CoNDyNet

STROMNETZE
Forschungsinitiative der Bundesregierung

JÜLICH
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CoNDyNet Project & Workshop: Key findings & some remarks

12.6.2017 | Dirk Witthaut
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Max-Planck Institute for Dynamics and Self-Organization, Göttingen

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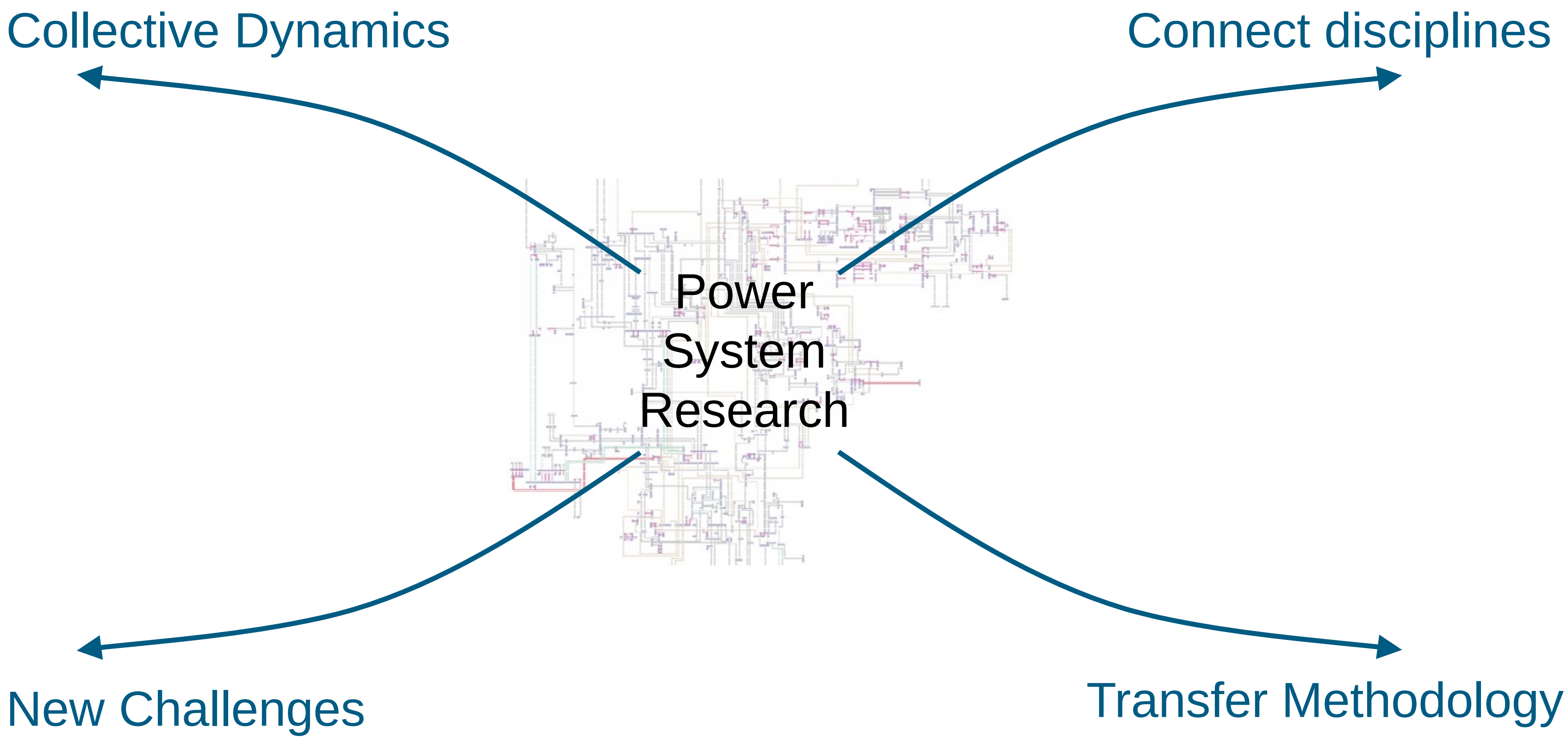
Scope of the project

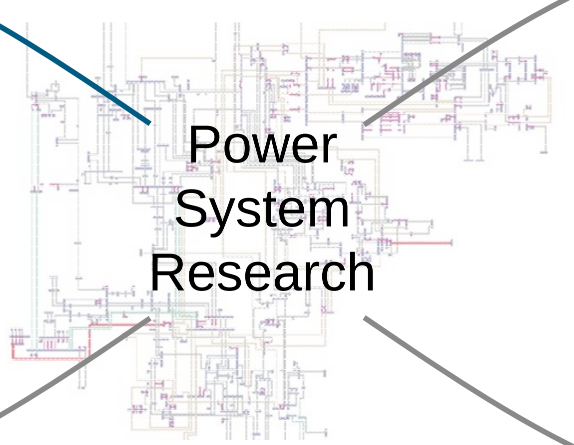


Scope of the project

Collective Dynamics

- Stability
- Noise
- Structure
- Connectivity

Connect disciplines



Power System Research

New Challenges

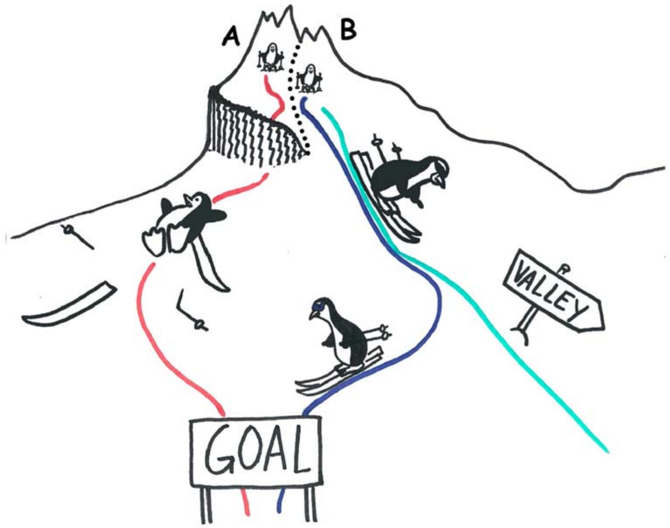
Transfer Methodology

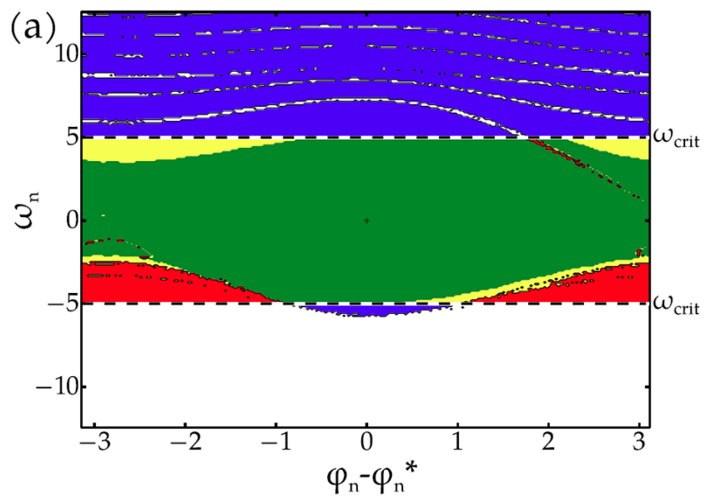
Network Dynamics: Stability and Relaxation

