Resonance Interaction from Forcing to Inter-Area Oscillations in Power Systems (work performed at Fingrid)

2nd International Workshop "*Dynamic Stability Challenges of the Future Power Grids* ***DynPOWER*** 2018"

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Introduction

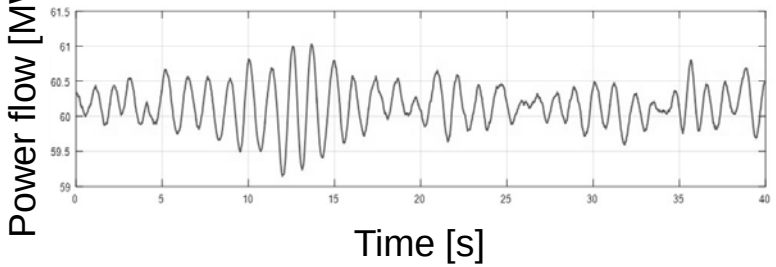
Electromechanical oscillations

Natural electromechanical oscillations

Phenomenon where generators accelerate and decelerate around their synchronous speeds

Damping may be a limiting factor for the transfer capacity of the system

Are excited by changes in

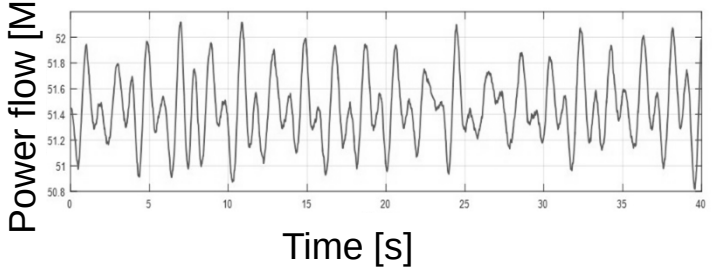


Forced oscillations

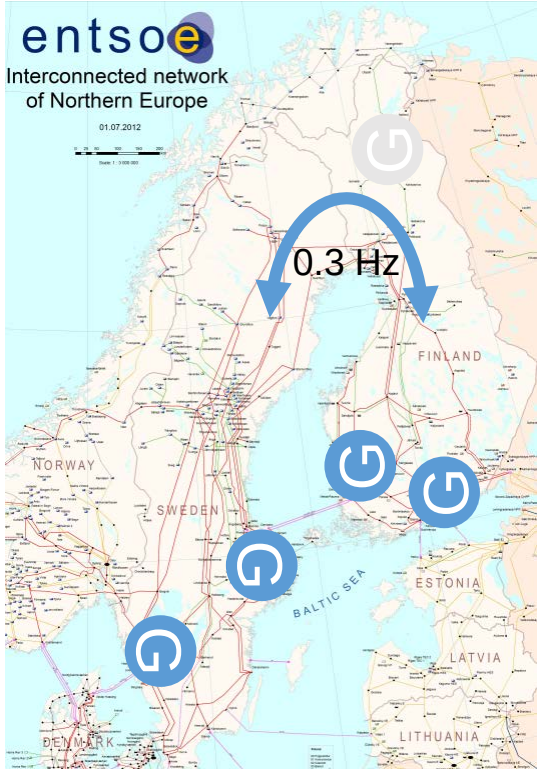
Are typically related to inadequate tuning of control systems

Their damping is typically close to zero

Are becoming a more common problem in power system operation



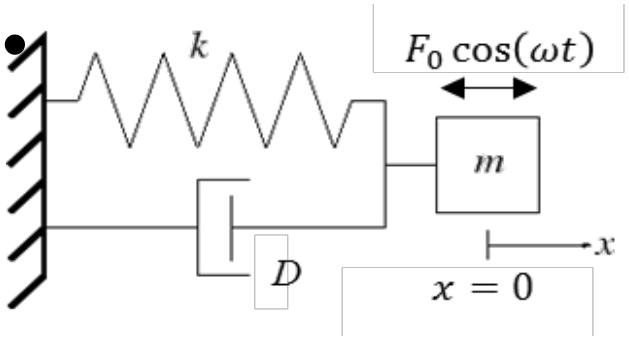
Nordic power system – Example



What if forced oscillations are at the same frequency as the natural modes?

Resonance

Spring mass model



$$m\ddot{x} + D\dot{x} + kx = F_0 \cos(\omega t)$$

$$A = \frac{F_0/m}{\sqrt{\underbrace{(\omega_0{}^2 - \omega^2)}_{1} + \underbrace{(\omega\gamma)^2}_{2}}}$$

