Frequency Dynamics of Power Grids

Julian Fritzsch

Young Researchers' Day

16. September 2022

Swiss National Science Foundation

UNIVERSITÉ DE GENÈVE
FACULTY OF SCIENCE
Department of Quantum Matter Physics

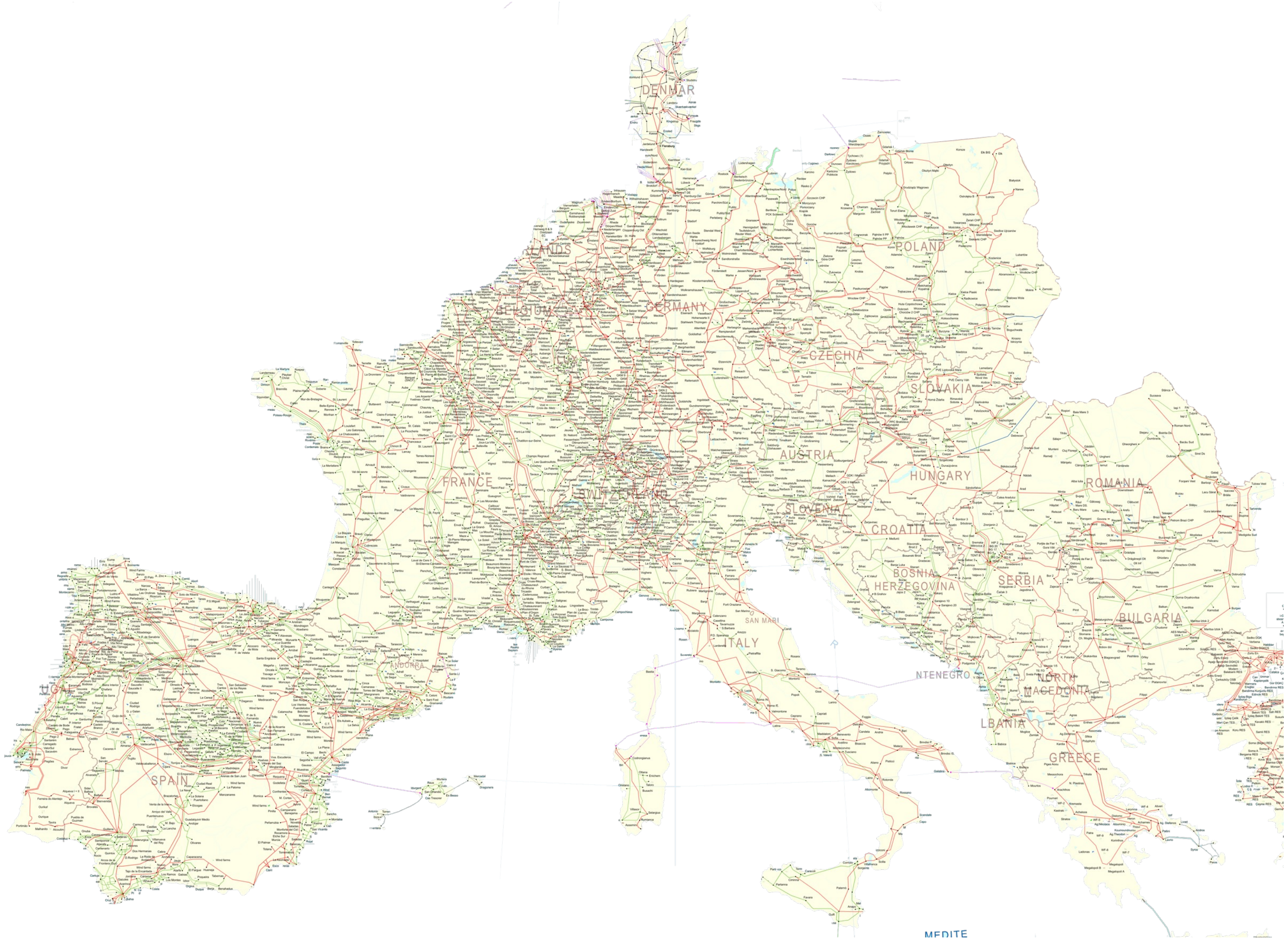
Hes·so // VALAIS WALLIS
School of Engineering

Motivation

https://www.entsoe.eu/data/map/downloads/

Motivation

- Power grids are large connected networks



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Motivation

- Power grids are large connected networks
- How do single components interact?

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Motivation

- Power grids are large connected networks
- How do single components interact?
- Can we use techniques from theoretical physics?

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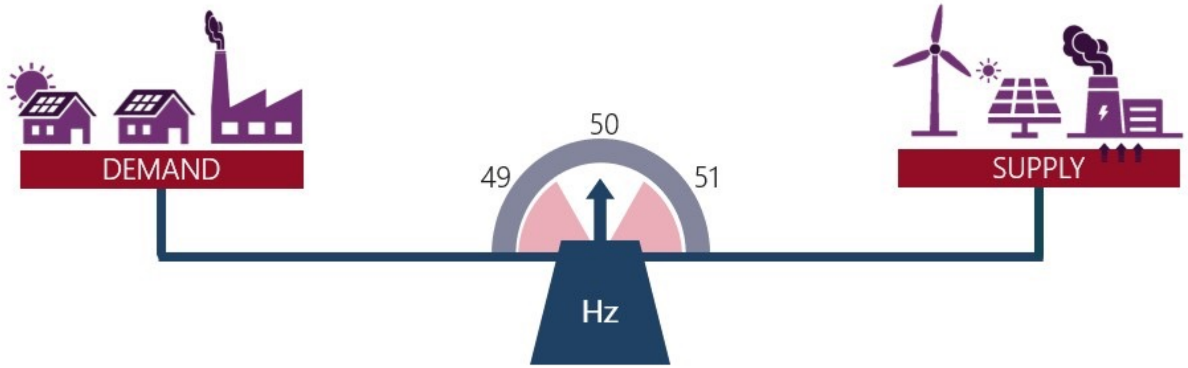
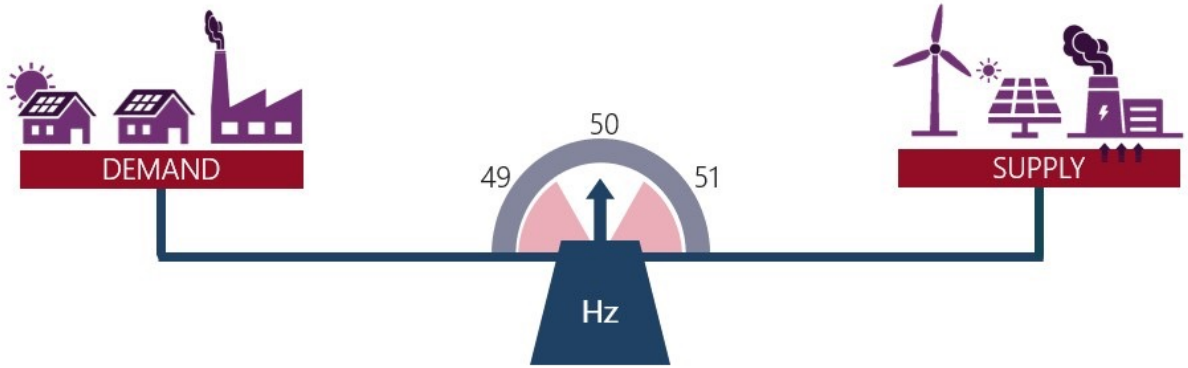
Grid Frequency



https://aemo.com.au/learn/energy-explained/energy-101/energy-explained-frequency

Grid Frequency

- Grid Frequency is an important measure of grid stability



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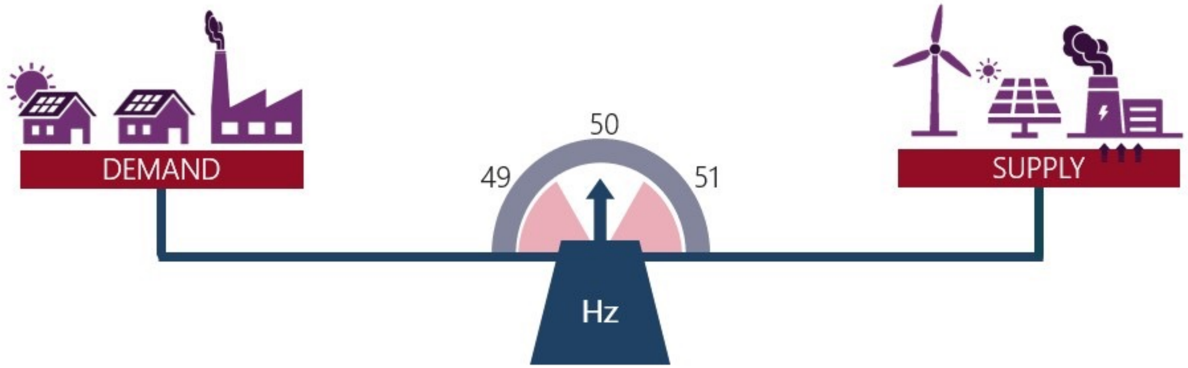
Grid Frequency

