Ensuring Power Grid Stability Despite Renewable Instability

Holger Hermanns

Dependable Systems and Software
Saarland University, Saarbrücken, Germany

joint work with Pascal Berrang and Arnd Hartmanns
with contributions by Ivan Pryvalov and Lars Reiter

and inspirations from Holger Wiechmann, EnBW
Martin Ney, Luxea, and Mats Larsson, ABB

Challenge

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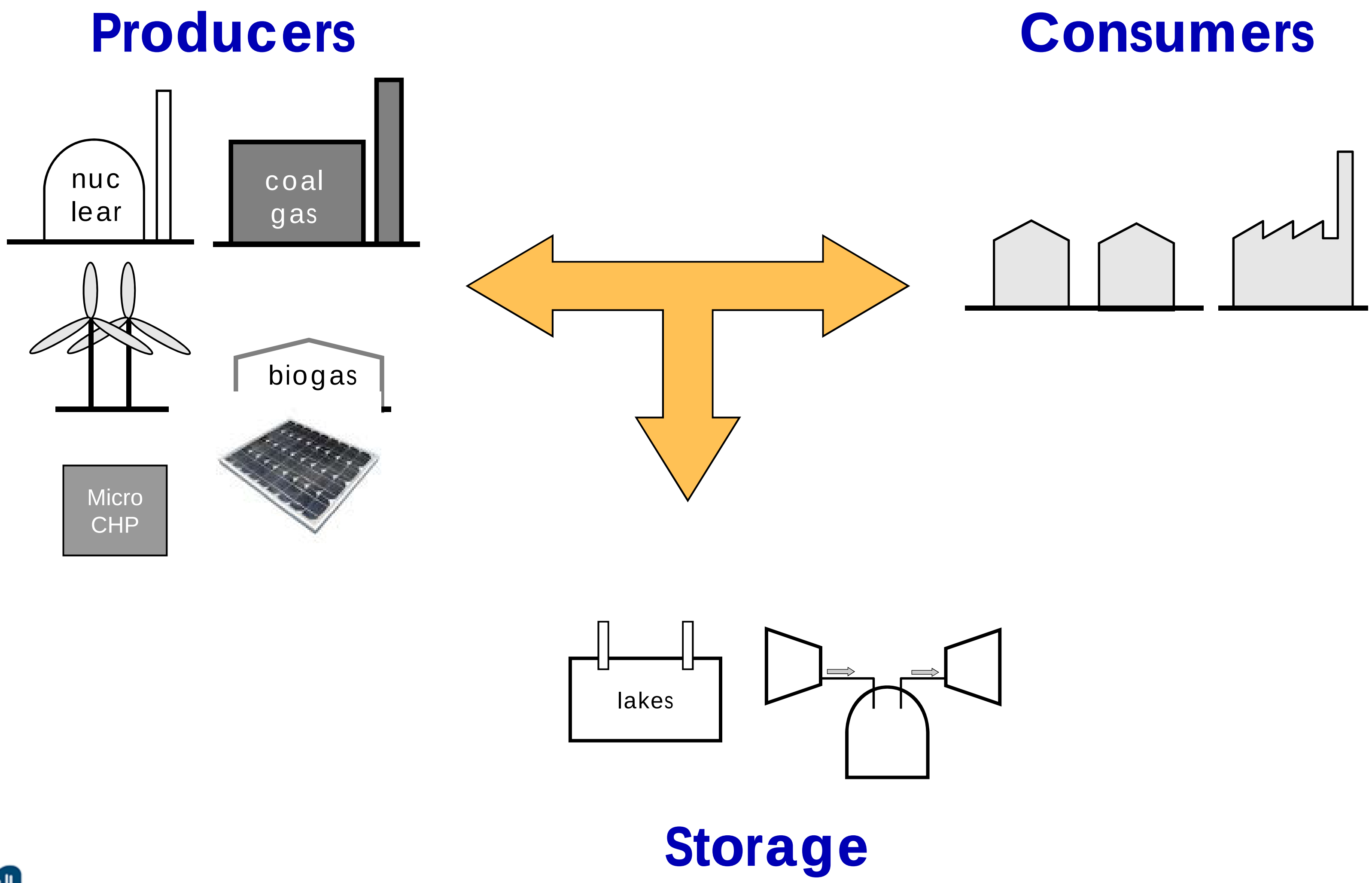
Electric Power Distribution Grids



Principal Electricity Market Considerations

electric power demand never exceeds the potential offer

Production follows → Consumption

- producers are fully controllable
- barely any regulation on the consumer side

Opposite principles

- producers are hardly controllable
- simple mechanisms to control the consumer side

Consumption follows → Production

electric power can only be consumed if it is available

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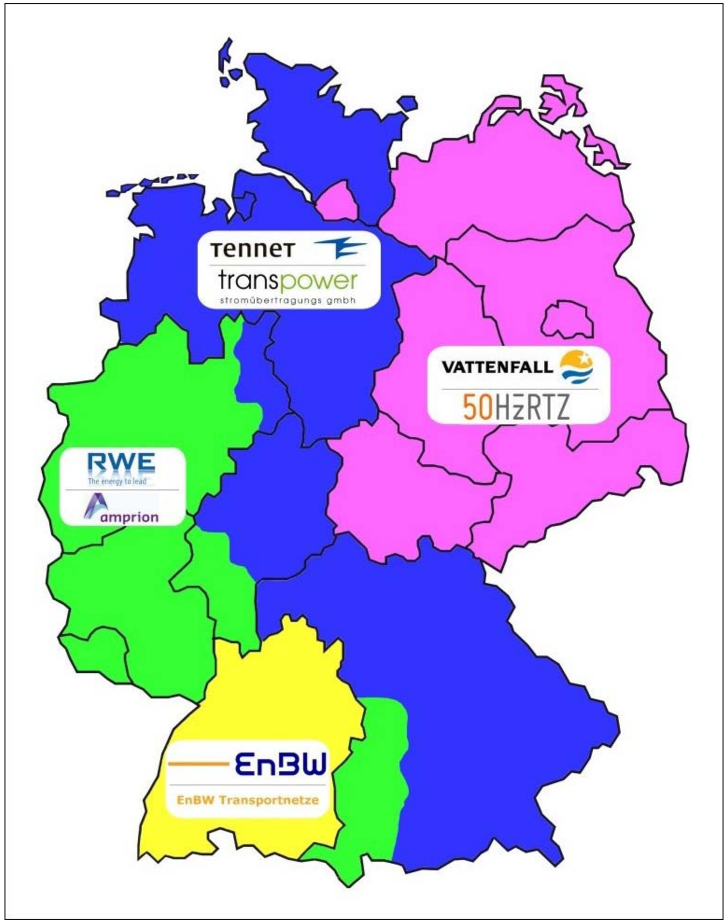
Electricfying Challenge

Germany

- gives priority to
  renewable sources

- rewards renewable energy
  above market price

- dropped nuclear energy
  after Fukushima incident



source: http://www.wikipedia.org

More challenges:

Sweden, UK, France, ...

Electrictifying Basics

- Guiding principle: **Production follows Consumption**

- Base Assumptions:
  - Consumption is a well-understood stochastic process
  - Production is deterministic and fully controllable
  - Mass effects ensure smooth consumer behaviour
  - Grid state is observable (frequency, voltage)

- Thus, good predictions and a bit of fine tuning do the job.

Control energy, can be subtracted or added to the grid. Mostly pump storage.

- Indeed, this was the case for several decades.

Now: Things change rapidly. Minds change slowly.