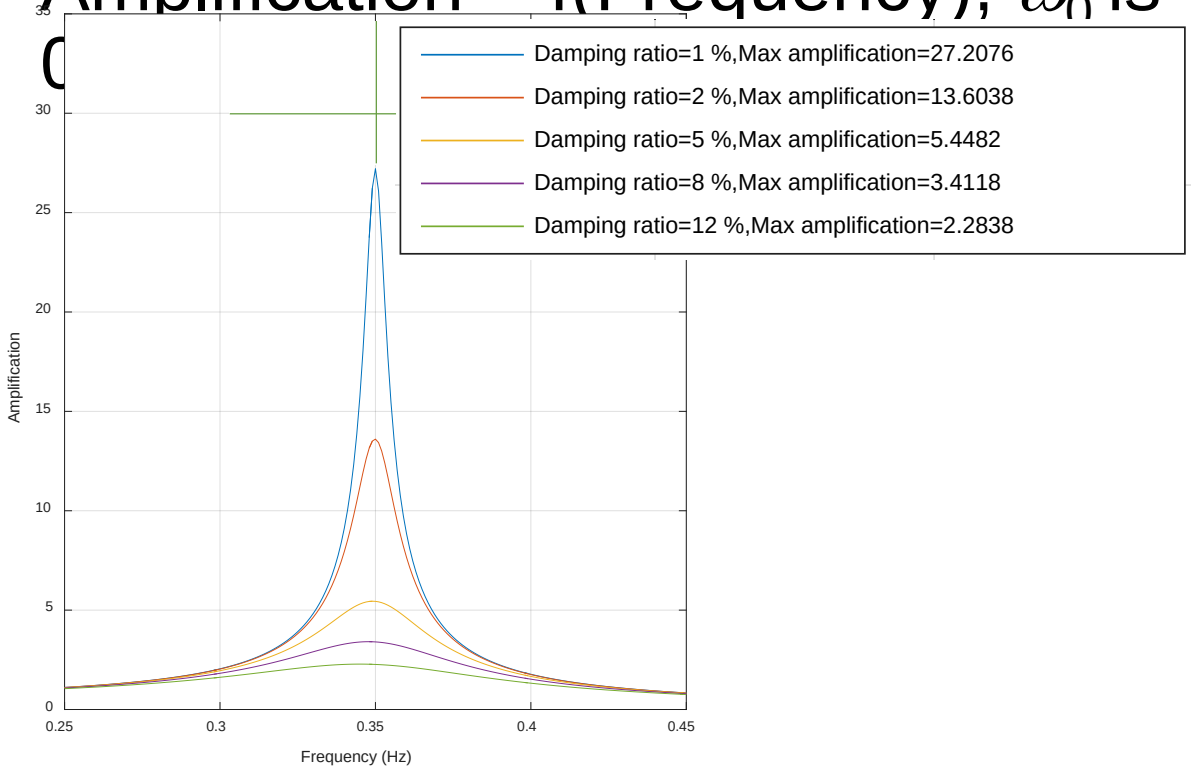
$$\omega_0 = \frac{k}{m}$$

$$\gamma = \frac{D}{m}$$

Amplification increases as:

1) frequency difference →0
2) damping →0 .

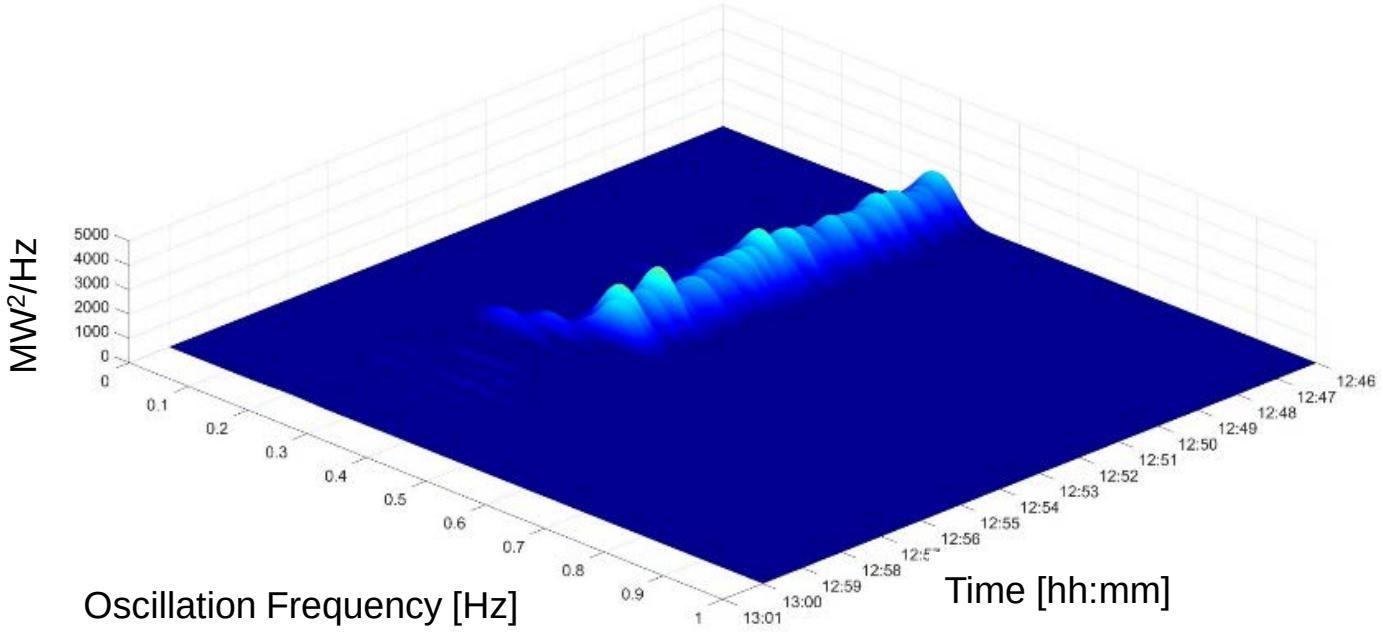
- Amplification = f(Frequency), ω_0 is C



