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Wide area monitoring and control activities in Norway and the Nordic power system

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Outline

- The Nordic power system
- WAMS activities, objectives and applications
- Power oscillation monitoring
  - PMU measurements
  - On-line monitoring
- From WAMS to WACS.. (ongoing and future work)
- Concluding remarks

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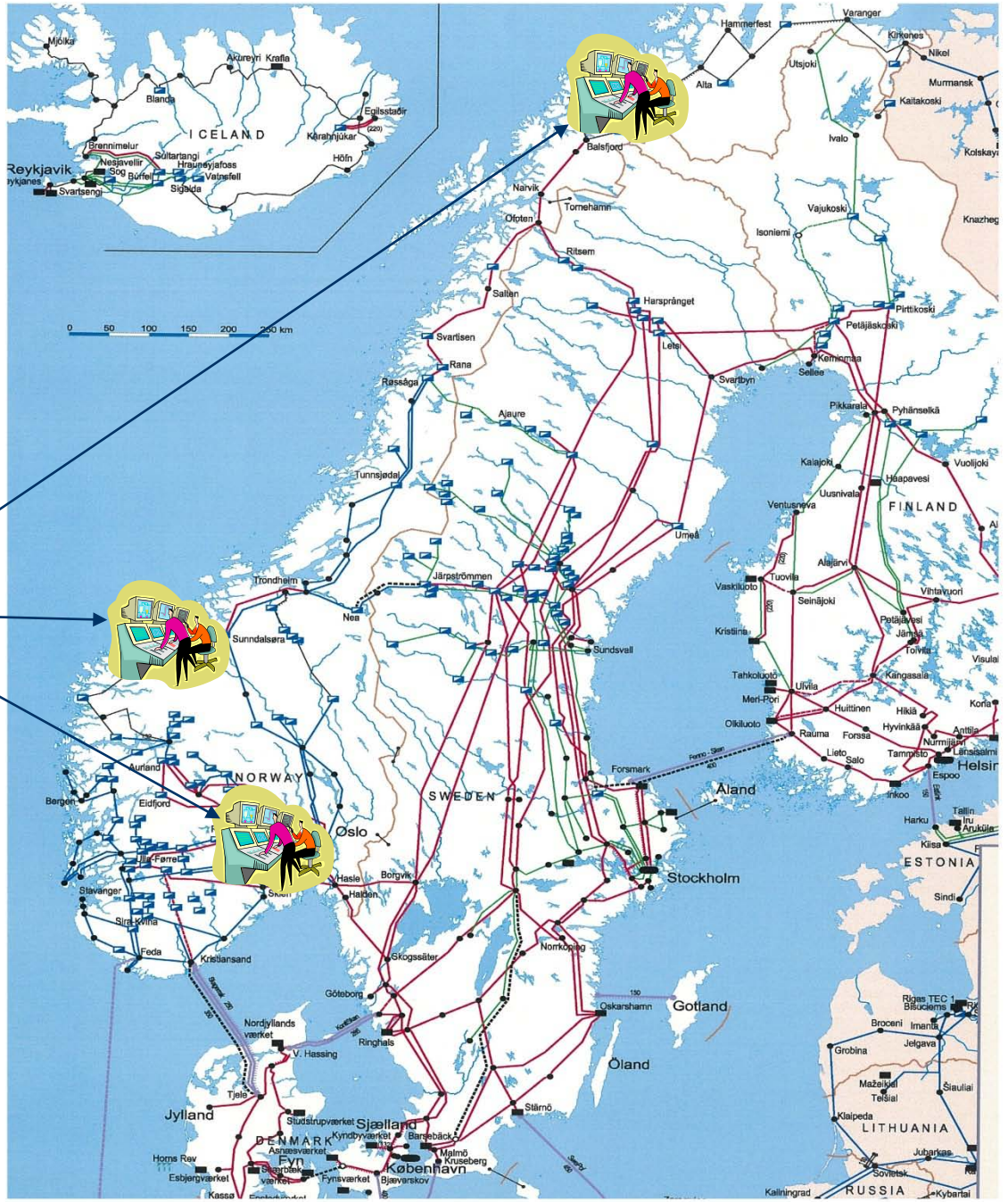
The Nordic Power system

Norway (TSO Statnett): Regional control centres

National control Centre - Oslo



Nordic system dynamic characteristics

- Modal Analysis:
  - Identified and classified oscillatory modes

Oscillatory Frequency	Relative Damping	Mode Classification	Main Observability Area
0.33 Hz	**5.40 %**	**Inter-area mode**	**Finland / Southern Norway**
0.48 Hz	**2.48 %**	**Inter-area mode**	**Sweden / Southern Norway**
0.55 Hz	3.39 %	Local area mode	Northern Norway
0.62 Hz	6.20 %	Inter-area mode	Sweden / Central Norway
0.76 Hz	1.48 %	Local area mode	Western Norway

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Statnett's assessment of potential benefits and applications of WAMS

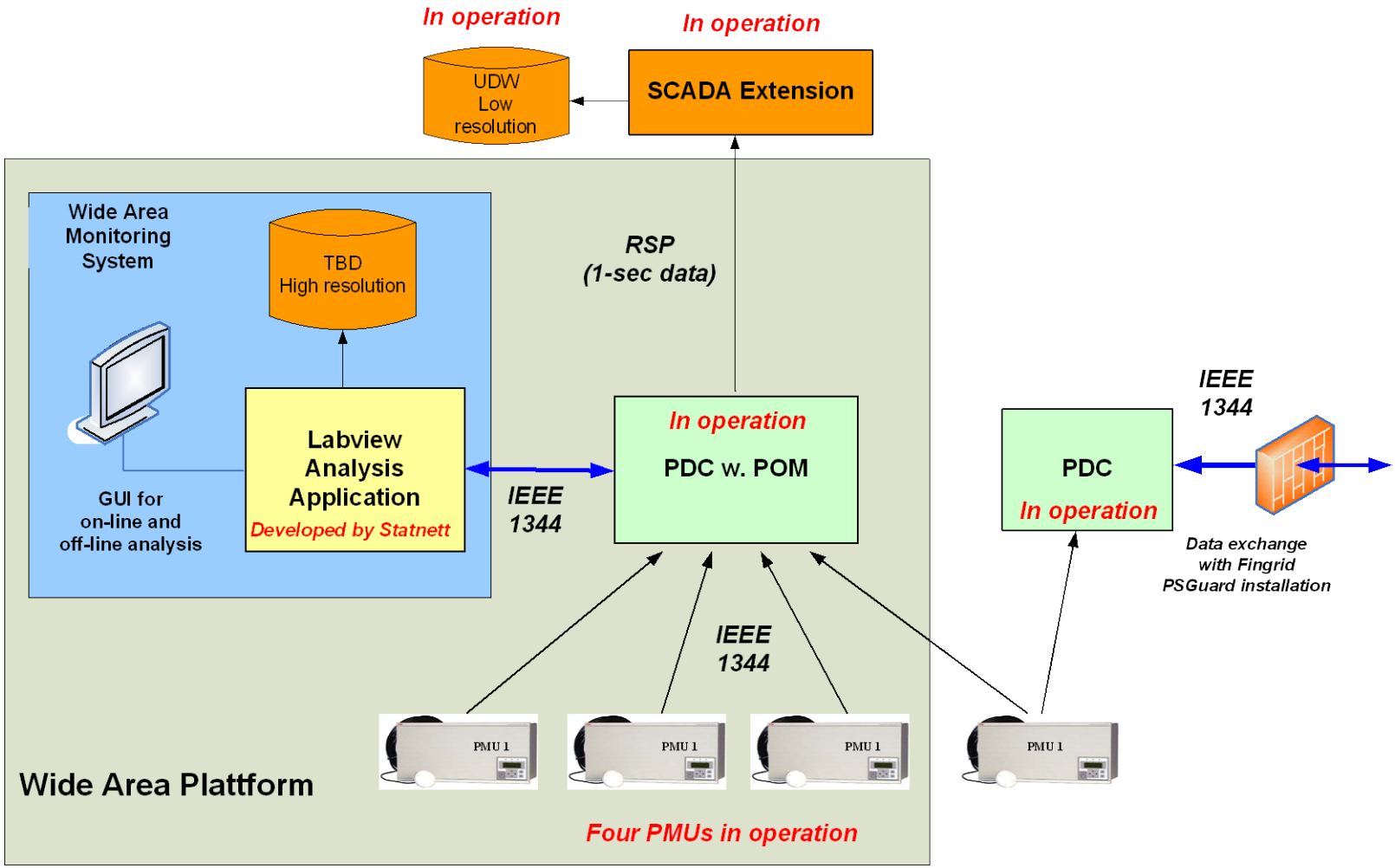
- Workshop at Statnett in 2006 to assess promising functions and benefits
  - In operation
  - Operation planning
  - For protection and fault analysis

