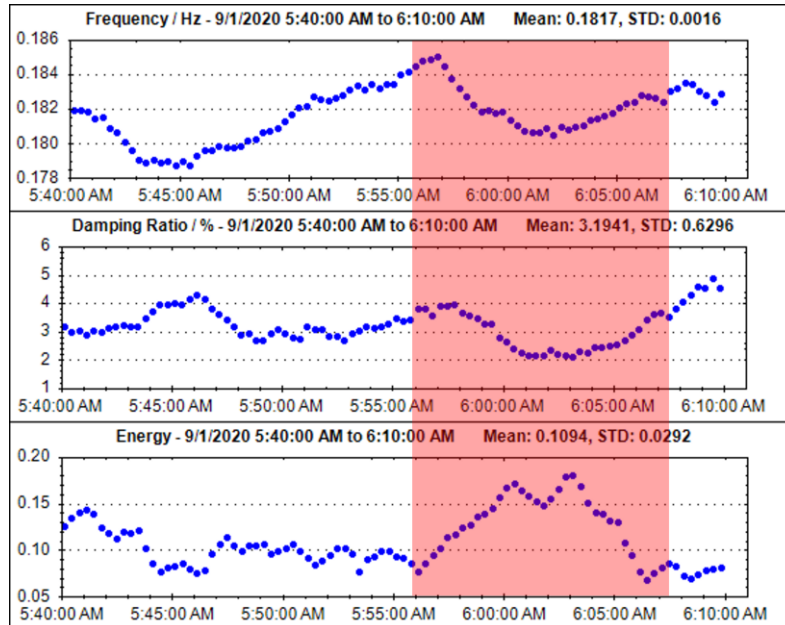
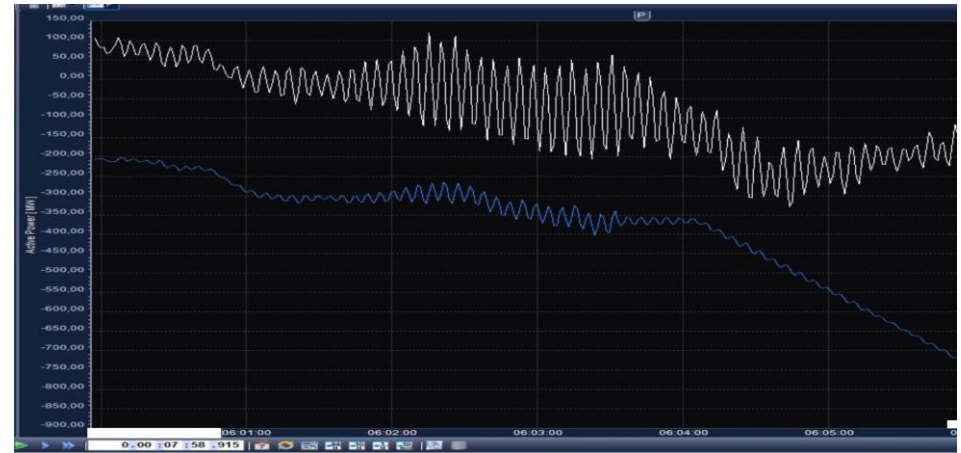
Constraints mainly when export from Spain to France

Remedial actions with impact on RTE:

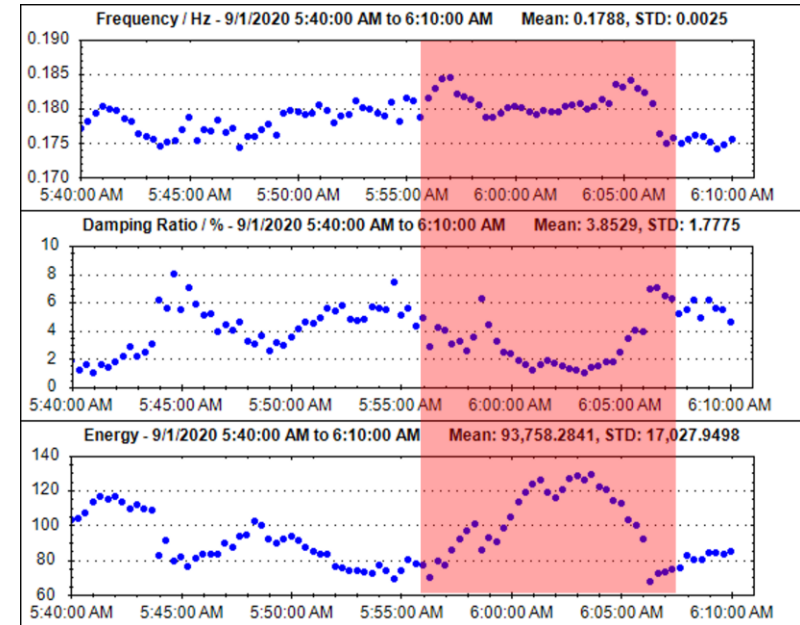
- Increase HVDC Flow
- Reduce HVAC exchange between Spain and France

# Case 1: Low-damped Interarea Oscillation

- Disturbance resulting in 0.18 Hz oscillation in the RTE system.
- Mode estimation was done by ambient as well as ring-down algorithms.
- Both FFDD and FSSI detected decreased damping of the mode.