Global stability: For which fraction of initial states

- do we converge to the goal?

- do we never leave the desirable region?





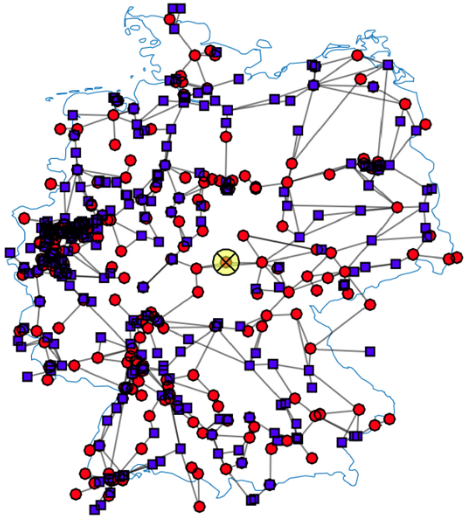
Hellmann, F., Schultz, P., Grabow, C., Heitzig, J., Kurths, J. Sci. Rep. 6, 29654 (2016)
see also Schultz et al, New J. Phys. (2017), New J. Phys. (2014)

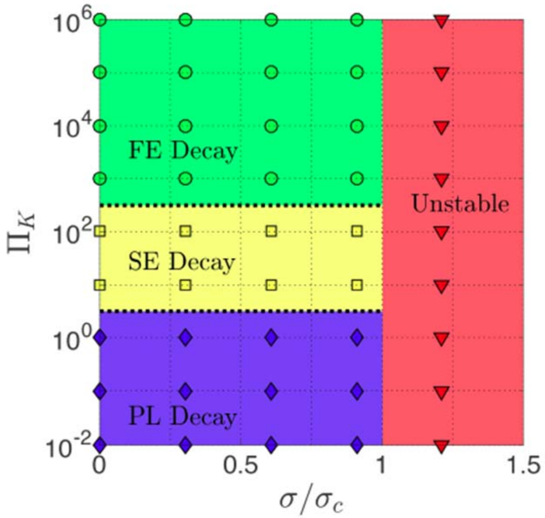
Network Dynamics: Stability and Relaxation

After a perturbation:

- How fast do we converge back to the goal?

- How does relaxation depend on structure?

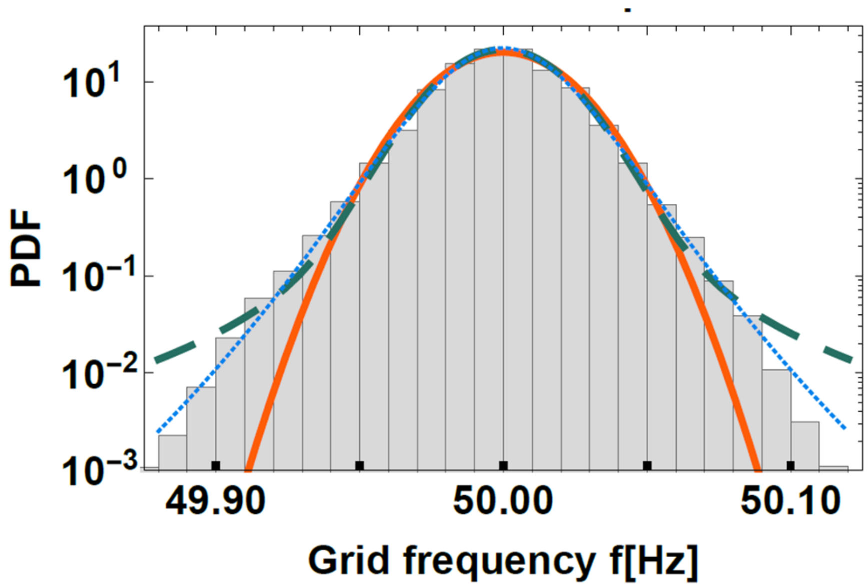




 S. Tamrakar, M. Conrath, and S. Kettemann, under review

Network Dynamics: Impact of noise

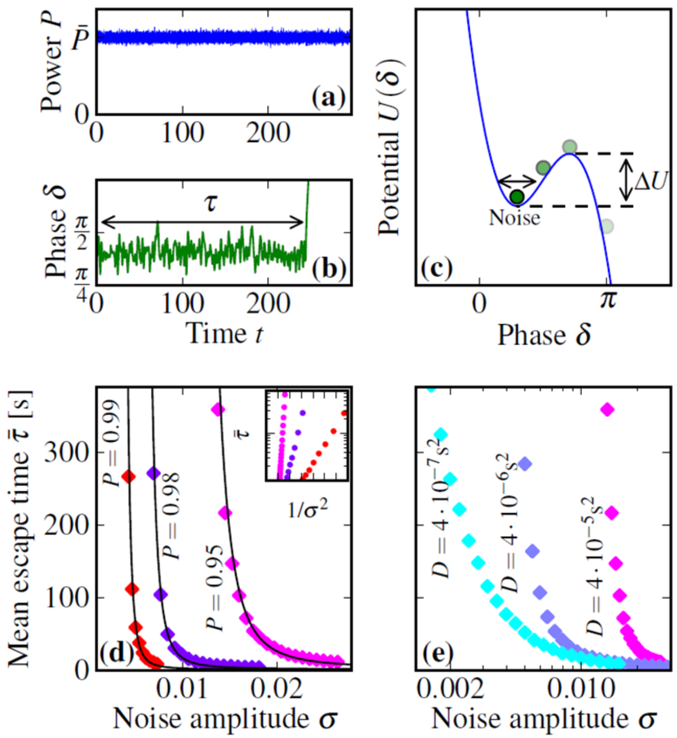
Stochastic stability: Impact of weak noise