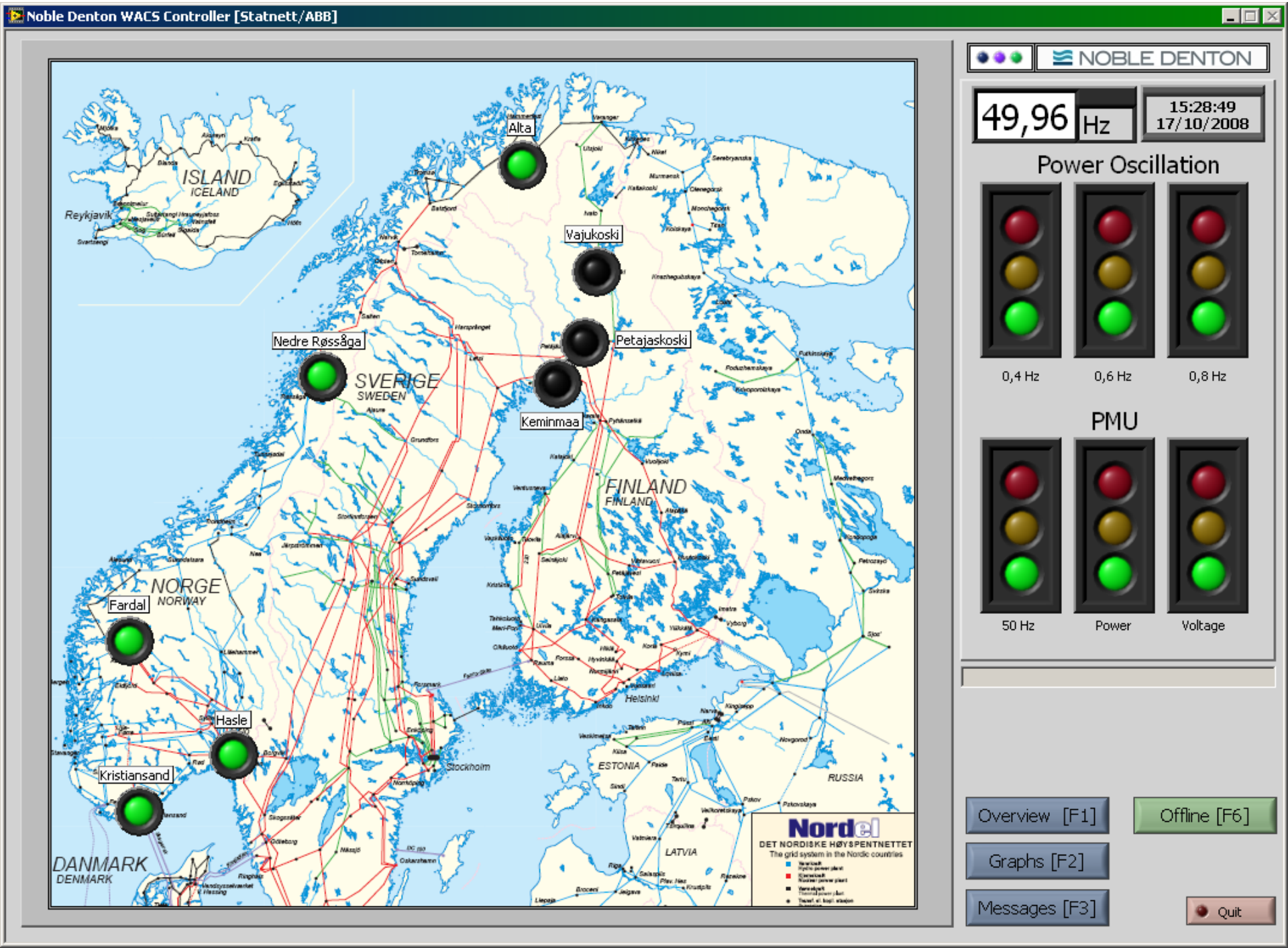
- On-line functions
  - Various displays and indicators
  - Power oscillation monitoring, voltage instability, voltage flicker,..
- Off-line functions
  - Plotting and display functions
  - Analysis tools
  - Trigging functionality (for identification of events and storing data)

Main findings

- On-line information and trending of complex information is not considered as very useful.
  - Operators do not have time to look at this information, especially not in stressed situations.
- Simple alarms and information quantifying presence and characteristics of power oscillations is useful.
  - Such information is not available today.
- On-line calculation of high voltage flicker levels is useful in some substations.
- Off-line: Good tools for storing, displaying and analysing phasor data are important.
  - Useful for many off-line analysis purposes, including forensic analyses and model validation.

WAMS prototype




Noble Denton WACS Controller [Statnett/ABB]
NOBLE DENTON
49,96 Hz
15:28:49
17/10/2008
Power Oscillation
0,4 Hz
0,6 Hz
0,8 Hz
PMU
50 Hz
Power
Voltage
Overview [F1]
Offline [F6]
Graphs [F2]
Messages [F3]
Quit
Alta
Vajukoski
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DET NORDISKE HØYSPENTNETTET
The grid system in the Nordic countries

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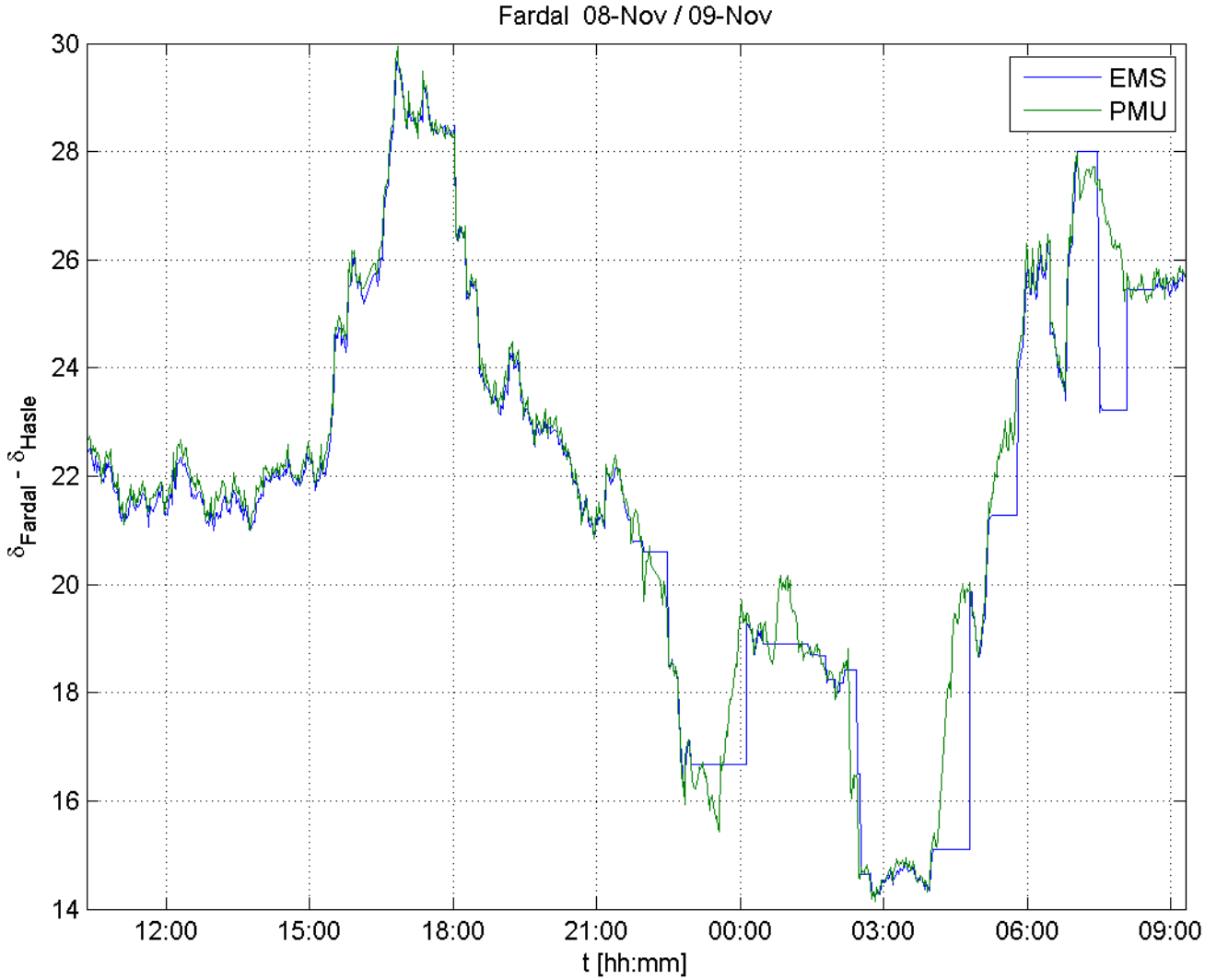
Comparing Phasor Measurements with EMS-State Estimator - Voltage angle differences