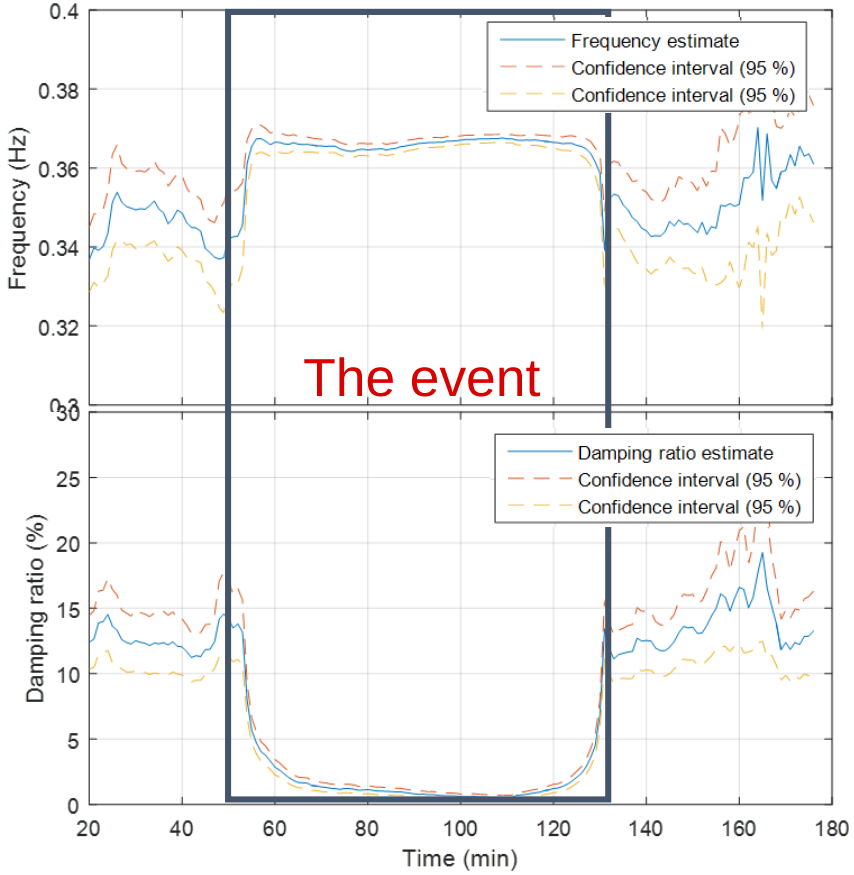
Measurements from the Finnish power system

Observations

October 18, 2016: Forced oscillation source is a generator in Southern Finland



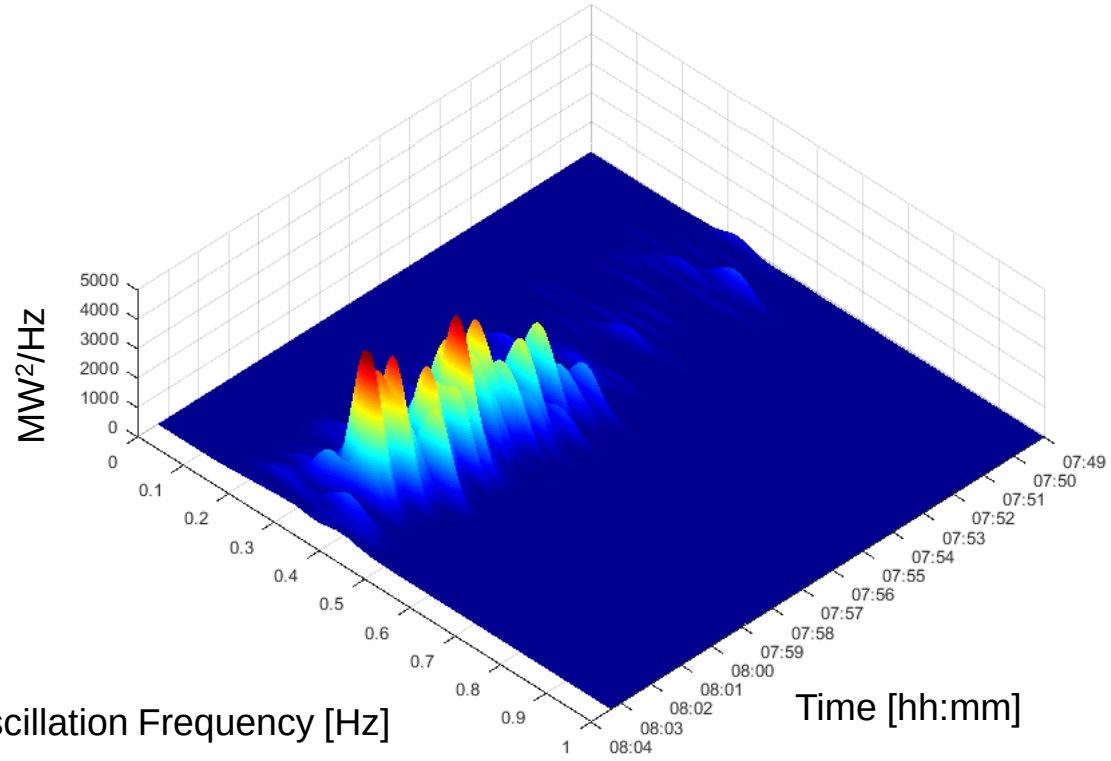
Spectrogram of the total power exchange Finland and Sweden.



