Interarea oscillations and some late observations including nuclear power plants

Robert Eriksson

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Agenda

> Background of oscillations

> Monitoring system

> Master thesis work – Forced oscillations

> Events observed in the Nordic power system

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Oscillation

- Common mode – Nordic 40-60 s oscillation
- Electromechanical 0.1-3 Hz
  - Natural
  - Forced
- Subsynchronous > 3 Hz

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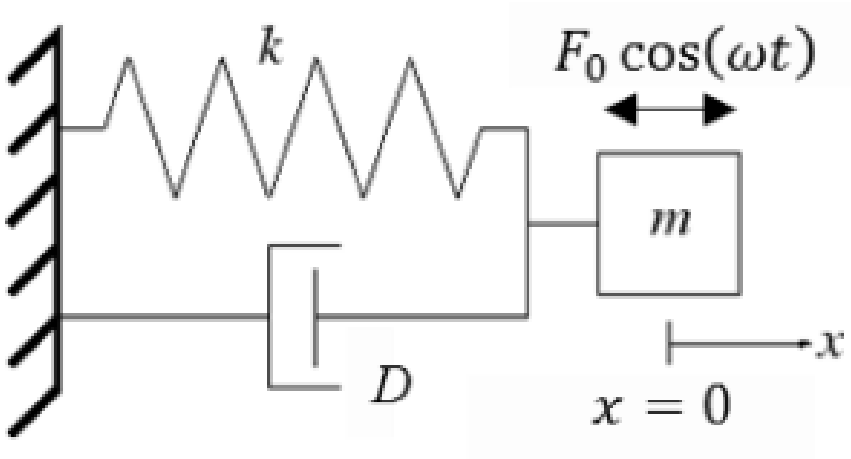
Electromechanical oscillations

- Natural
  - One excitation
- Forced
  - Continous excitation



Electromechanical oscillations

> Grid code: Dämpning av effektpendlingar

5 § För enskilda synkrona generatorer > 75 MVA i stora anläggningar, skall spänningsregleringen vara försedd med dämpfunktion. Den skall, vid vinkelpendlingar av aggregatet gentemot yttre nät, kunna bidra till aktiv dämpning. Det aktiva dämpbidraget skall finnas inom frekvensområdet 0,25-1 Hz.

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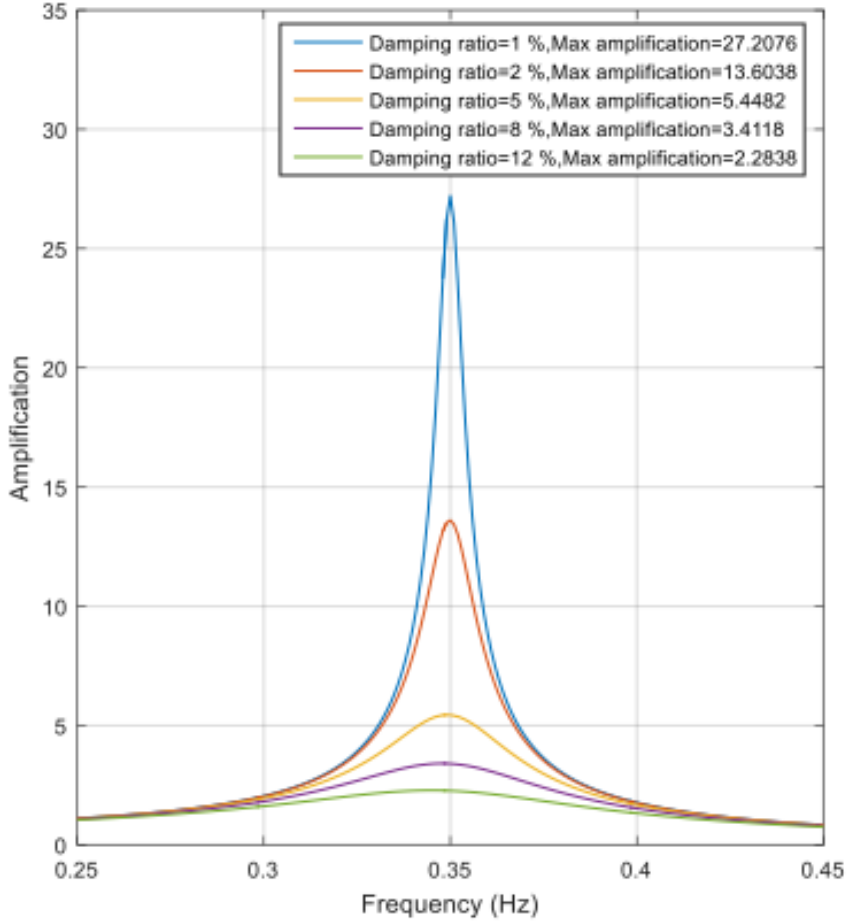
Forced oscillations – Resonance phenomenon



Amplification of the forcing oscillations. The resonance frequency is 0.35 Hz in this case.
Source: "Resonance Impact on Inter-Area Oscillations of the Nordic Power System"

High Resonance Effect when:

1. Forced Oscillation frequency is close to System mode frequency
2. System mode is poorly damped

$$A = \frac{\frac{F_0}{m}}{\sqrt{(\omega_0{}^2 - \omega^2)^2 + (\omega\gamma)^2}}$$

1 **2**

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Historic observations

> 0.5 Hz and 0.25-0.3 Hz

Förbättrad dämpning av effektpendlingar i nordelnätet genom optimering av inställbara reglerparametrar för dämptillsatser

Terje Lysfjord
NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
STATSKRAFTVERKENE

Tapio Keränen
IMATRAN VOIMA OY

Lars Messing
SYDKRAFT

Torben Østrup
ELKRAFT

Bengt Ingemars
STATENS VATTENFALLSVERK

Nätfel Luleälven - mellersta Norrland: I detta fall utbildas pendling med periodtid 2 sekunder mycket tydligt. I Sverige pendlar Luleälven kraftigast. Motriktad denna pendling är maskingrupperna i Finland, Norge och Själland och i viss mån Sydsverige.

Nätfel Forsmark - Stockholm: Även här utbildas pendling med periodtid 2 sekunder. I Sverige pendlar generatorerna i Forsmark kraftigast. I övrigt liknar detta fallet ovan.

Nätfel Själland - Sverige: Även här utbildas pendling Norge-Själland. Periodtid blir omkring 2 sekunder.

Nätfel i södra Finland: Här utbildas ett par pendlingsfrekvenser. Den dominerande periodtiden för Finlandsgeneratorerna blir 3,5-4 sekunder.

hög överföring norrut i Finland och vidare mot Sverige.

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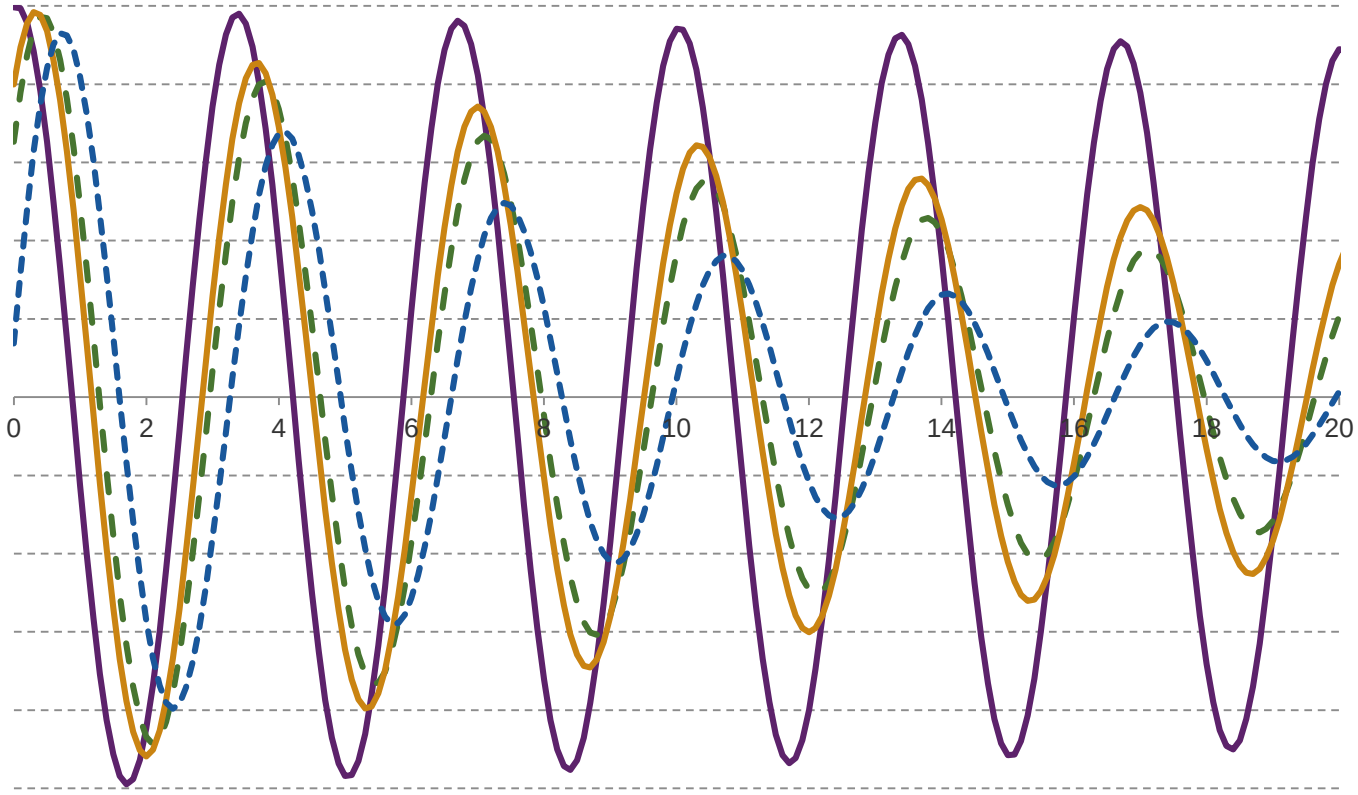
Acceptable damping



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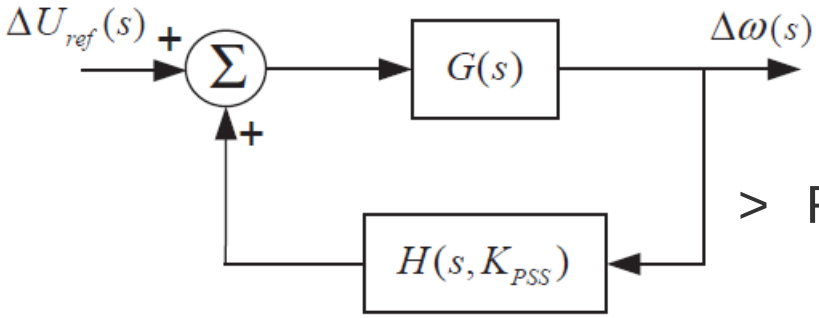
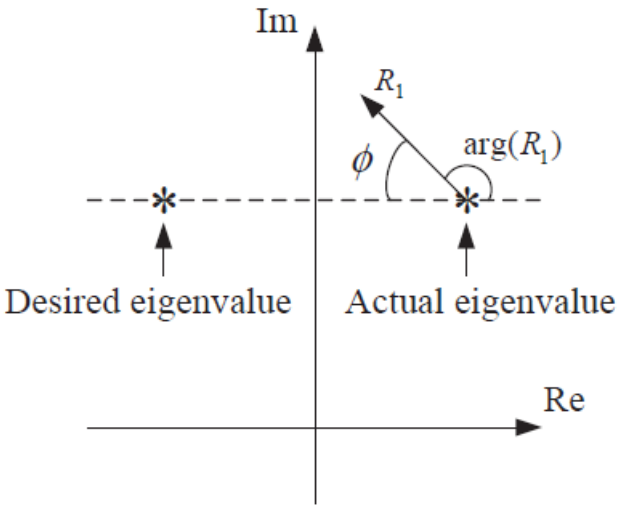
Design of PSS



> University approach

> Linearization



> Real life approach

> Find G(s) incl. transfer function of excitation system.