- Grid Frequency is an important measure of grid stability
- Coupled to power balance



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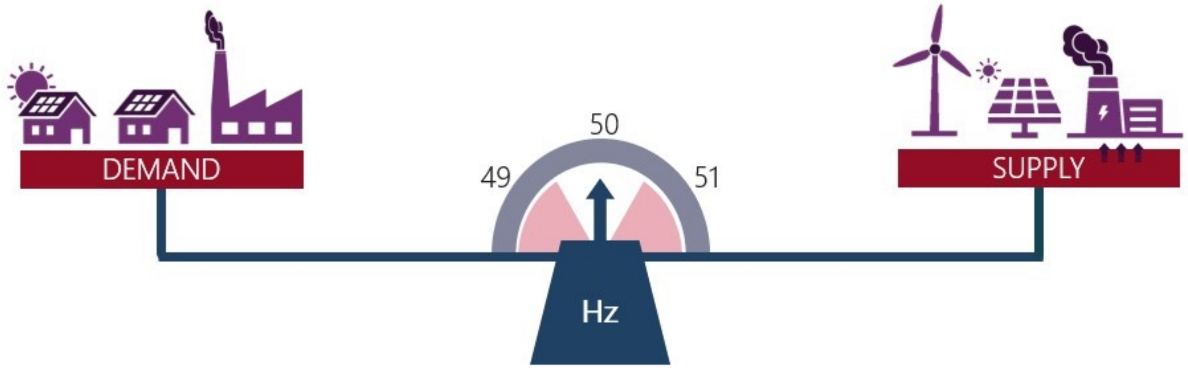
Grid Frequency

- Grid Frequency is an important measure of grid stability
- Coupled to power balance
- What happens in case of imbalance?



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Swing Equations

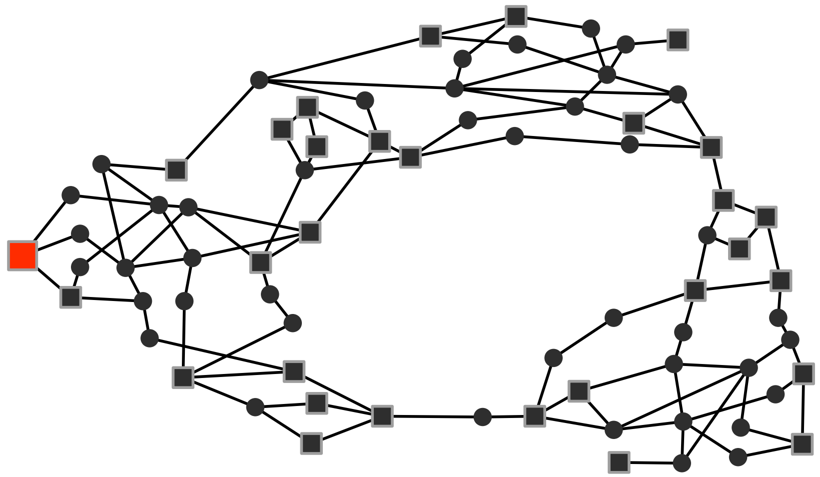
$$m_i \dot{\omega}_i + d_i \omega_i = P_i - \sum_j b_{ij} \sin(\theta_i - \theta_j)$$

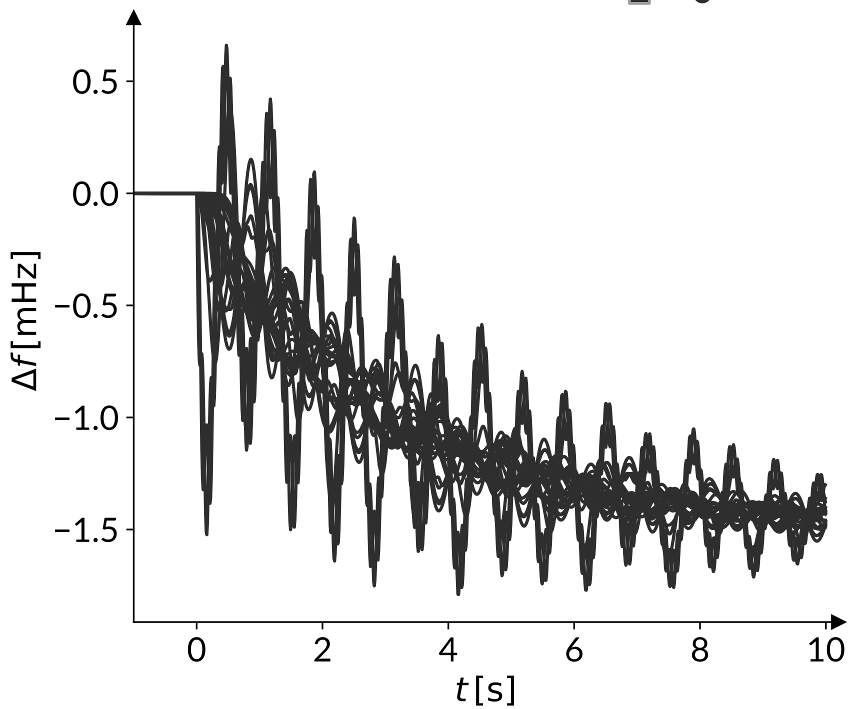
$$d_i \omega_i = P_i - \sum_j b_{ij} \sin(\theta_i - \theta_j)$$

When linearized around a fixed point:

$\mathbf{M}\dot{\omega} + \boldsymbol{D}\boldsymbol{\omega} = \boldsymbol{P} - \boldsymbol{L}\boldsymbol{\theta}$