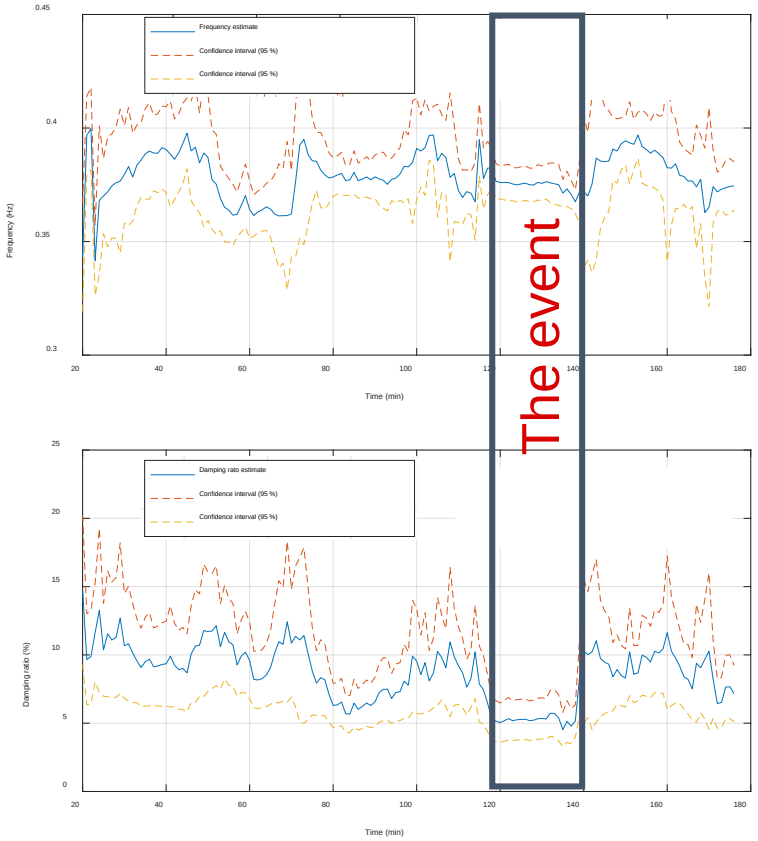
Modal identification results with MAR method.

Observations

October 20, 2017: Source in Northern Finland



Spectrogram of the total power exchange Finland and Sweden.



Modal identification results with MAR method.

Observations

Amplification as a function of frequency difference of the forced oscillation and the natural mode frequency

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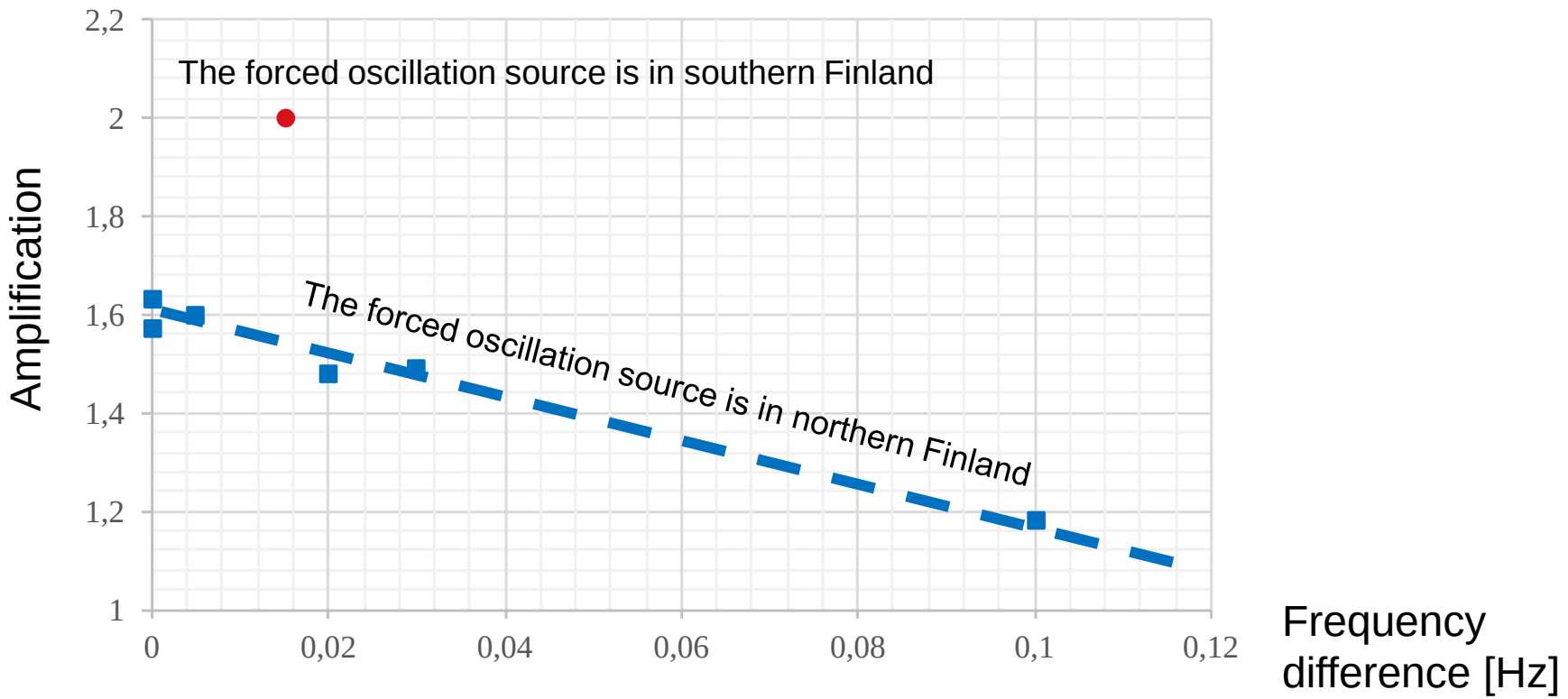

