Using wide area measurements to improve situational awareness and power system analytics in Finnish power system

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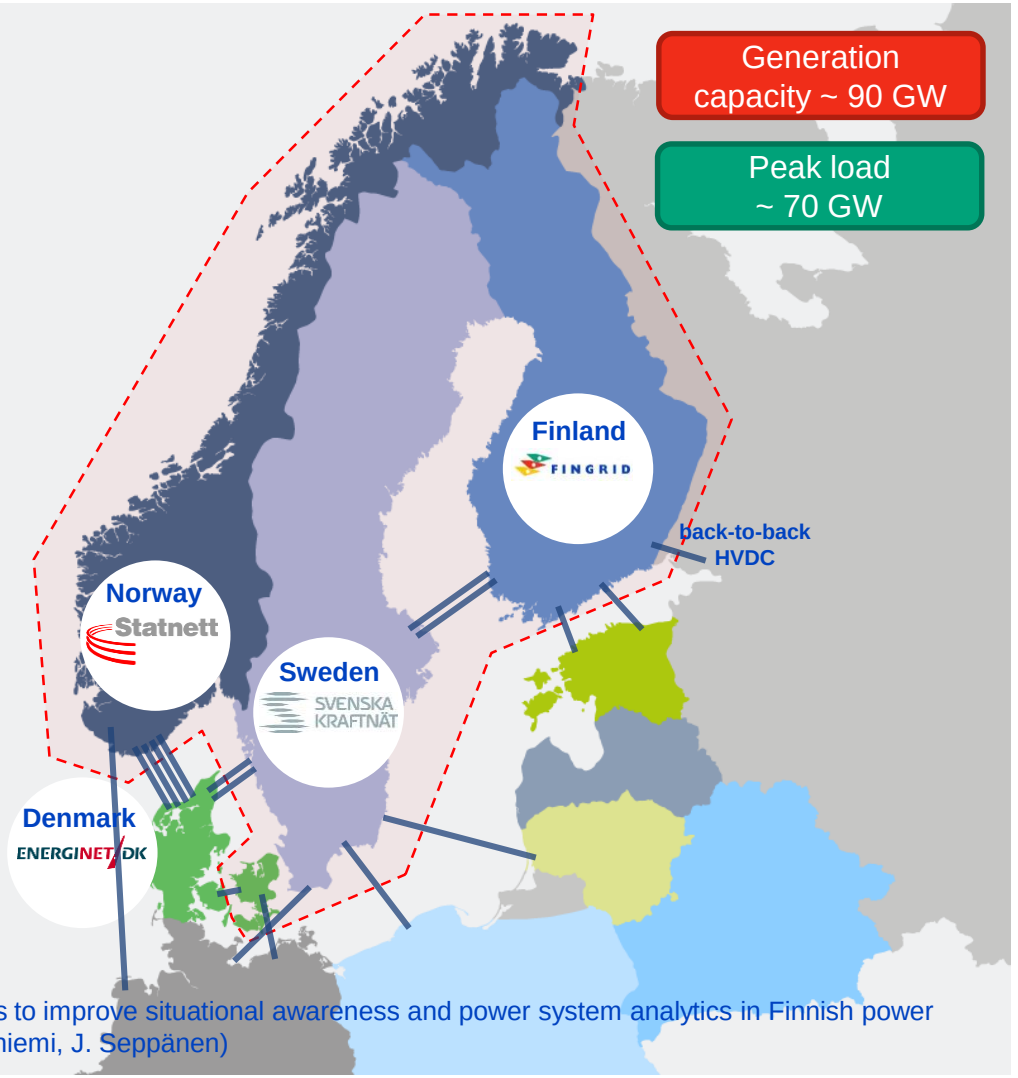
Nordic synchronous transmission system

- The Nordic electricity grid is used according to jointly agreed rules
  - N-1 principle
  - operation shall return to normal in 15 minutes
- Transmission system operators have system responsibility
  - technical use of the power system
  - managing power balance
  - imbalance settlement and energy reporting
- Power exchanges
  - electricity price formation
  - market-based allocation of cross-border transmission capacity