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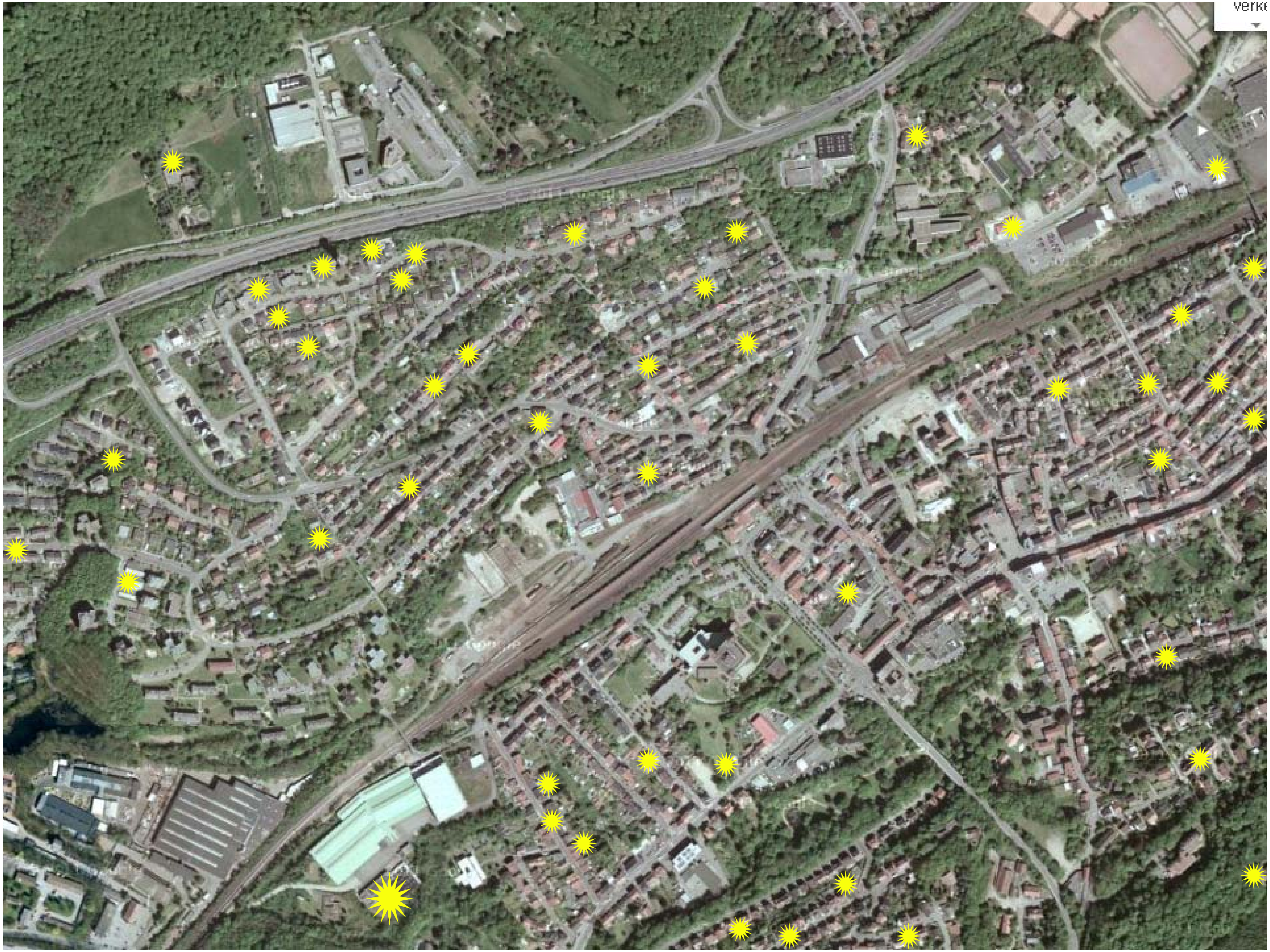
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So, what‘s the challenge?

The integration of renewable energy

Renewable energy has much higher volatility and this volatility is uncontrollable.

Production turns into a stochastic process, as well!

Needed: increased prediction efforts for grid stabilization.

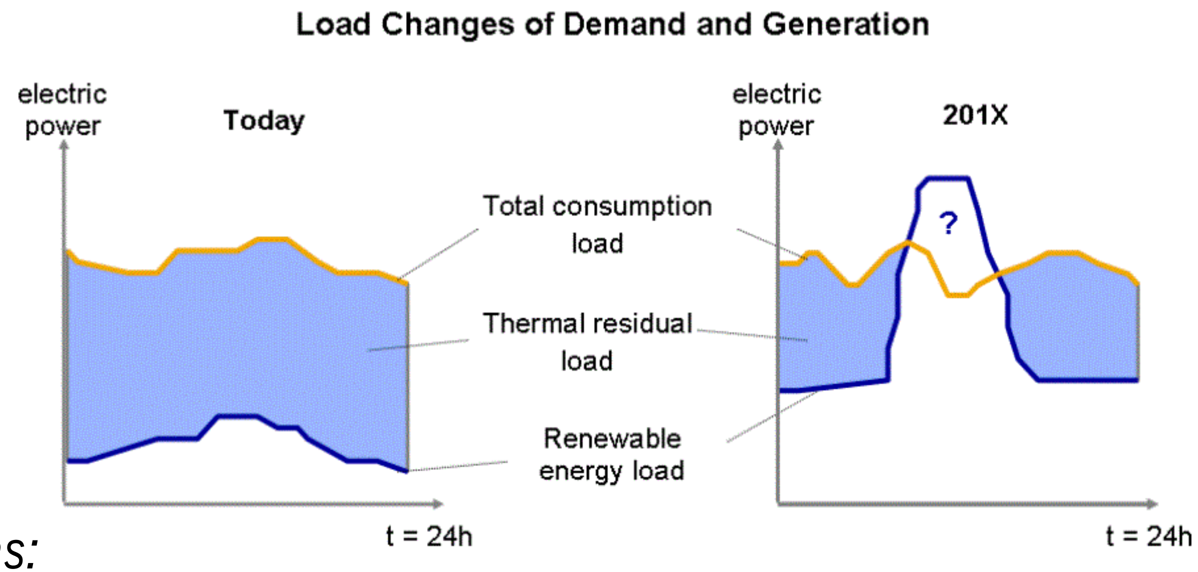
Volatility may exceed the available control energy.

On September 6, 2010:

- Drastically more solar power in the net than announced the day before
- Germany @ lunchtime: surplus of 7 GW
- Complete negative control energy exhausted (- 4.3 GW)
- Emergency reserve imported from neighbouring countries (- 2.8 MW)

Challenges for Economic Electricity Usage?

- Volatility effects the market price for short term electricity.
- Changes workload characteristics for traditional power plants.



Some Concerns:

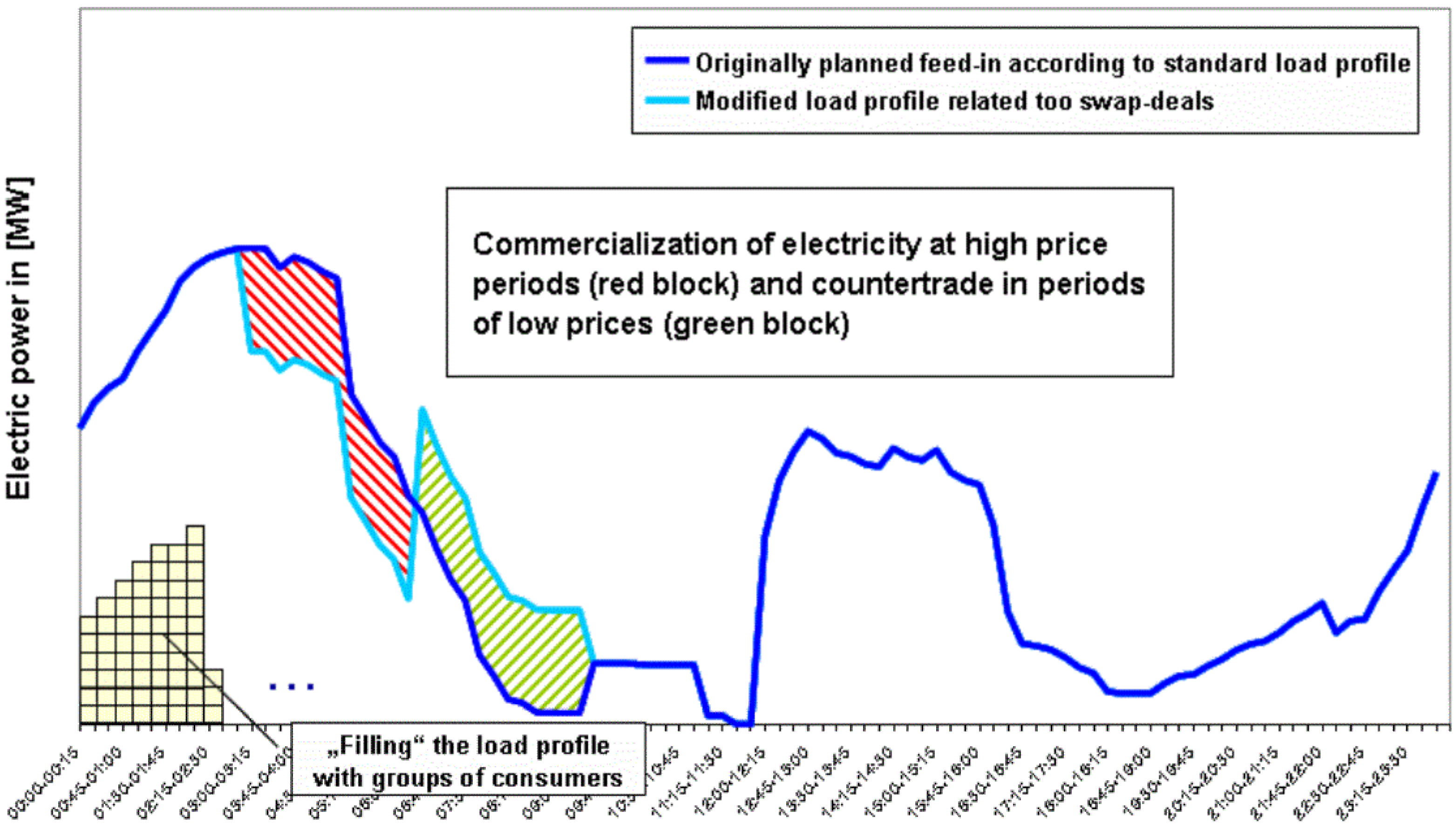
What happens once renewable energy production is higher than total consumption?