Observations

Amplification as a function of damping of the natural mode

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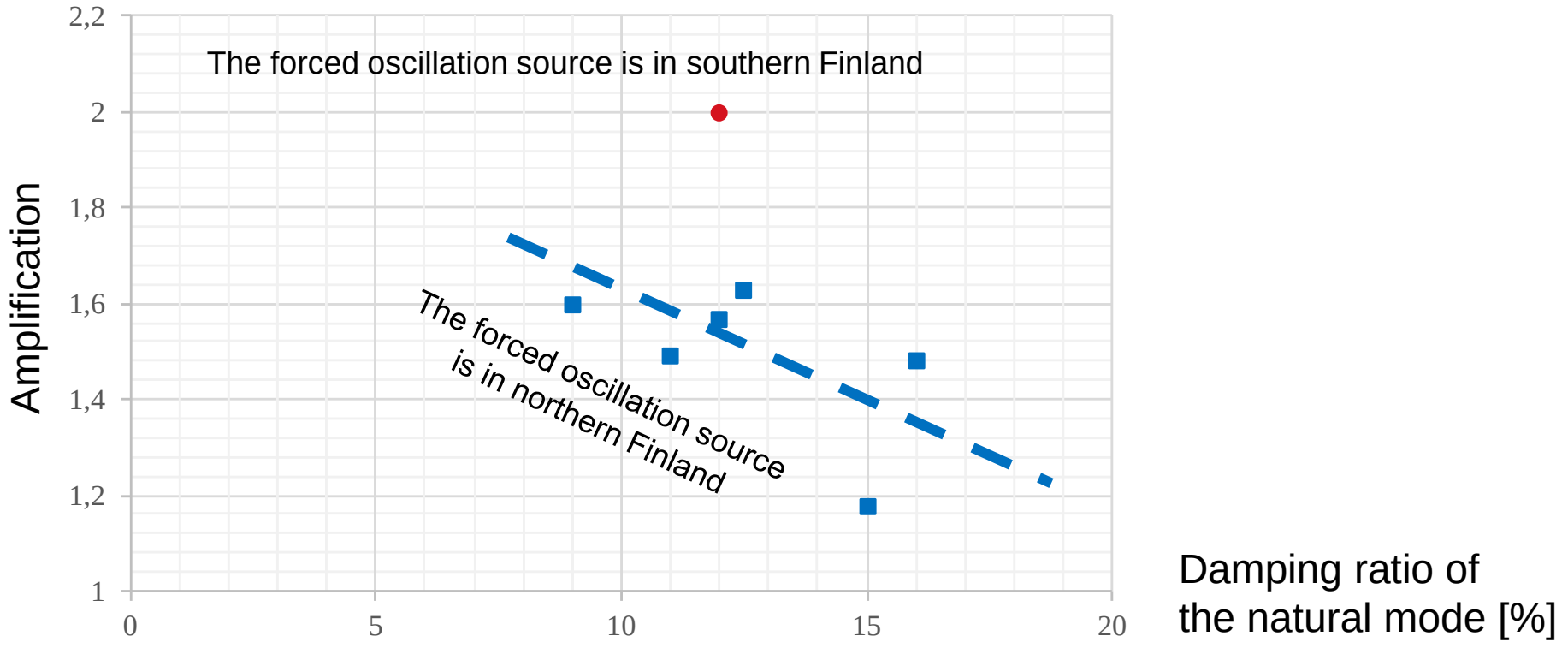
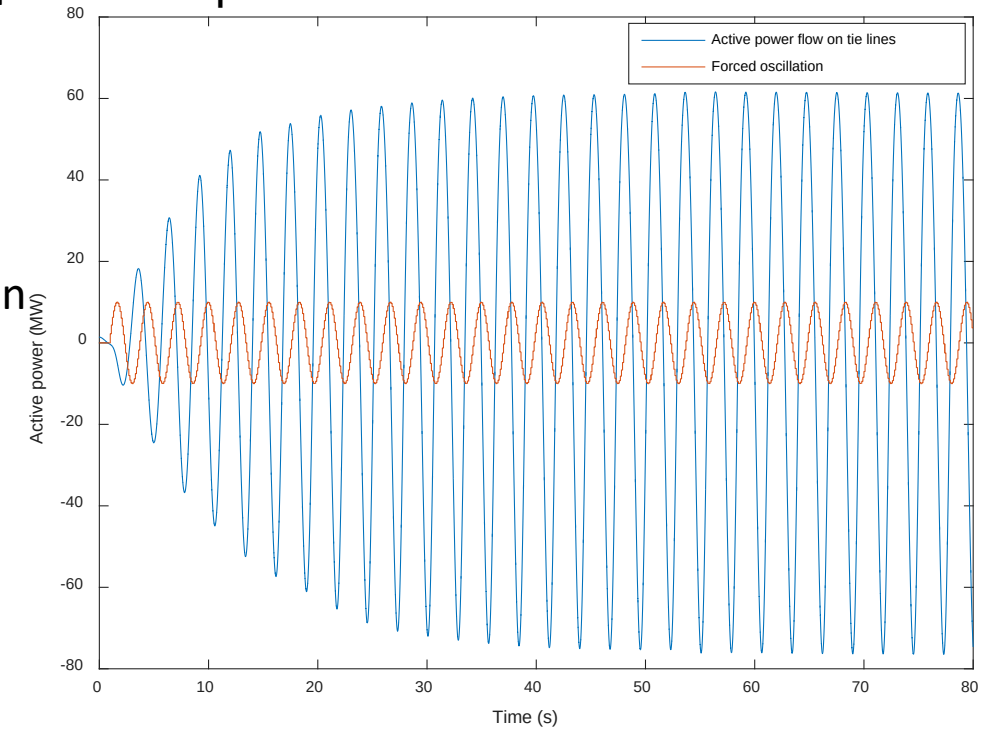