$\boldsymbol{L}$ captures network structure





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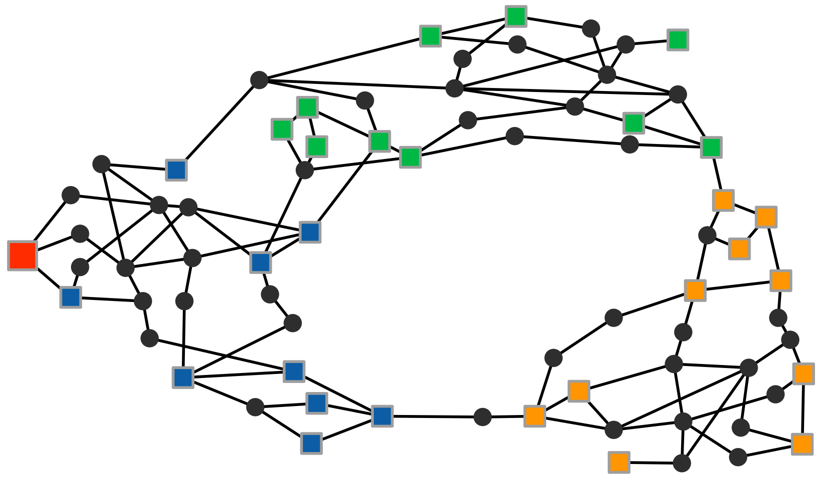
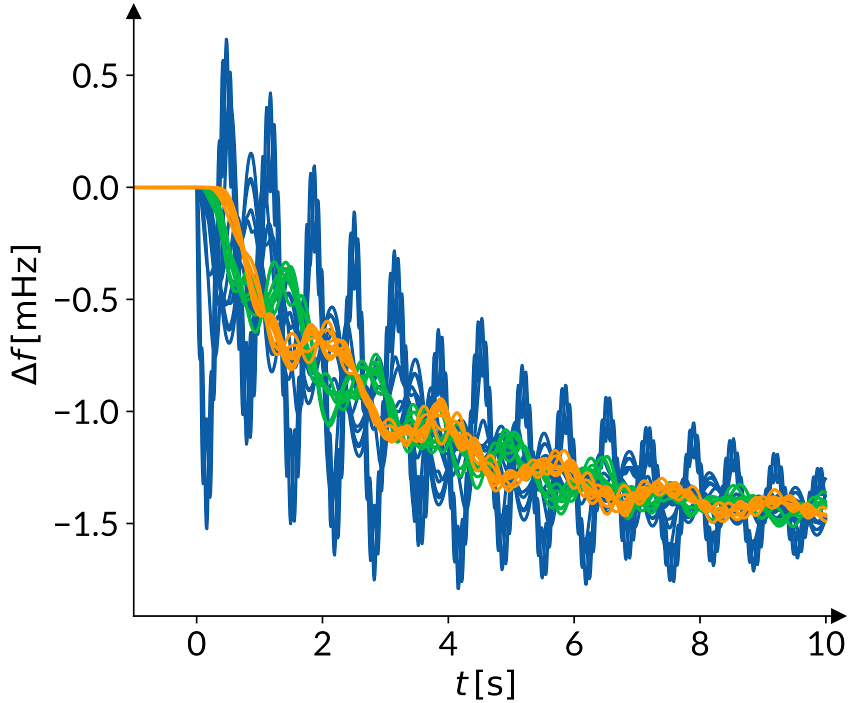
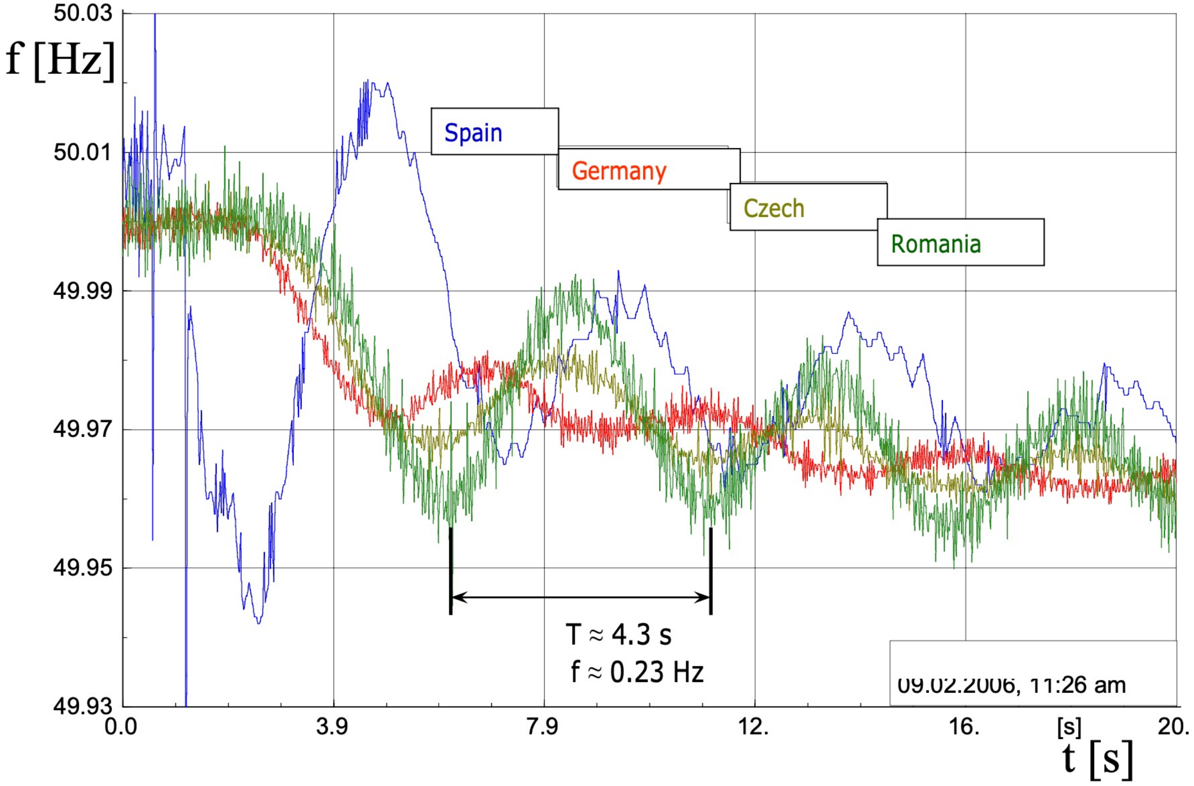
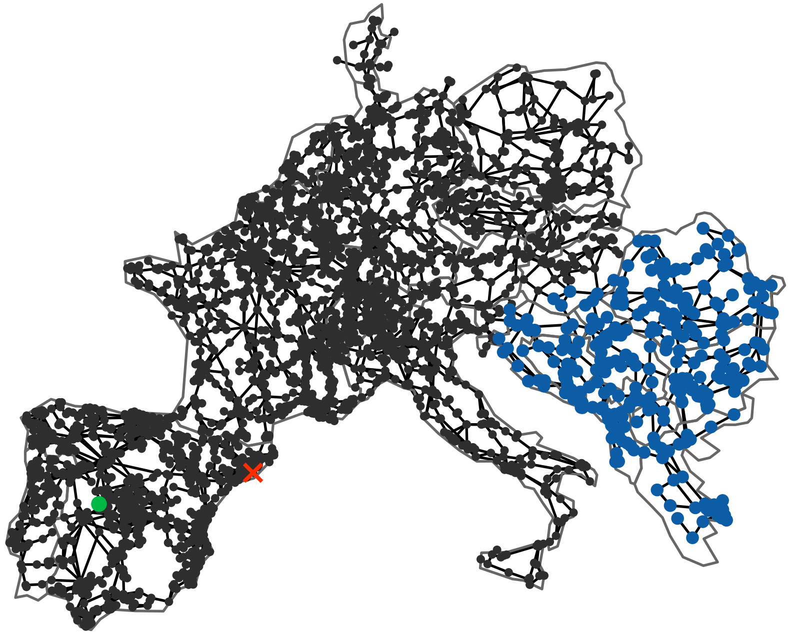