What production entities are needed, if all base consumption is covered by renewable energy?

[H, Wiechmann: EFTA 2009]

How to make money with this?

The Principle of electrical Swap-Deals (schematic account)



while keeping the network stable?

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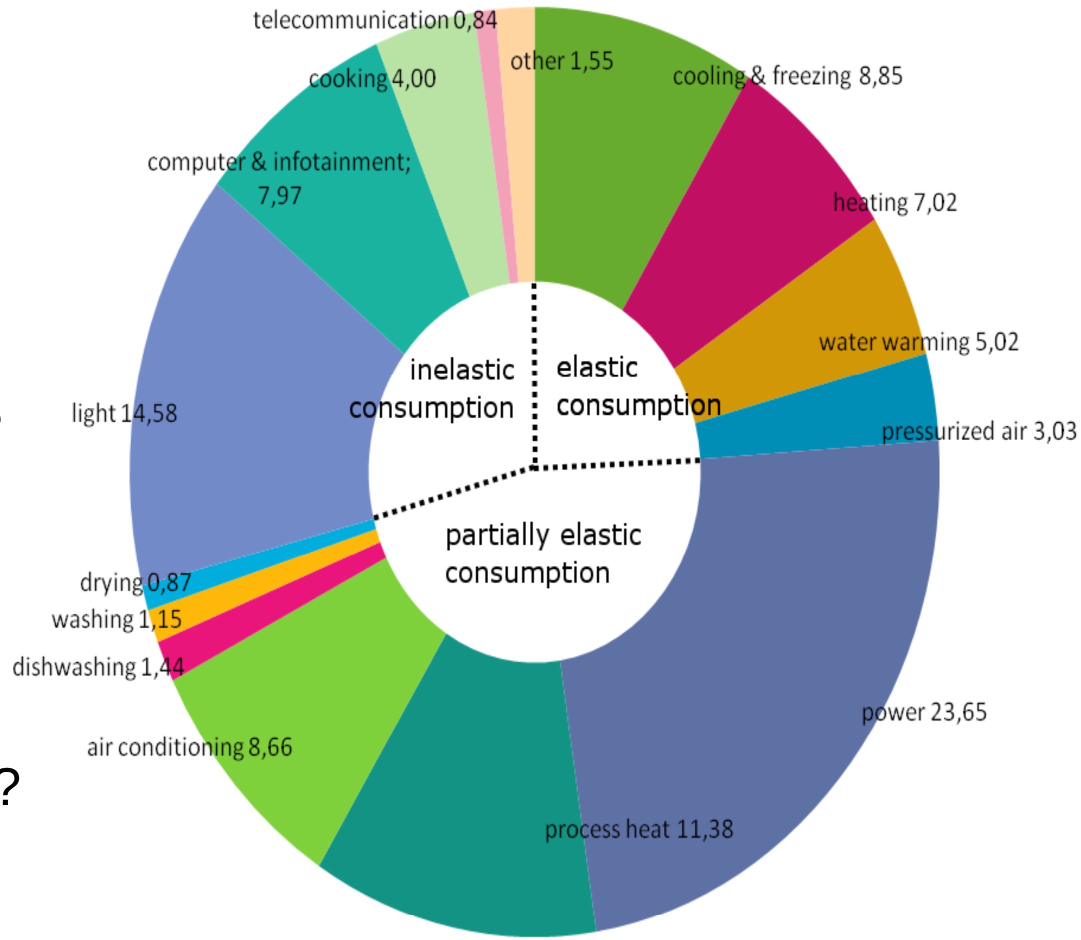
What to control on the consumer side?

- Light bulbs?
- Ironing?
- PC?
- TV?
- Electrical water warming?
- Climate control?
- Cooling?
- Air pressure applications?
- Off-peak storage heating?
- Geothermal heating?
- Electrical and hybrid electrical vehicles?



The segment of **elastic consumers** in Germany is in the order of a few tens of GW.

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Challenges for Stable Electricity Usage?

• Volatility and synchrony of solar power affects grid stability

EWE interventions 2009: <1 per week

2011: >1 per day

- 75% of all installations are non measured micro-generators

are balanced out once per year.

- Starting 2000, regulations are being adjusted at an increasing pace.

- Local distribution grid coordinators thus far reported averages

- without considering up-to-date weather conditions

seasonal differences, day-night differences

forbidden as of January 1, 2011

-Target growth 1.5 GW per year as of 2009 -- then10 GW

Actual growth in 2011 is 7.5 GW -- now 25 GW

A concrete problem:
Distributed Stabilisation

The problem:

Legal bodies ruled in 2007 that a solar power generator observing the frequency to overshoot 50,2 Hertz, must shut off.

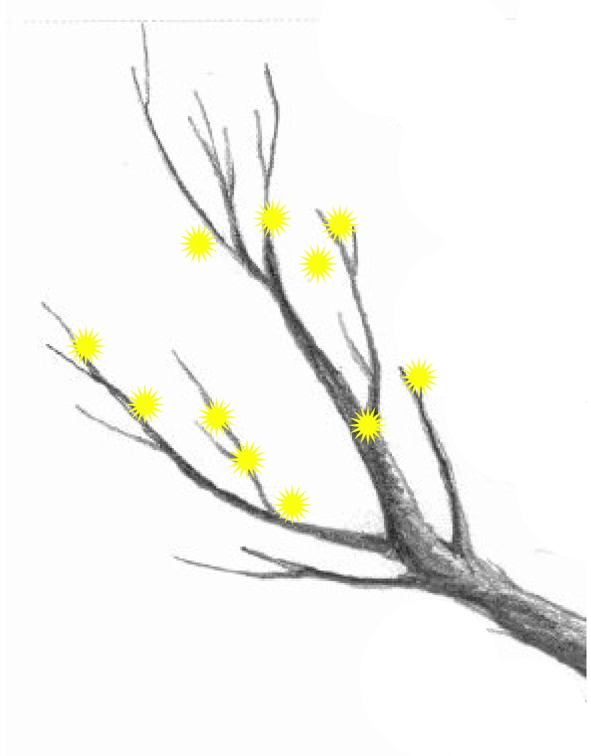
Because of the synchronicity of observations, this leads to oscillations, if not blackouts.

What we do:

We get inspired by network protocols.

Last mile distributed control

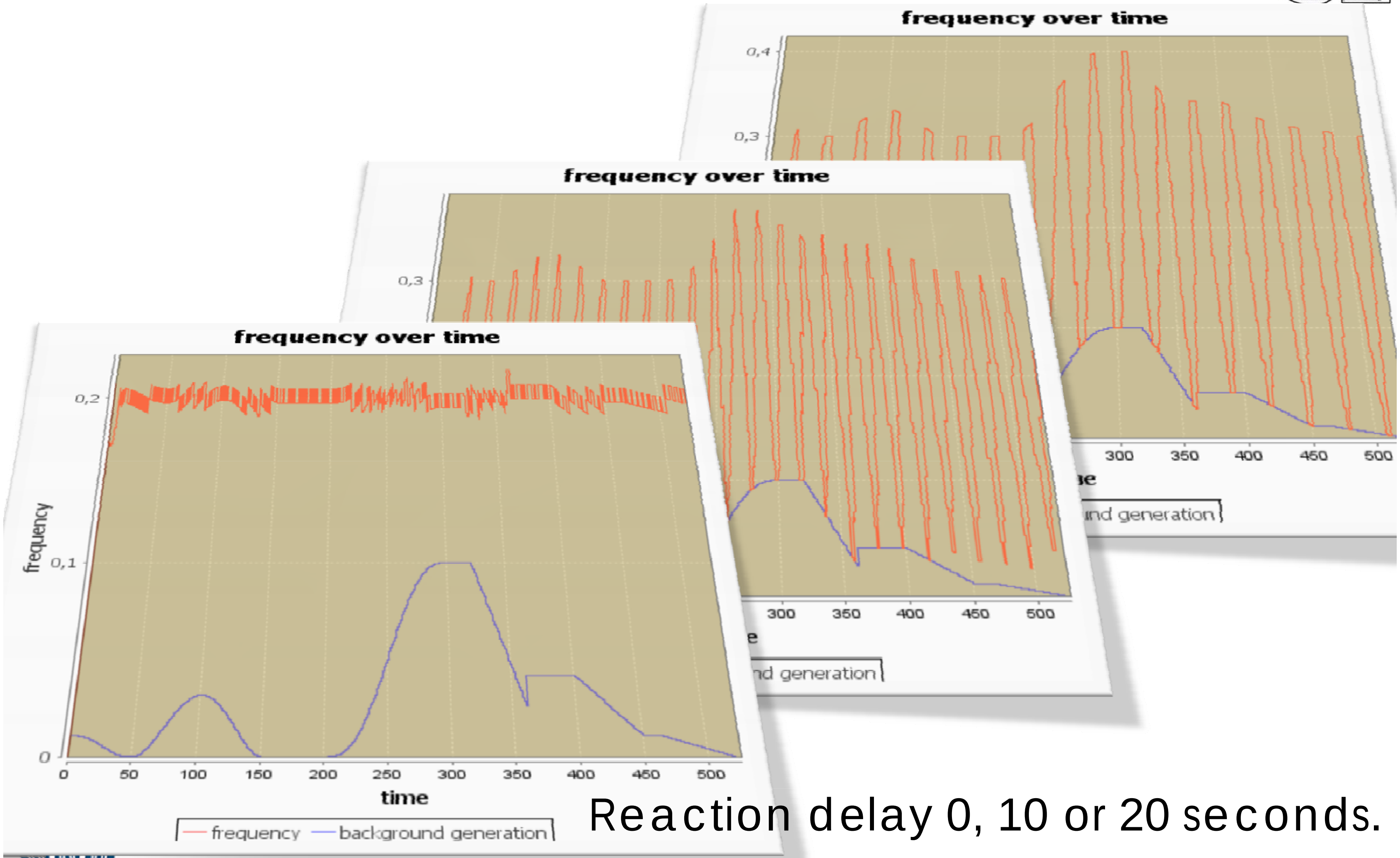
“Too many microgenerators
to roll out centralized control“