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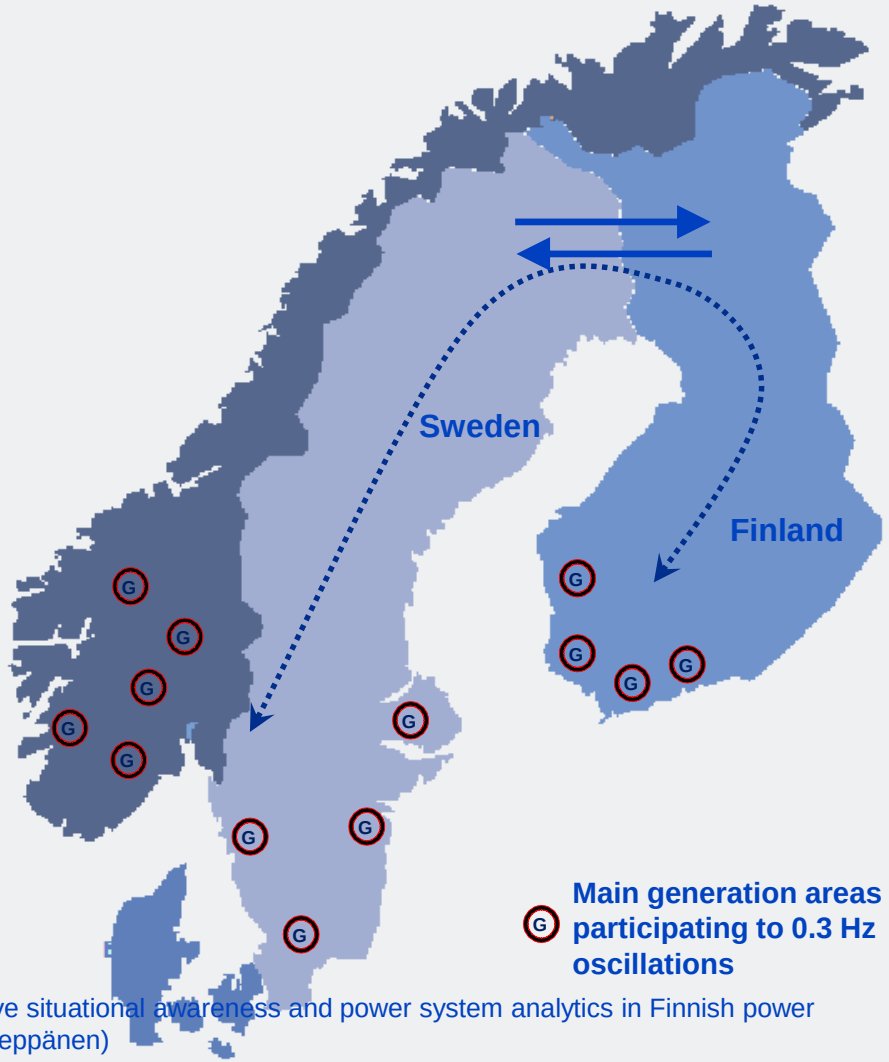
Stability phenomena as seen from Finland

- Power transfer from Finland to Sweden
  - Transmission distance ca. 2000 km
  - Damping of electromechanical oscillations (0,3 Hz) limits power transfer
- Power transfer from Sweden to Finland
  - Transmission distance ca. 1000 km
  - Voltage stability limits power transfer
- Integration of large power generating units and renewable generation
  - Frequency stability
  - Power system inertia
- WAMS and synchrophasor technologies provide new tools to analyze dynamic performance of the power system