> Phase compensate over a frequency range

> Should not affect

> Voltage control in steady state

> Power setpoint change/frequency control

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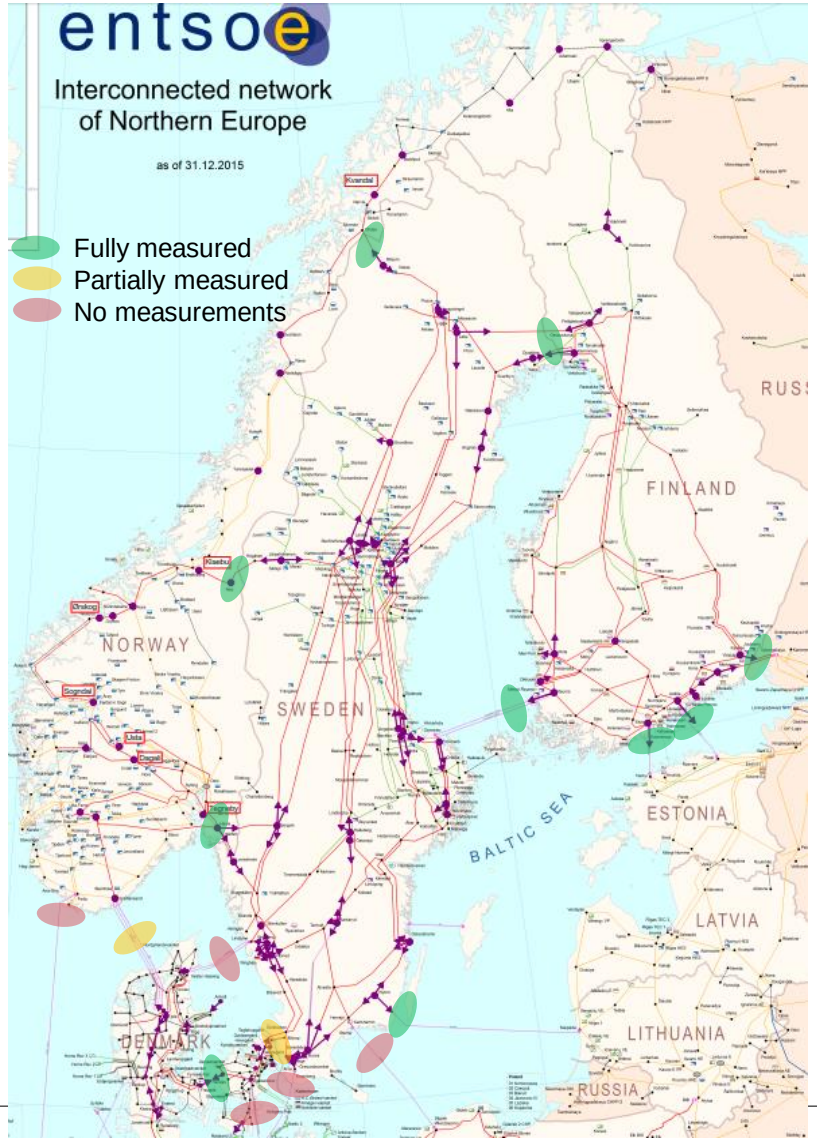
PMU-installations

- ~60 PMU in Sweden
- ~200 PMUs in Nordics
  - Wide area
  - Real time
  - Finer time resolution
  - Synchronized



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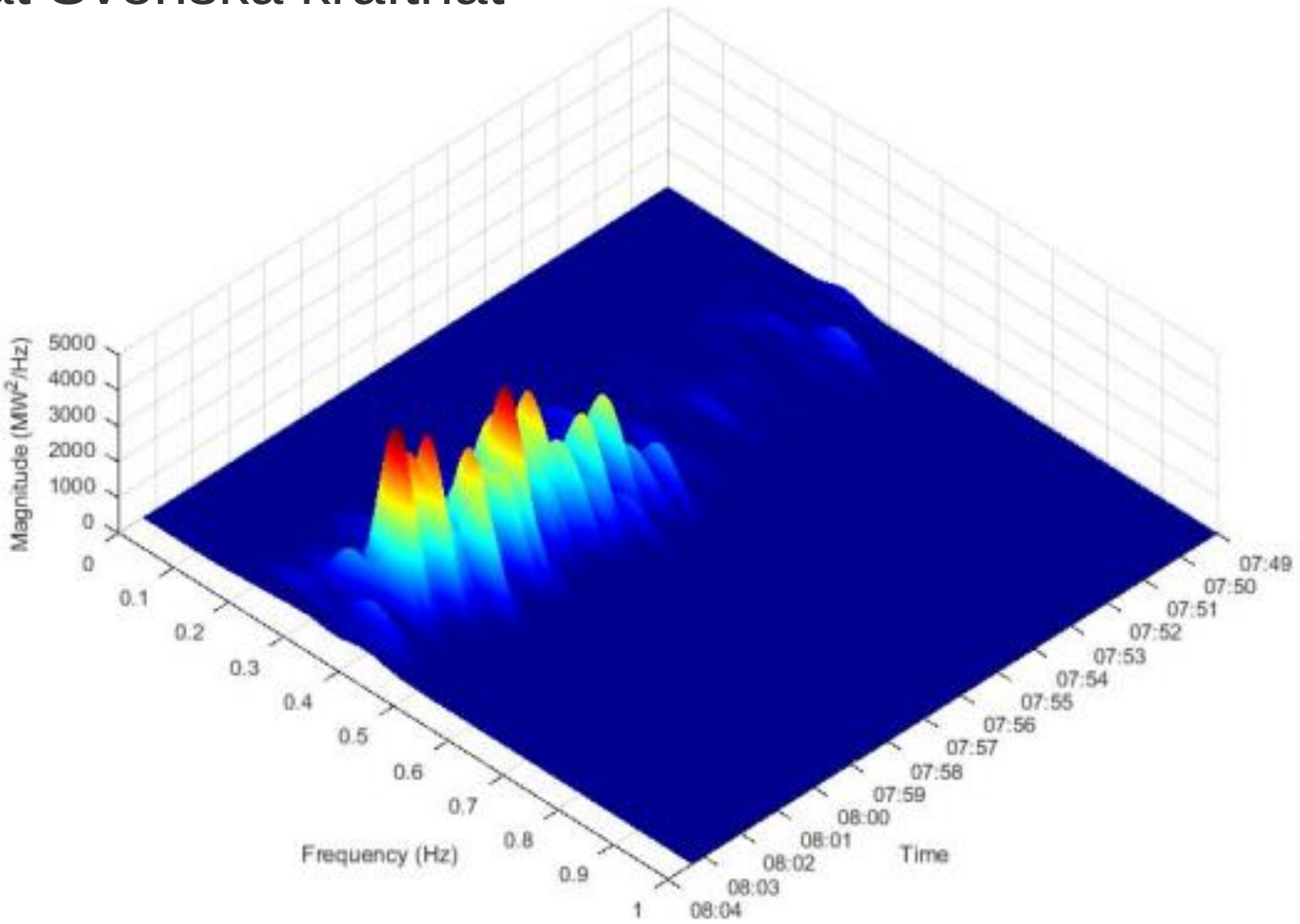
Monitoring system at Svenska kraftnät

- PhasorPoint by GE
- Applications
  - Oscillation monitoring
  - Power corridors
  - Angle difference
  - Disturbance monitoring
  - Model validation

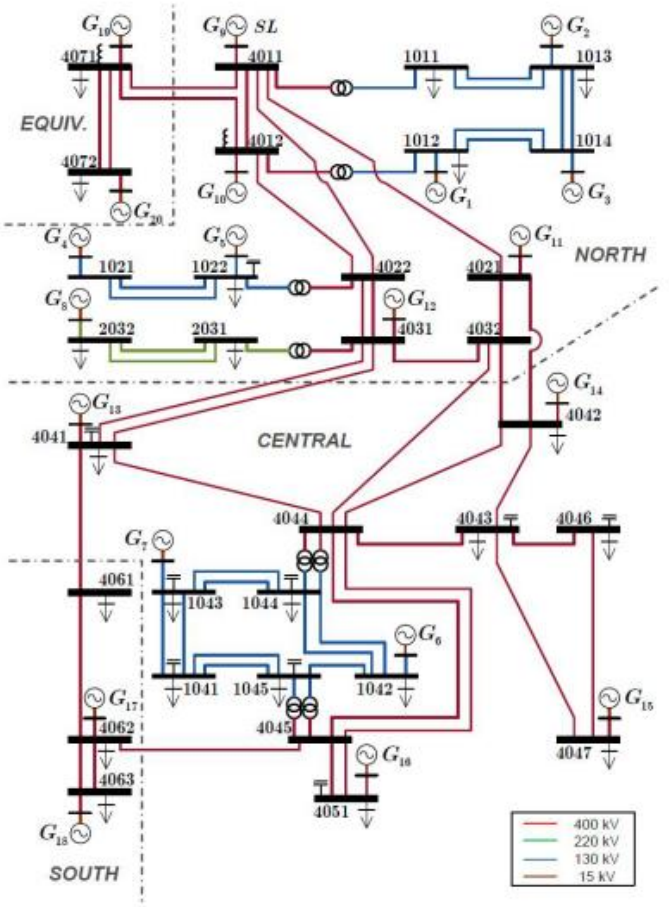


Master thesis worker - Dimitrios Dimitropoulos

> Title “**Resonance Impact on Inter-Area Oscillations of the Nordic Power System**”