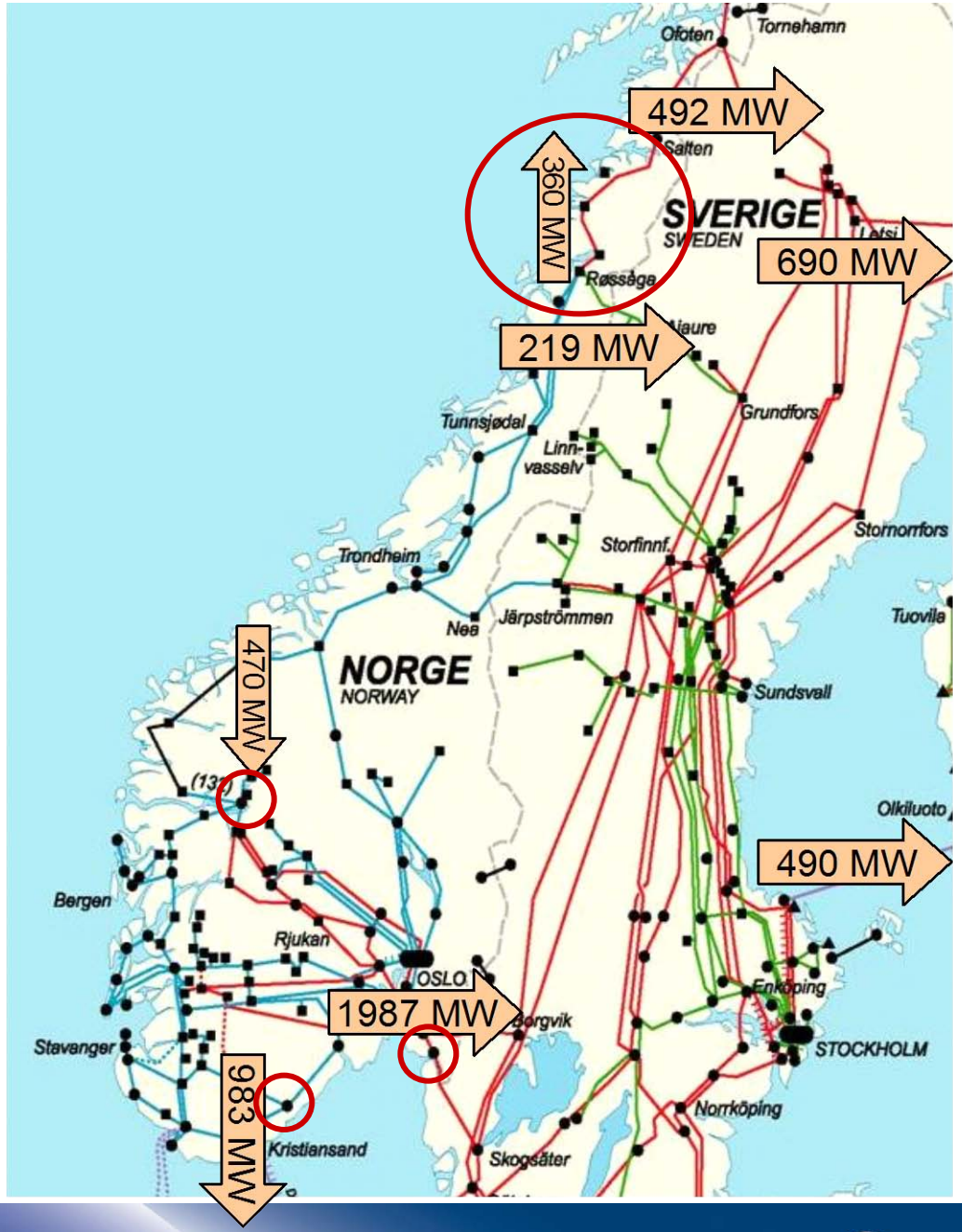


Measurements from a disturbance in the Nordic grid on August 14, 2007

- What system information can be obtained from the PMU-measurements ?
- What is the additional information compared to available SCADA-measurements ?
- ➢ What is the additional benefit of WAMS ?

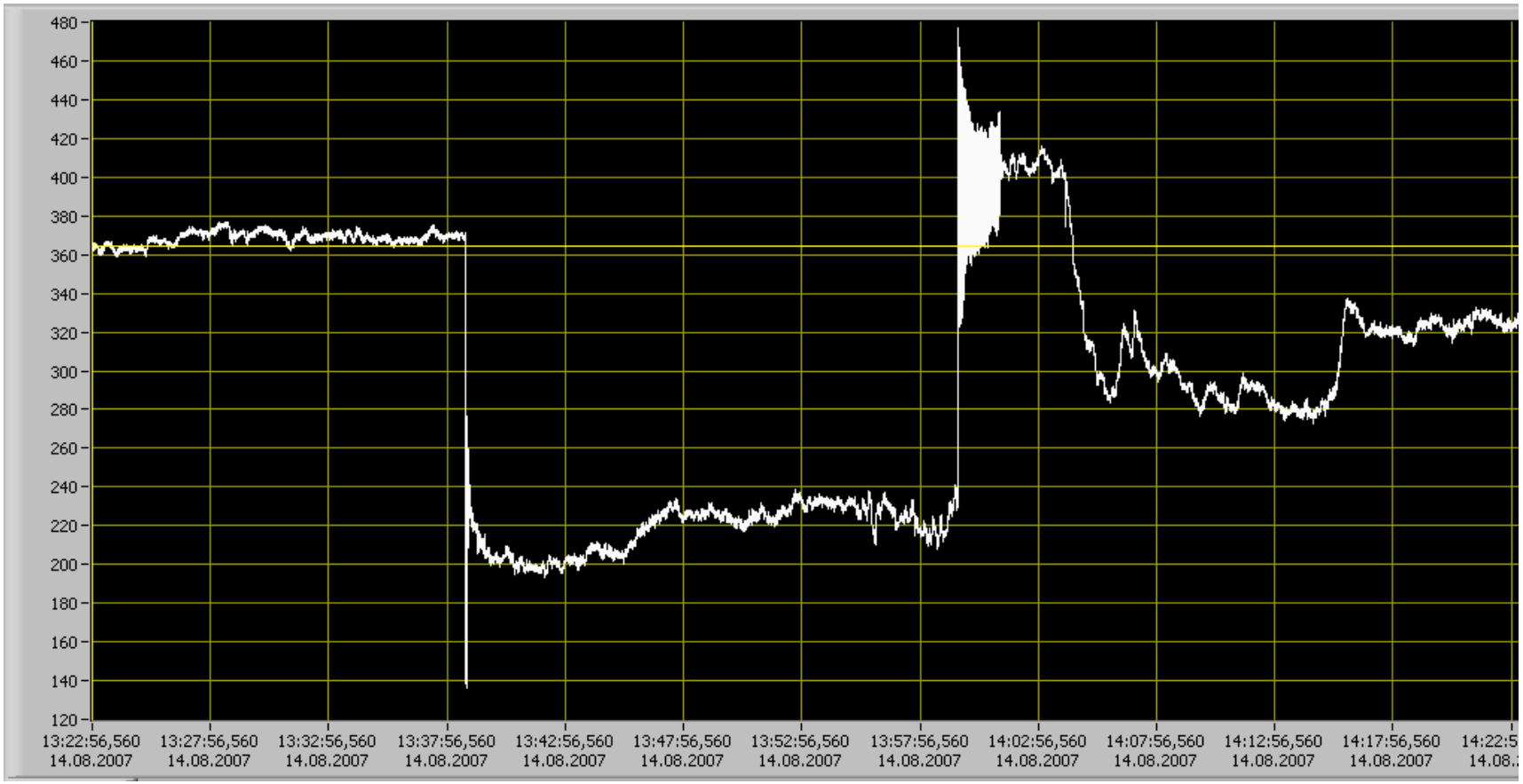
Operating condition on August 14, 2007

- Light load situation
- Surplus of hydro power
- Main power flows:
  - West → east
  - North → south
- Network split in Mid-Norway