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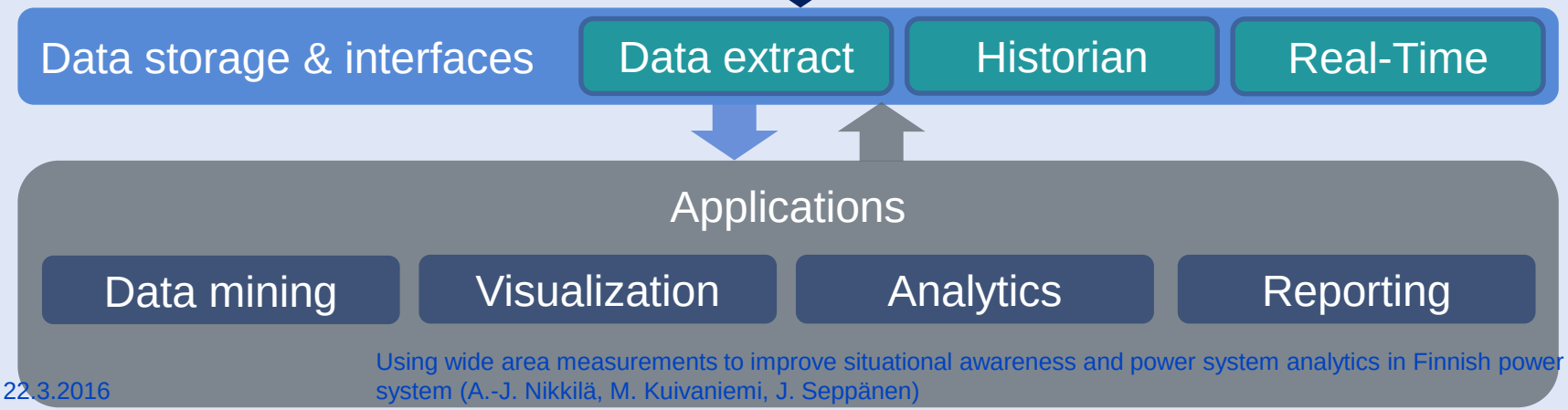
WAMS architecture and applications

Real-time data streams with other transmission system operators

Fingrid WAMS

- ~ 15 PMUs in Finland
- All data are available for 400 days (20 ms resolution)
- Selected data are available for ~5 years (100 ms resolution)



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Development of PMU and WAMS applications