> Collaboration: KTH+RISE+Svk+ABB+UPC

> Studies in PowerFactory of the Nordic32



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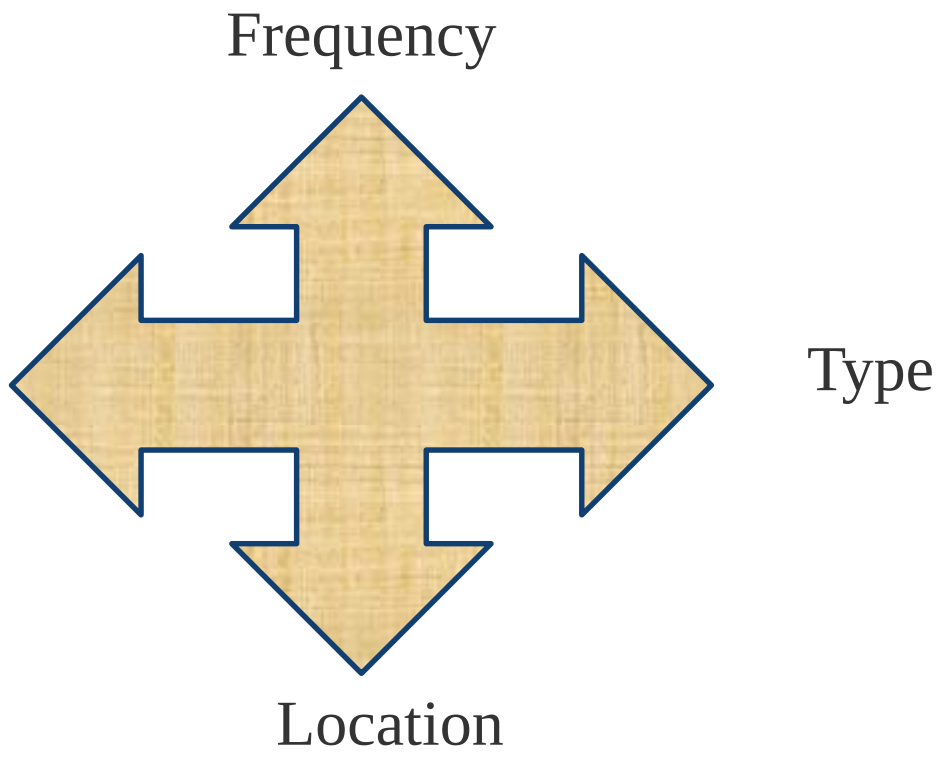
Principles

- Interarea oscillation
  - Excite by load modulation
- Utilising the concepts of
  - Controllability
  - Observability

4 Sensitivity Factors



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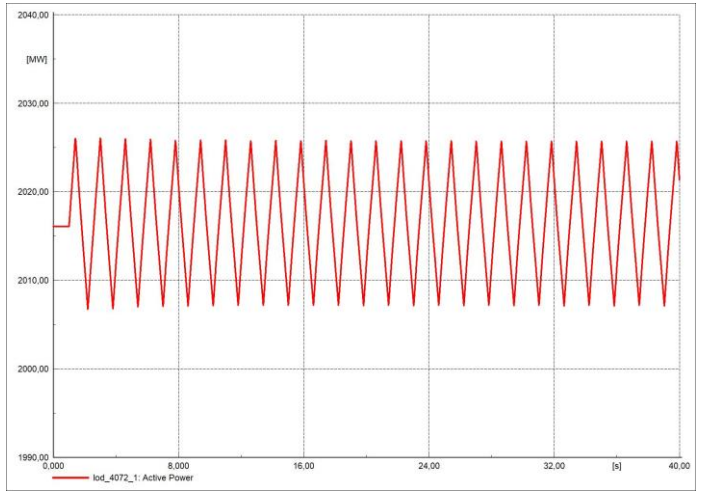
Sensitivity to frequency of forced oscillations

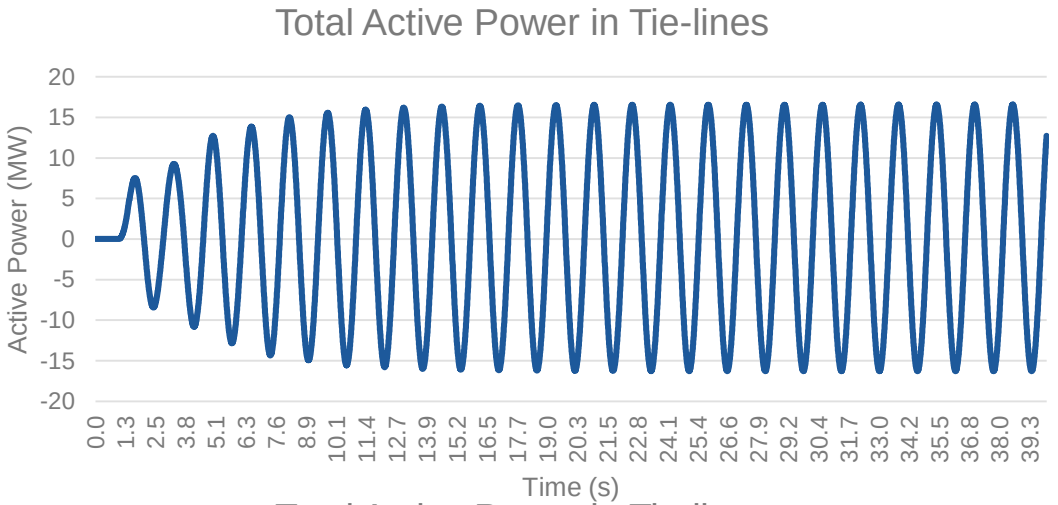
Load Variations Signal

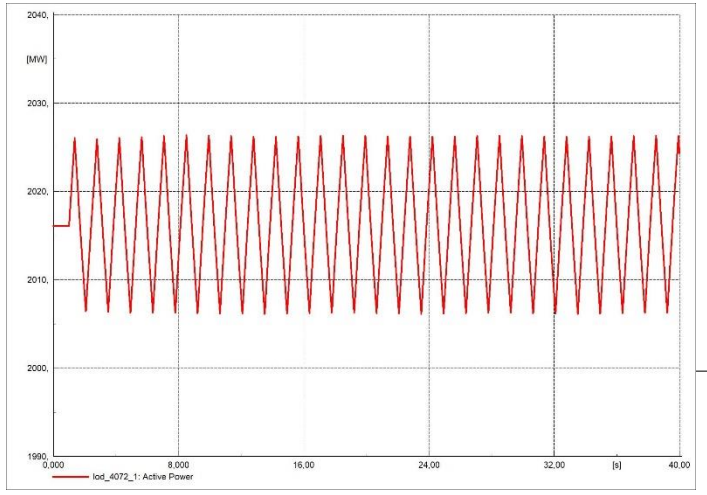


Frequency: 0.62 Hz
(Inter-area mode)

Amplification factor
1.65

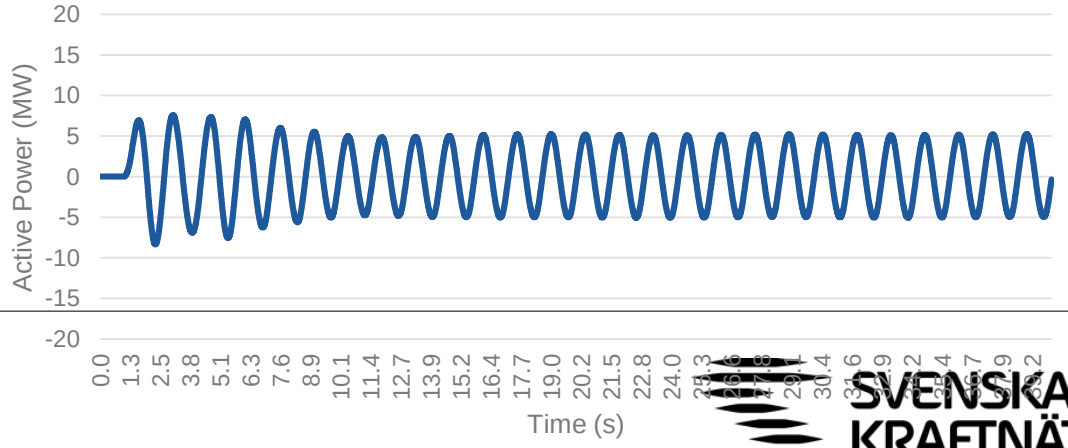
Resulting Oscillation at the tie-lines between External area and the rest system





Frequency: 0.7 Hz

Amplification factor
0.5



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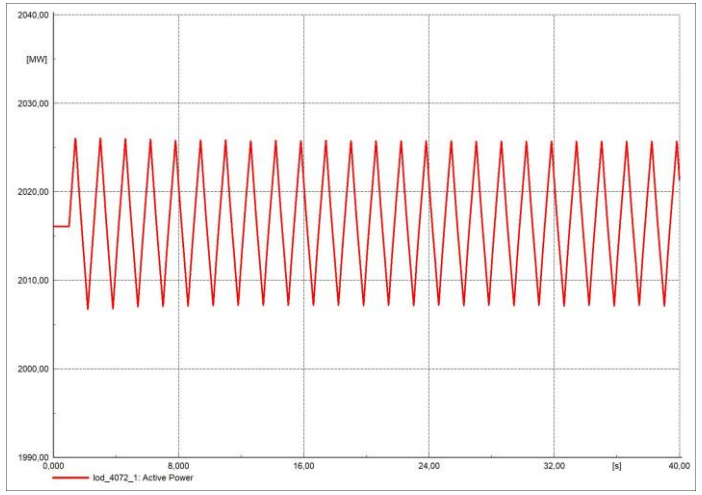
Sensitivity to amplitude of forced oscillations