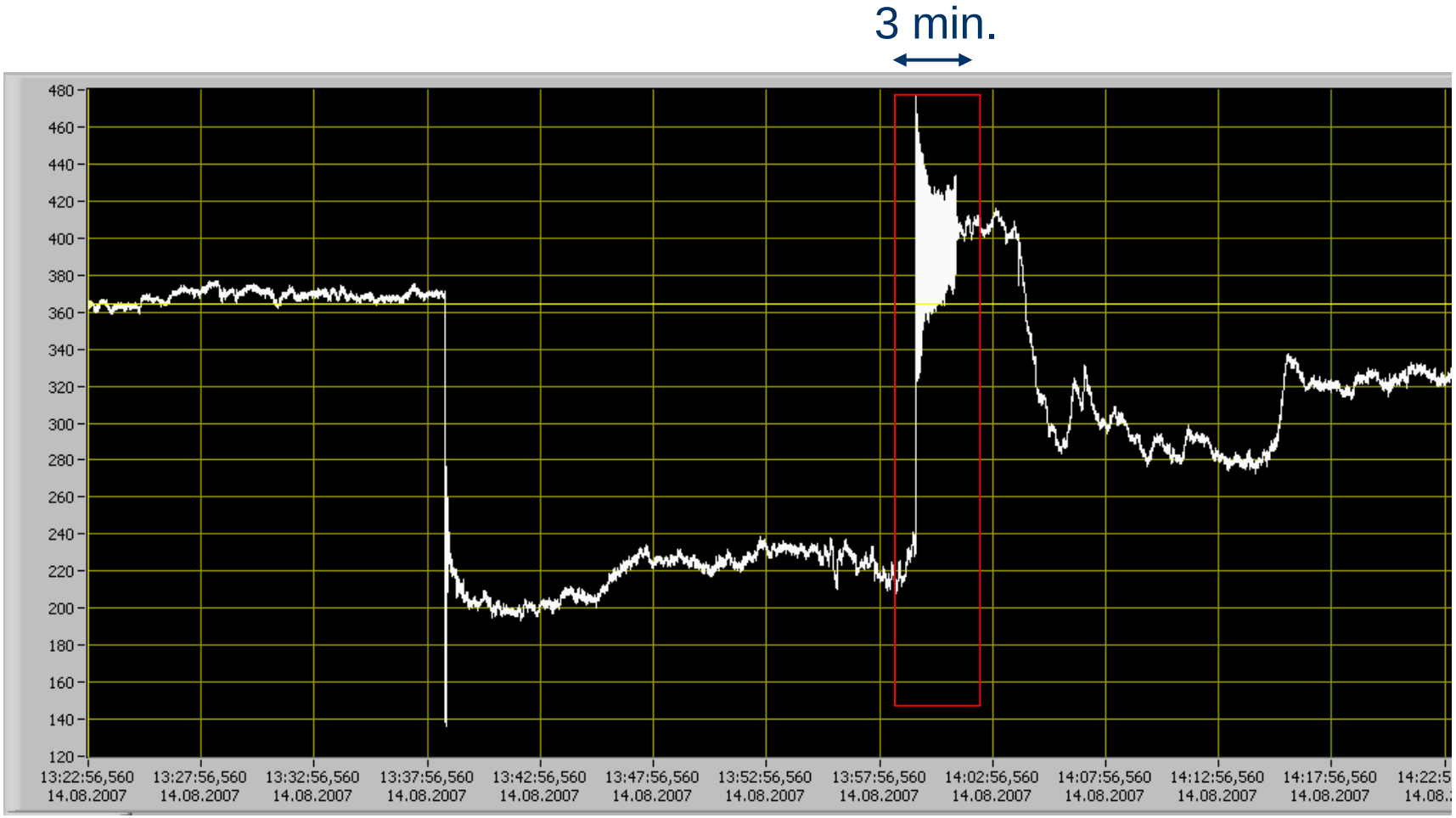
PMU sites

Power flow Røssåga-Rana

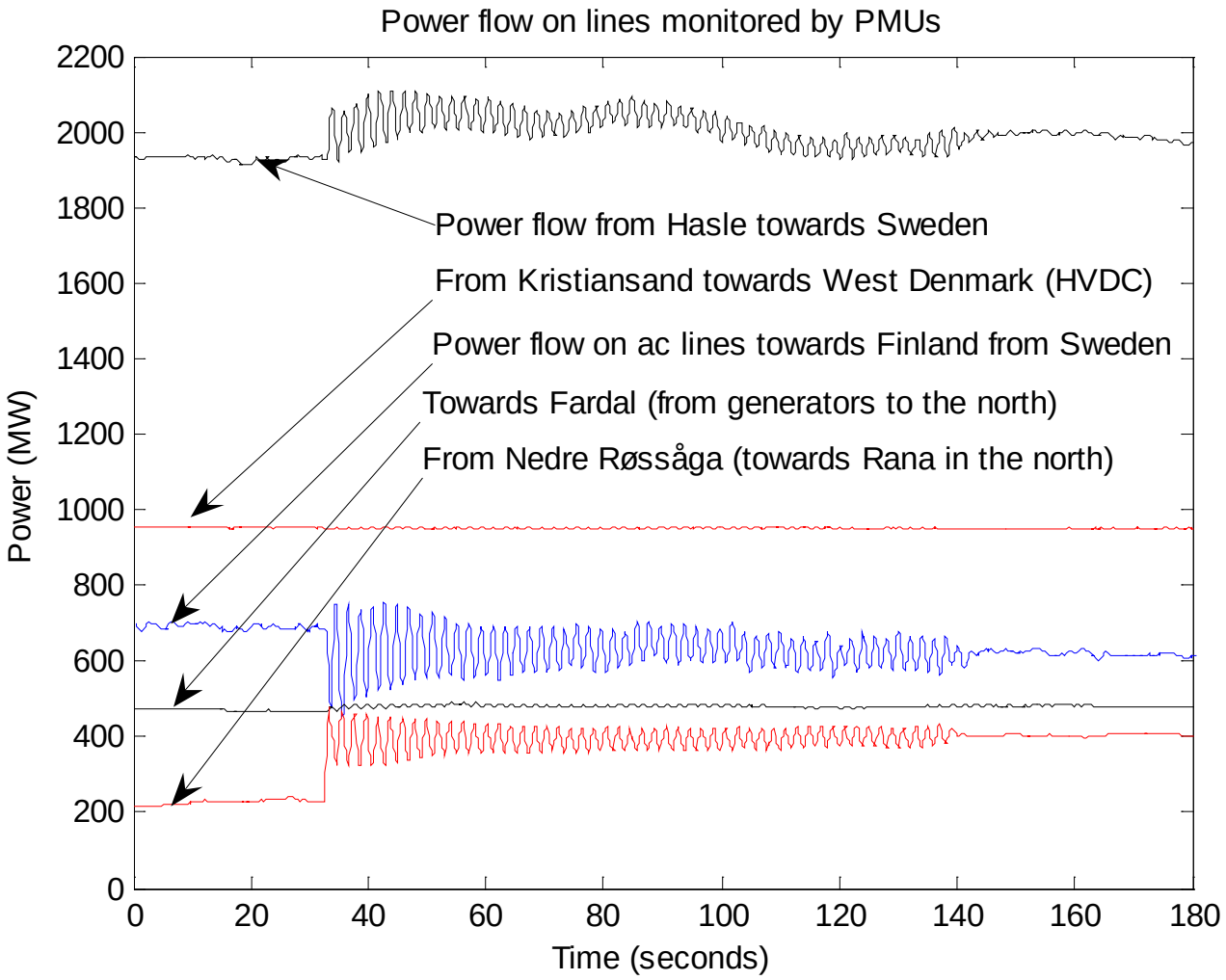


1 hour

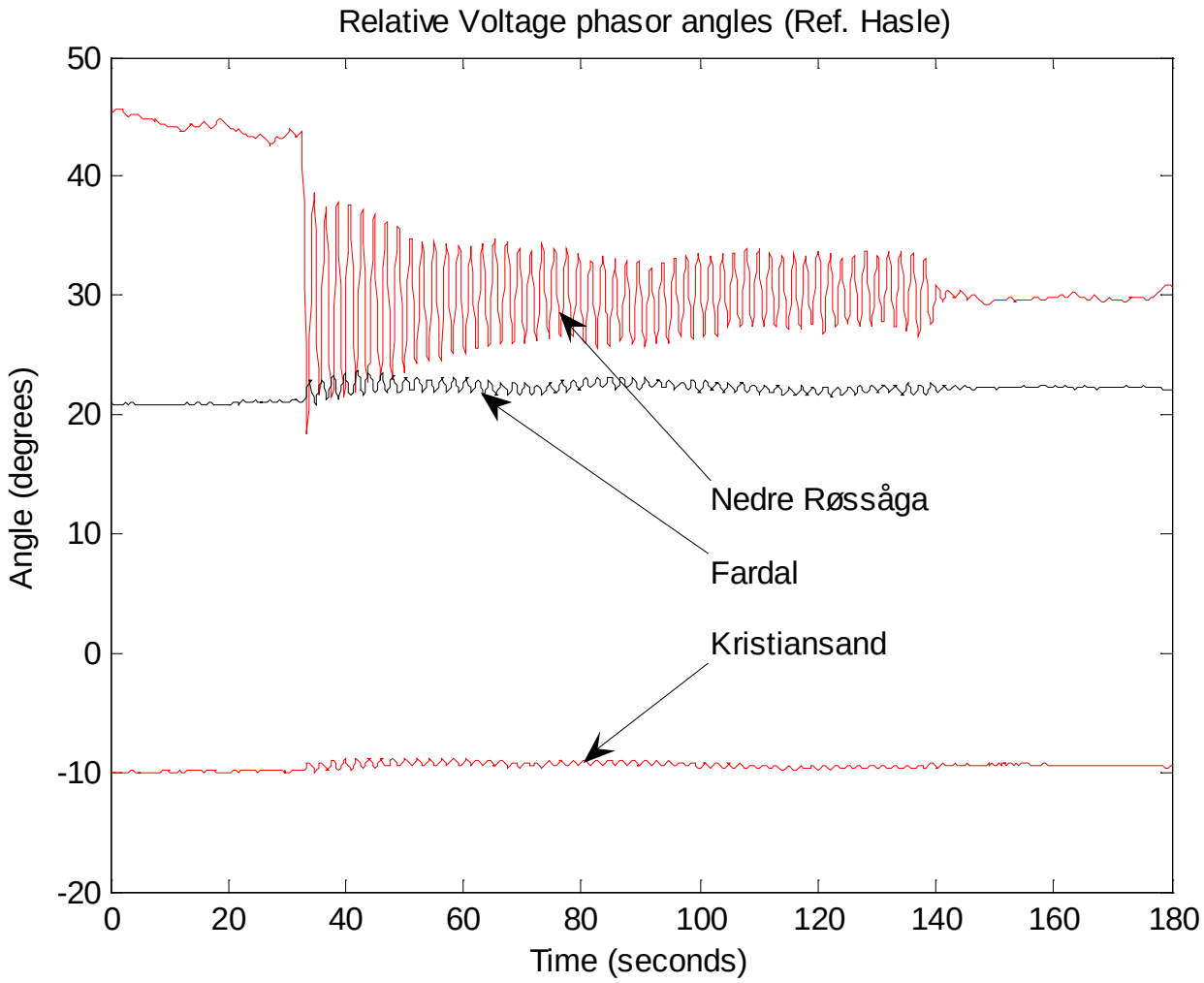
Power flow Røssåga-Rana



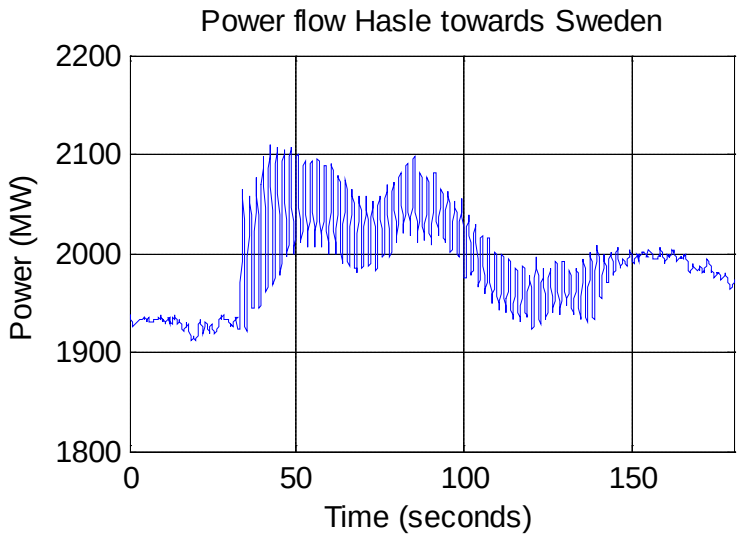
Power flow on main transmission lines

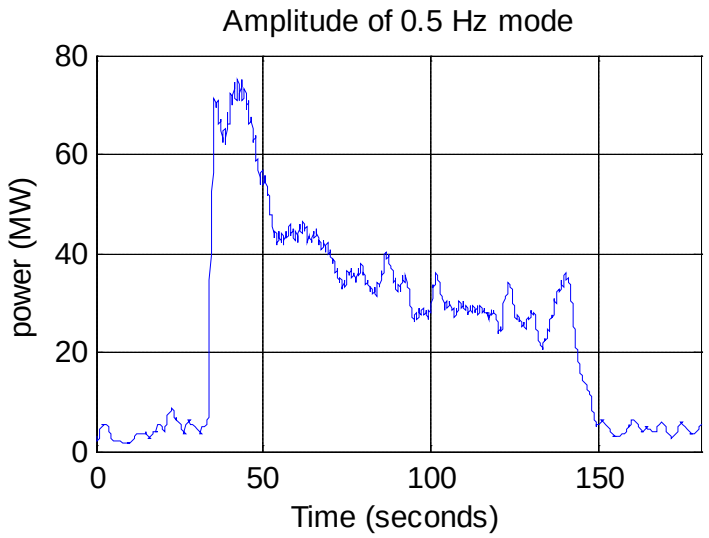


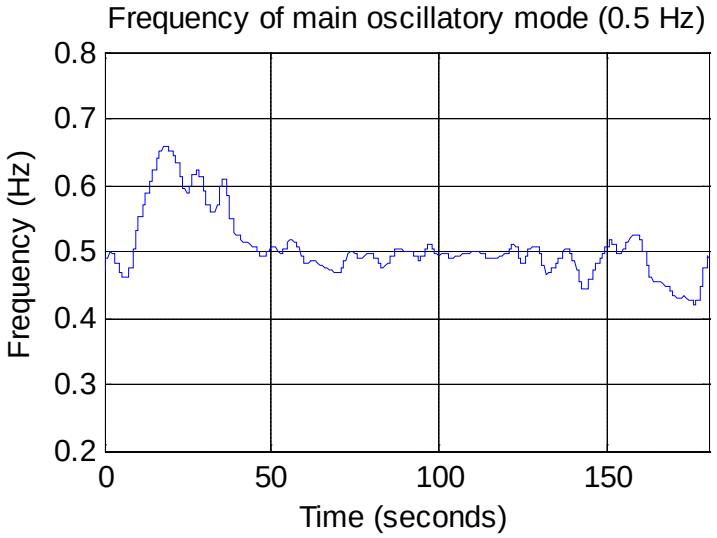
PMU-monitored voltage angles

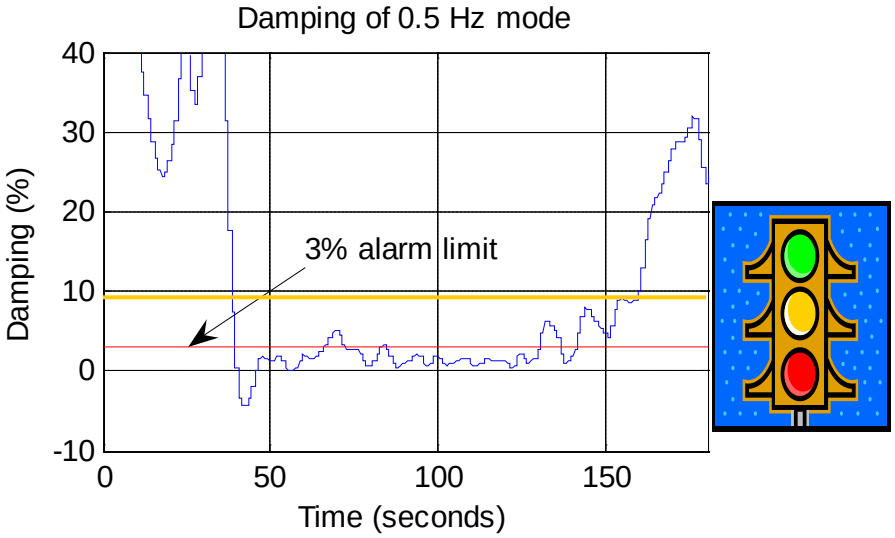


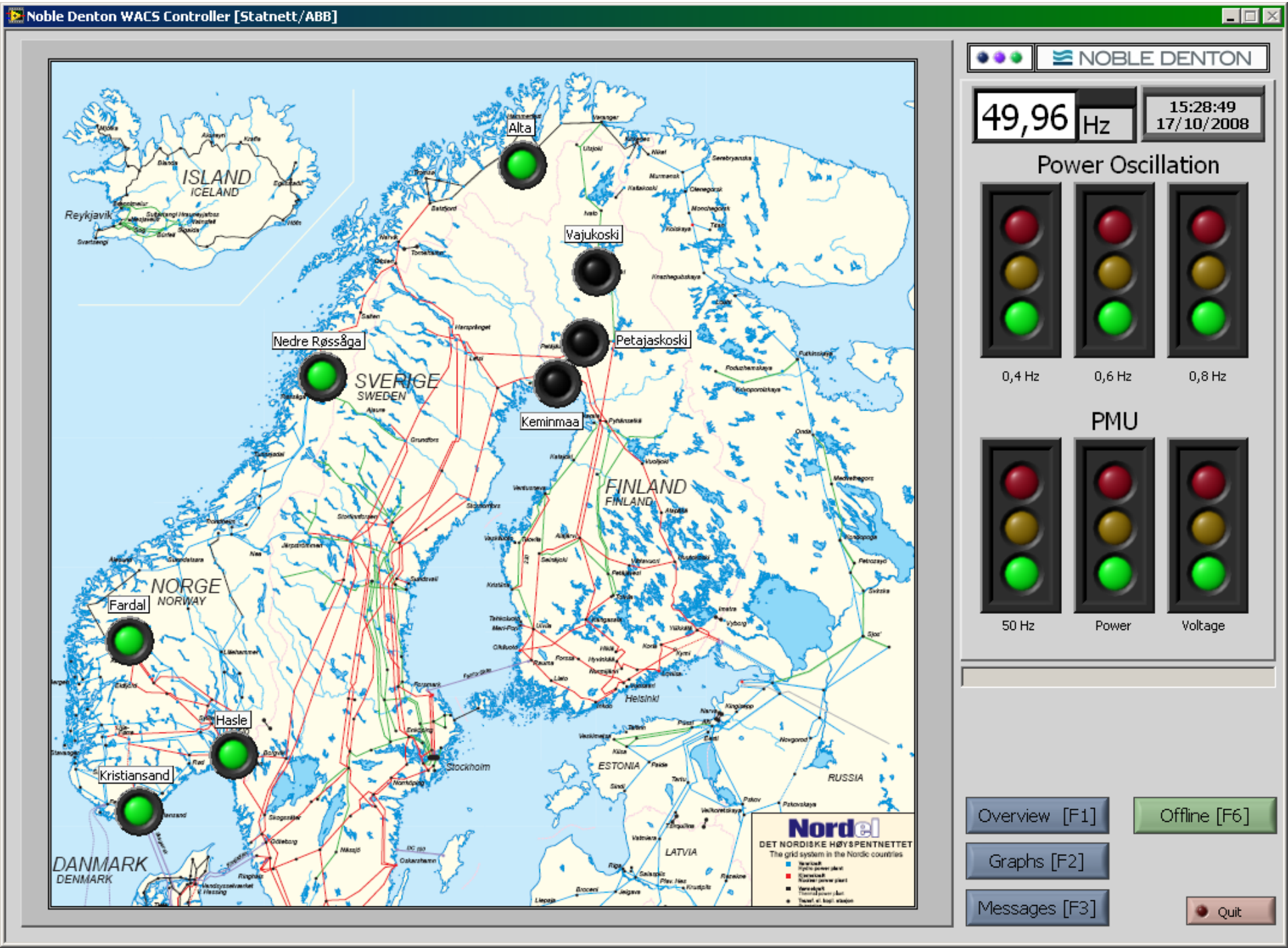
Power oscillation monitoring function







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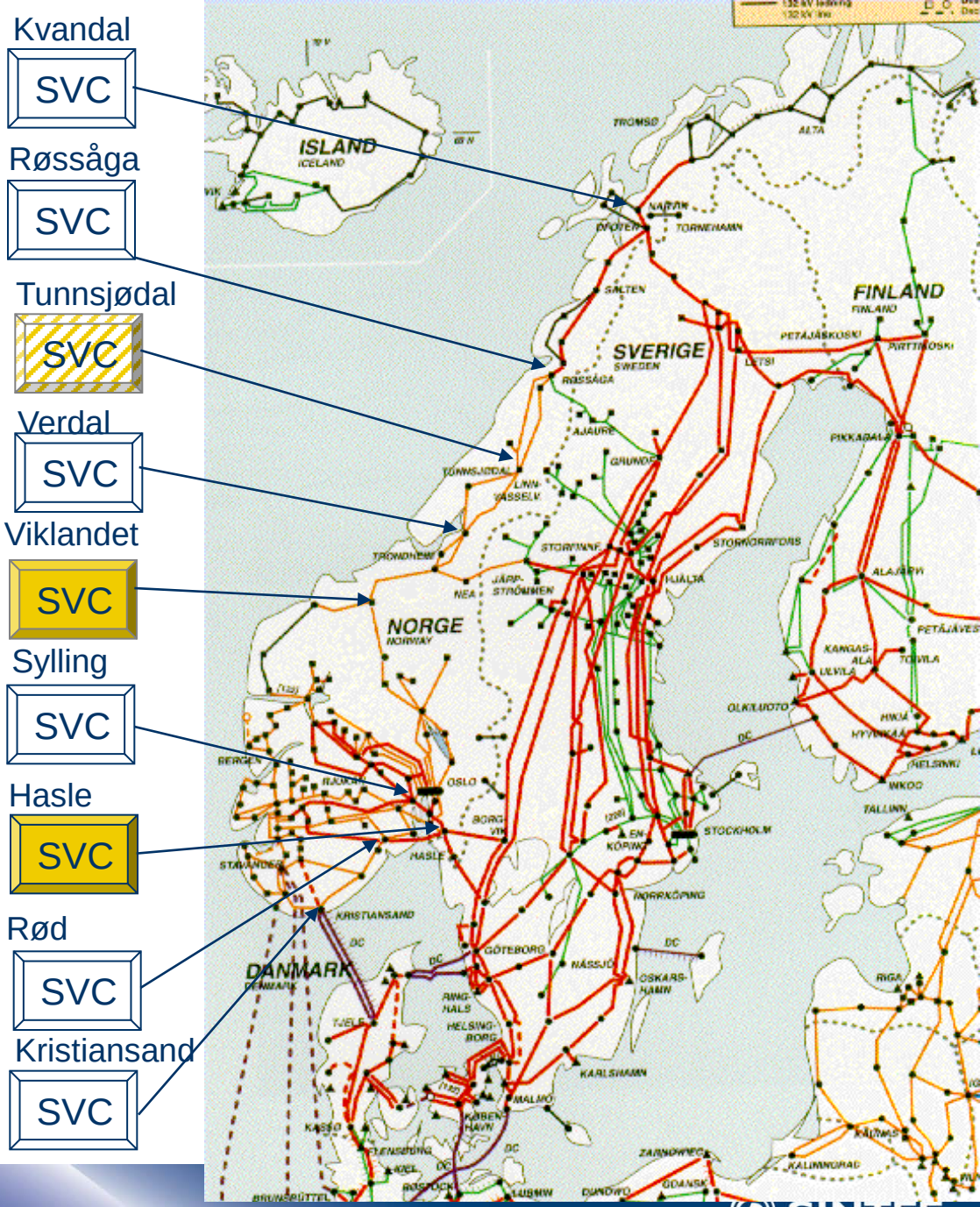