P. Jacquod et al, in preparation; B. Schäfer et al, under review

Network Dynamics: Impact of noise

Stochastic stability: Vulnerability to strong noise

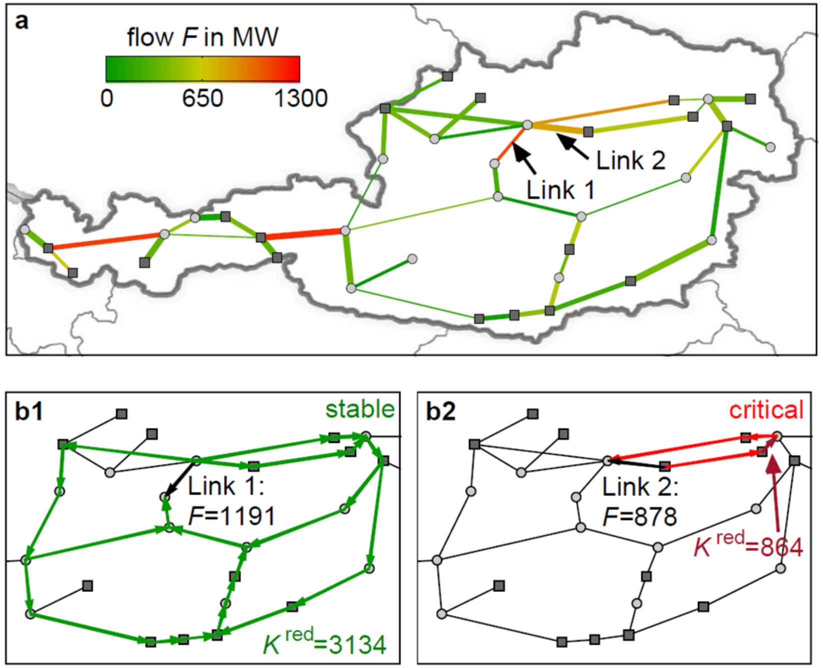


2nd order model with stochastic feed-in

Escape probability from Kramer's escape rate theory

Network Dynamics: Structure and Stability

A heuristics for N-1 security from the graph theoretical max-flow-min-cut problem:



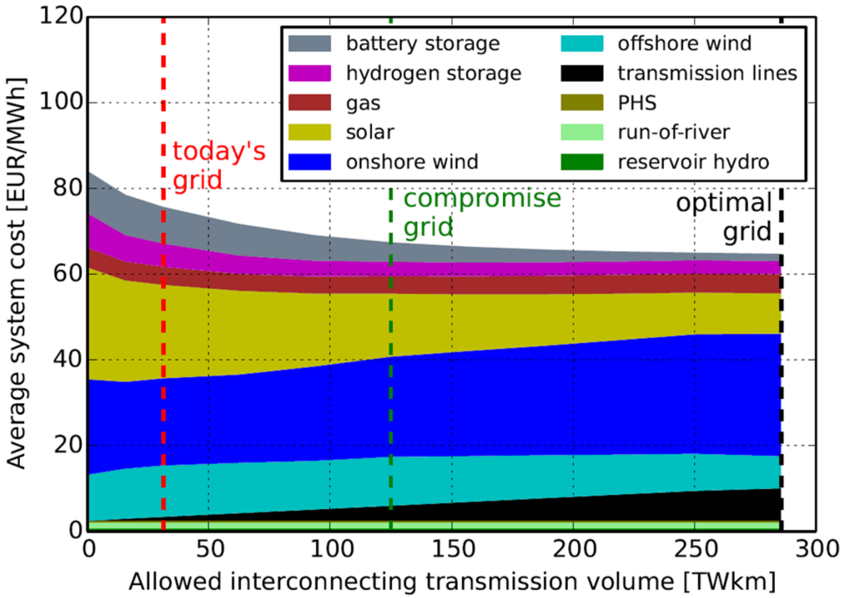
A high load is a very coarse indicator for the importance of a line…

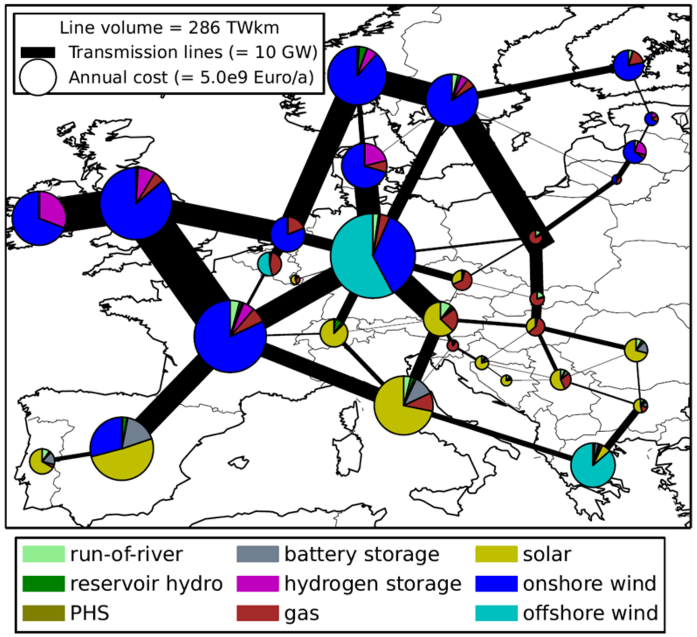
… because it does not account for redundancy

DW et al, Phys. Rev. Lett. 116, 138701 (2016); Rohden et al, New J. Phys. 19, 013002 (2017)

Network Dynamics: Optimum connectivity?