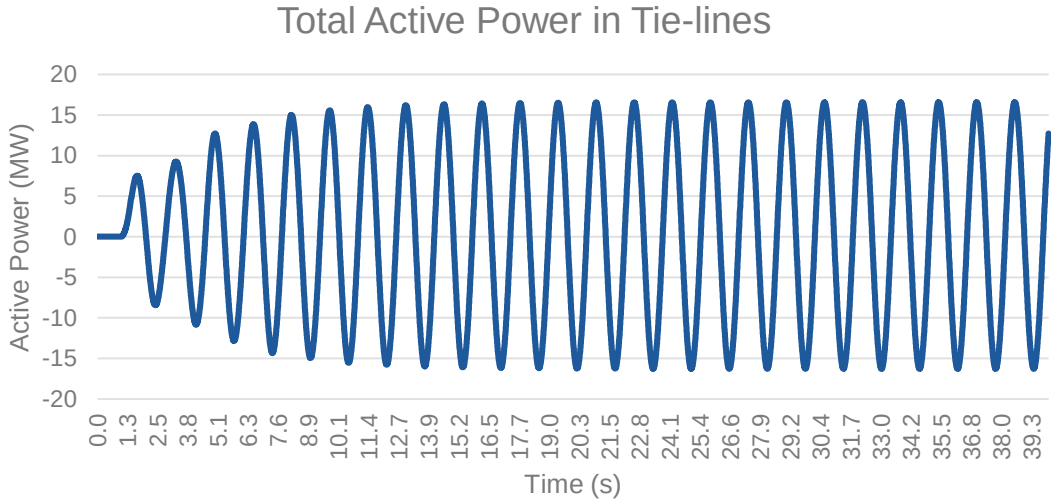
Load Variations Signal

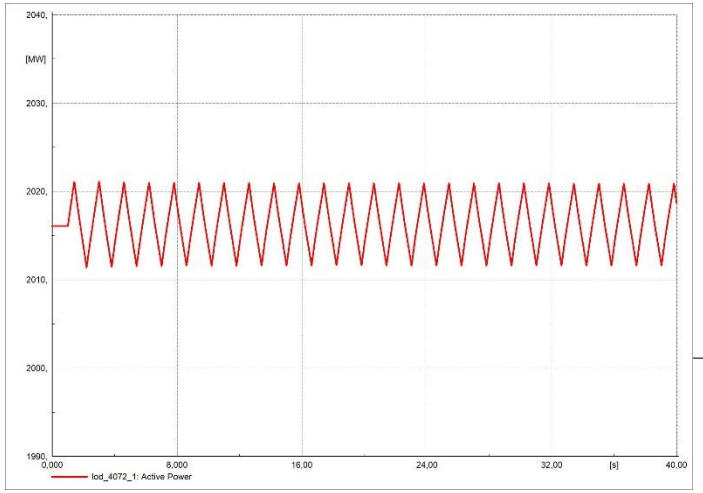


Amplitude:
20 MW p-p

Amplification factor
1.65

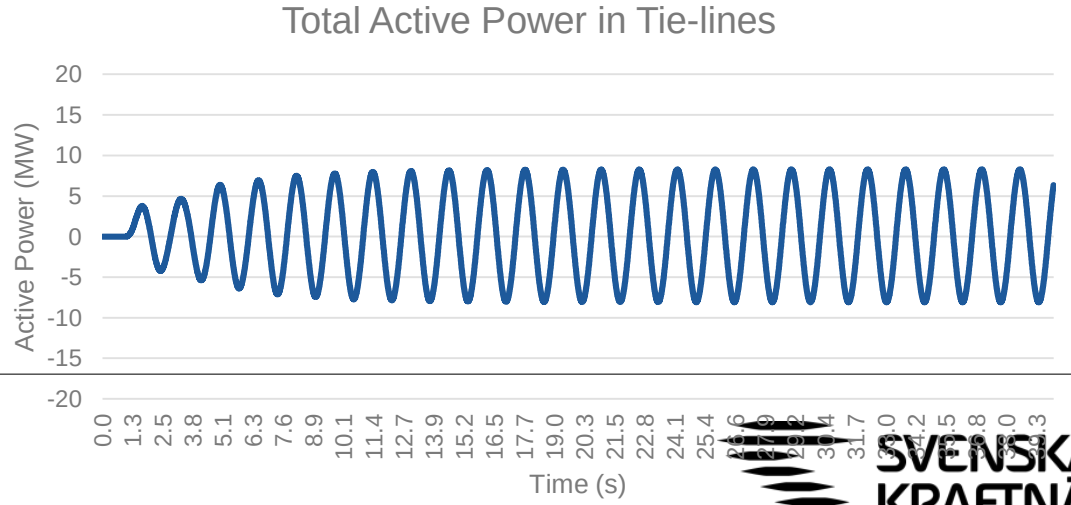
Resulting Oscillation at the tie-lines between External area and the rest system





Amplitude:
10 MW p-p

Amplification factor
1.60



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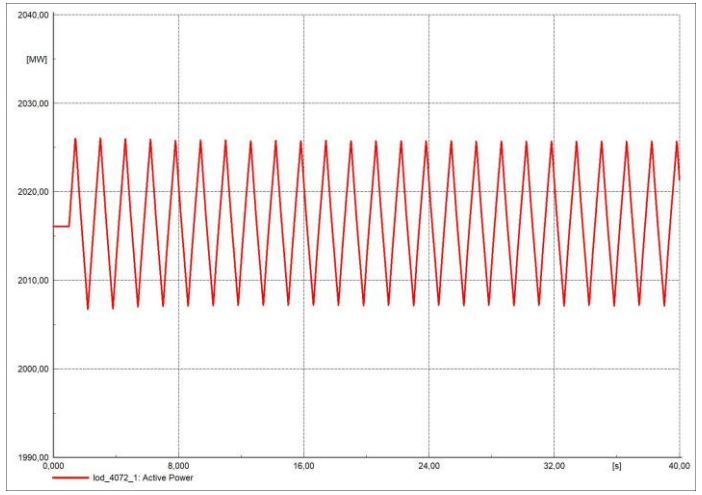
Various periodic signals

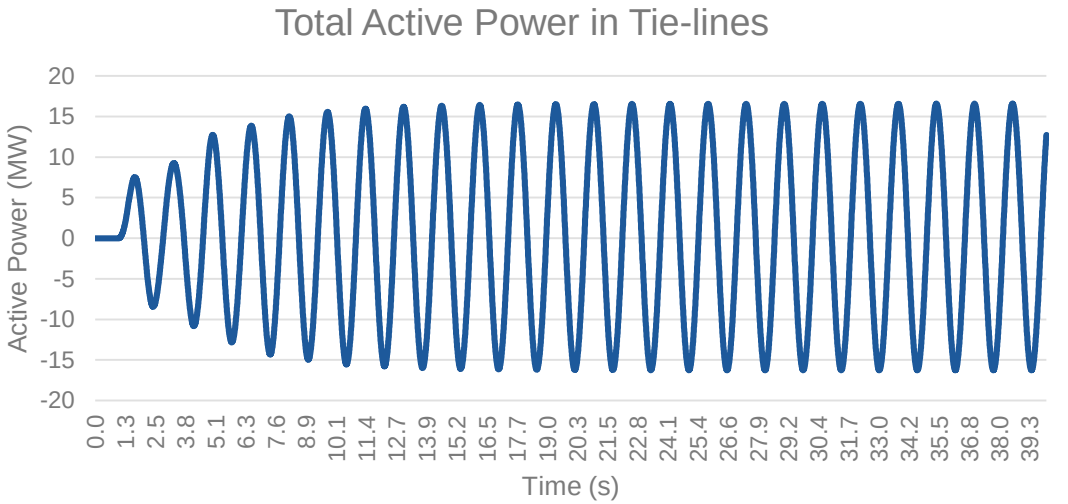
Load Variations Signal

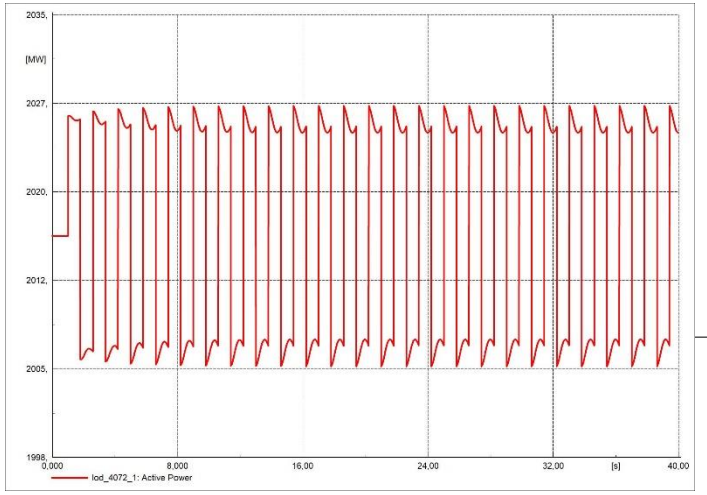


Ramp load events
Frequency: 0.62 Hz

Amplification factor
1.65

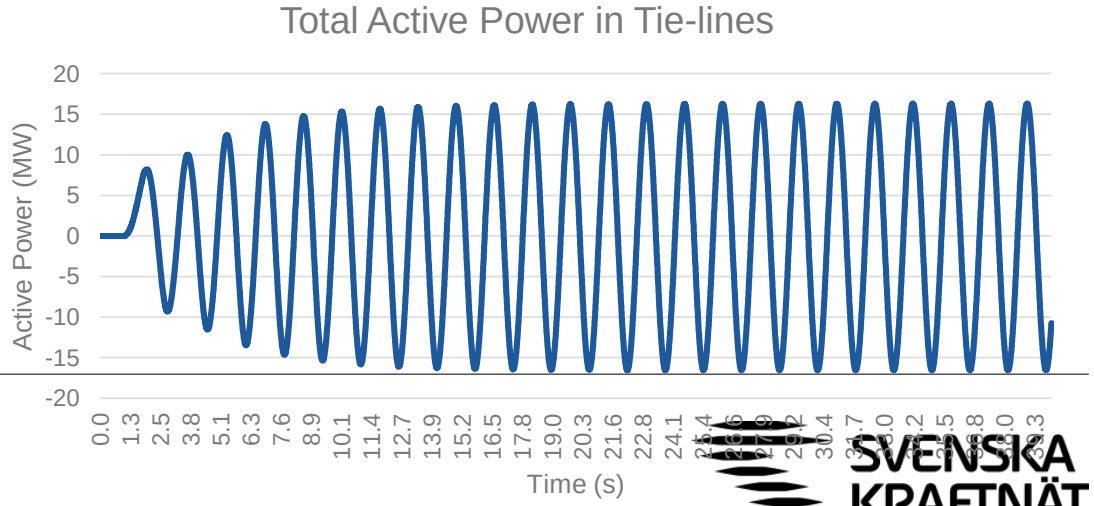
Resulting Oscillation at the tie-lines between External area and the rest system





Step load events
Frequency: 0.62 Hz

Amplification factor
1.67



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Controllability and participation

> Mode 1

Busbar/Load	Amplification factor	Controllability	Participation
4072	1.65	1	1
63	1.325	0.25	0.80
1043	0.4	0.02	0.05

> Mode 2

Busbar/Load	Amplification factor	Controllability	Participation
4072	0.67	1	0.12
63	2.05	0.98	1
1043	0.53	0.08	0.05