FFDD estimates

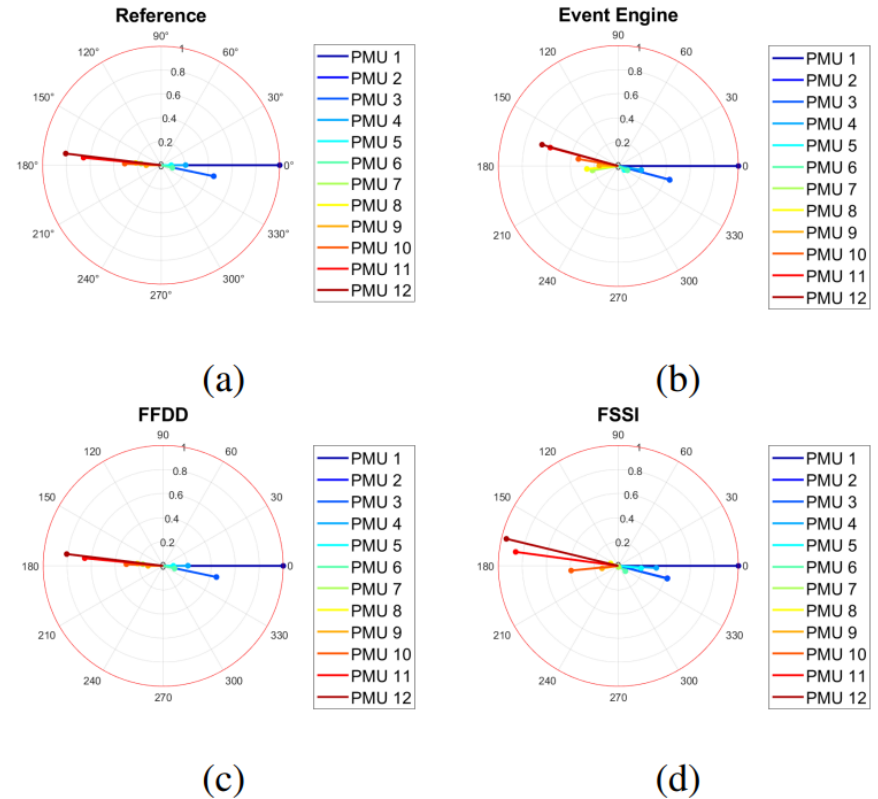


FSSI estimates



# Case 1: Low-damped Interarea Oscillation

- Consistent low-damped estimates were obtained from the ring-down analysis algorithms.
- Obtained mode shapes were consistent with the east-center-west mode's reference mode shape.
- An **Alarm** signal was generated for the operator.



(a) Reference mode shape. Mode shapes of low-damped estimates from (b) Event engine, (c) FFDD, (d) FSSI.

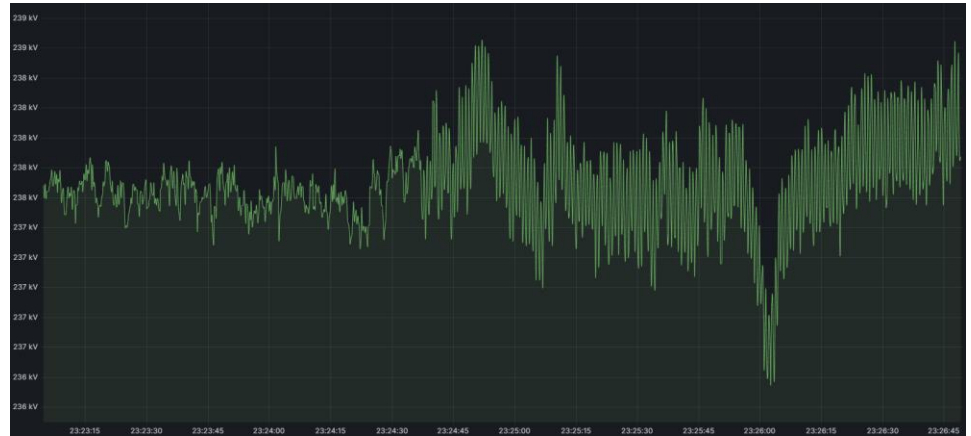
Algorithm	Window							
	1 <sup>st</sup>		2 <sup>nd</sup>		3 <sup>rd</sup>		4 <sup>th</sup>	
	F	DR	F	DR	F	DR	F	DR
HTLS	0.170	-6.7%	0.174	-3.5%	0.167	-3.7%	0.173	-2.1%
MP	0.172	-5.6%	0.171	-1.6%	0.168	-1.3%	0.174	-4.6%
ERA	0.165	-1.3%	0.171	-1.6%	0.167	-1.3%	0.174	-4.6%