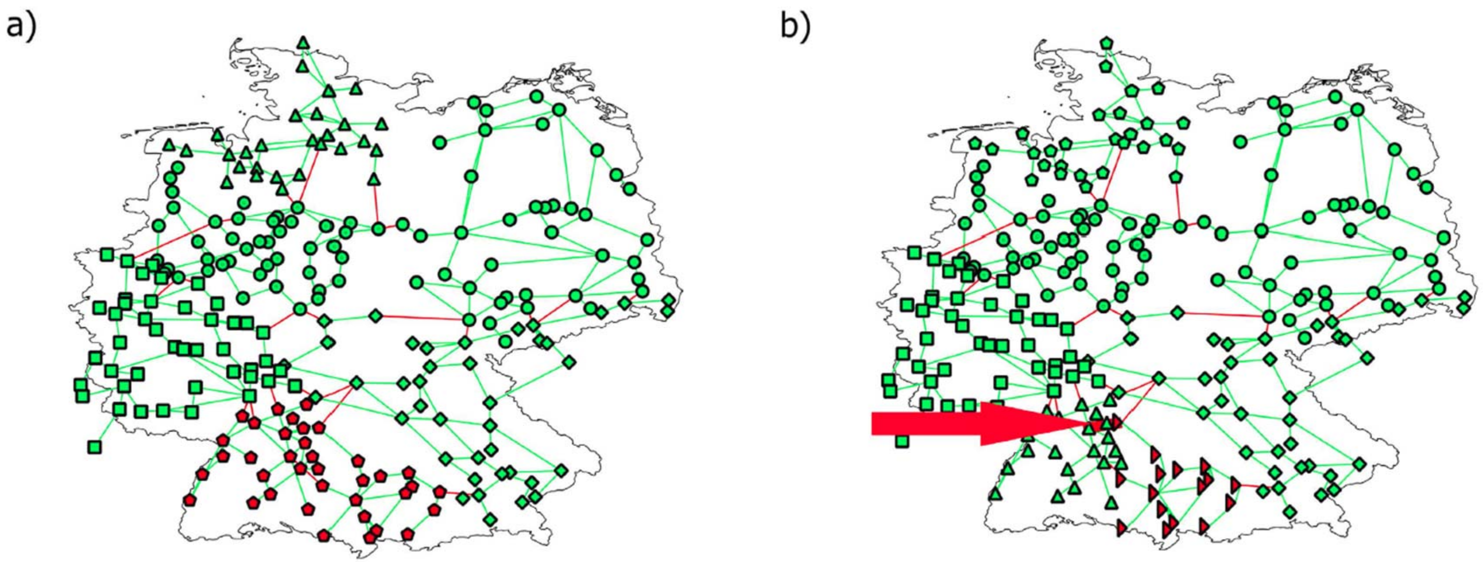
On large scales the extension of transmission lines is one of the cheapest options for system integration of fluctuating renewables.





Network Dynamics: Optimum connectivity?

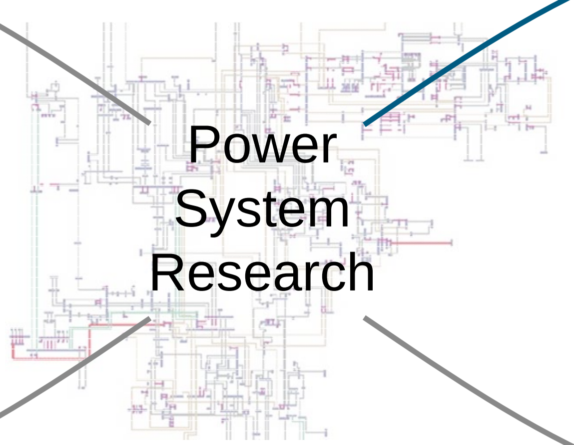
But sometimes less is more: Containing a blackout after a series of failures by *intentional shutdown* (SciGrid Model for Germany)



Scope of the project

Collective Dynamics

Connect disciplines



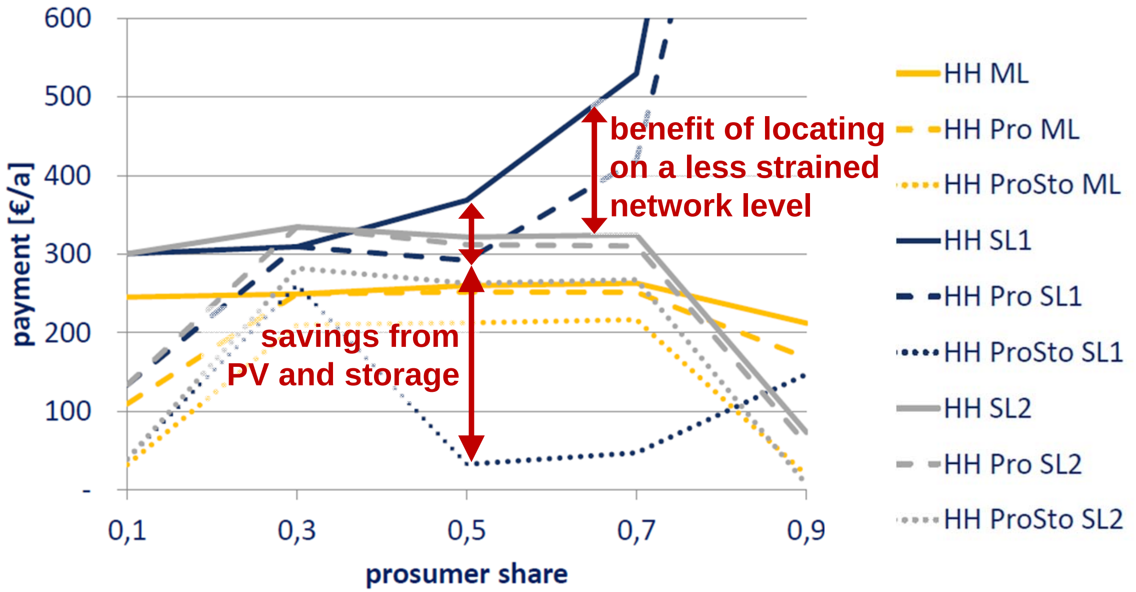
New Challenges

Transfer Methodology

Energy and Economy

Steering network users with economic incentives

example: network charges based on users' contribution to grid level peak load for households (HH) with PV (Pro) and Storage (ProSto) on 3 grid levels (ML, SL1, SL2)



- ➢ growing incentives for coordinating with the grid with rising shares of prosumers