> Location of excitation source => Controllability

> PowerFactory calculates controllability based on angle NOT power

  > Similar controllability does not necessary mean similar excitation

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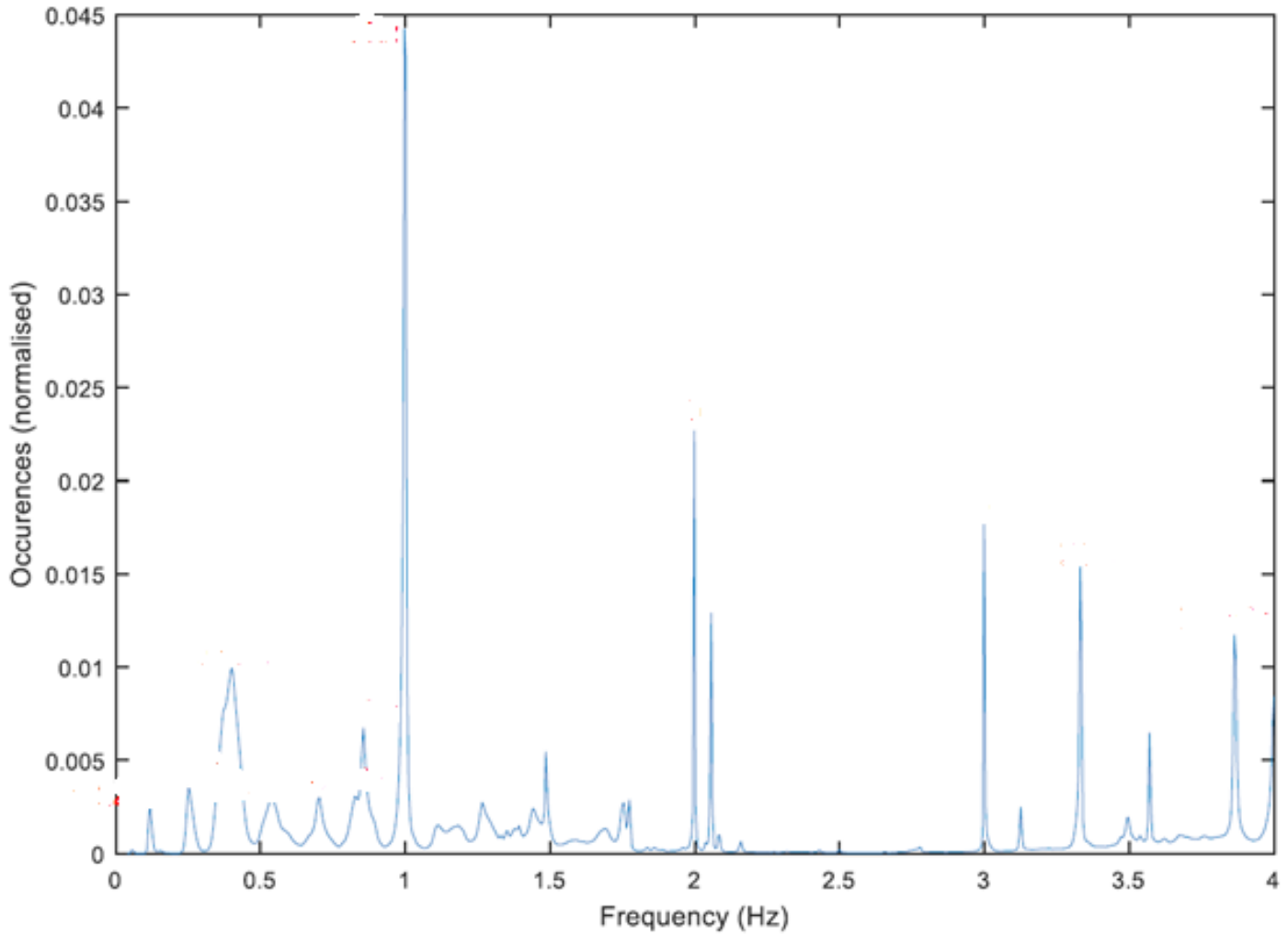
Analysis of real data

- One year of data (2018-2019)
- Find events
- Interarea modes
- Damping



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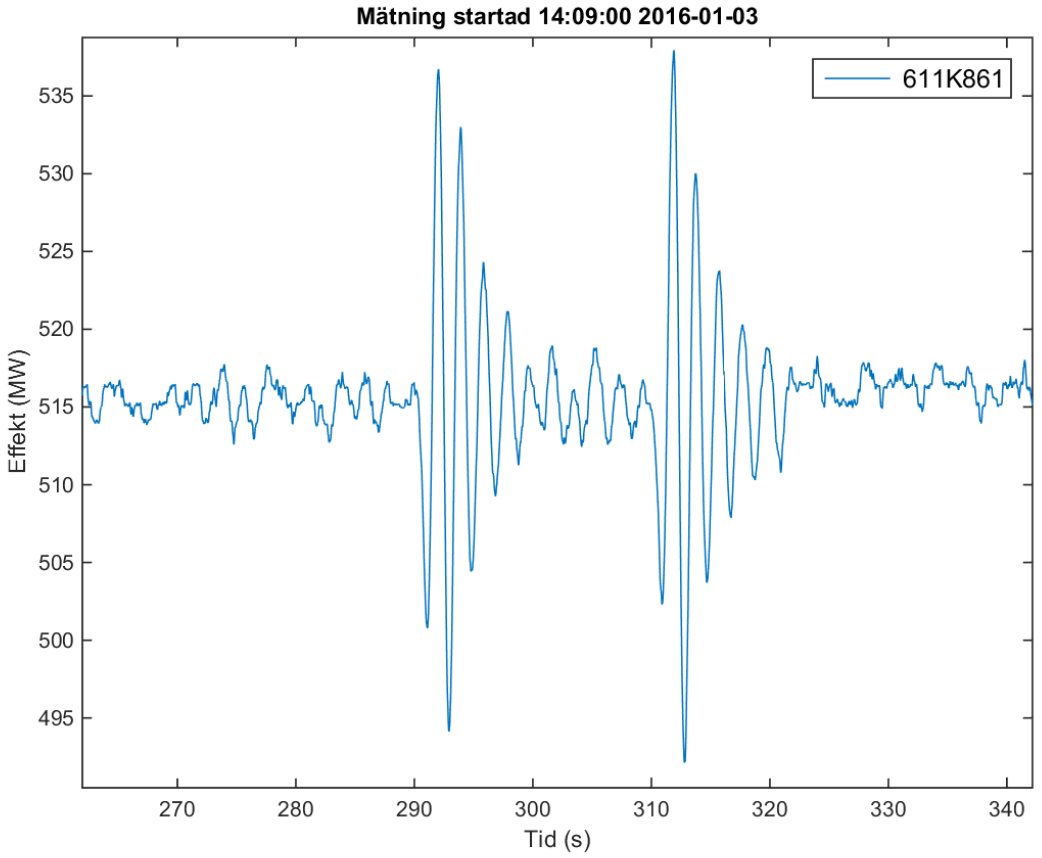
EVENT 1 (1) – From 2016

- Occurance about 40 times over some days
- No SCADA alarms
- What is the cause?



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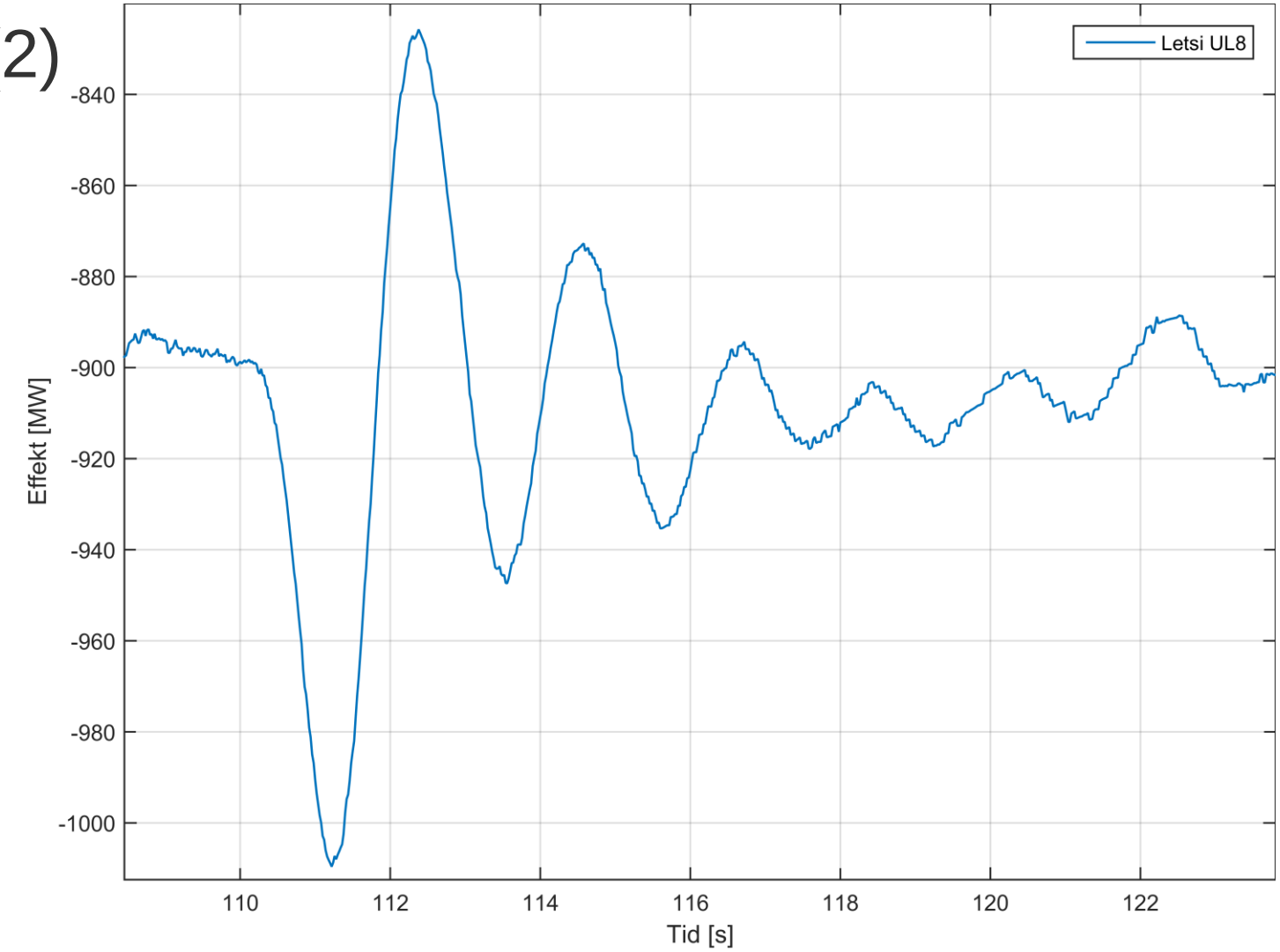
EVENT 1 (2)

