Herbert Mangesius* & Matthias Huber**

POWER SYSTEMS RESEARCH - WHY WE SHOULD COOPERATE

Institute for Information-Oriented Control* & Energy Economy and Application Technology**

Motivation

(Innovative) electric power systems
= critical infrastructure that supports population

Hypothesis:

1. The dynamic behavior is far from fully understood !

2. Reliable operation of future power systems requires large efforts & interdisciplinary cooperation in research – today!

Business as usual …

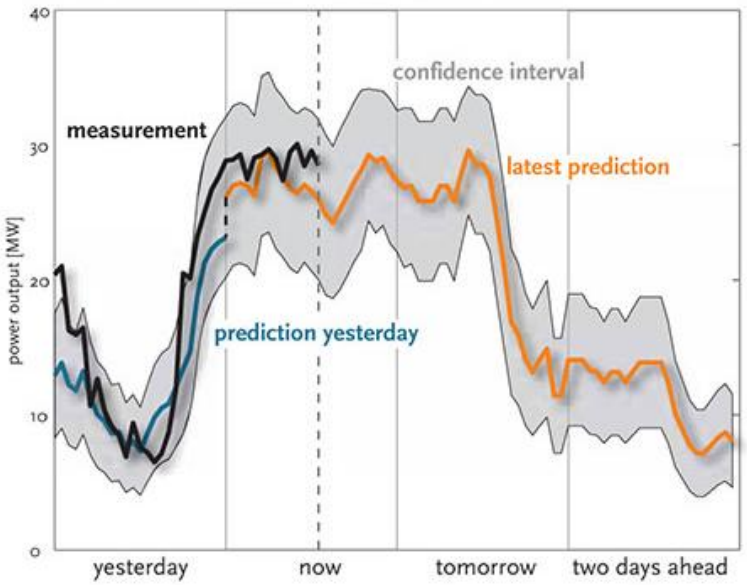
… can lead to large blackouts …

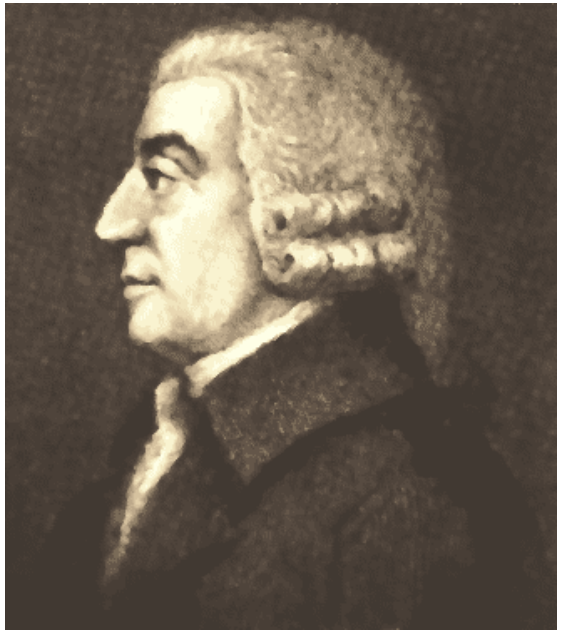
Die Meyer Werft

Stromausfall in Europa

… and reminds us of our limited understanding!

System not fully understood – but restructuring requires deep understanding





Consequences:

- Unpredictable and uncertain generation and load
- Higher amounts of dynamically transported energy
- Efficiency vs. reliability
- Investment dilemma (capacities)
- Big data & security in real time