Simulations

Simulations

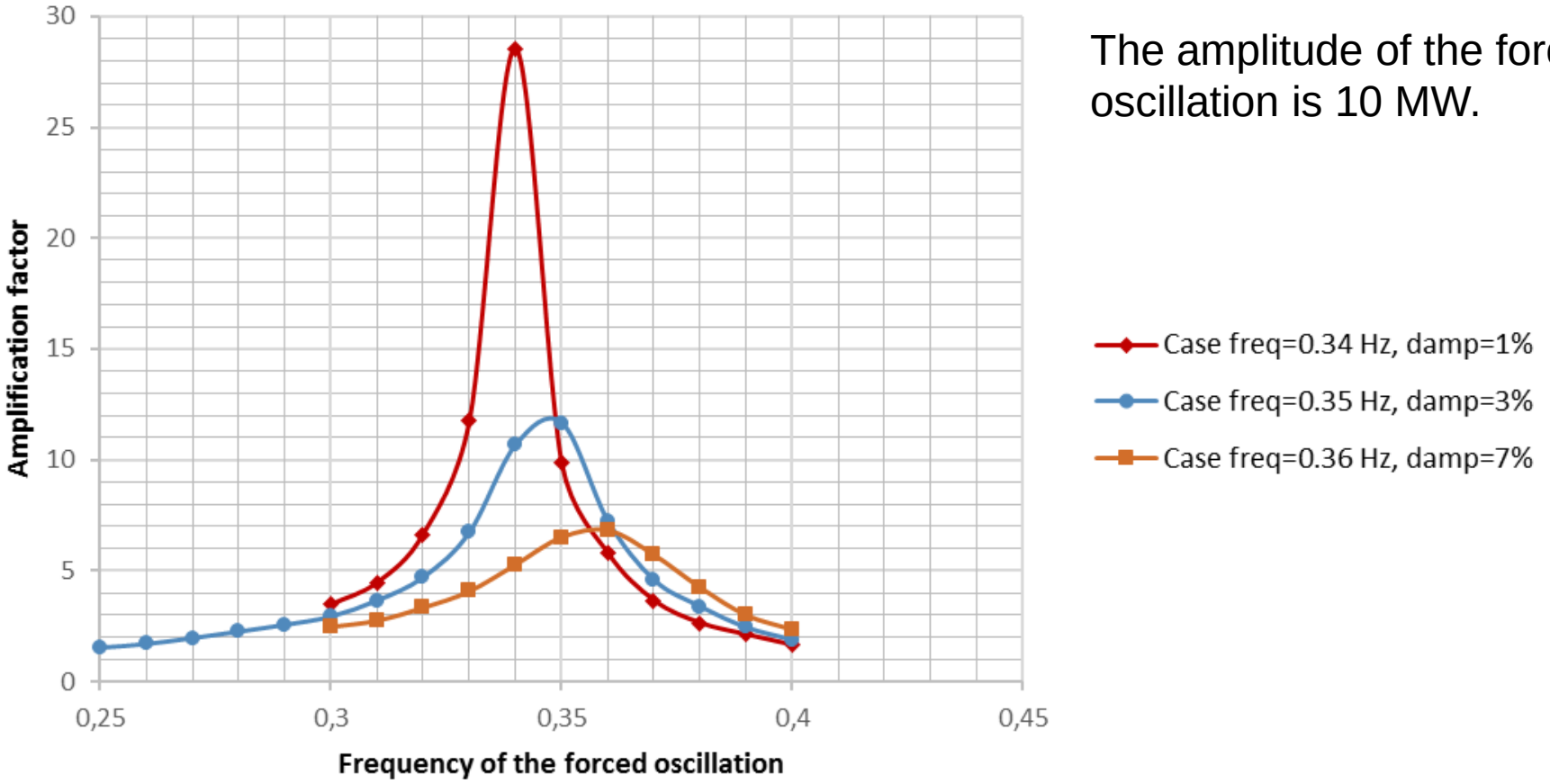
- Simulations carried out with the full Nordic power system simulation model
- A selected load is varied sinuisoidally (forced oscillation source) with different frequencies and amplitudes
- Amplification measured from the oscillations on the tie lines between Finland and Sweden. Amplification = amplitude of active power flow on Finland-Sweden tie lines / forced oscillation source amplitude
- Analysis done with 3 different cases - damping ratio of the Finland-Sweden inter-area mode: 1 %, 3%, and 7 %.