$\Delta P = 100\ MW$

~0.5 Hz



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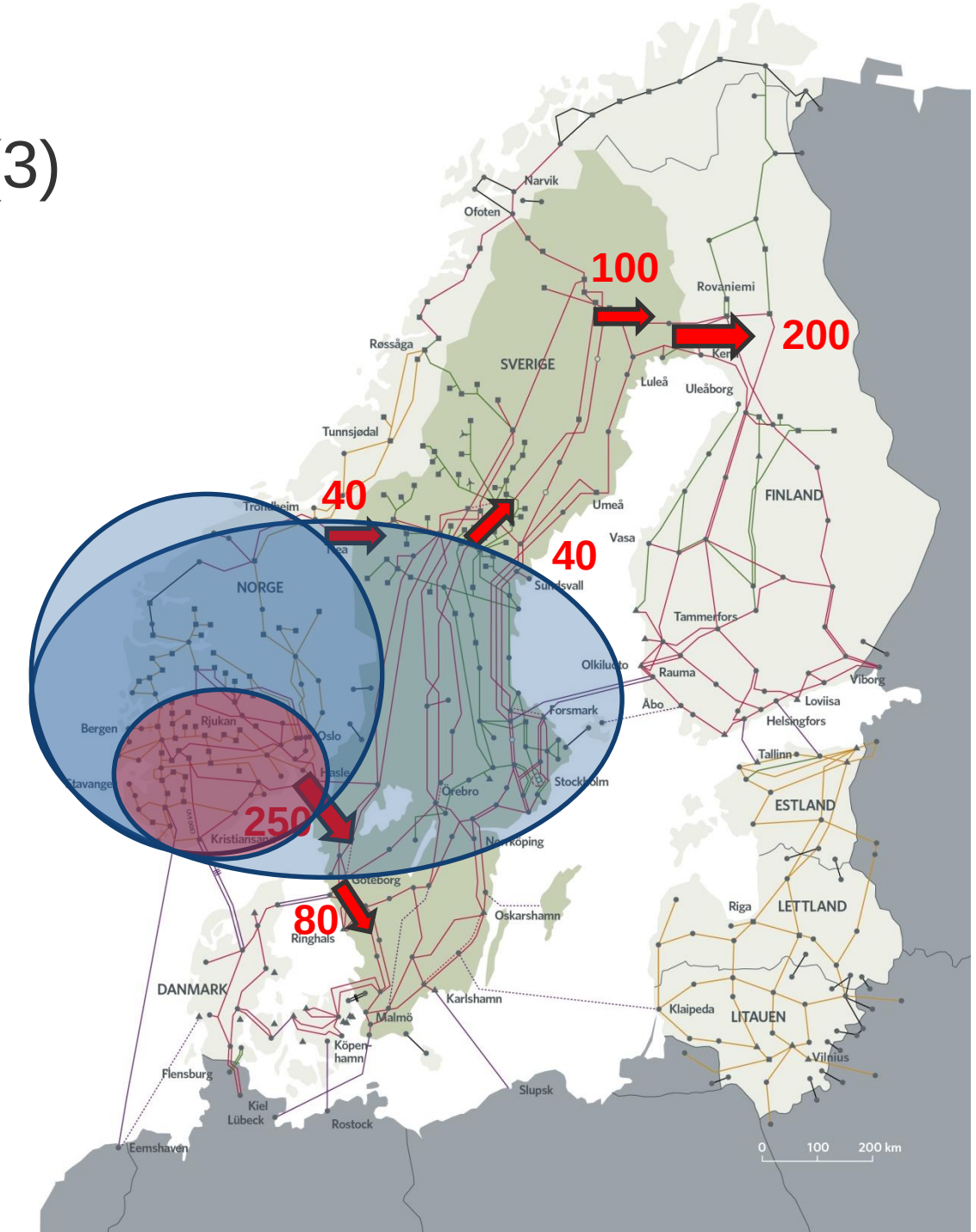
EVENT 1 (3)



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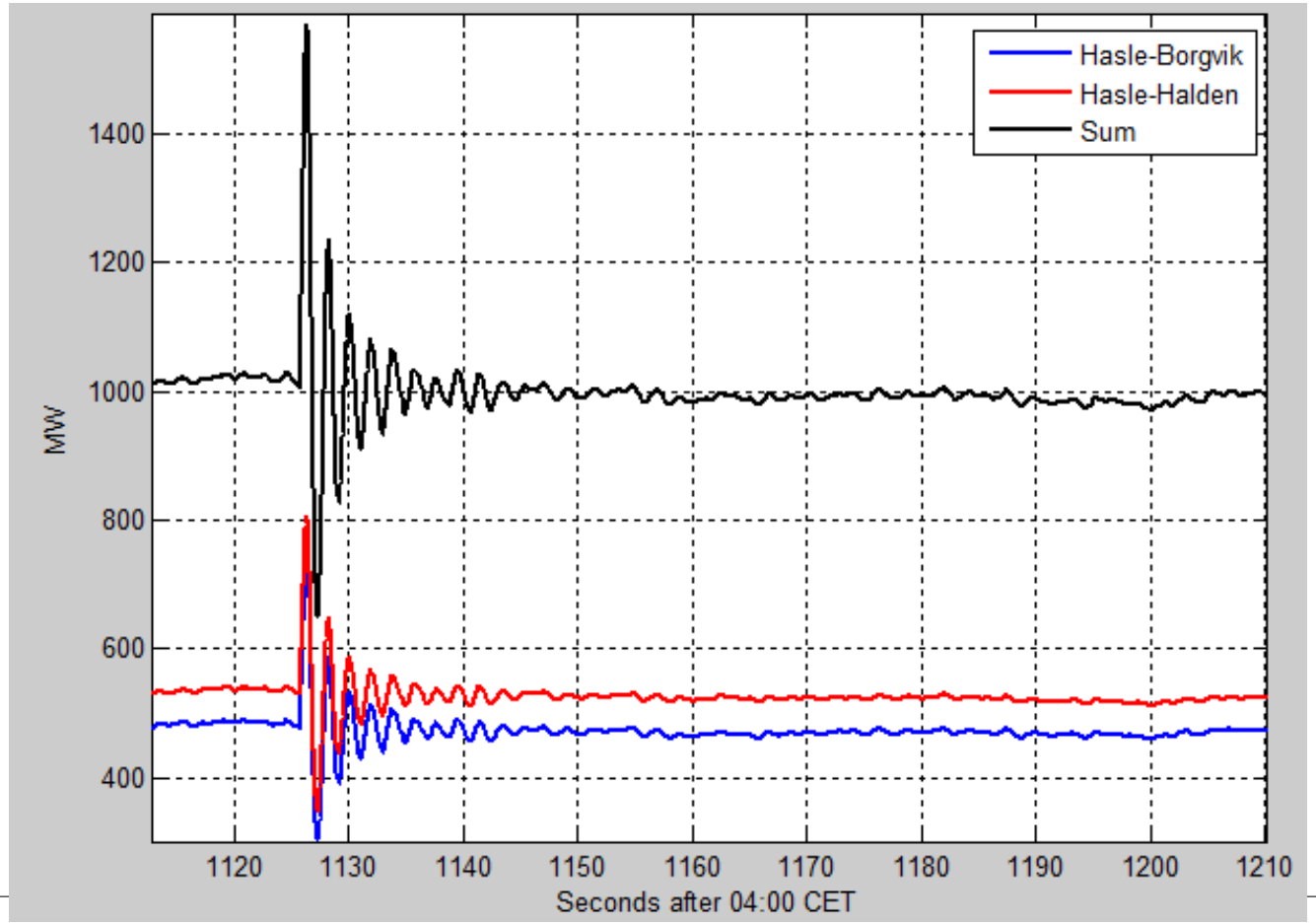
EVENT 1 (4)



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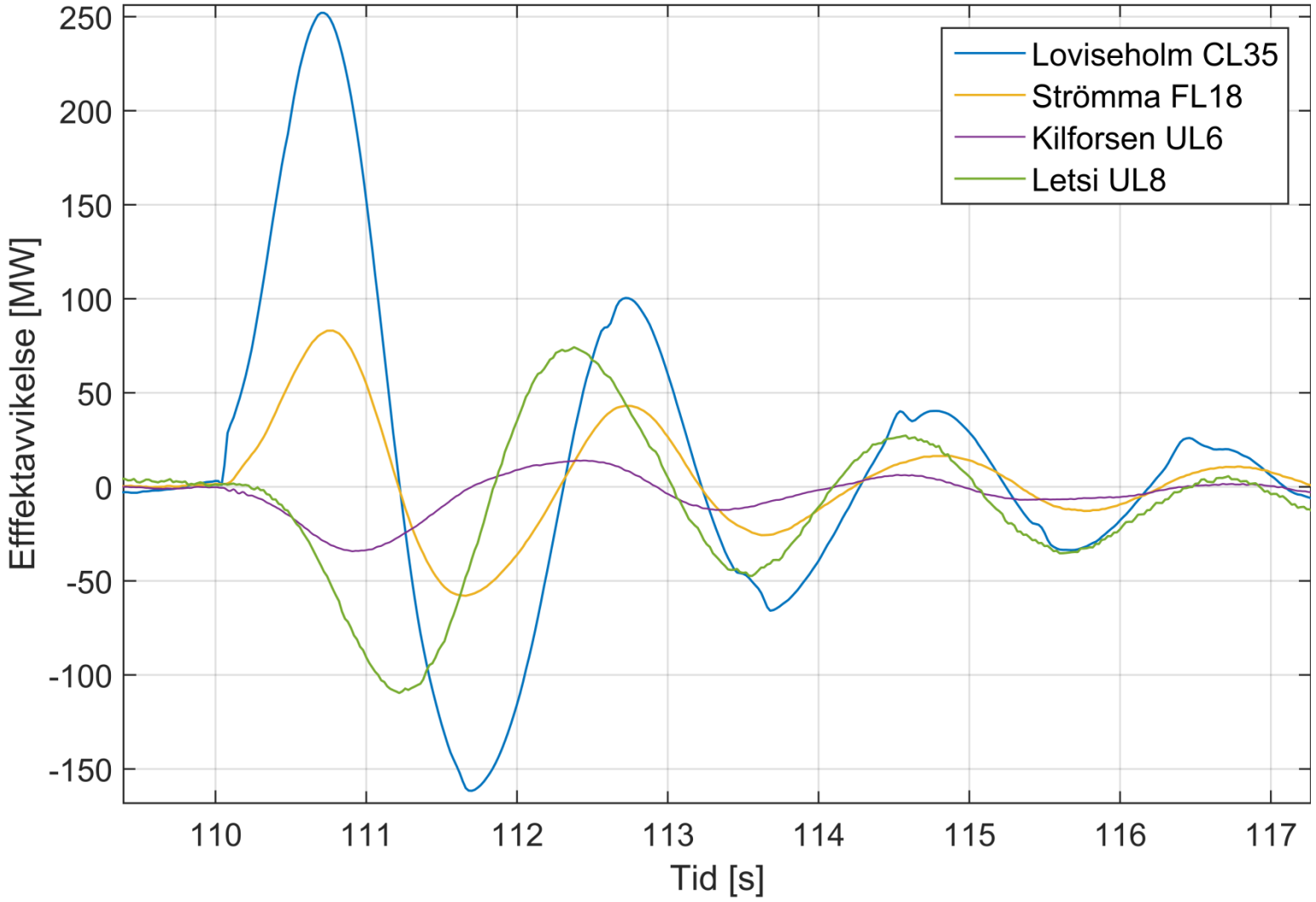
EVENT 1 (5)