- Self stabilization problem
  but with a shared state:
  - Frequency
    and voltage
- Oscillations are a problem.
- Current state of legislation: off at 50.2 Hz
- Current state of engineering:
  Linear decrease between 50.1 and 52.2

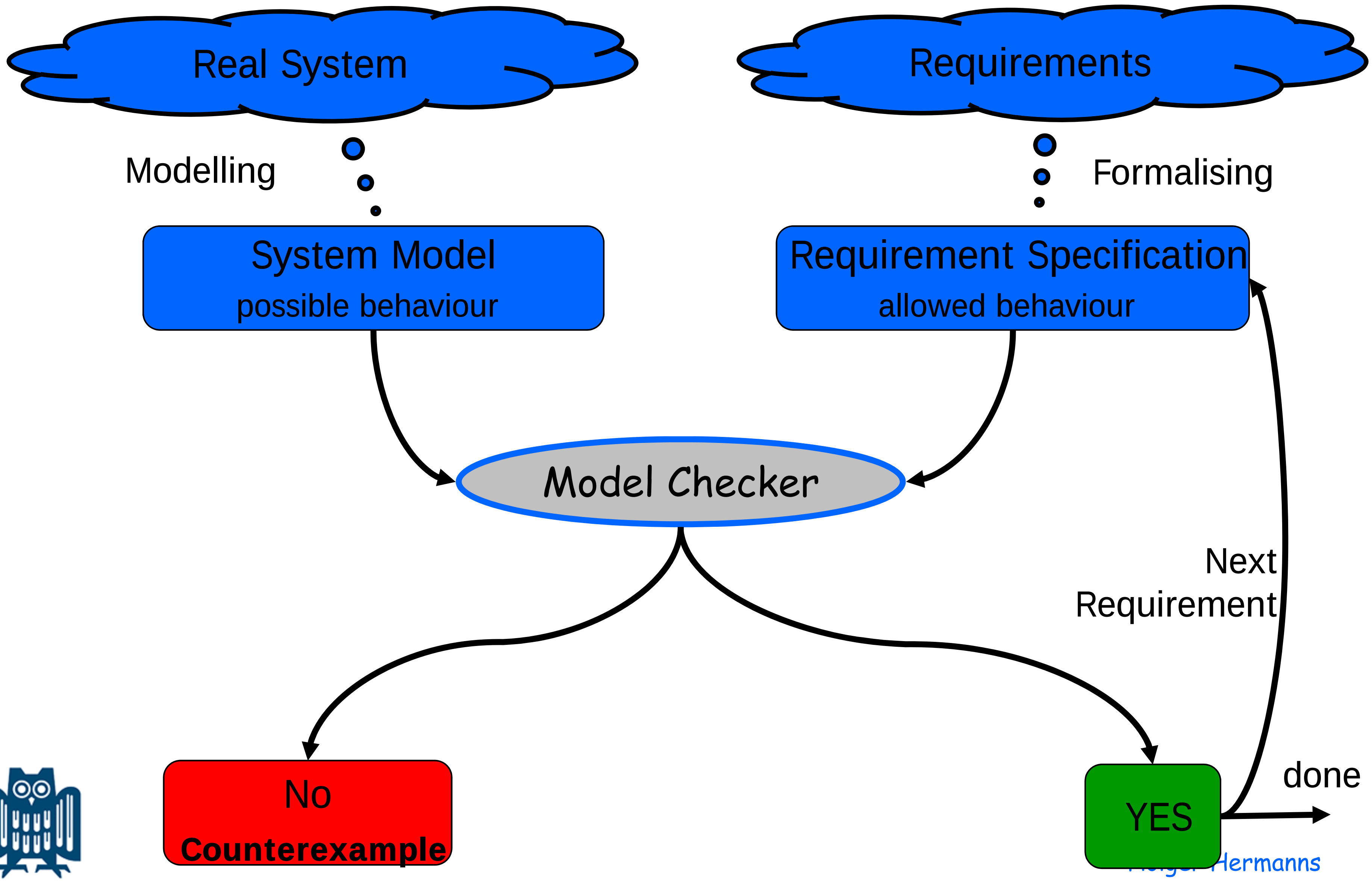
VDE proposal

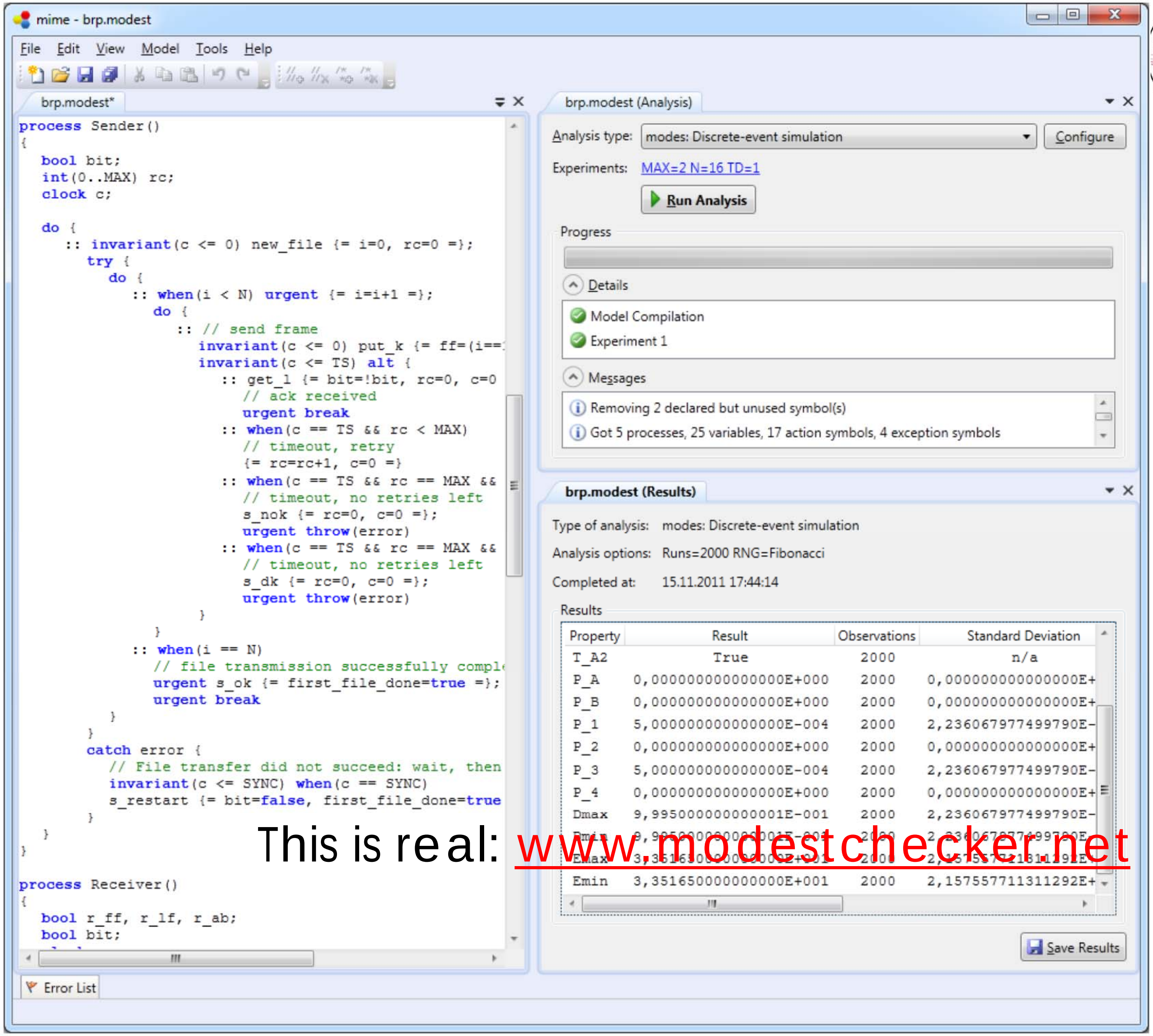
What the rules say



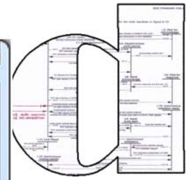
Reaction delay 0, 10 or 20 seconds.