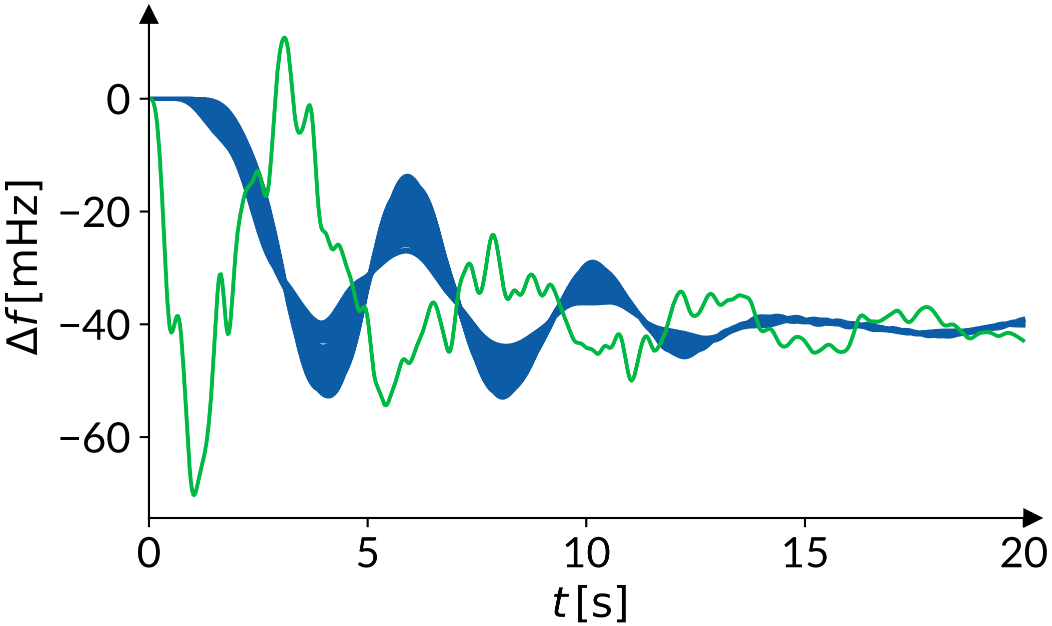


Larger Grids

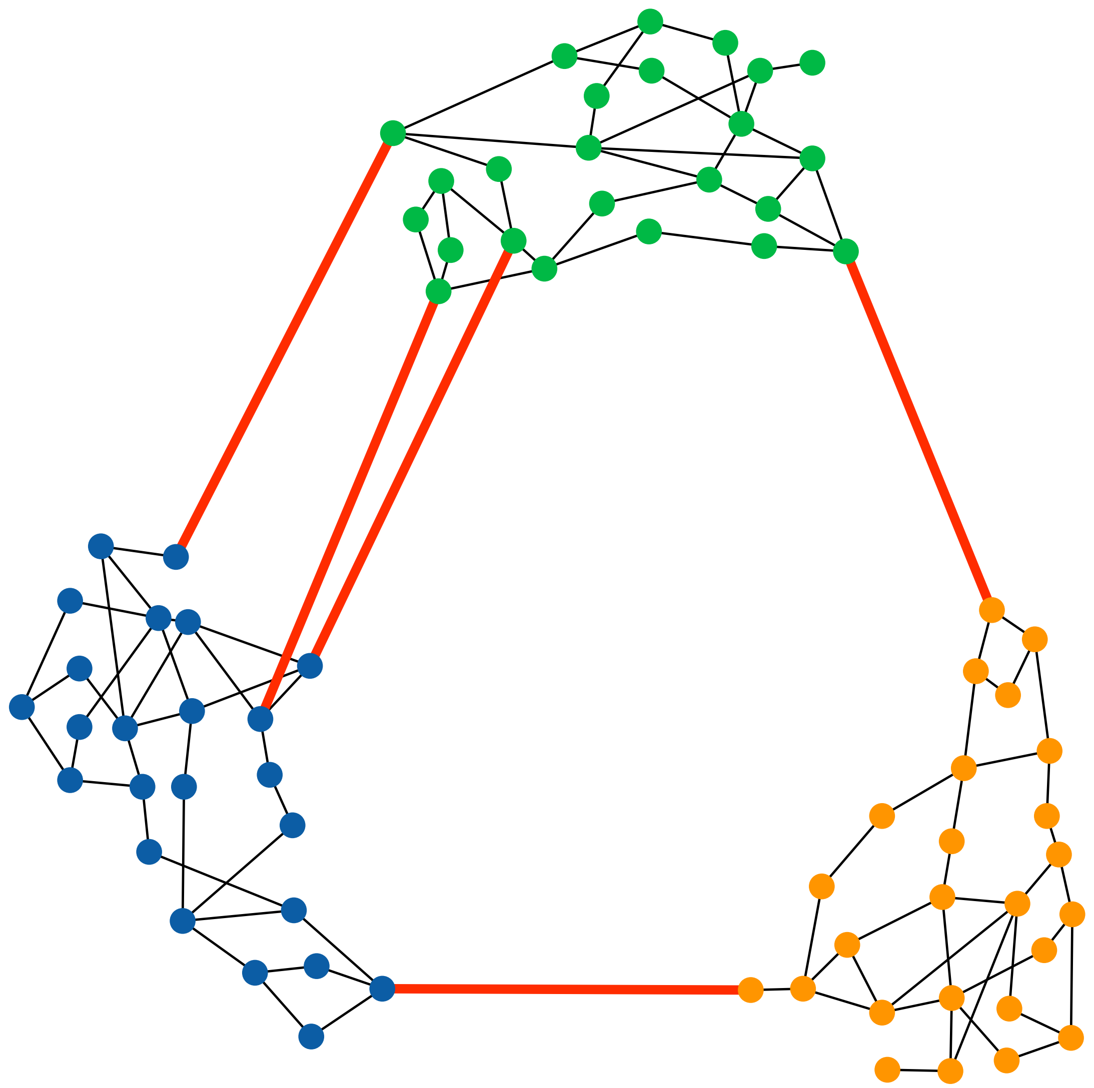


Al-Ali et al. – 17th Power Systems Computation Conference 2011



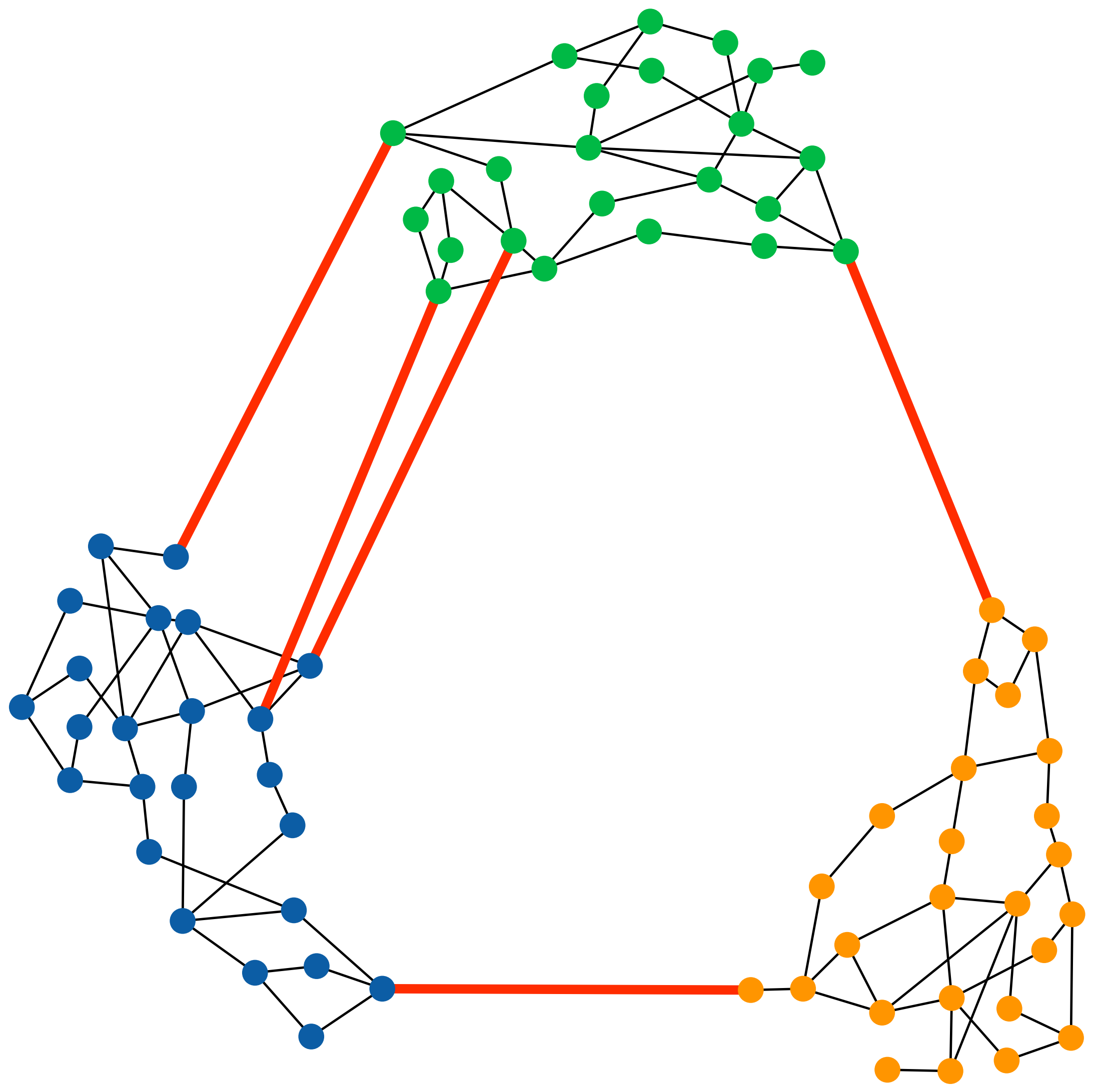


Perturbation Theory



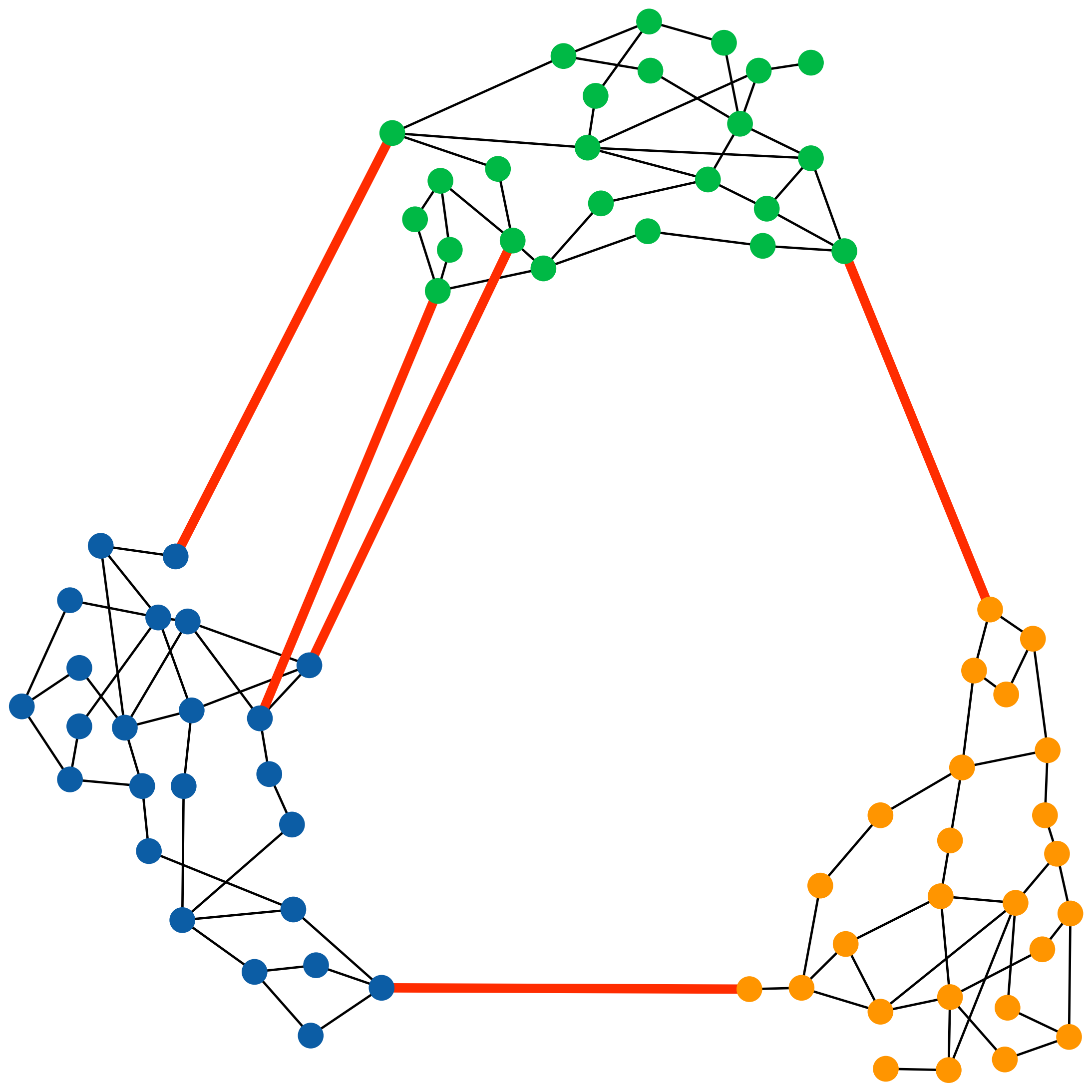