When/how to utilize PMUs and WAMS for power system control?

- When there is a need for
  - system wide information (more than just local information) AND
  - high resolution dynamic information AND/OR
  - time synchronized measurements
- Power oscillation damping
- Voltage collapse protection (based on fast detection of voltage instability problems)
- Frequency instability (out of step) protection
- Emergency control / System protection schemes
- How:
  - Power system stabilisers (coordinated design)
  - Control of SVC/FACTS and HVDC (active and reactive power control)
  - Generator tripping / Load shedding
  - Network splitting (breaker control)

“Wide-area POD”

Goals:

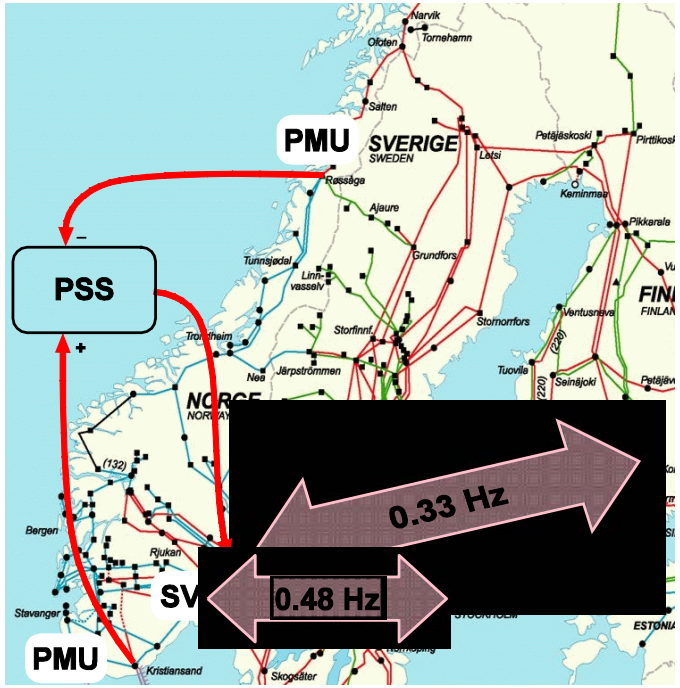
- Study the use of PMUs as measurement signals,
- Investigate coordinated stabilizer design, using SVCs
- Identify benefits and challenges with wide area measurements, compared to traditional local measurements



POD - Power Oscillation Damper Design and testing

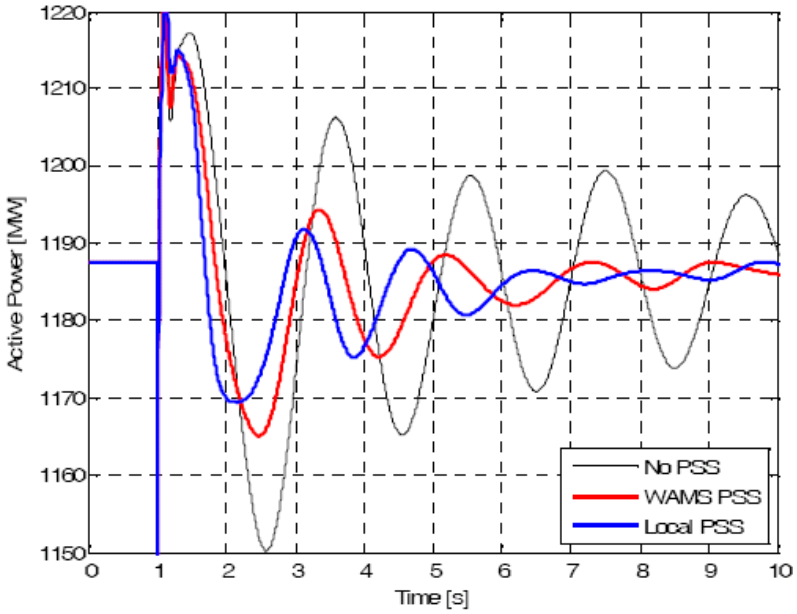
- Control-loop design
  - Wide-area and local POD controllers

POD	Measurement	Control
WA-POD	Voltage angle difference: Kristiansand – Røssåga	Hasle SVC
Local POD	Power flow: Hasle corridor (Sweden-Norway)	Hasle SVC