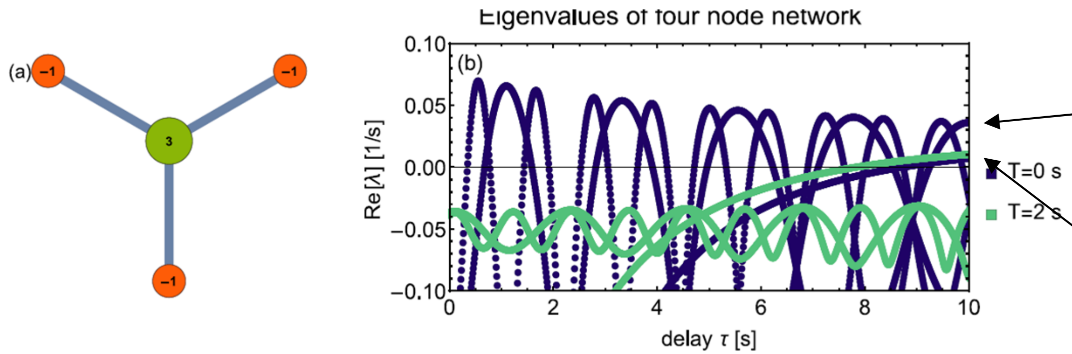
Nonlinear Dynamics & Economy

A power grid with distributed control

Equations of motion: $\dot{\delta}_i = \omega_i$

(including a delay) $I\dot{\omega}_i - D\omega_i = P_i(t) + \sum_j K_{ij} \sin(\delta_i - \delta_j)$

$P_i(t) = \bar{P}_i - \gamma\omega_i(t-\tau)$



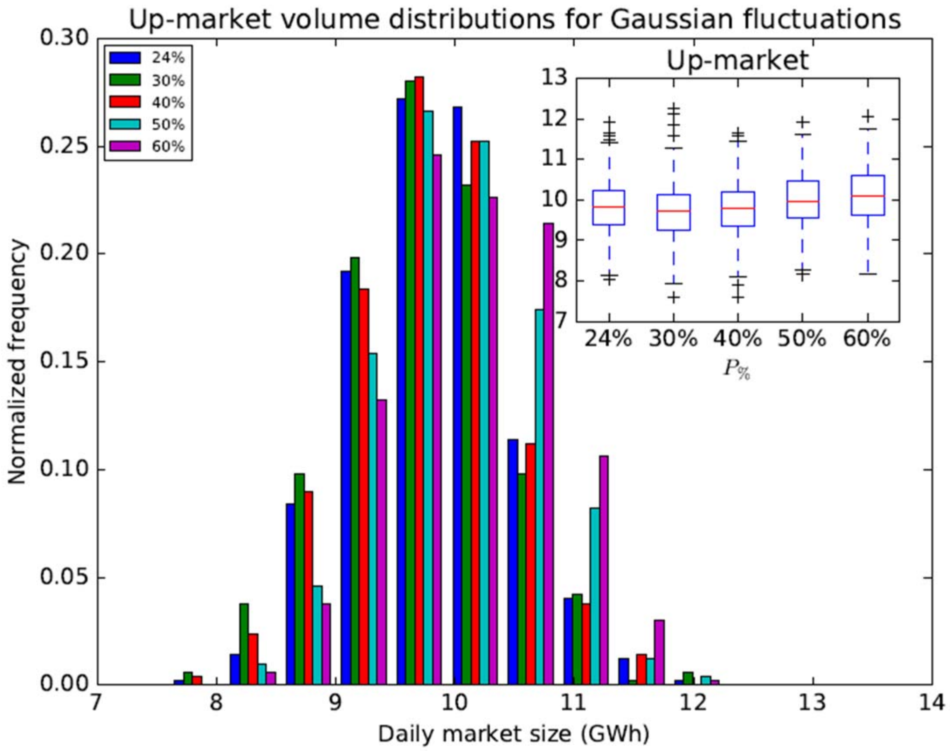
Resonant excitations

“Pork Cycle”
≙ Cobweb model

B. Schäfer et al, New J. Phys. 17, 015002 (2015), Eur. Phys. J. ST 225, 569 (2016).

Statistical Physics & Economy

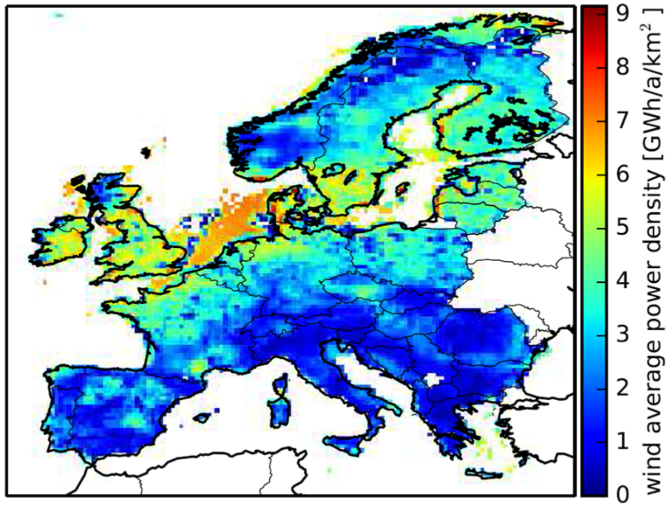
A physicist's view on extreme prices in energy markets:

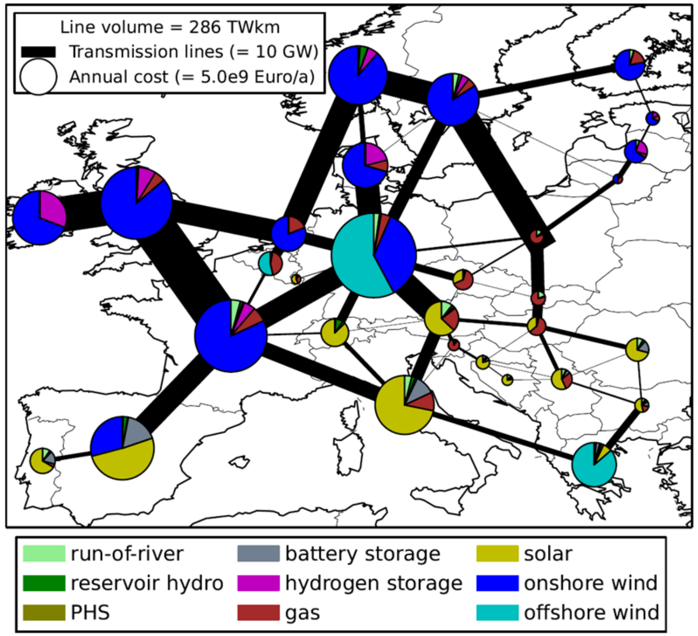


Energy and Climate

Renewable energy systems depend on wind and solar resources.