Amplification is around 6 in this case



Simulation results

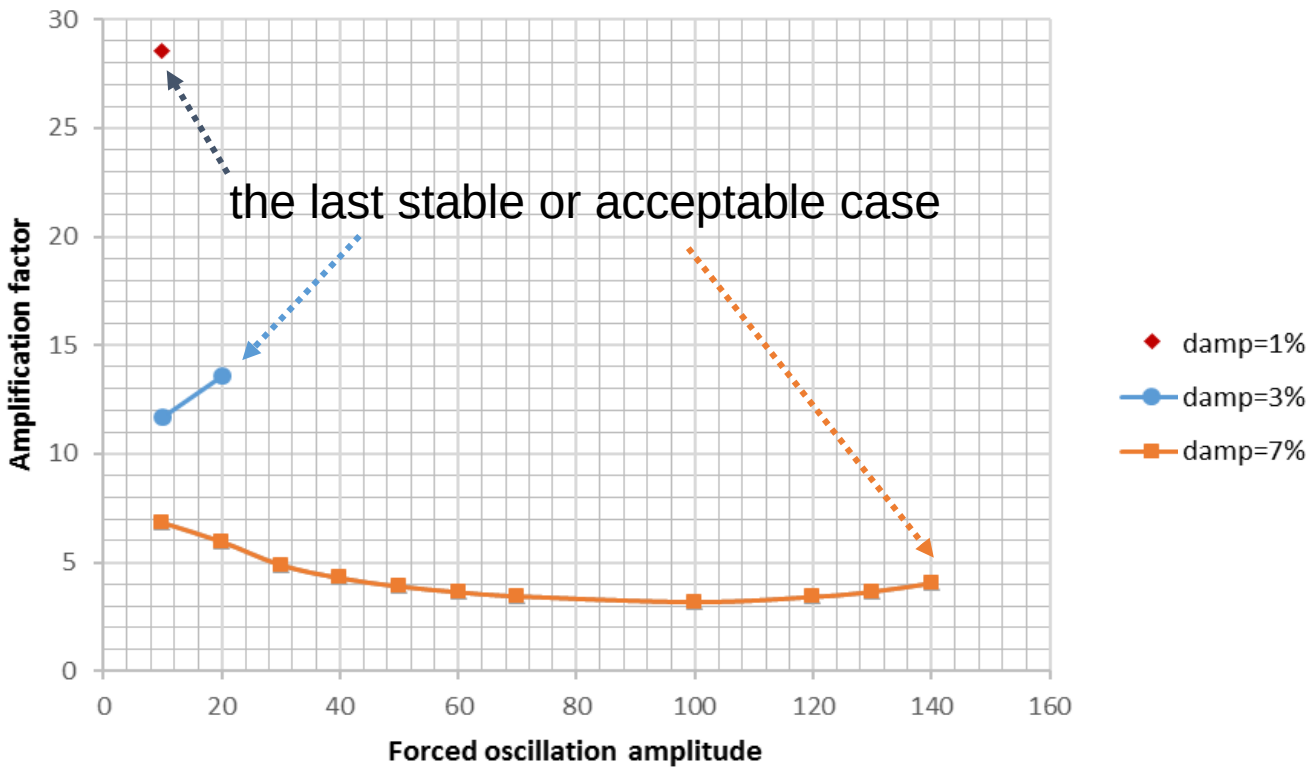
Amplification as a function of the forced oscillation frequency



The amplitude of the forcing oscillation is 10 MW.