Perturbation Theory

- Start with disconnected areas



Perturbation Theory

- Start with disconnected areas
- Connections are perturbations



Perturbation Theory

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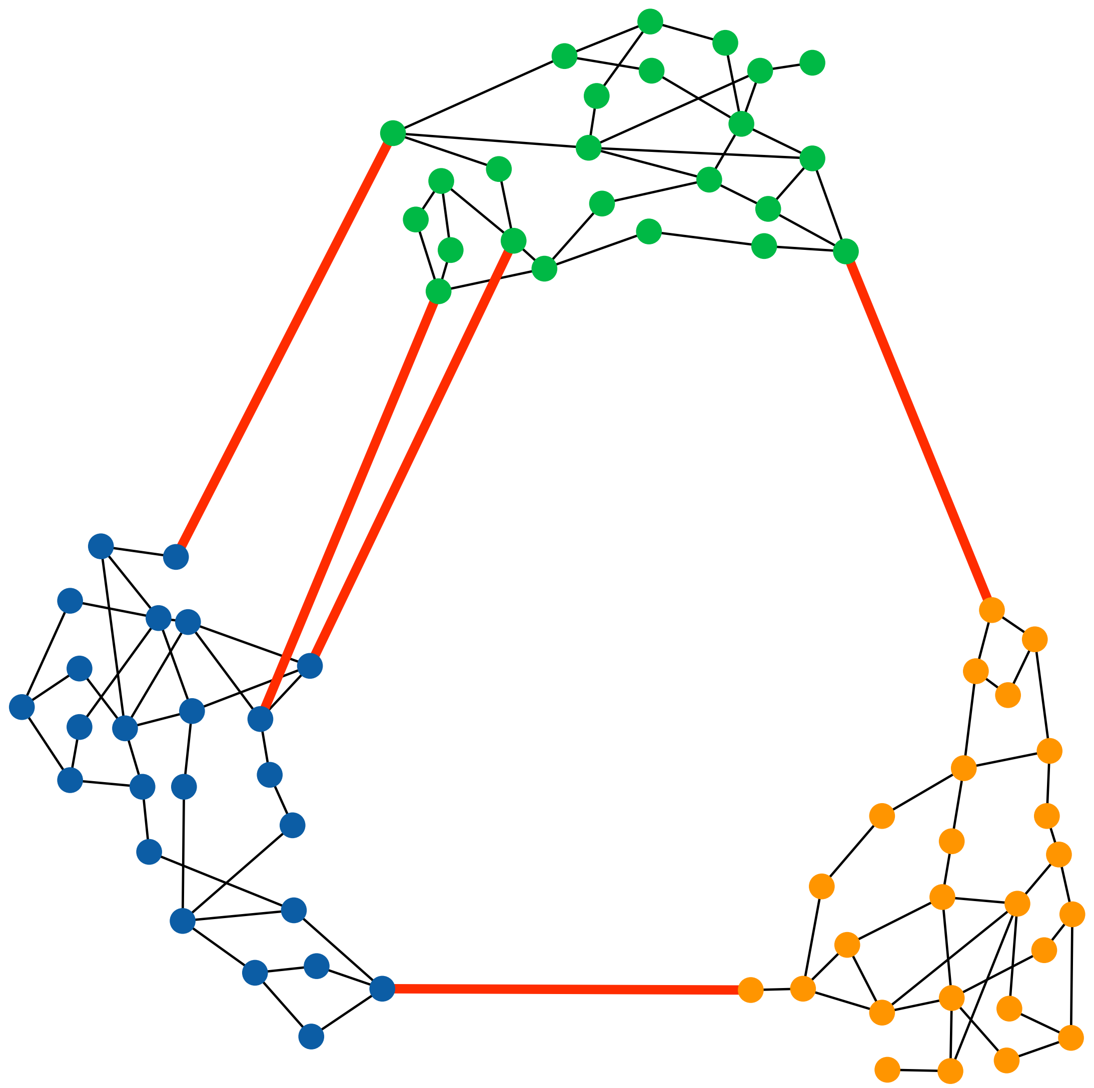
- How do they interact?