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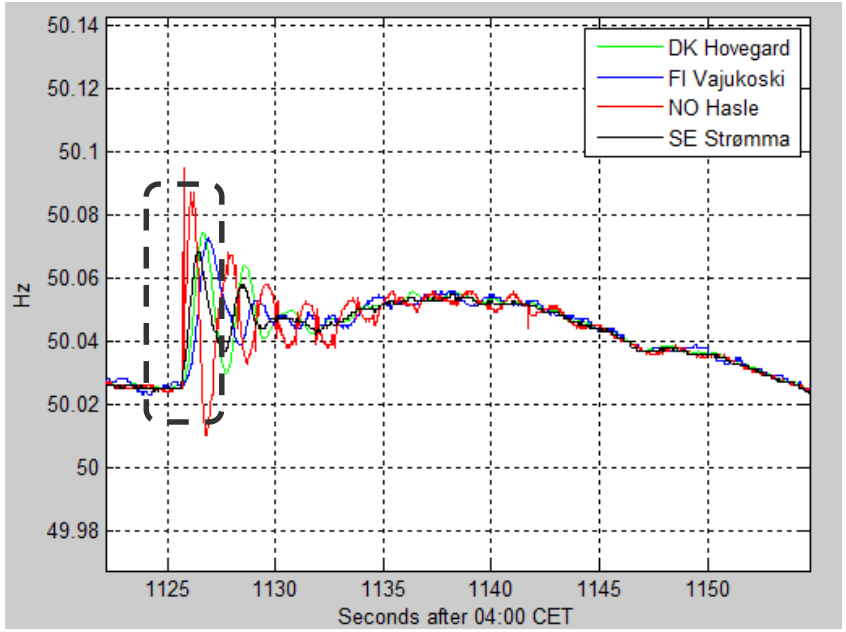
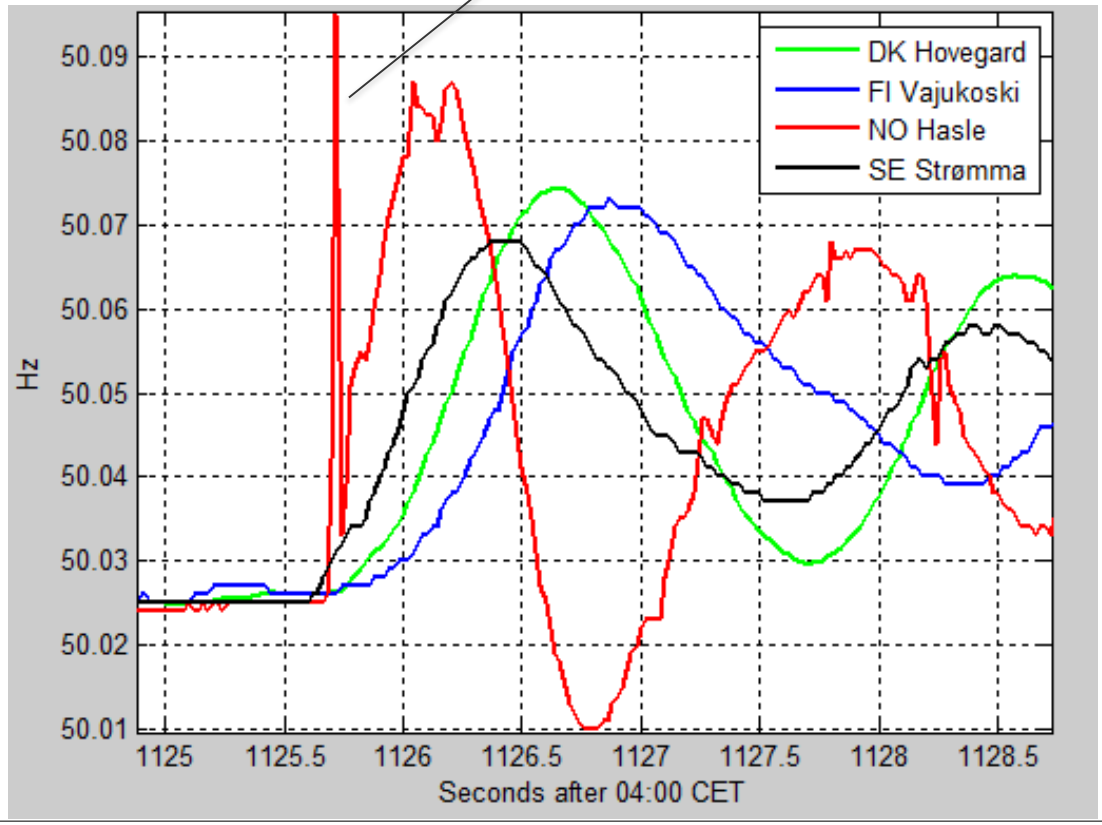
EVENT 1 (6) PMU frequency measurement in the system



Indication that the fault is west of Hasle and travelling east/north



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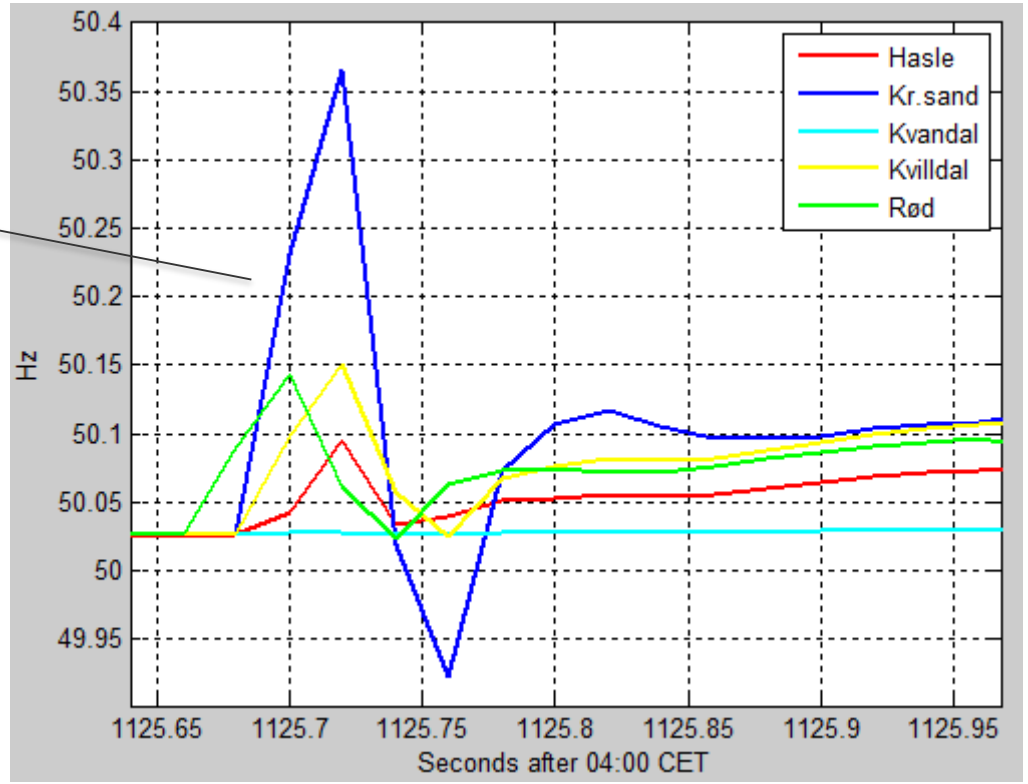
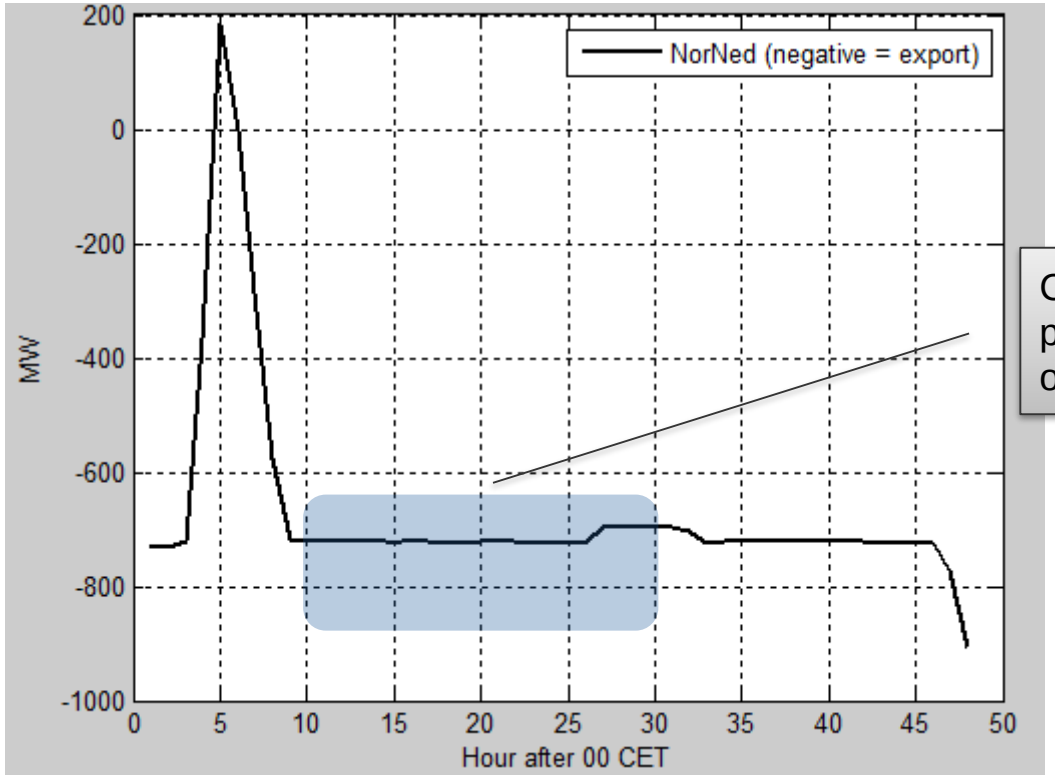
EVENT 1 (7) PMU frequency measurements in Norway