Analysis: Model Checking





This is real: www.modestchecker.net



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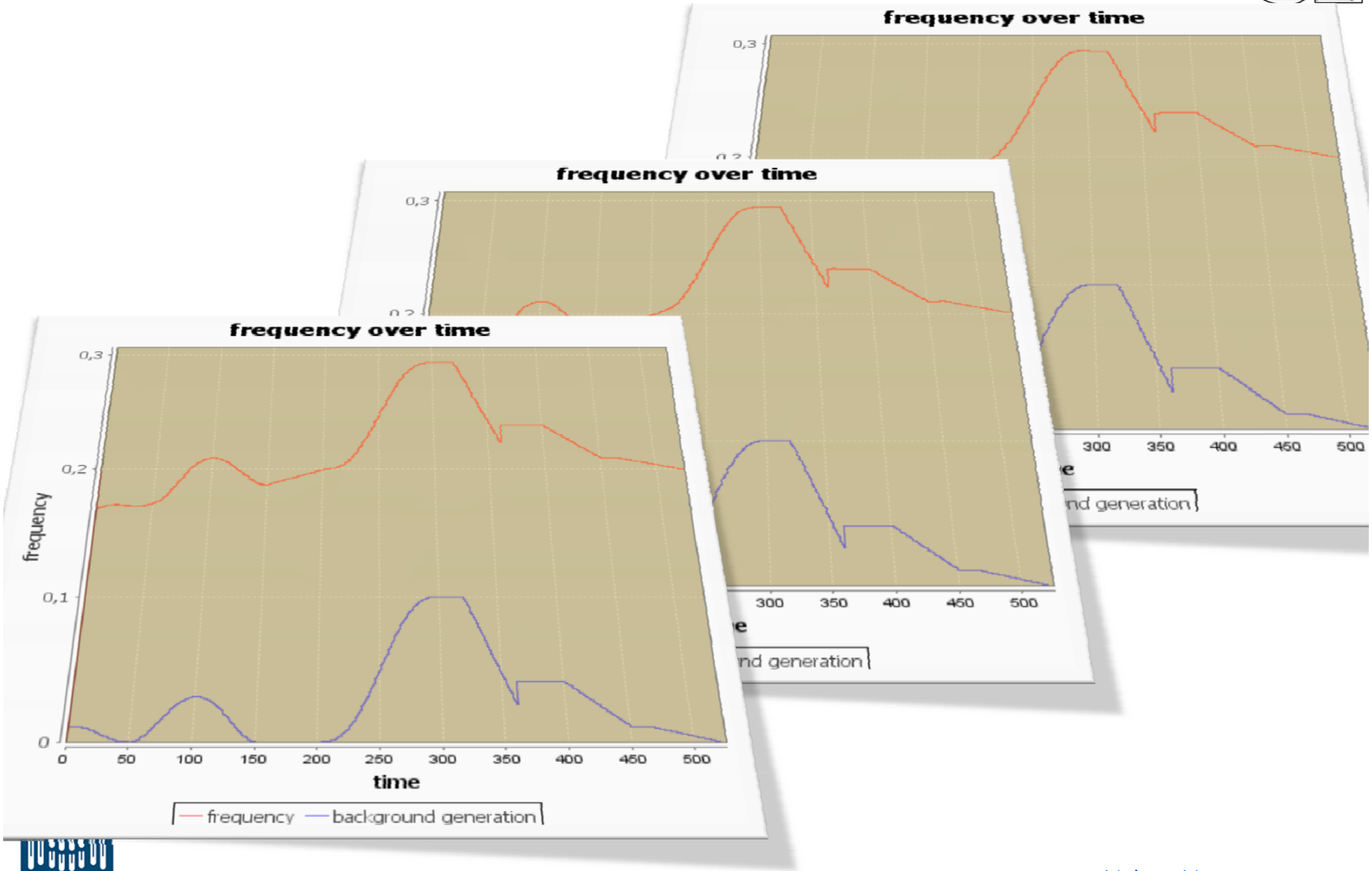
What the VDE suggests



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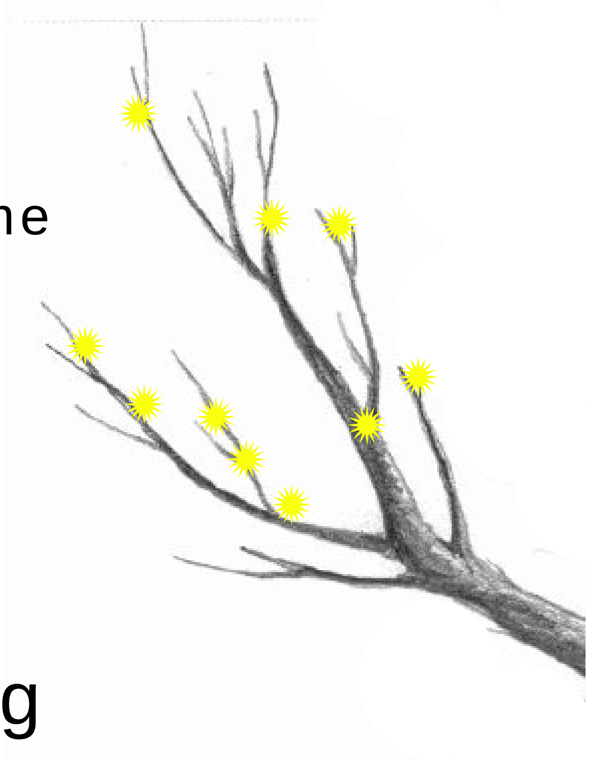
What we do

- Study populations of solar producers in a last mile
- Controllers
  - on-off
  - VDE
  - probabilistiic with dynamic size of die
  - with or without reaction time
  - with or without exponential backoff



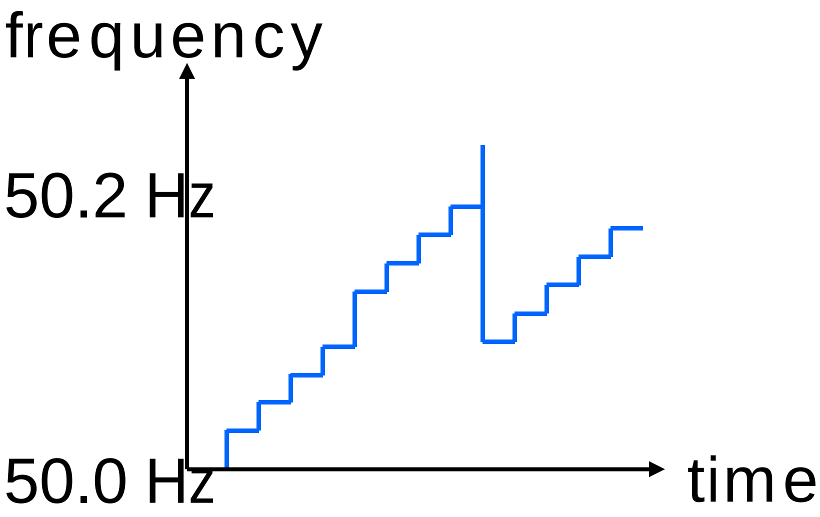
- Synchronous, asynchronous, drifting
- Stochastic background load scenarios
  - Constant   Profiles   Random walk
  - Markov modulated Bernoulli processs

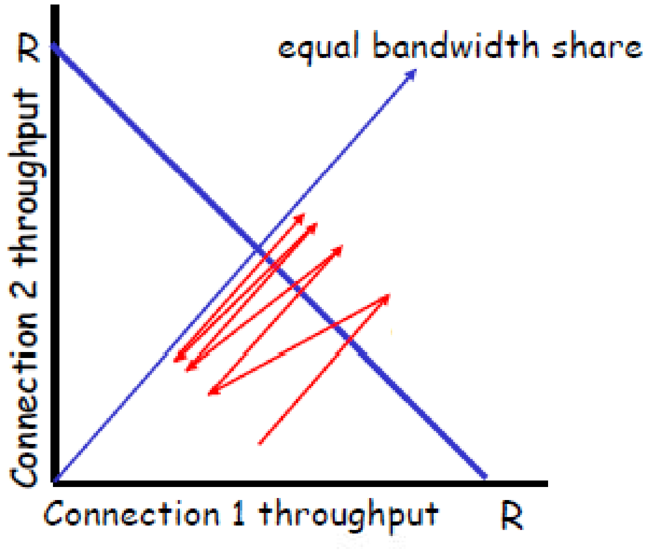
Additive-increase, multiplicative decrease