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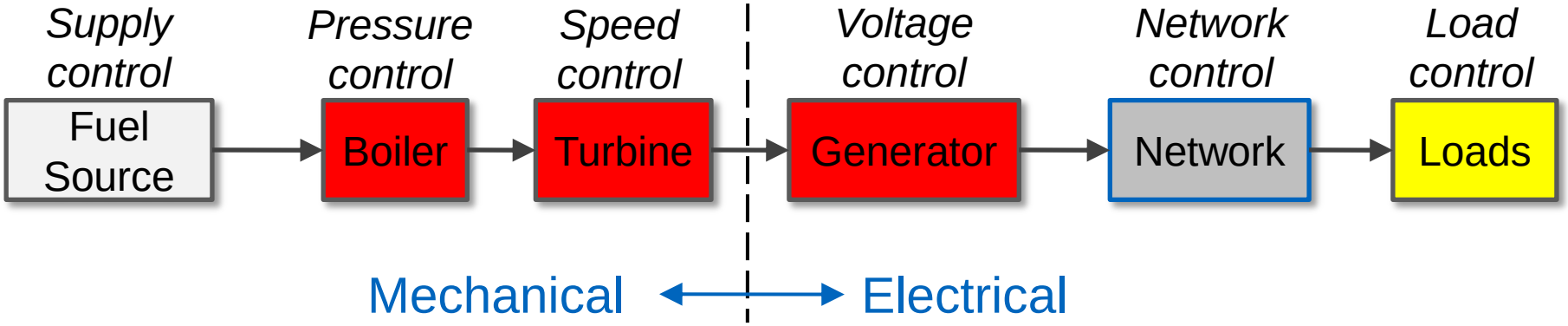
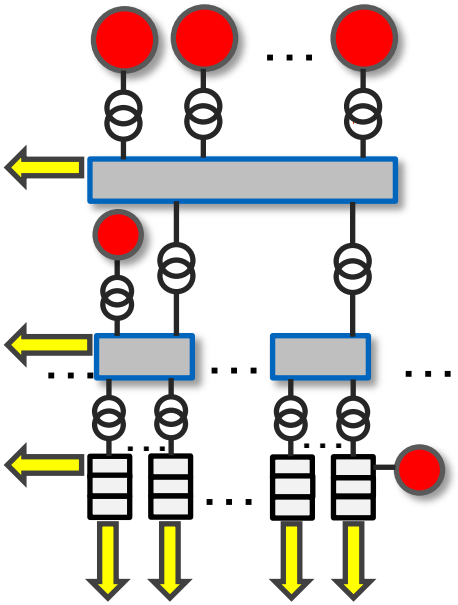
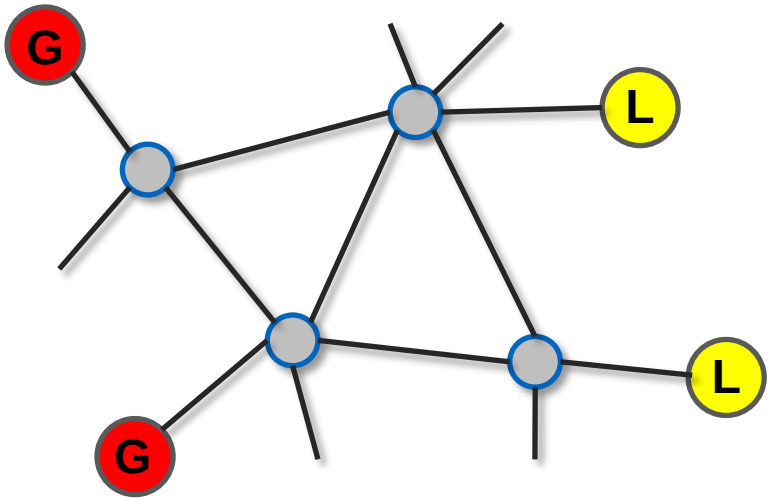
Physical and engineering structure …







… engineering and mathematical structure …

Power balance - Static

Capacity based ←
Transport over graph ←
Power flow & Kirchhoff ←
Economic dispatch ←

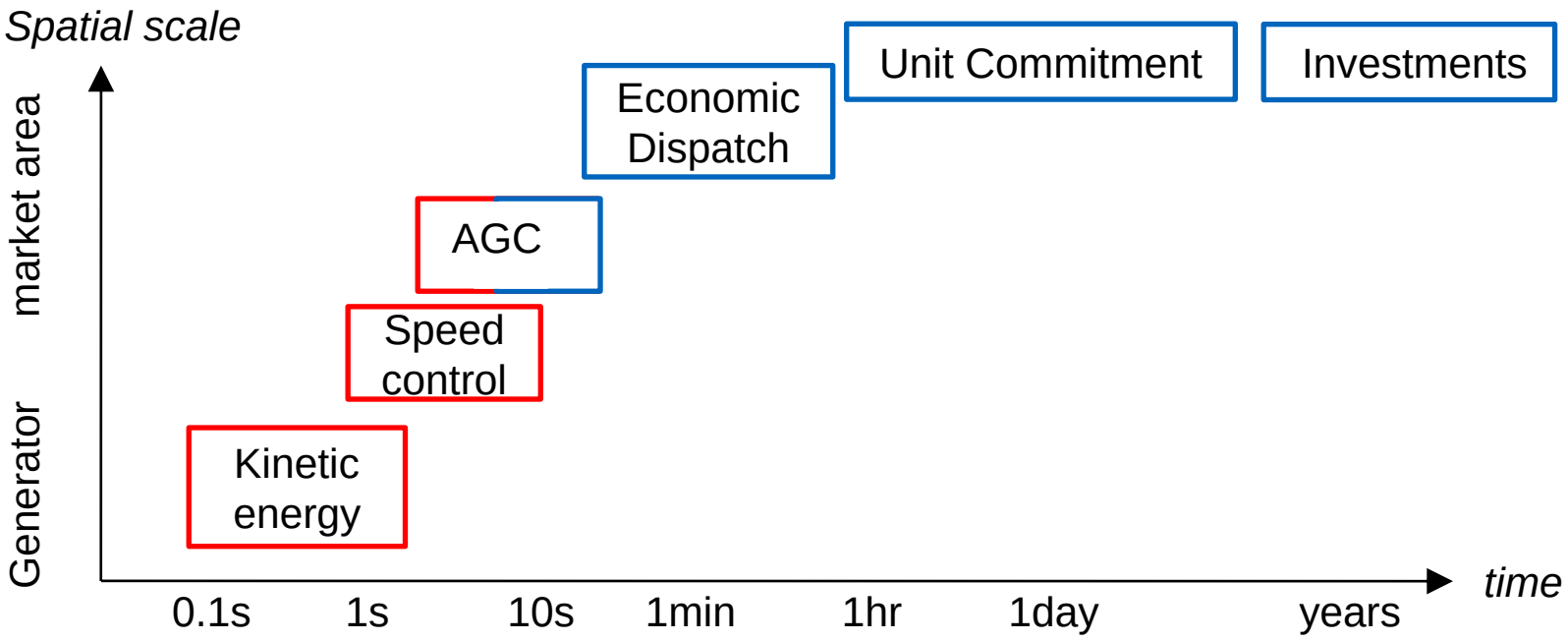
$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{y})$$