➢ Optimum system design determined by local climate:





D. Schlachtberger, T. Brown, S. Schramm, M. Greiner, Energy (in print)

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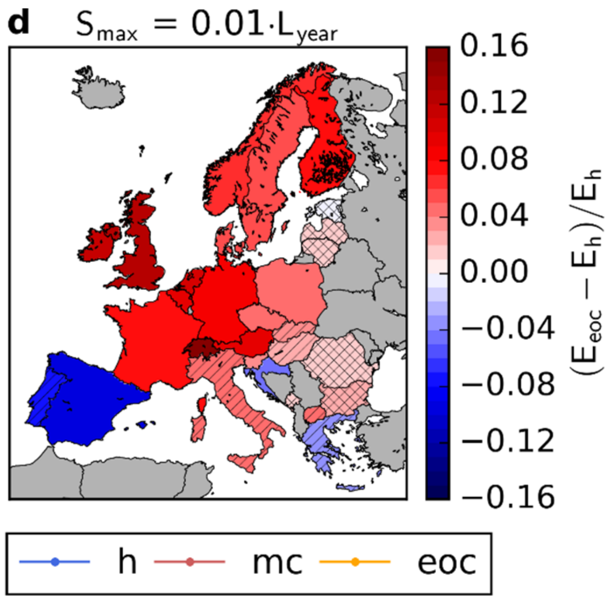
Energy and Climate

Renewable energy systems depend on wind and solar resources.

➢ Systems Operation gets vulnerable to climate change:



Mitglied der Helmholtz-Gemeinschaft

Ju. Weber et al, under review, J. Wohland et al, preprint at DOI:10.5194/esd-2017-48

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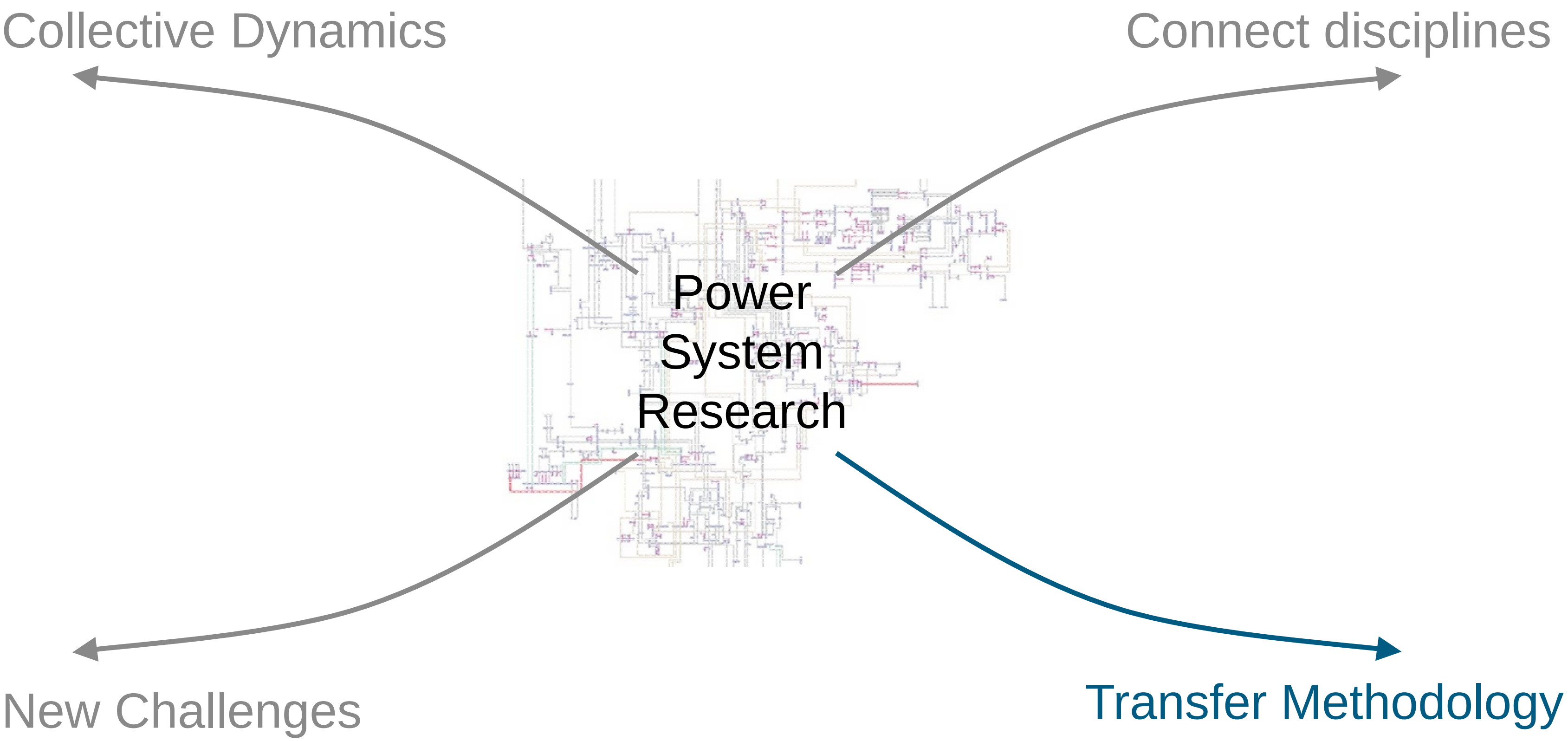