Used in:TCP

Goal: Use maximal bandwidth, but share it fairly

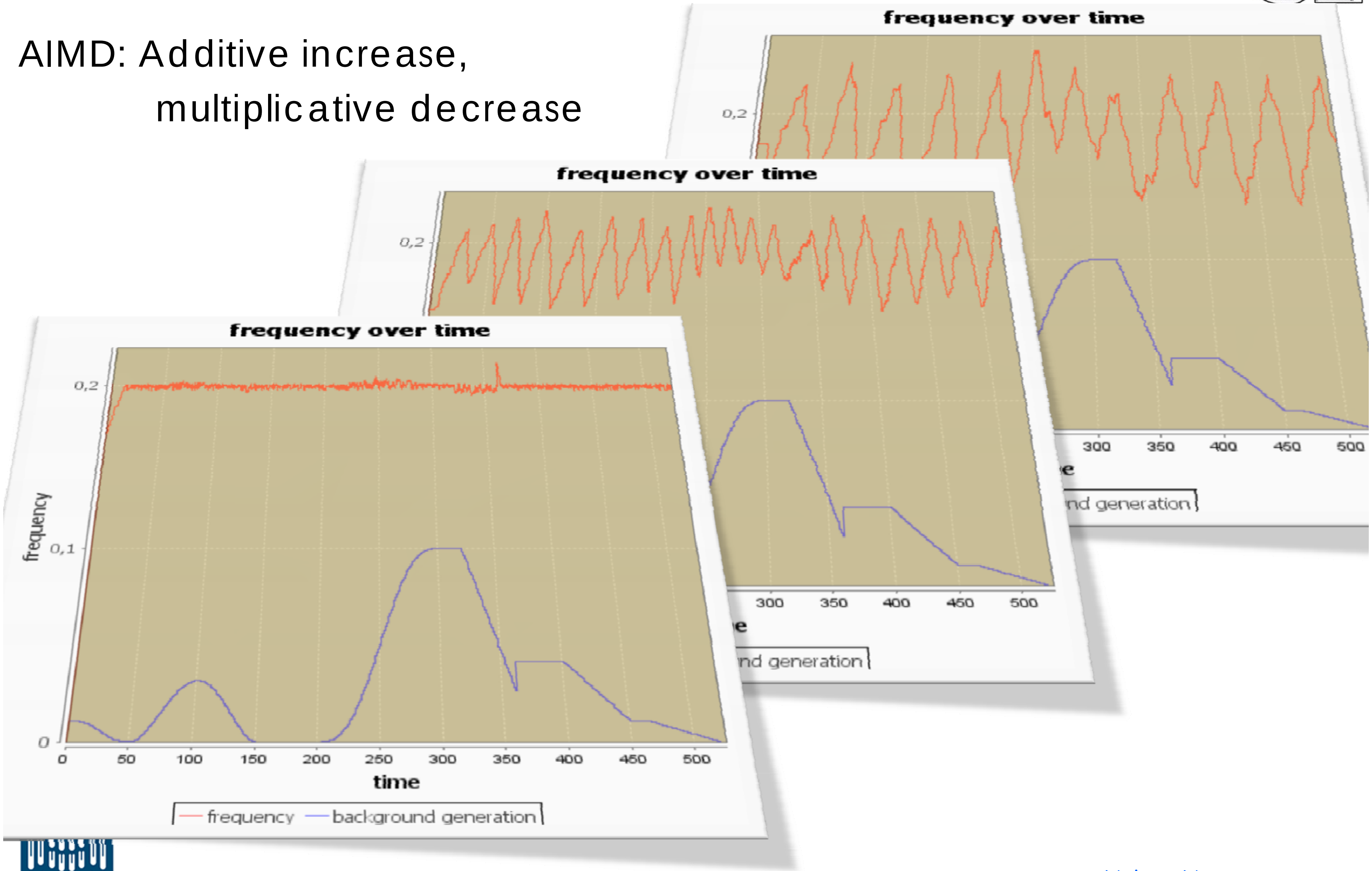
Idea: Increase use in small, additive steps
Decrease on bad event by a factor <1





What we are thinking of

AIMD: Additive increase,
multiplicative decrease



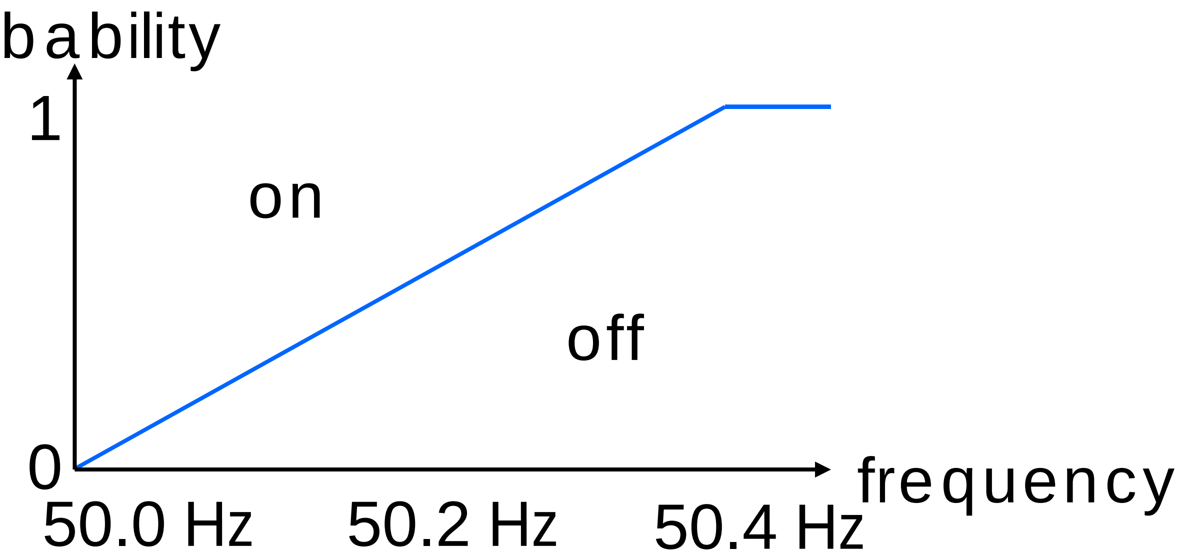
Frequency-dependent probabilistic switching