$$\mathbf{0} = \mathbf{g}(\mathbf{x}, \mathbf{y})$$

Dynamics – local devices

→ Mechanical machines
→ Control equipment
→ Supply & load
→ Stability & performance

Application dependent **separation** of models → **methodological gap !**



Methodological gap VS smart grid vision

What can we do ?

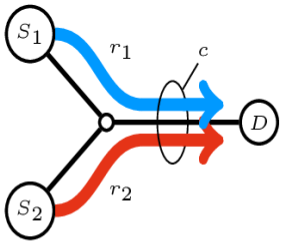
A phd workshop as starting point for cooperation

- 20 PhDs
- 10 different institutes
- EI + IN
- 3 days
- Guests: Industry/Policy

- Knowledge exchange
- Unbiased thinking
- Report: Status quo @ TUM
- Research Gaps

Cooperation in Methods and Applications possible

Ex 1: Method transfer from communication to power



Network Utility Maximization

primal problem:

$$\underset{r_1, r_2}{\text{maximize}} \quad U_1(r_1) + U_2(r_2)$$

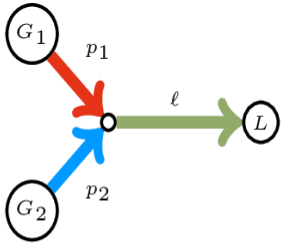
$$\text{subject to} \quad r_1 + r_2 = c$$

dual problem:

$$\underset{\lambda}{\text{minimize}} \quad \lambda c - U_1^*(\lambda) - U_2^*(\lambda)$$

S_1, S_2	sources
D	destination
$U_i(r_i)$	utility function
r_i	rate emitted by S_i
c	link capacity

interpretation: dual variable λ is the price sources are charged for using the link



Optimal Power Flow

primal problem:

$$\underset{p_1, p_2}{\text{minimize}} \quad C_1(p_1) + C_2(p_2)$$

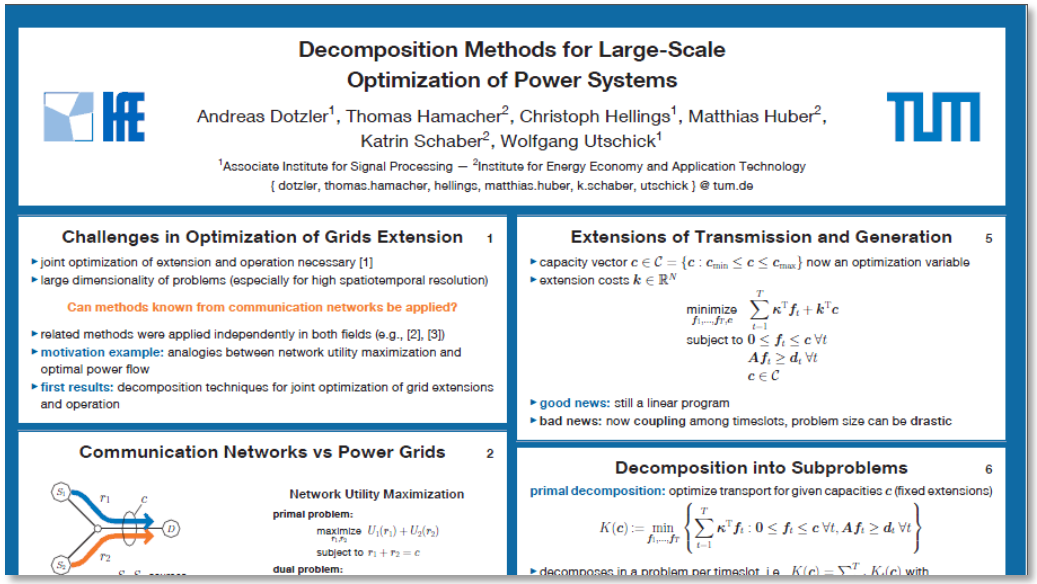
$$\text{subject to} \quad p_1 + p_2 = \ell$$