Perturbation Theory

- Start with disconnected areas
- Connections are perturbations
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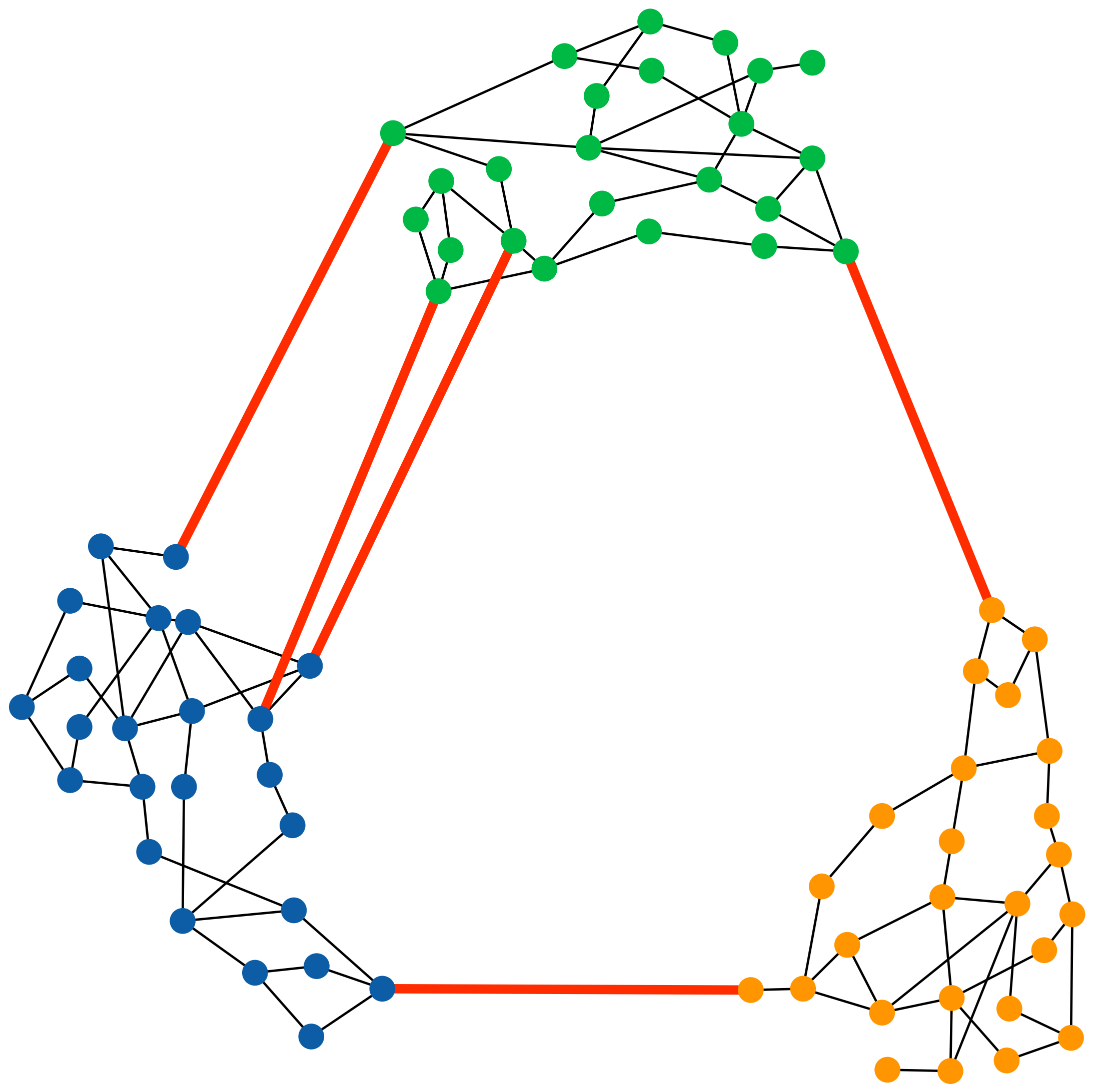
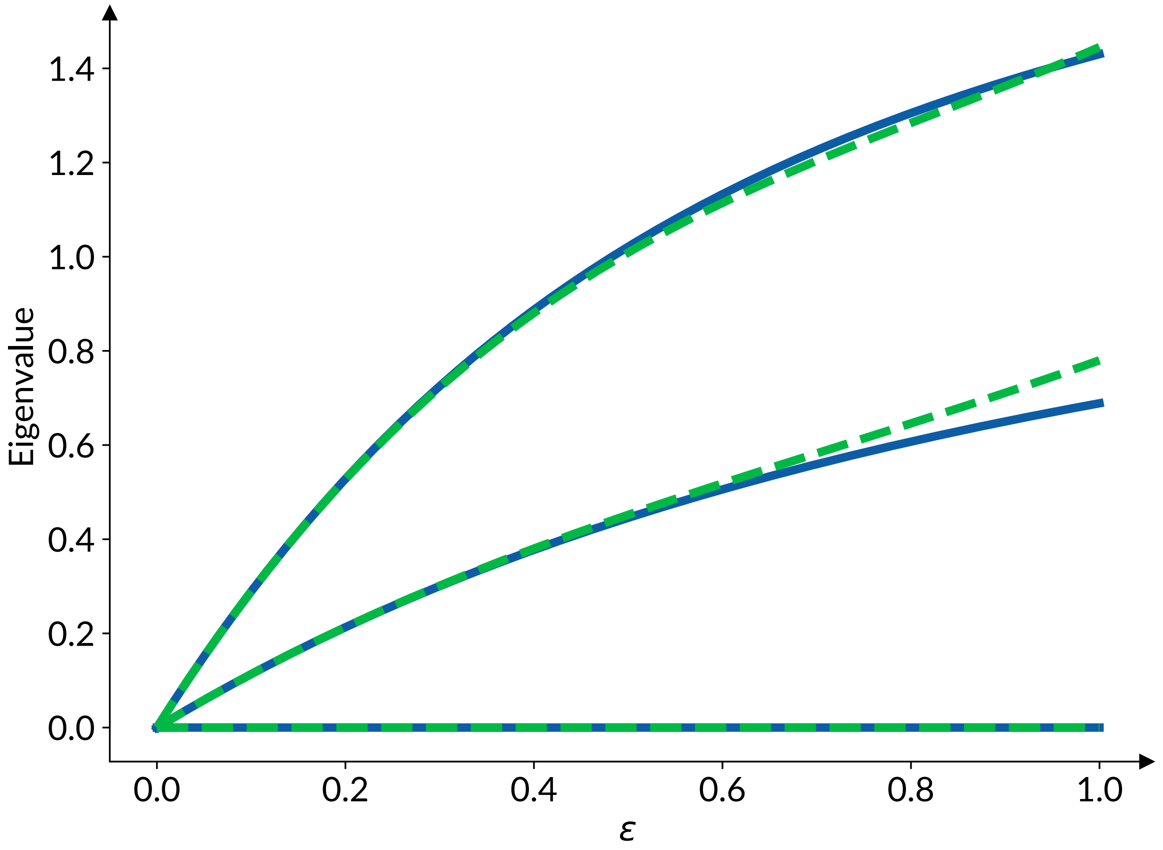
$$L = \begin{bmatrix} L_1 & 0 & 0 \\ 0 & L_2 & 0 \\ 0 & 0 & L_3 \end{bmatrix} + \varepsilon L_i$$