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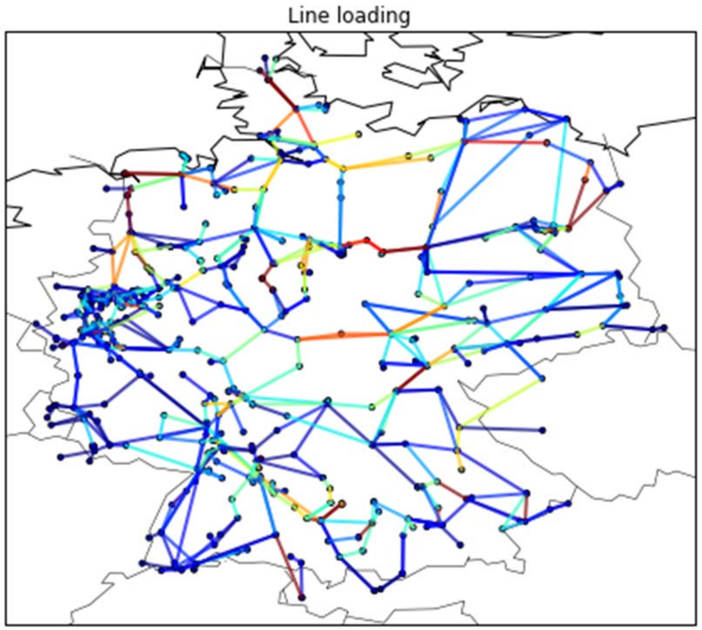
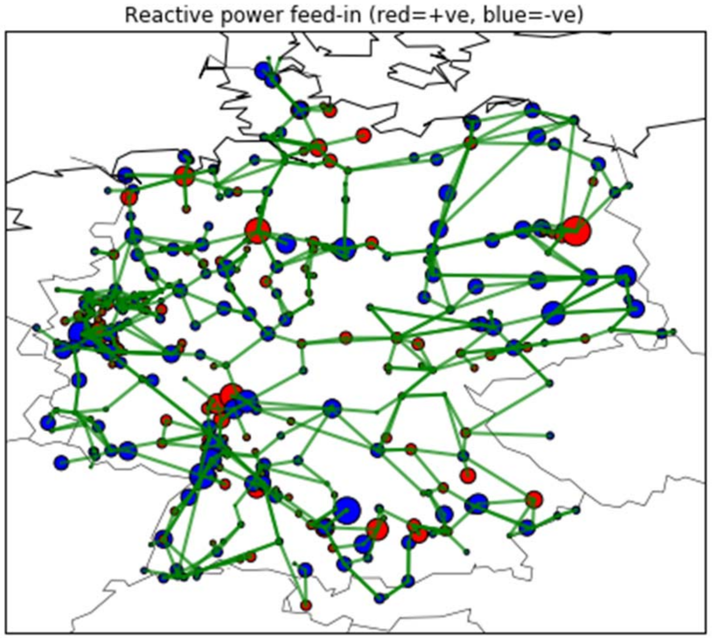
Software

PyPSA: Open-Source Power System Analysis in Python

Technical Modelling:





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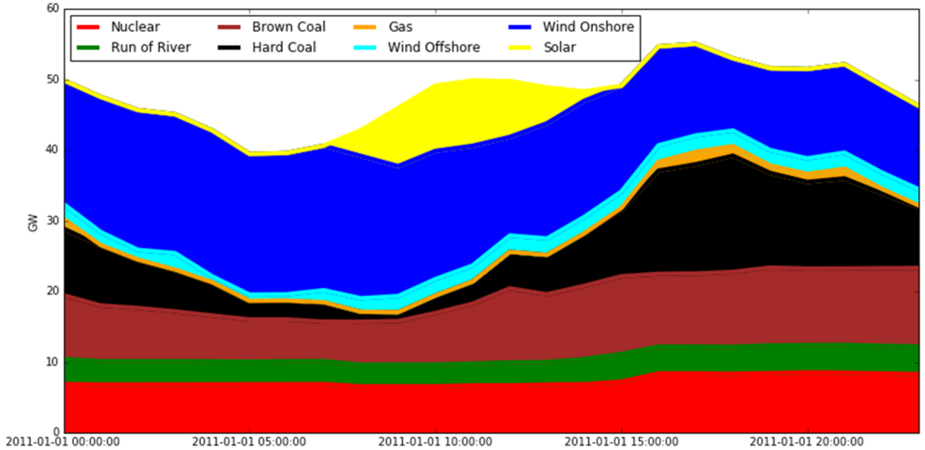
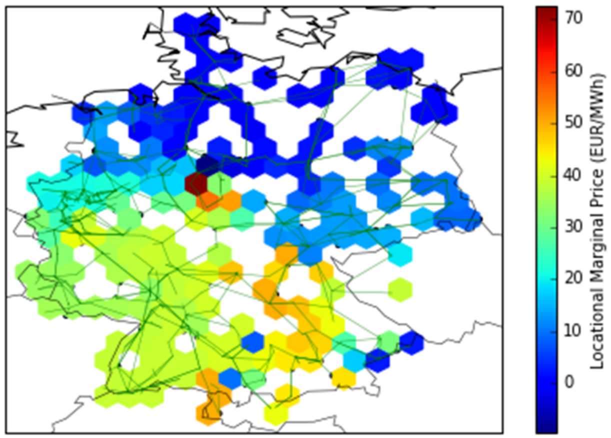
Software

PyPSA: Open-Source Power System Analysis in Python

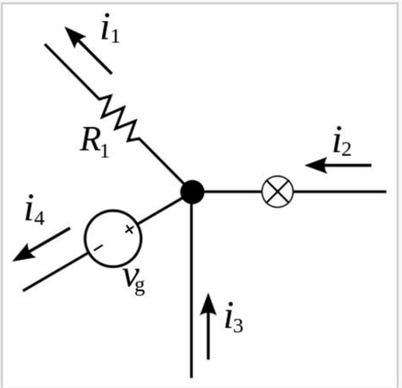
Techno-economic Simulation:



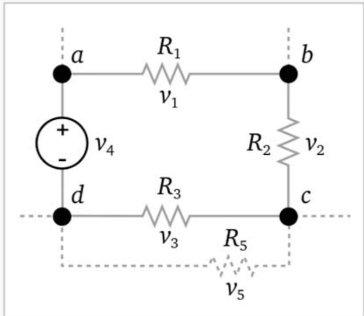


Algorithms I

Back to the roots: Kirchhoff's laws



The current entering any junction is equal to the current leaving that junction. $i_2 + i_3 = i_1 + i_4$



The sum of all the voltages around a loop is equal to zero. $v_1 + v_2 + v_3 - v_4 = 0$

Node-based formulations are often simpler.

Cycle-based formulations can be faster.

➢ Algebraic Graph Theory

Pictures: https://en.wikipedia.org/wiki/Kirchhoff's_circuit_laws

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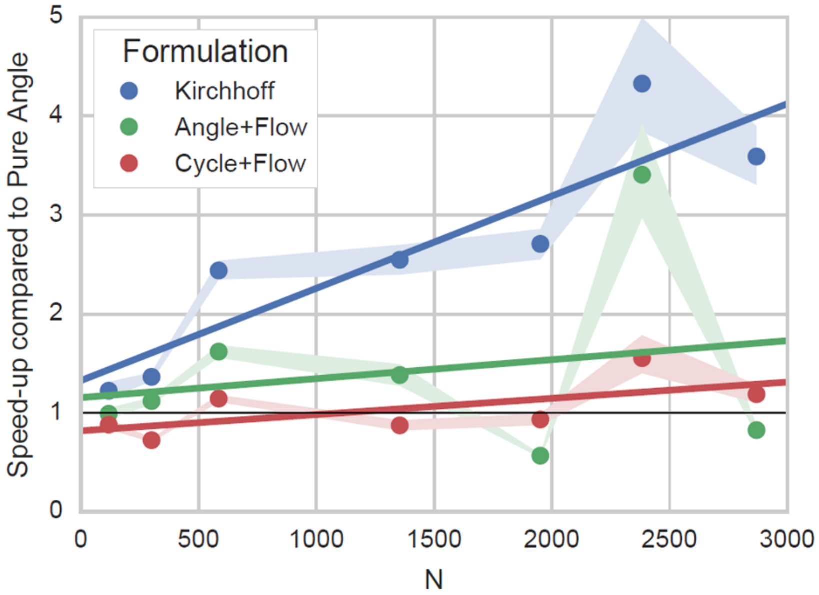
Algorithms I: Operation & Optimization