Low-damped estimates of ring-down algorithms

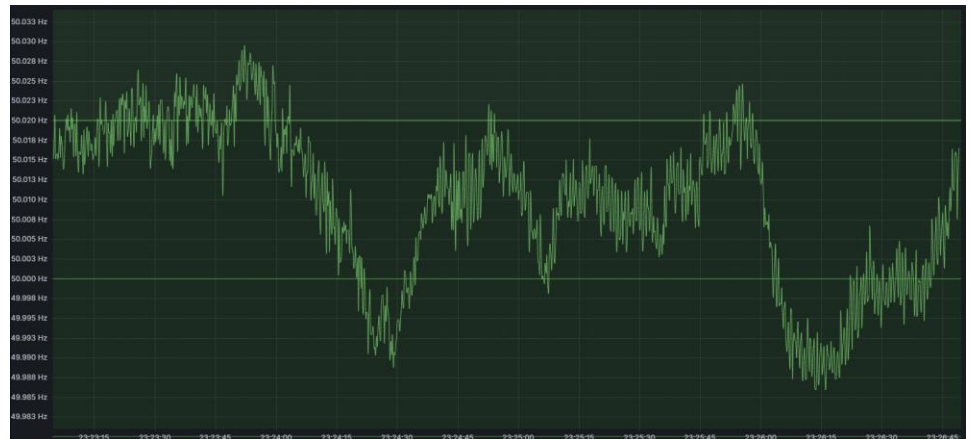


## Case 2: Low-damped Local Oscillation

- Oscillations seen in the RTE system due to PSS malfunction in a power plant.
- Small amplitude oscillations, so no estimation was done by ring-down analysis algorithms.
- Oscillations were more observable in the voltage measurements than in the frequency measurements.