Offline analysis using PMU data for many years
WAMS development step by step

Testing methods estimating status of electromechanical oscillations, R&D

Online applications for power system analysis

- Disturbance/event analysis
- Visulization, trends, spectrograms

Analysis of power system performance over large data sets, long-term trends

Key requirements for Fingrid

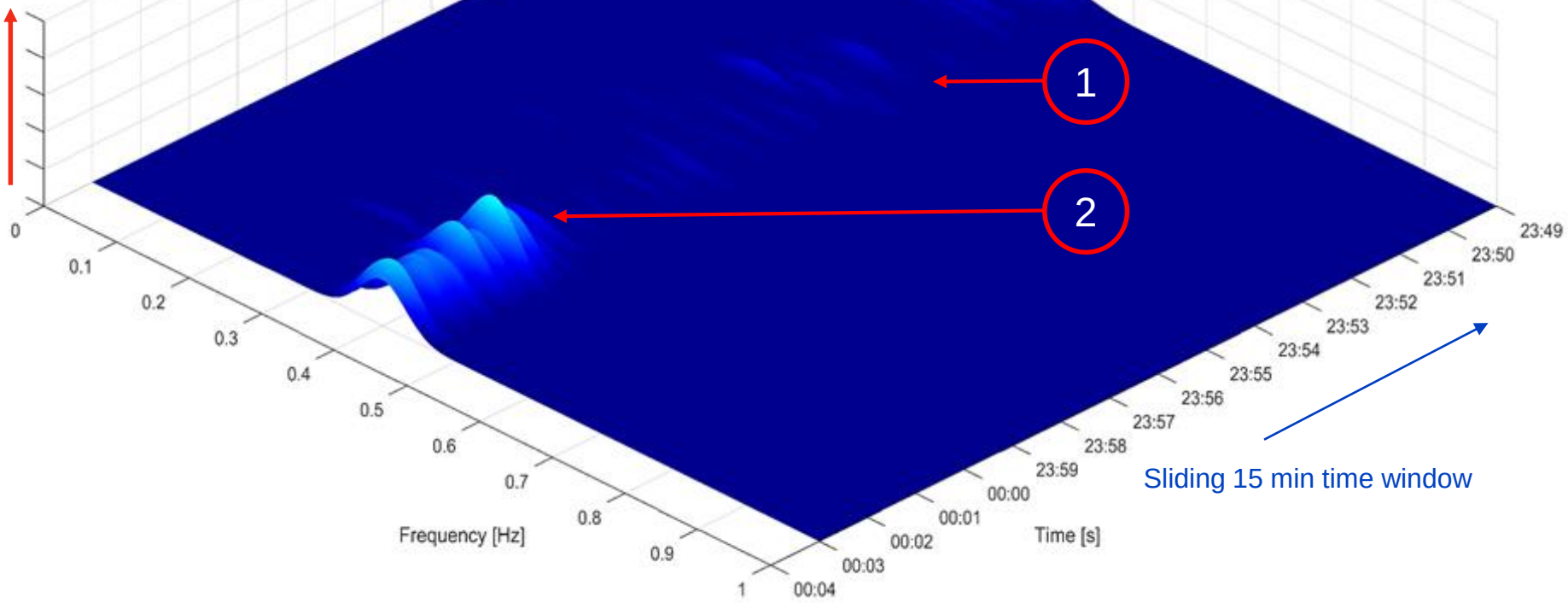
- Flexible interfaces and platform between data and analysis applications
- Transparency of the analysis routines and algorithms

Power spectral density visualizes oscillations and transients in real-time

1 Ambient oscillation at ~ 0,33 Hz frequency

2 Increased oscillation at 0,40 Hz frequency

[MW^2 / Hz] scale is selected so that anomalities are clearly identified and ambient oscillation is still visible



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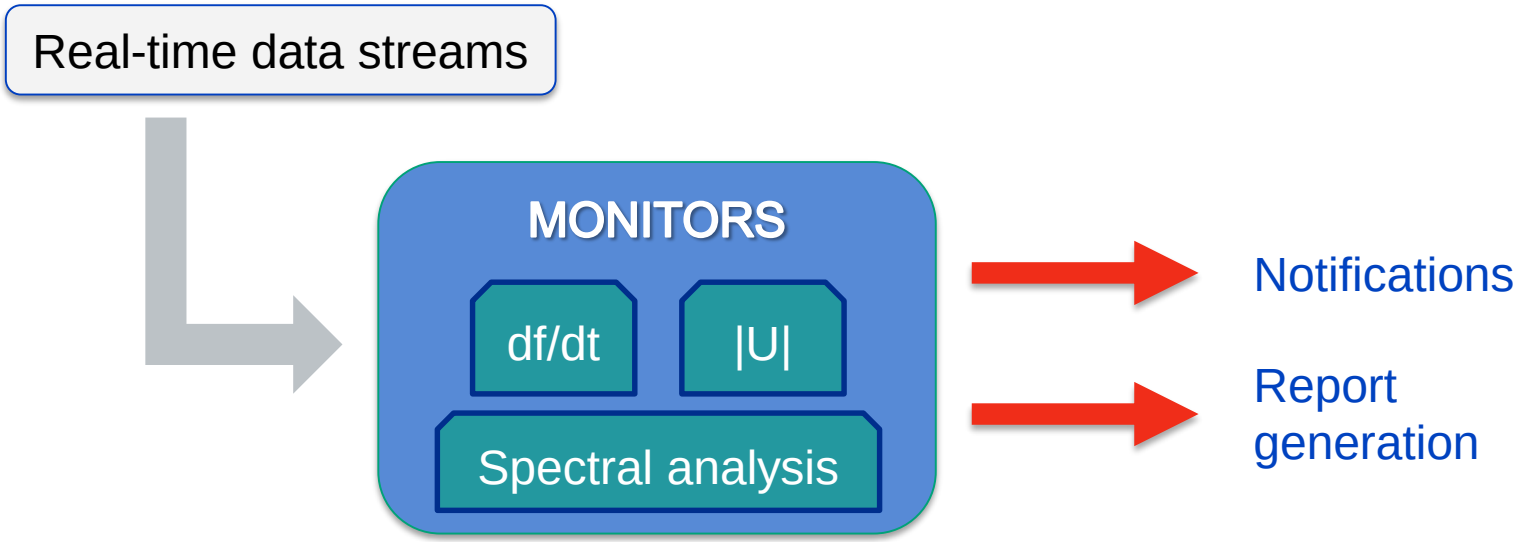
Experiences from spectrograms in the control center