Indicates fault location close to Kristiansand

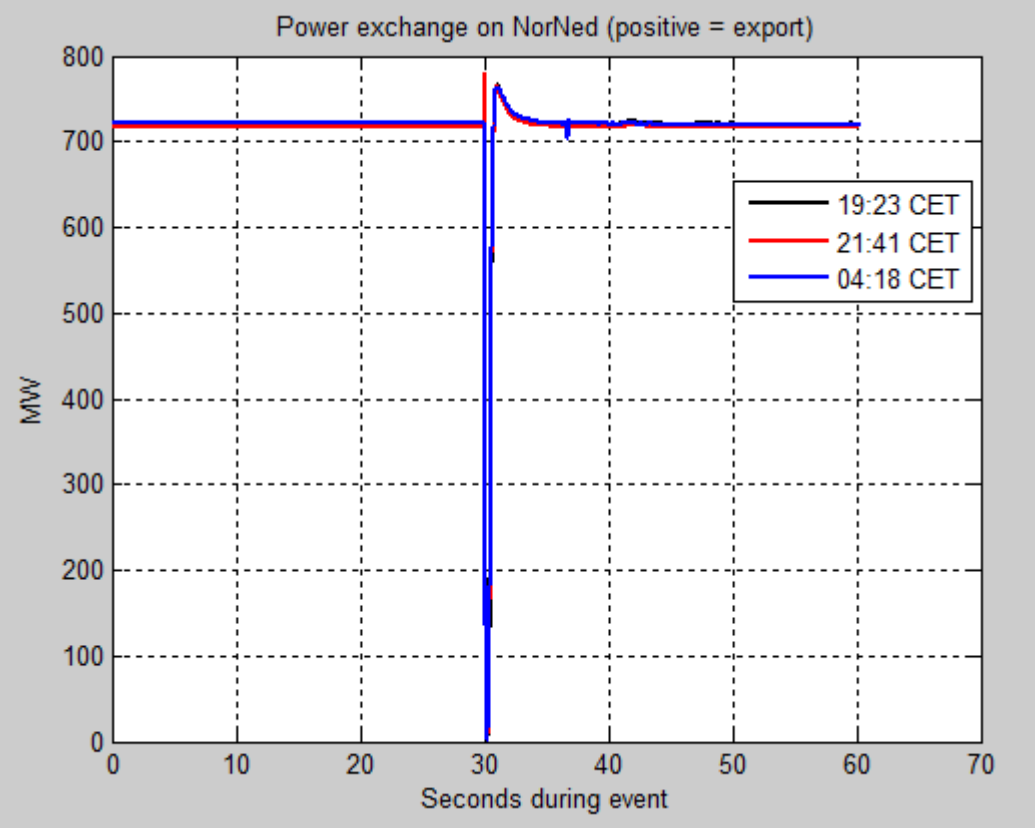


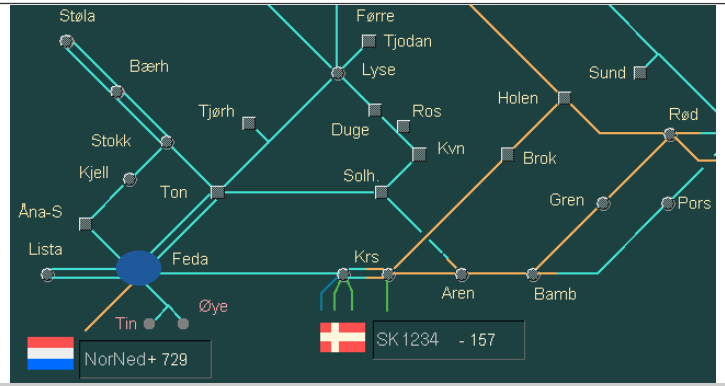
EVENT 1 (8) NorNed import/export - market data

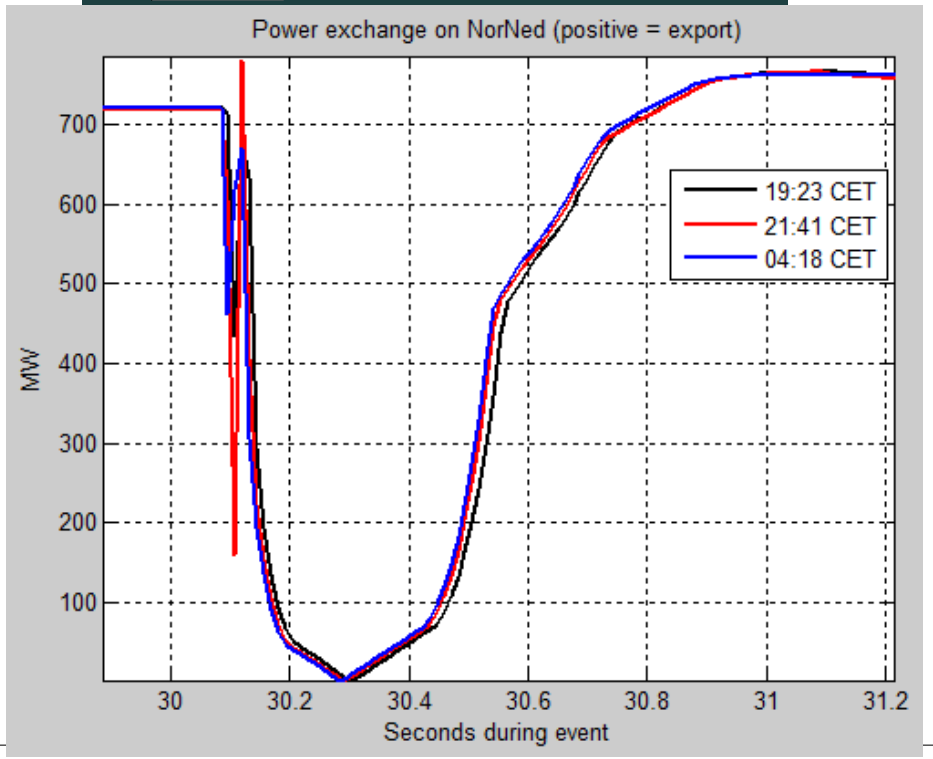


Constant export during the prescense of the oscillations

EVENT 1 (9) Fault recorder at Feda

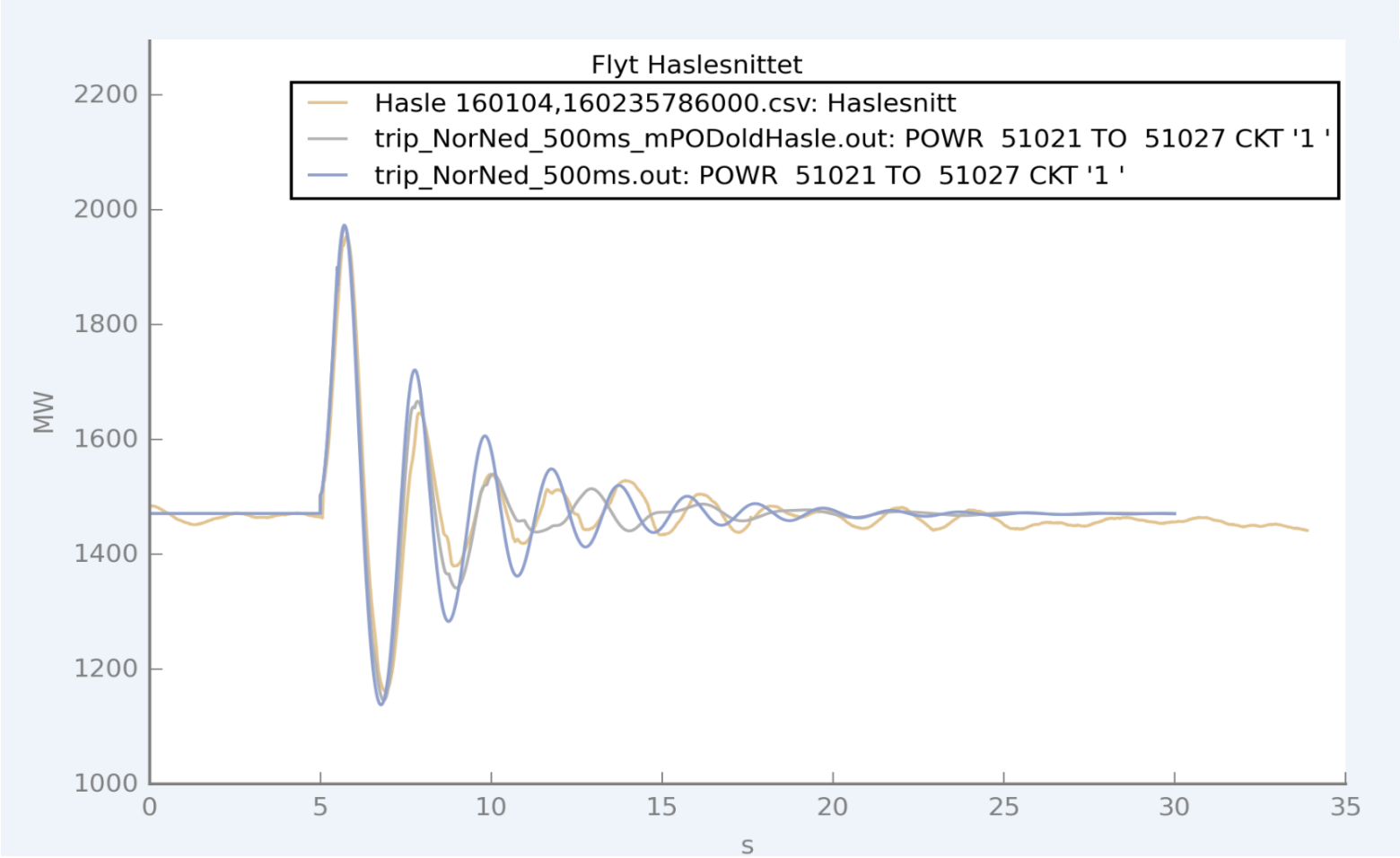






EVENT 1 (10) Trip NorNed - PSS/E vs PMU measurements, Hasle cut

- Yellow line: PMU measurements.
- Blue/grey line: Simulation with/without POD in Hasle activated.
- PSS/E simulation
  - with the common Nordic high load case, not tuned against actual system state/operation.



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Events 2-8 have been delete – non-public information

Observations

- Not always easy in real time to distinguish between forced and undamped oscillations
  - Post analysis, any disturbance or changes recorded in SCADA?
  - Check leading signal
- Several events where large power plants excite system wide oscillation
  - 0.37 - 0.45 Hz and 0.54 Hz
- Interarea modes are in general well damped > 6 % (often around 10 %)

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