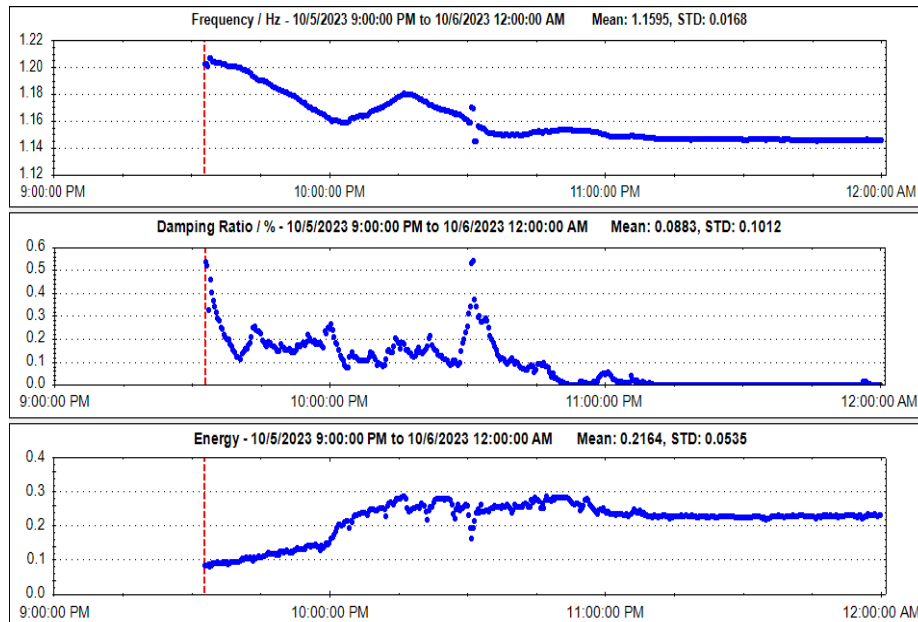
Voltage Oscillations



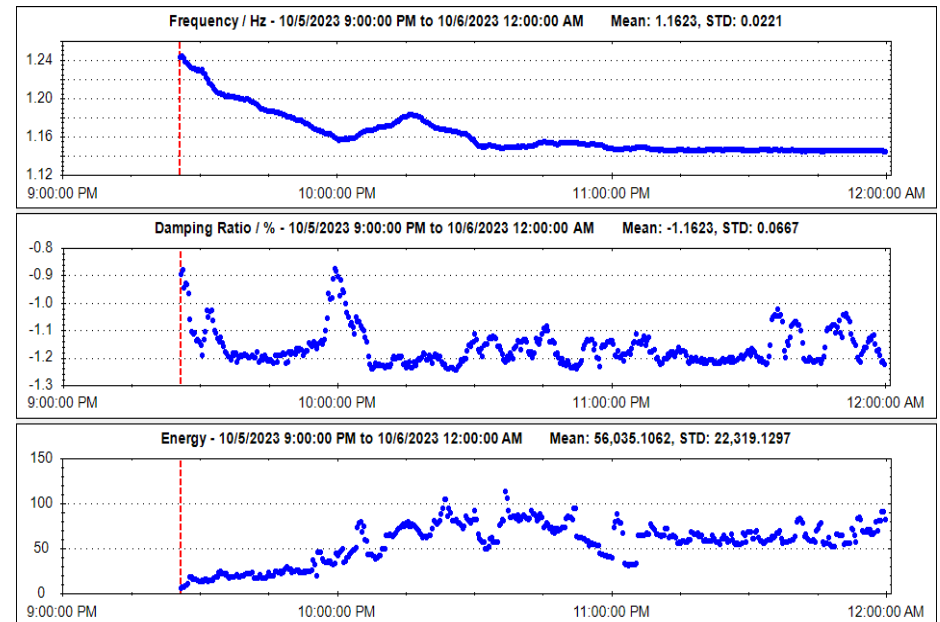
Frequency Oscillations

## Case 2: Low-damped Local Oscillation

- Both FFDD and FSSI detected low-damped modes at 1.2 Hz after the malfunction of the PSS.
- An **Alert** signal was generated by MANTRA as the mode frequency and mode shape were not consistent with the target east-central-west mode.



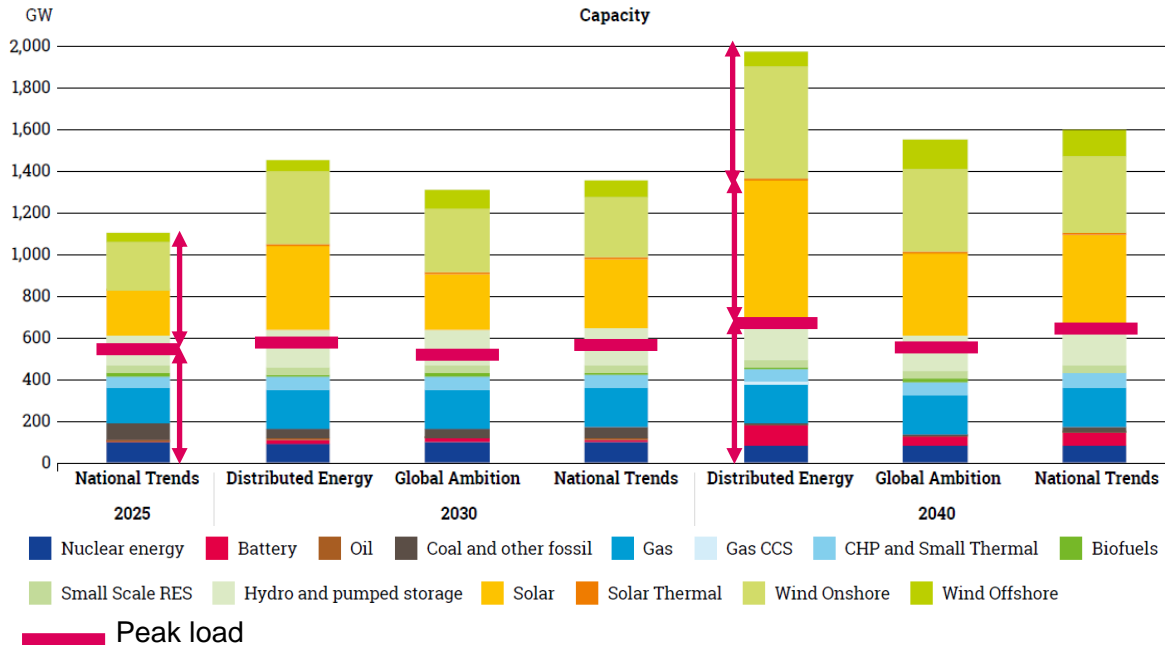
FFDD estimates



FSSI estimates



# The future...



The share of RES (wind and solar) is increasing drastically:

⇒ Many projects to reinforce the network due to increasing flows

Ref : ENTSOE – Ten Year Network Development Plan 2020

New connections to CE Network: Ukraine connected in 2022, Baltics planned in 2025, others?

⇒ The modes of tomorrow could be different and more variable than the modes of today

⇒ Real-time monitoring and mitigation are necessary