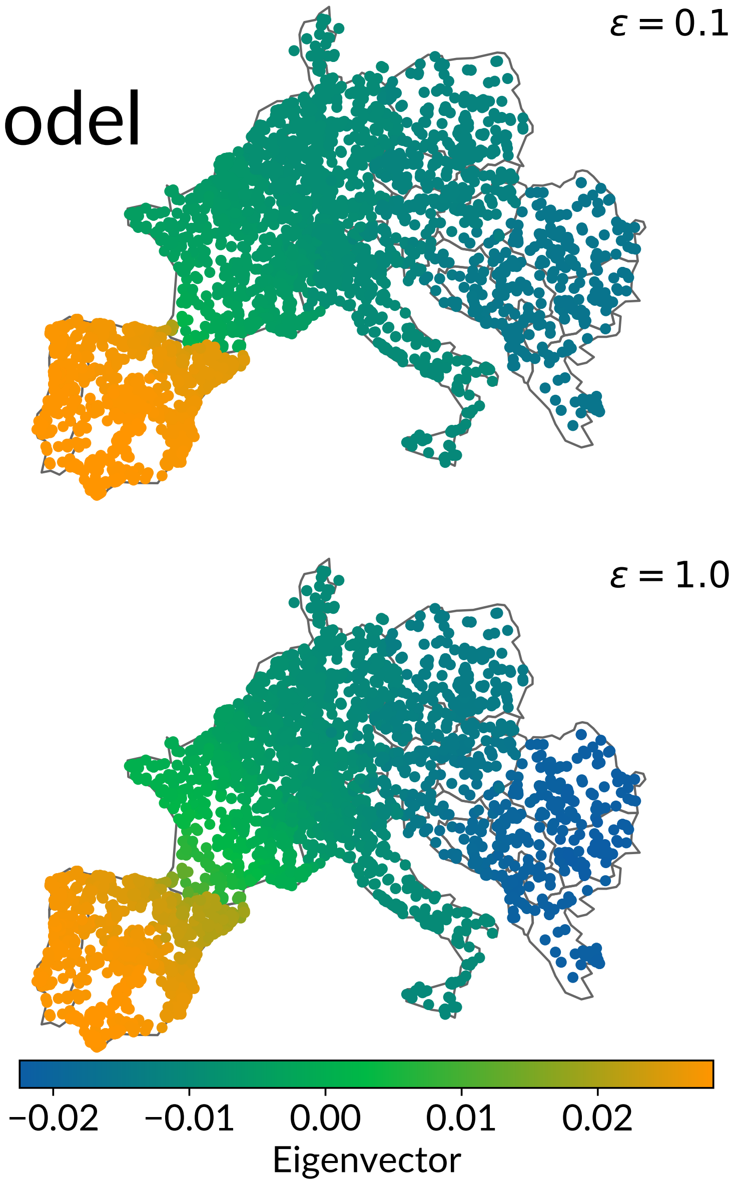


Results

3 Areas



European Model



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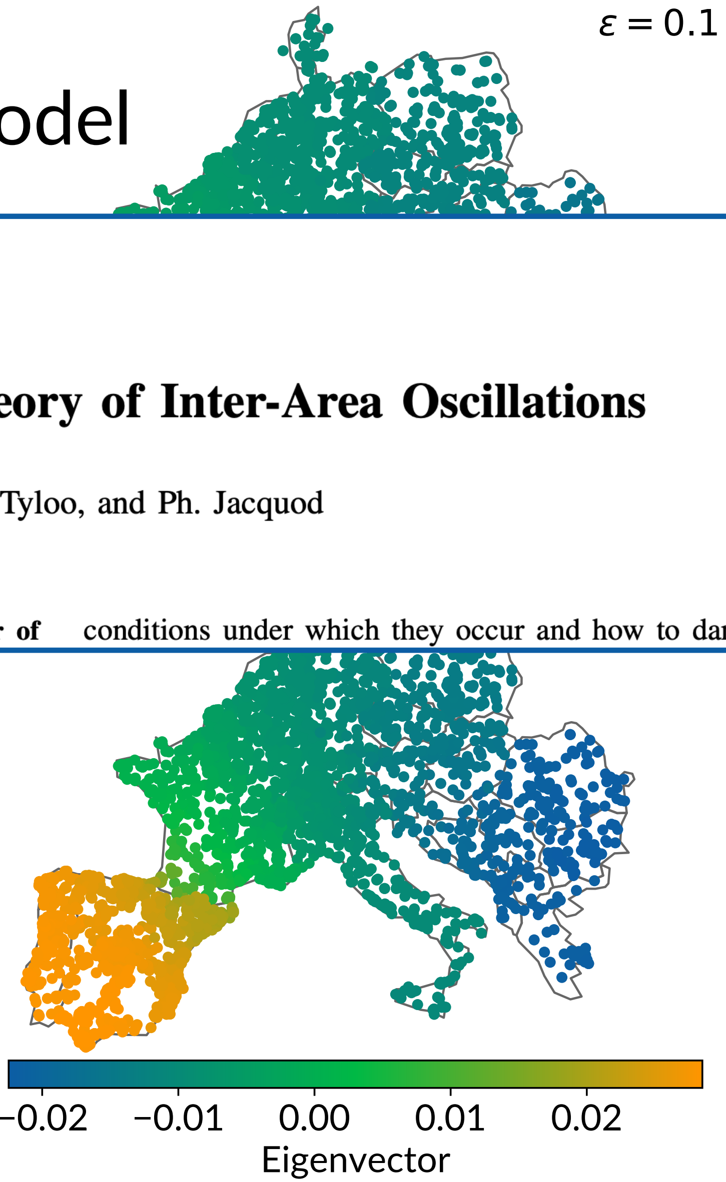

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Matrix Perturbation Theory of Inter-Area Oscillations

J. Fritzsch, M. Tyloo, and Ph. Jacquod

a number of conditions under which they occur and how to damp these

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Long Wavelength Coherency in Well Connected Electric Power Networks

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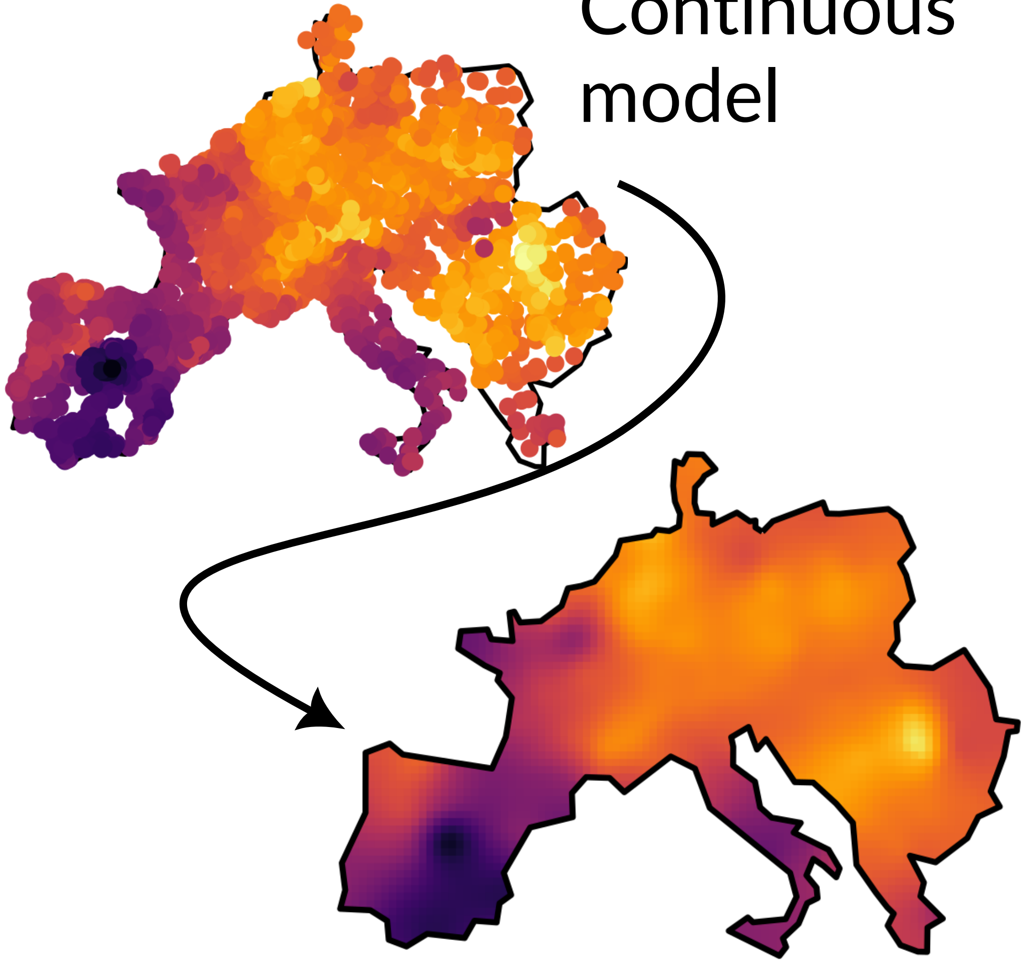
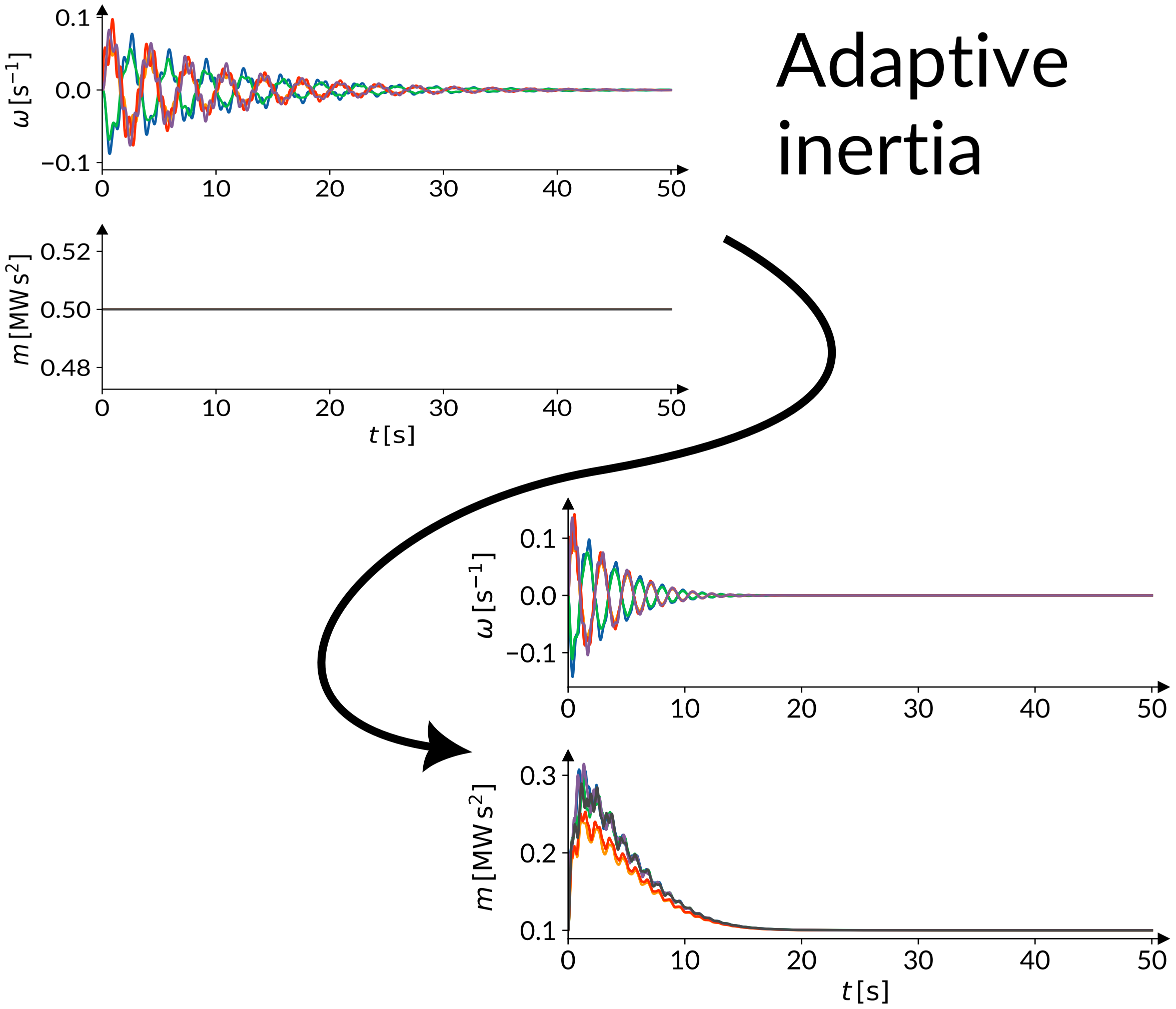
Outlook