dual problem:

$$\underset{\mu}{\text{maximize}} \quad \mu\ell - C_1^*(\mu) - C_2^*(\mu)$$

G_1, G_2	generators
L	load
$C_i(p_i)$	cost function
p_i	power output of G_i
ℓ	total system load

interpretation: dual variable μ is the price paid to generators for inducing power



Decomposition Methods for Large-Scale Optimization of Power Systems

Andreas Dotzler[1], Thomas Hamacher[2], Christoph Hellings[1], Matthias Huber[2], Katrin Schaber[2], Wolfgang Utschick[1]

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Challenges in Optimization of Grids Extension 1

- joint optimization of extension and operation necessary [1]
- large dimensionality of problems (especially for high spatiotemporal resolution)

Can methods known from communication networks be applied?

- related methods were applied independently in both fields (e.g., [2], [3])
- **motivation example:** analogies between network utility maximization and optimal power flow
- **first results:** decomposition techniques for joint optimization of grid extensions and operation

Communication Networks vs Power Grids 2

Network Utility Maximization

primal problem:

$$\underset{r_1, r_2}{\text{maximize}} \; U_1(r_1) + U_2(r_2)$$

subject to $r_1 + r_2 = c$

dual problem:

Extensions of Transmission and Generation 5

- capacity vector $\boldsymbol{c} \in \mathcal{C} = \{\boldsymbol{c} : \boldsymbol{c}_{\min} \leq \boldsymbol{c} \leq \boldsymbol{c}_{\max}\}$ now an optimization variable
- extension costs $\boldsymbol{k} \in \mathbb{R}^N$

$$\begin{aligned} \underset{\boldsymbol{f}_1, \ldots, \boldsymbol{f}_T, \boldsymbol{c}}{\text{minimize}} \quad & \sum_{t=1}^{T} \boldsymbol{\kappa}^\mathrm{T} \boldsymbol{f}_t + \boldsymbol{k}^\mathrm{T} \boldsymbol{c} \\ \text{subject to} \quad & \boldsymbol{0} \leq \boldsymbol{f}_t \leq \boldsymbol{c} \; \forall t \\ & \boldsymbol{A}\boldsymbol{f}_t \geq \boldsymbol{d}_t \; \forall t \\ & \boldsymbol{c} \in \mathcal{C} \end{aligned}$$

- **good news:** still a linear program
- **bad news:** now **coupling** among timeslots, problem size can be drastic

Decomposition into Subproblems 6

primal decomposition: optimize transport for given capacities $\boldsymbol{c}$ (fixed extensions)

$$K(\boldsymbol{c}) := \min_{\boldsymbol{f}_1, \ldots, \boldsymbol{f}_T} \left\{ \sum_{t=1}^{T} \boldsymbol{\kappa}^\mathrm{T} \boldsymbol{f}_t : \boldsymbol{0} \leq \boldsymbol{f}_t \leq \boldsymbol{c} \; \forall t, \boldsymbol{A}\boldsymbol{f}_t \geq \boldsymbol{d}_t \; \forall t \right\}$$

- decomposes in a problem per timeslot, i.e., $K(\boldsymbol{c}) = \sum^T K_t(\boldsymbol{c})$ with

Ex 2: Content transfer by coupling models

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Capacity based ←

Transport over graph ←

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Dynamics – local devices

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A Framework to Quantify Technical Flexibility in Power Systems Based on Reliability Certificates

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***Abstract*—Power systems are increasingly stressed by variable and unpredictable generation from various sources. We identify the qualitative framework of flexibility as an adequate tool to specify requirements that allow the system to handle this**

[5], the insufficient ramping resources probability is proposed on the basis of generation adequacy metrics supporting long term planning of power systems. In [6], a metric is presented to

Take away messages and thoughts

1. Cooperation is inevitable, but do it right!
   - → Locate methodological & application knowledge !
   - → Plan the interfaces & acquire knowledge! (huge initial effort)
   - → Bottom-up initiatives (PhDs) & top-down control (professors)

2. Nothing comes for free !
   - → Initial „Seed“-Funding necessary + Trust !
   - → Long-term thinking and investment: SFB?
   - → Set binding goals, next steps and commit to them !

3. Bundled knowledge‘s greater value asks for responsibility
   - → Responsibility of TUM in view of political decisions