- Improve knowledge on power system performance in general
  - Sufficient training for interpreting the results is important
- Helps to identify oscillations that may be difficult to see from time-domain trends
- Help to identify anomalities in power system performance in general
  - For example issues with HVDC systems
- Oscillation frequencies and amplitudes can be calculated and recorded from the spectrograms for further analysis
- Trade off between visualization experience and analysis accuracy
  - Proper selection of the signal processing parameters is important

Online detection and analysis of power system events

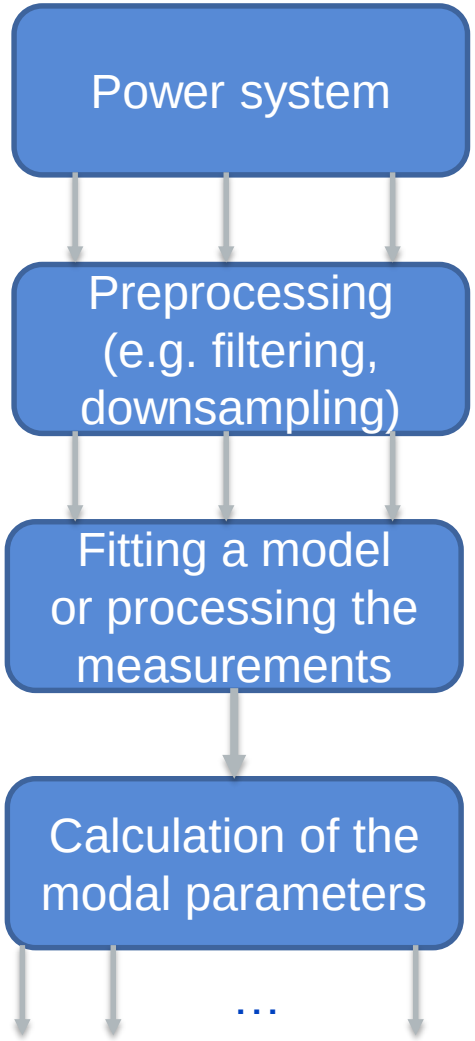


Main drivers for the development of the application

- Analysts felt that it is difficult to keep track of system events
- Acquiring measurement data and processing it into easily readable format was too difficult and laborious