Used in: IEEE 802.11e

avoid oscillations

Goal: Adapt to system state, but randomised

Idea: Switch on or off with probability dependent on observed frequency

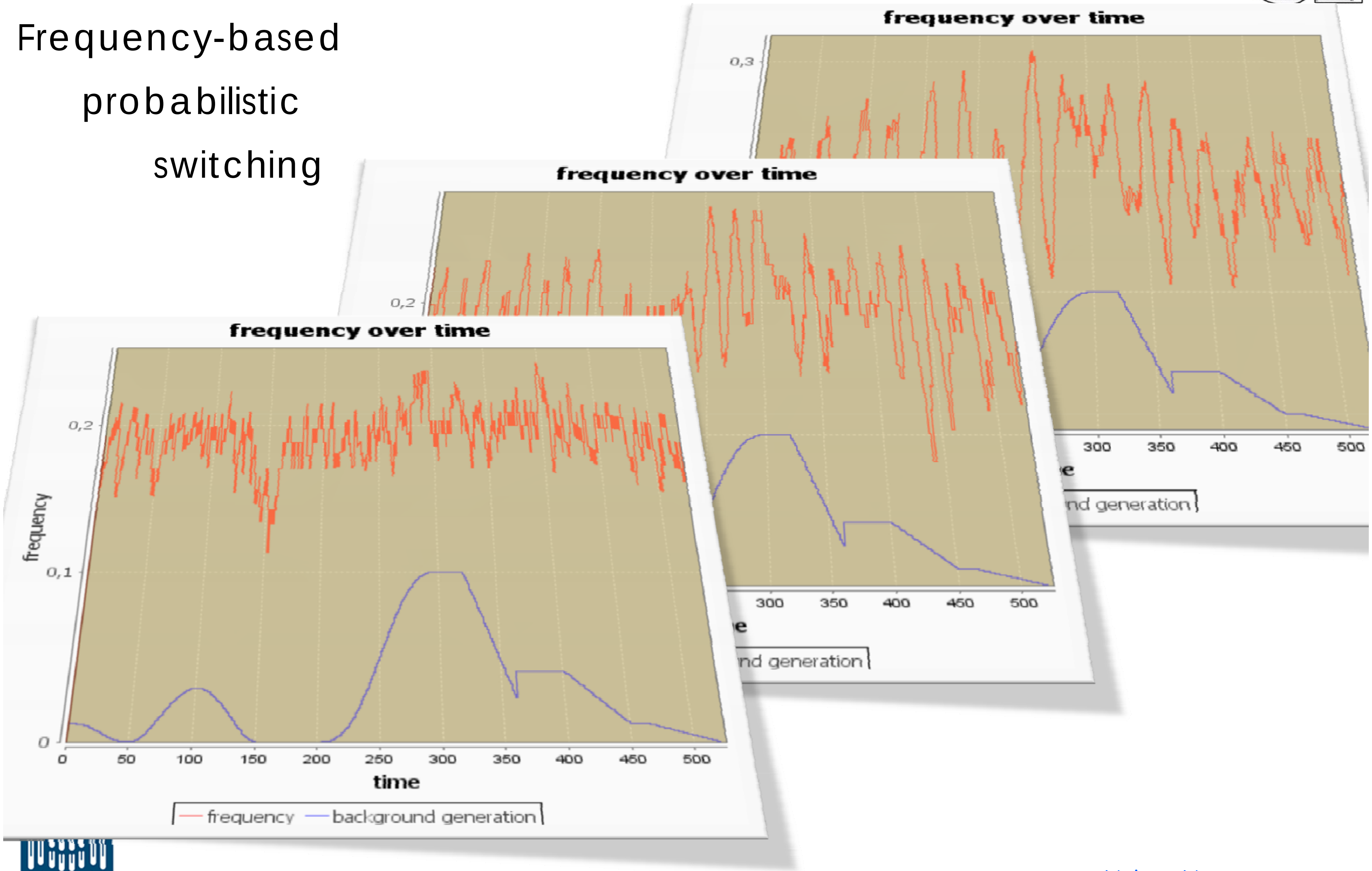


More of this kind

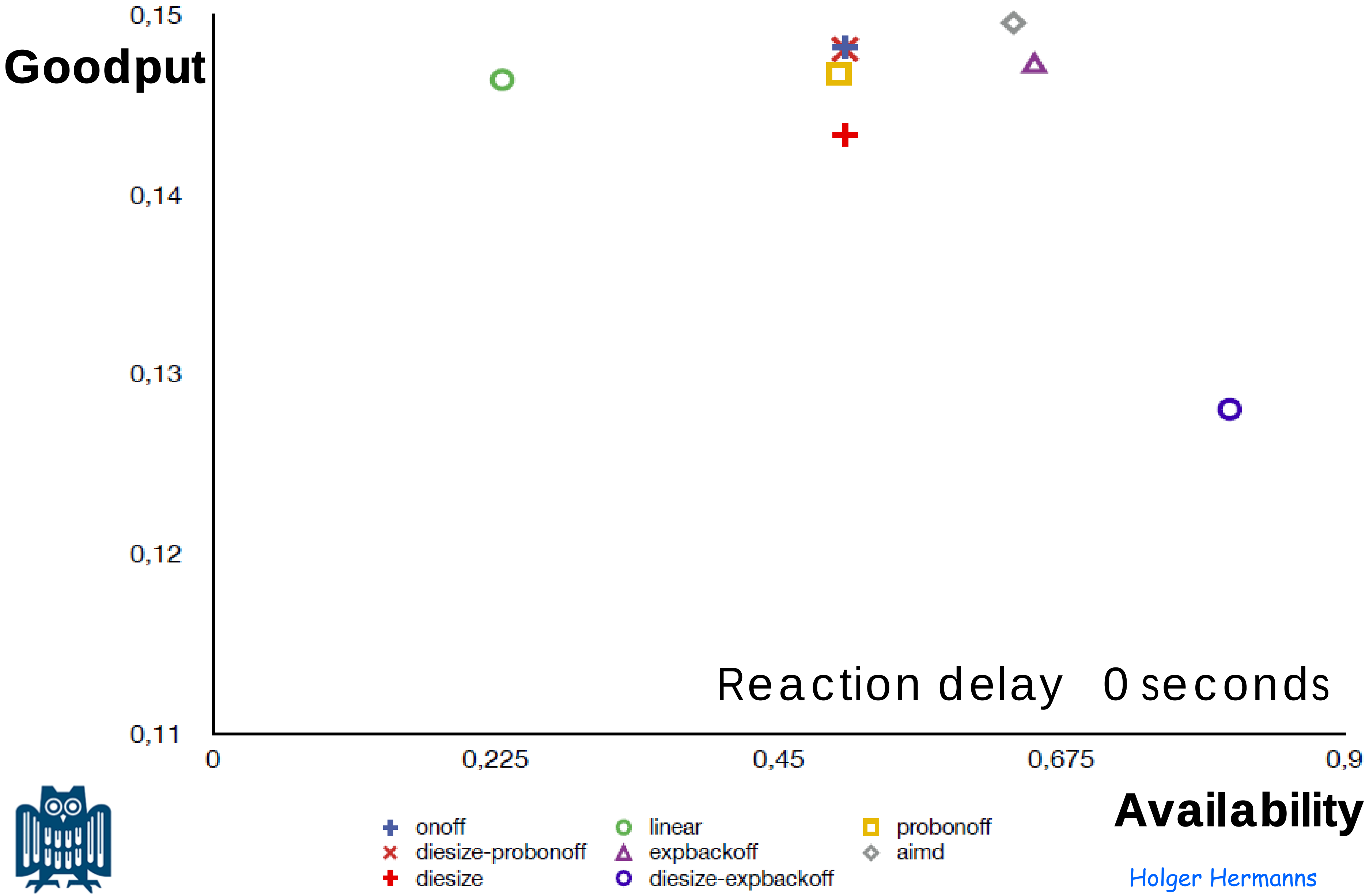
Frequency-based

probabilistic

switching



So?



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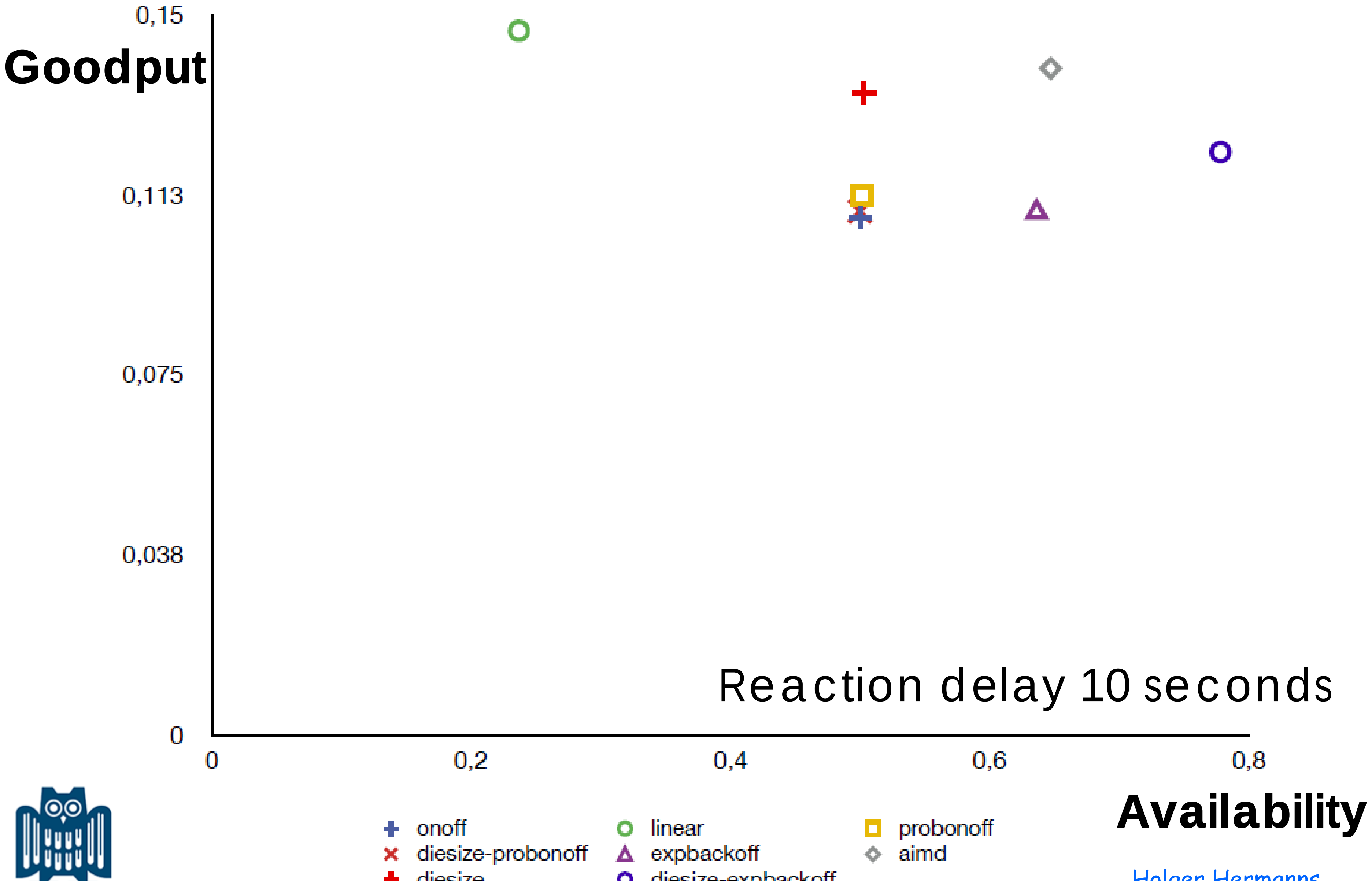
So?