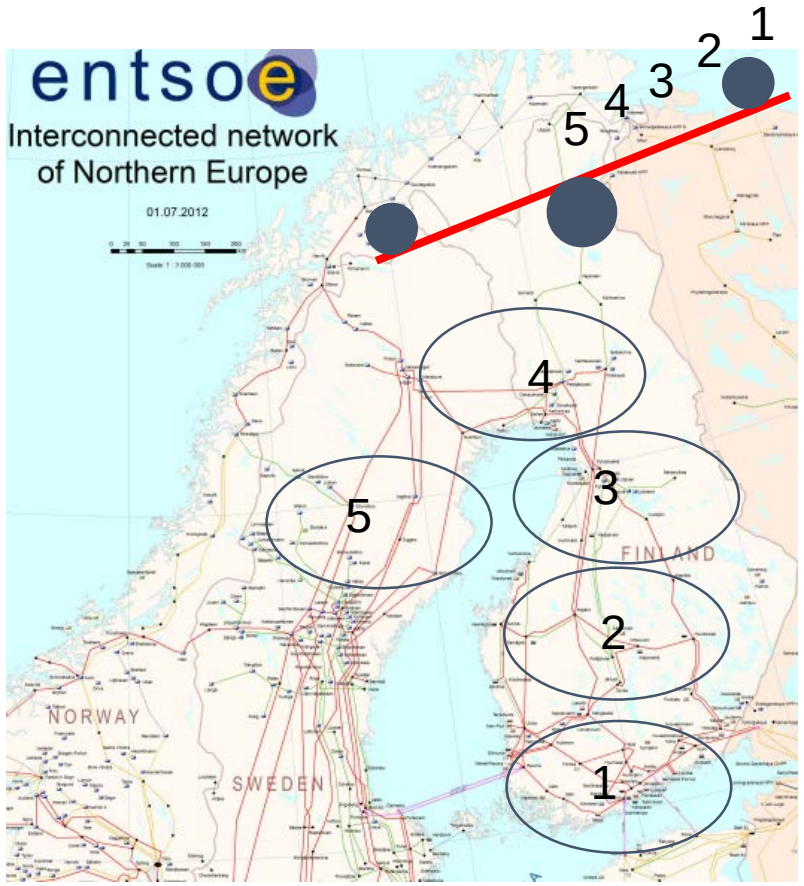
Simulation results

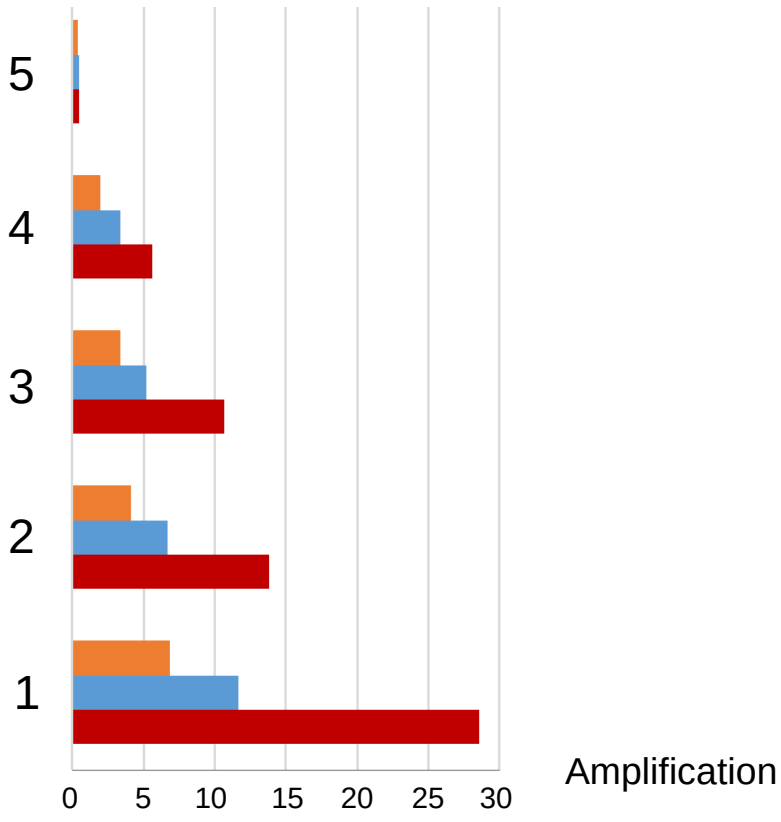
Amplification as a function of the forced oscillation amplitude (at resonance frequency)



Simulation results

Amplification as a function of the forced oscillation source location





The amplitude of the forcing oscillation is 10 MW.

damp=1%

damp=3%

damp=7%

Conclusions

1. **Resonance effects between forced and electromechanical oscillations may occur in power systems in certain situations. The resonance is dependent on many factors but the most important are:**
   - Location of the forced oscillation source
   - Damping of the natural oscillation mode
   - Frequencies of the forced oscillation source and the natural oscillation mode in the system
2. **In the worst case the resonance phenomenon could risk the system security**
3. **Resonance phenomenon should be considered by TSOs in their processes:**
   - Long-term planning: Consider and study the phenomenon in the planning process, create a processes for mitigating such phenomena
   - Operational planning: Consider the phenomenon in the planning process
   - Operation: Monitoring the system (WAMS is important here), create processes for reacting to such events, operator training

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