Monitoring power system state with modal analysis

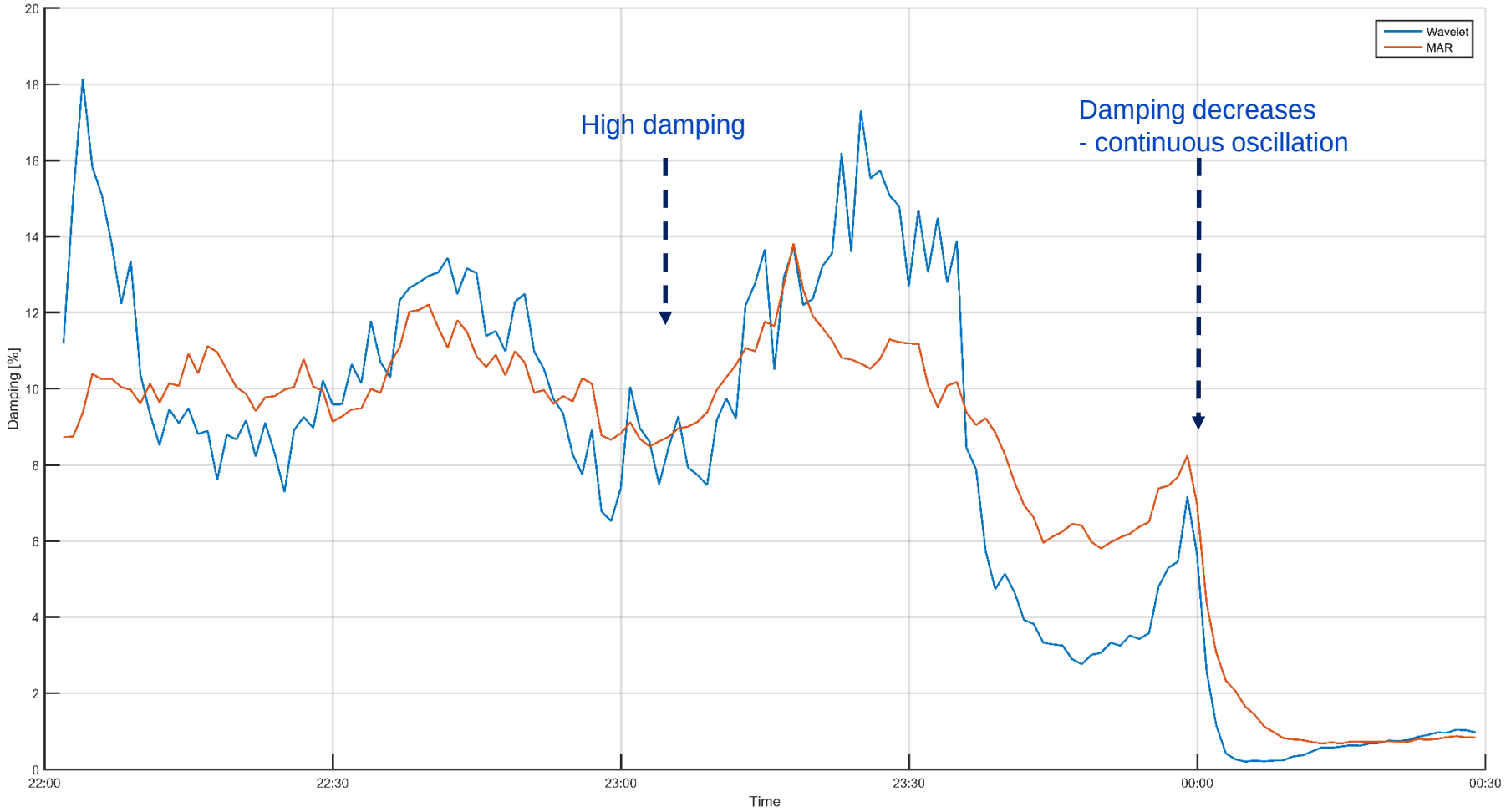
- The main focus is on the monitoring of inter-area oscillations:
  - 0.3 Hz inter-area mode between Finland and Sweden
- Monitored quantities:
  - Frequency of the modes
  - Damping of the modes
  - Amplitude of the modes
- Used methods:
  - Wavelet (Univariate method)
  - MAR (Multivariate AutoRegressive model, multivariate method)



Ambient PMU measurements

Modal estimates

Example of an oscillation event on 0,3 Hz mode



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Summary

- Synchrophasor data improves situation awareness and power system analysis
  - Even small and simple reporting and visualization applications may provide benefits for both control room operators and back office specialists
- Phenomena observed by WAMS may be complex
  - Flexible and transparent analysis algorithms are important
  - Algorithms need to be tested thoroughly
  - Sufficient training for interpreting the analysis results
- Applying signal processing algorithms requires high quality synchrophasor data
  - PMU installation practices and configuration settings are important

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