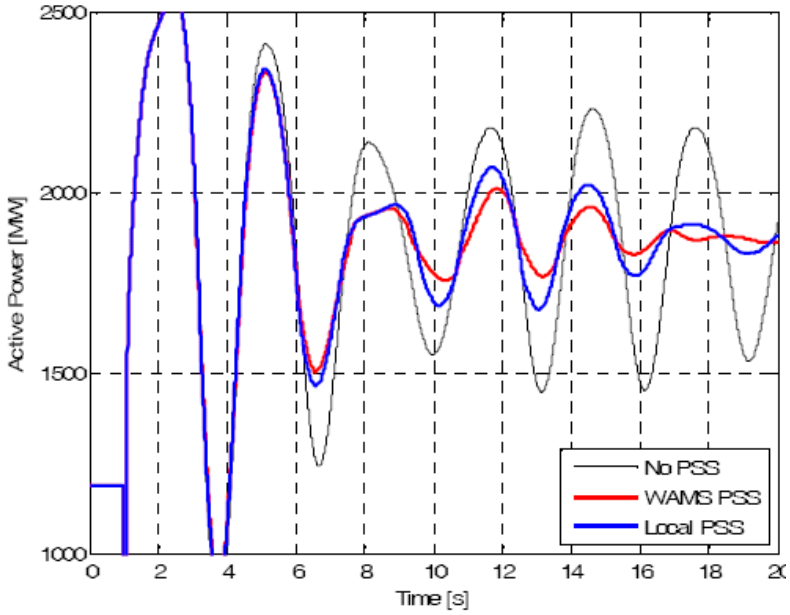


Time Domain Simulations

- Small Disturbance



Large Disturbance



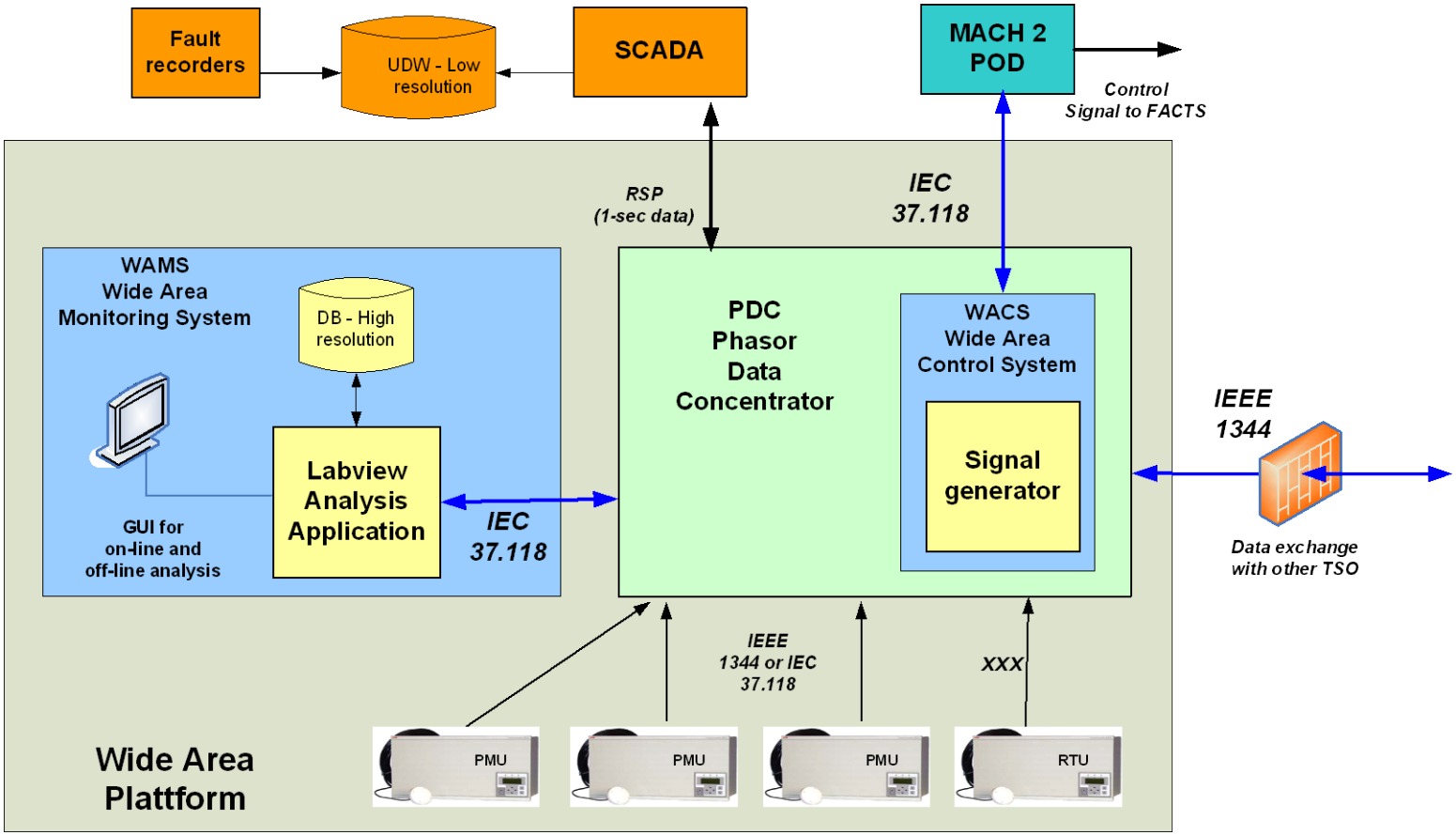
Active power flow: Norway-Sweden:

- Black curve: No PSS
- Red curve: WAMS Single-tuned PSS: Sylling (0.33 Hz) & Rød (0.48 Hz)
- Blue curve: Local Single-tuned PSS: Sylling (0.33 Hz) & Rød (0.48 Hz)

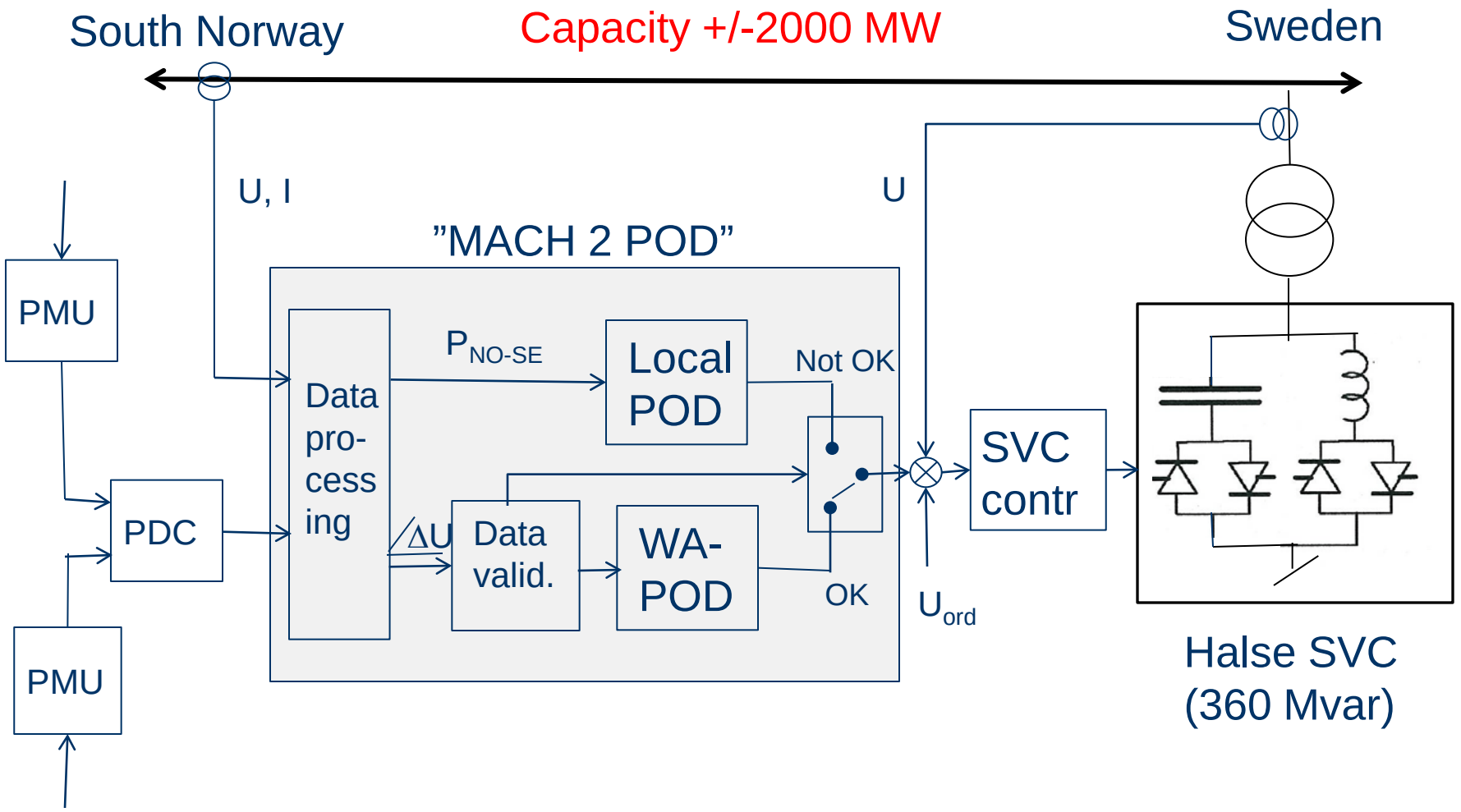
Result and Conclusions

- Stabilizers with local or wide area measurements considerably improves damping of inter-area power oscillations
- Wide-area solution can be more robust with better performance
  - for wider range of operating scenarios
  - and subject to larger disturbances
- Remote PMU measurements enhances observability
  - Simplifying stabilizer design
  - Improving damping on wider range of modes
- Potential PMU challenges: Availability and communication delays
  - Suggested solution: dual input solution
    - Possibility of fall-back to local signals
    - Provides increased robustness