The DC optimal power flow problem (multi-period with storage)

- Optimize dispatch D_g of generators such that costs are minimal
- Real power flows below thermal limits: $|F_\ell| \leq F_\ell^{\max}$

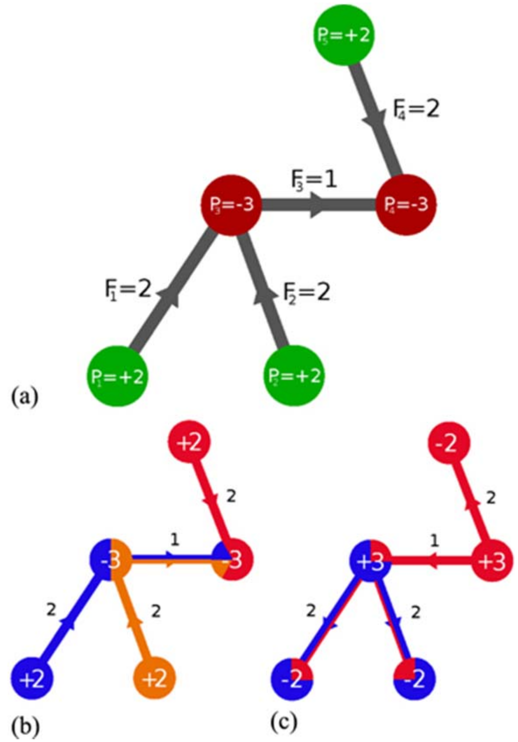


J. Hörsch, H. Ronellenfitsch, D. Witthaut, T. Brown, arXiv:1704.01881
H. Ronellenfitsch, M. Timme, and D. Witthaut, IEEE Trans. Power Syst. 32, 1007 (2017)

Algorithms II: Flow Tracing

Grid extensions are efficient for power balancing. But who pays?

- ➢ Attribute grid utilization to the users!
- ➢ Flow tracing algorithms

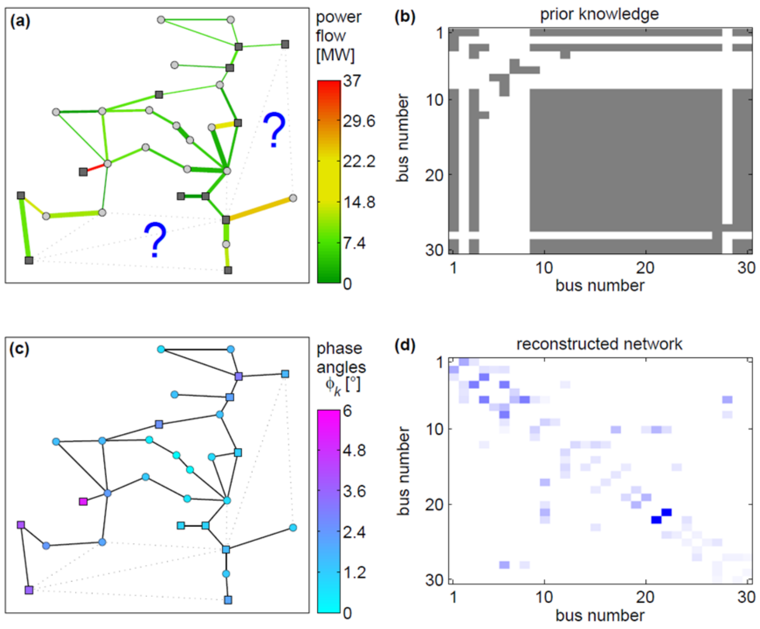


B. Tranberg et al, New Journal of Physics, 17(10):105002 (2015).

Algorithms III: Grid Monitoring

New challenges: Grid monitoring with few measurements and uncertain grid topology.

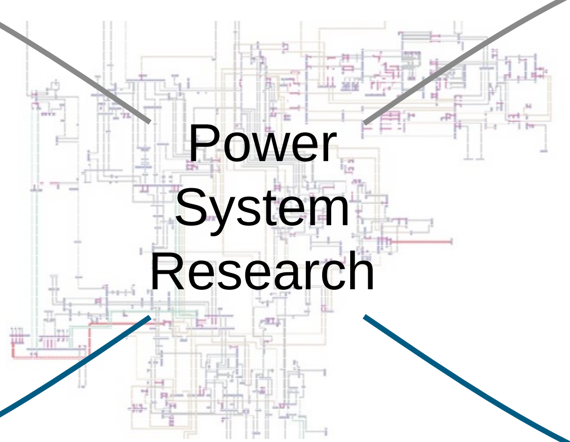
Algorithms based on network reconstruction & compressed sensing



Scope of the project

Collective Dynamics

Connect disciplines



Power System Research

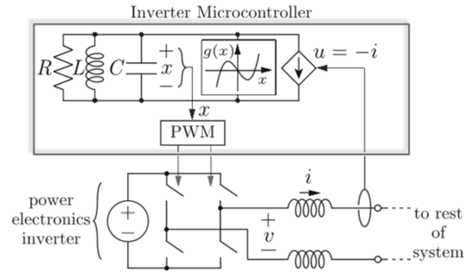
New Challenges
… for the project group

Transfer Methodology

New Challenges

- Ensuring stability in future renewable grids

  Control theory



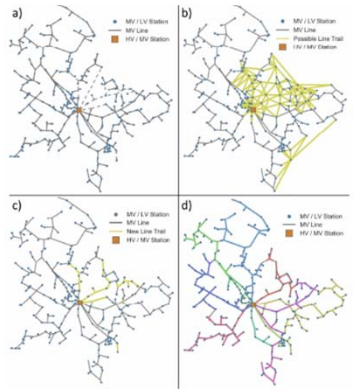
F. Dörfler, J. Raisch

- Power Balancing on intermediate/long scales

  Markets, Distribution Grids, Autonomous systems

- Systems design

  Optimization, Uncertainties, Software



M. Braun