Continuous model



Adaptive inertia



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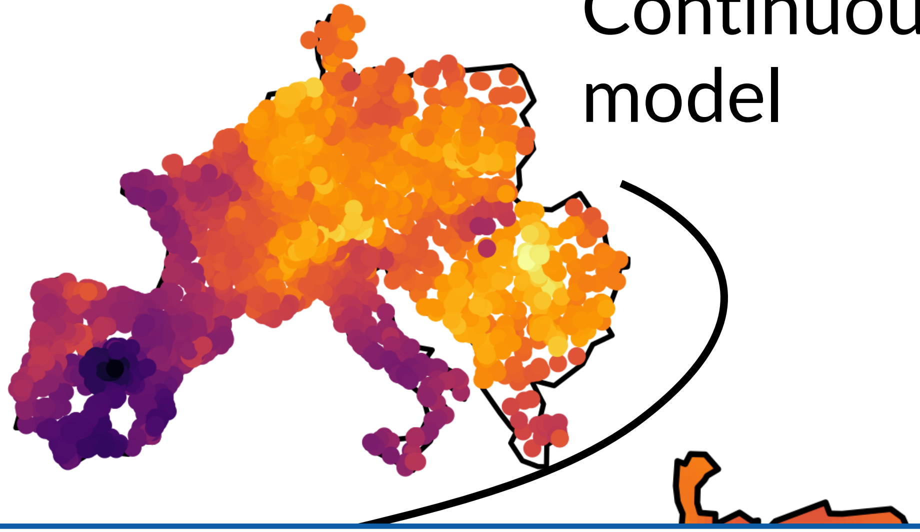

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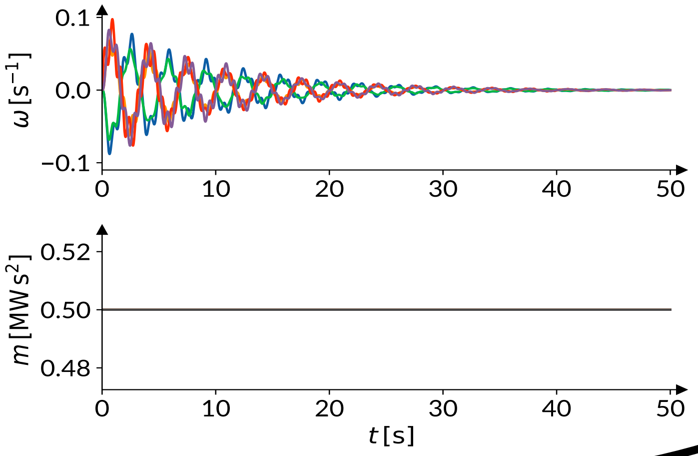

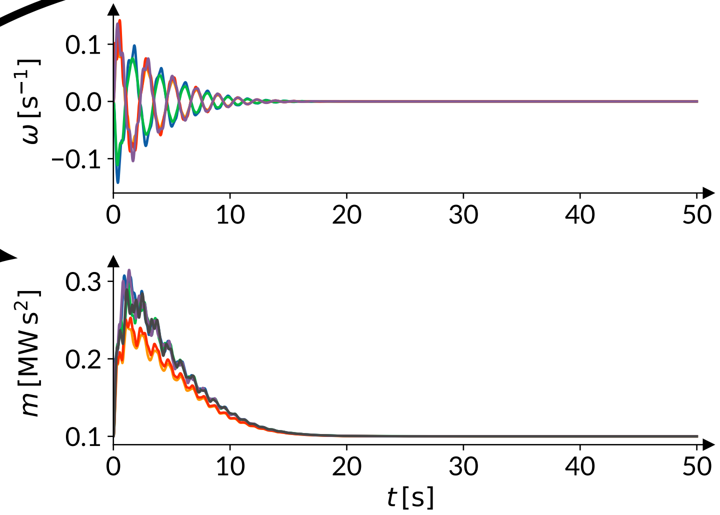

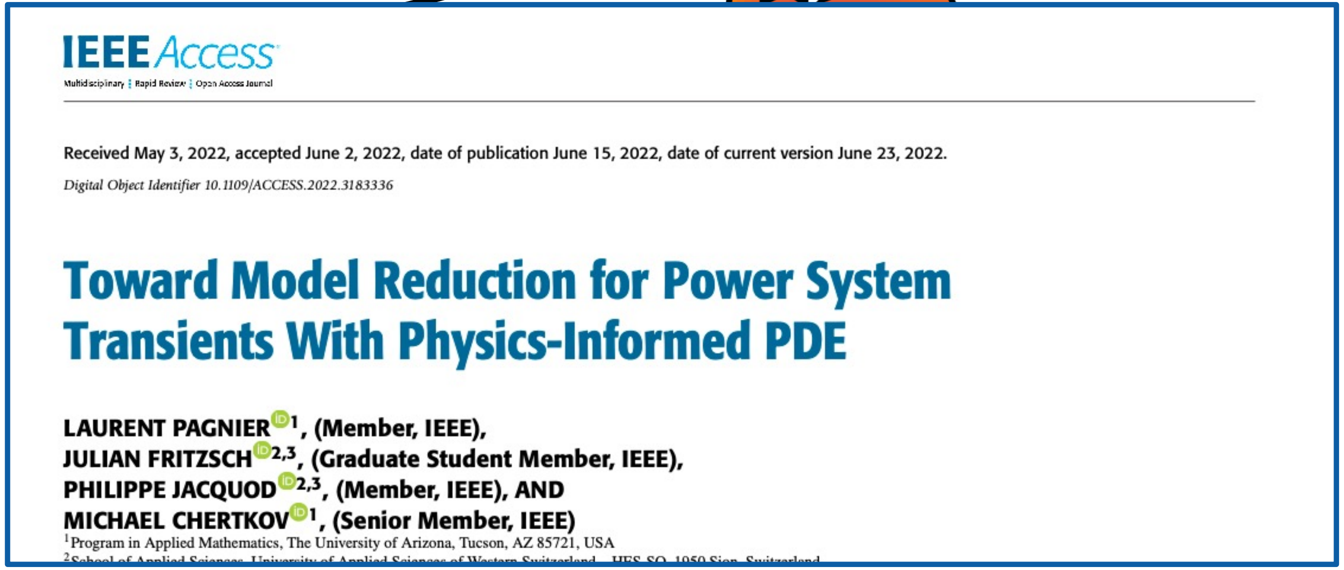

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Toward Model Reduction for Power System Transients With Physics-Informed PDE

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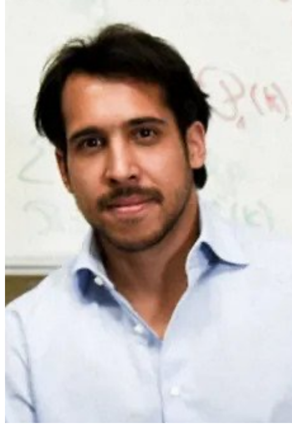

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