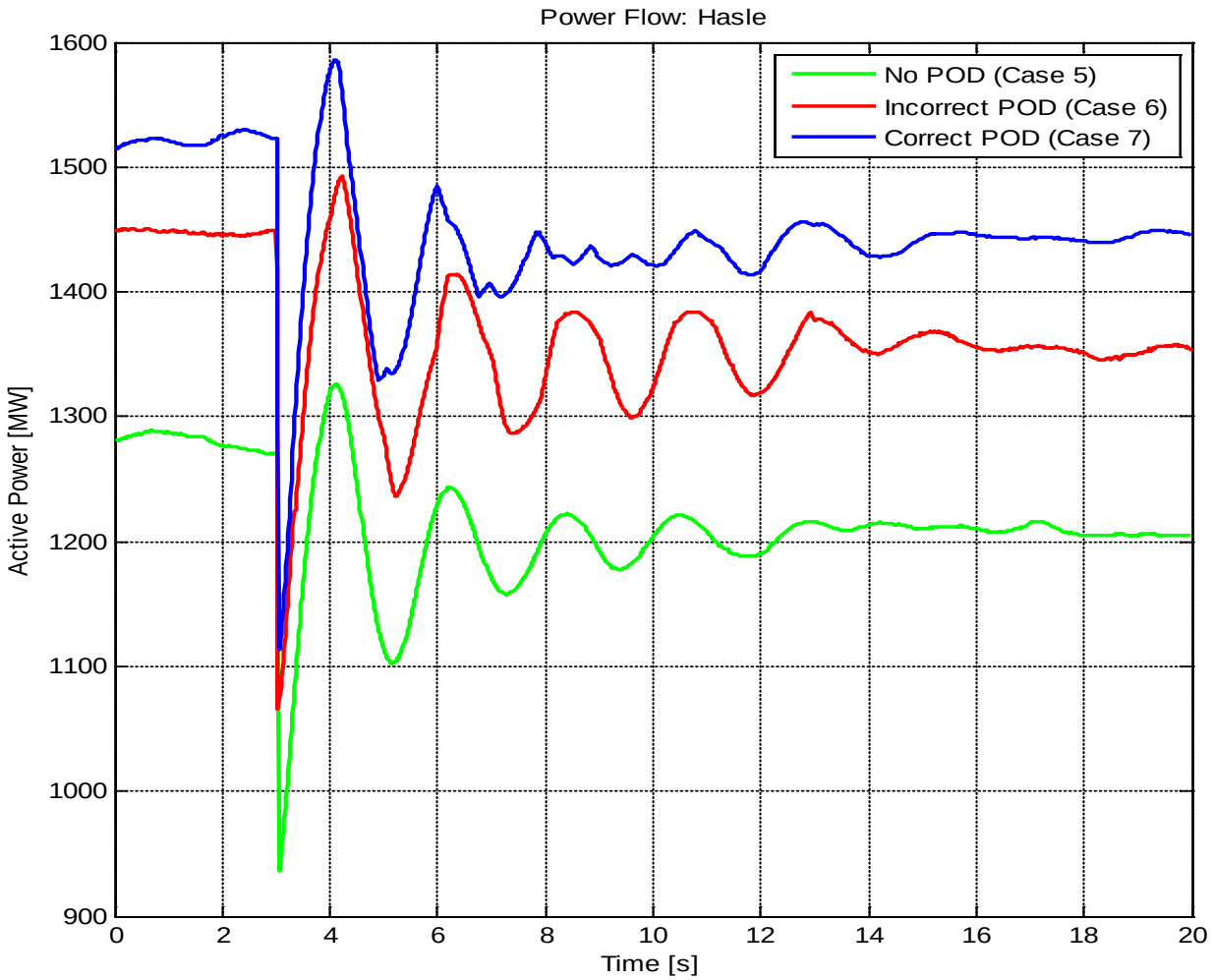
From WAMS to WACS..



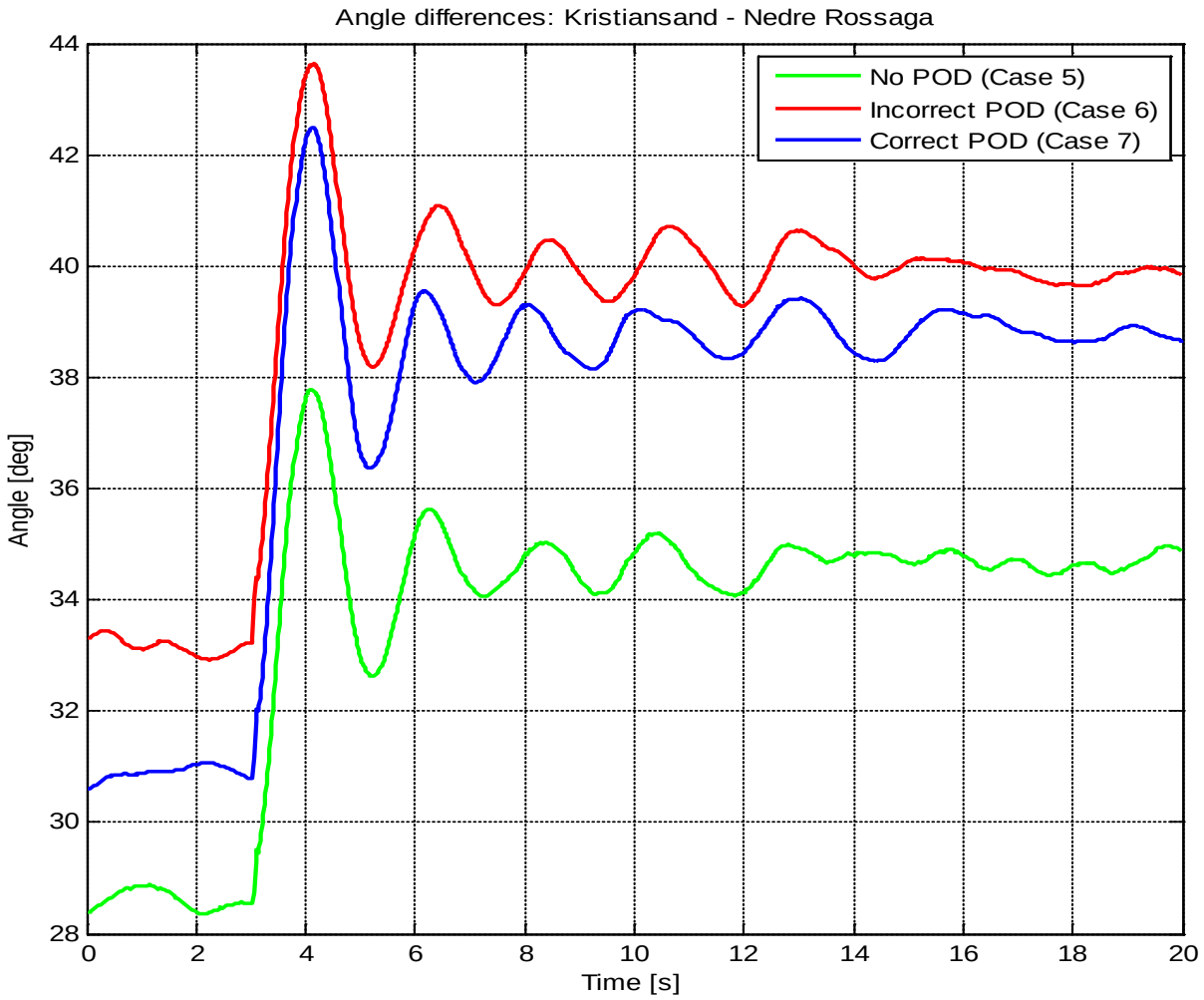
Wide-Area POD implementation



Testing the Local POD:
Power flow (Sweden → Norway)



Testing the Local POD:
Voltage angles



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Experiences and concluding remarks

- Several WAMS-applications have been assessed and tested by STATNETT
- Power oscillation monitoring (POM) is considered most useful by operators
- POM for post-disturbance analysis is demonstrated:
  - Cause of oscillations easily identified from PMU measurements
- Promising experiences with on-line POM
  - Amplitude, frequency and damping signals are robust when needed
- SVCs are shown to provide significant controllability on power oscillations:
  - Implementation and testing of a “Wide area POD” is ongoing.