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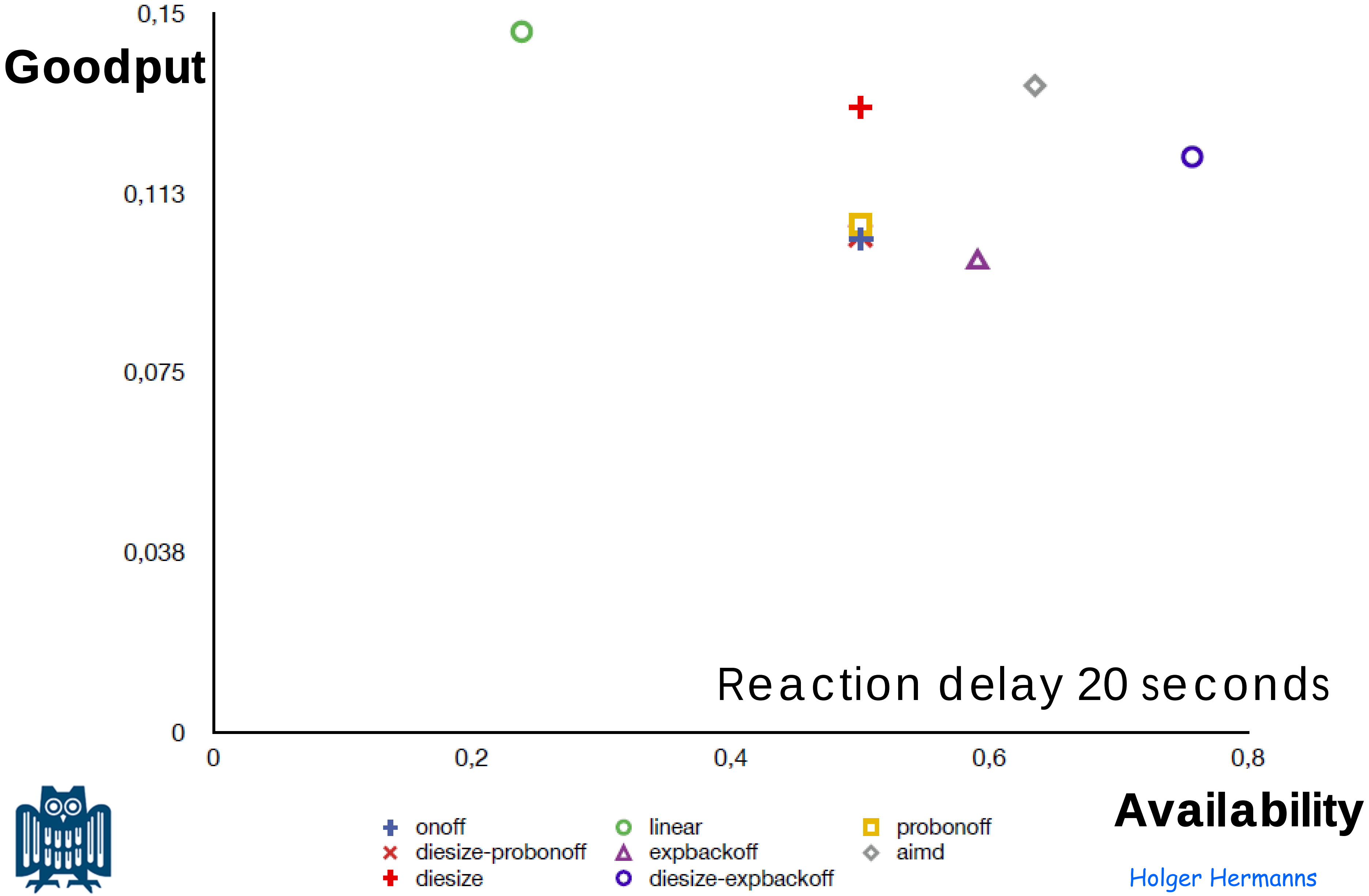
So?



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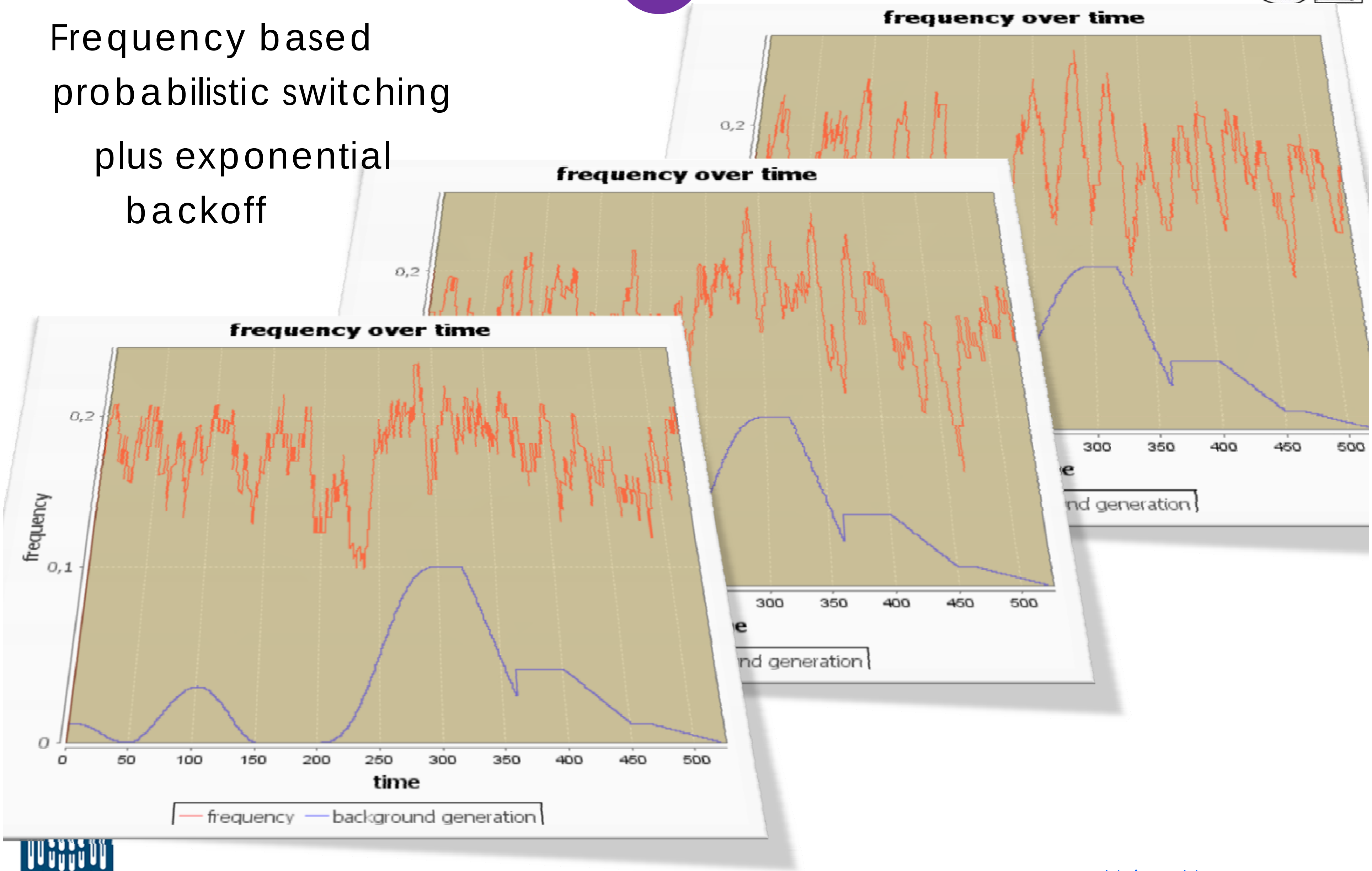
Our current favorite:

Frequency based probabilistic switching

plus exponential backoff



Exponential backoff

Used in: Ethernet

Goal: Mediate access to shared medium, decentralised

Idea: Try to send.
Collision? Wait time given by 2-sided die roll.
Try to send.
Collision? Wait time given by 4-sided die roll.
Try to send.
Collision? Wait time given by 8-sided die roll.
Try to send.
Collision? Wait time given by 16-sided die roll.
...

⇨ adjust wait time to number of competitors

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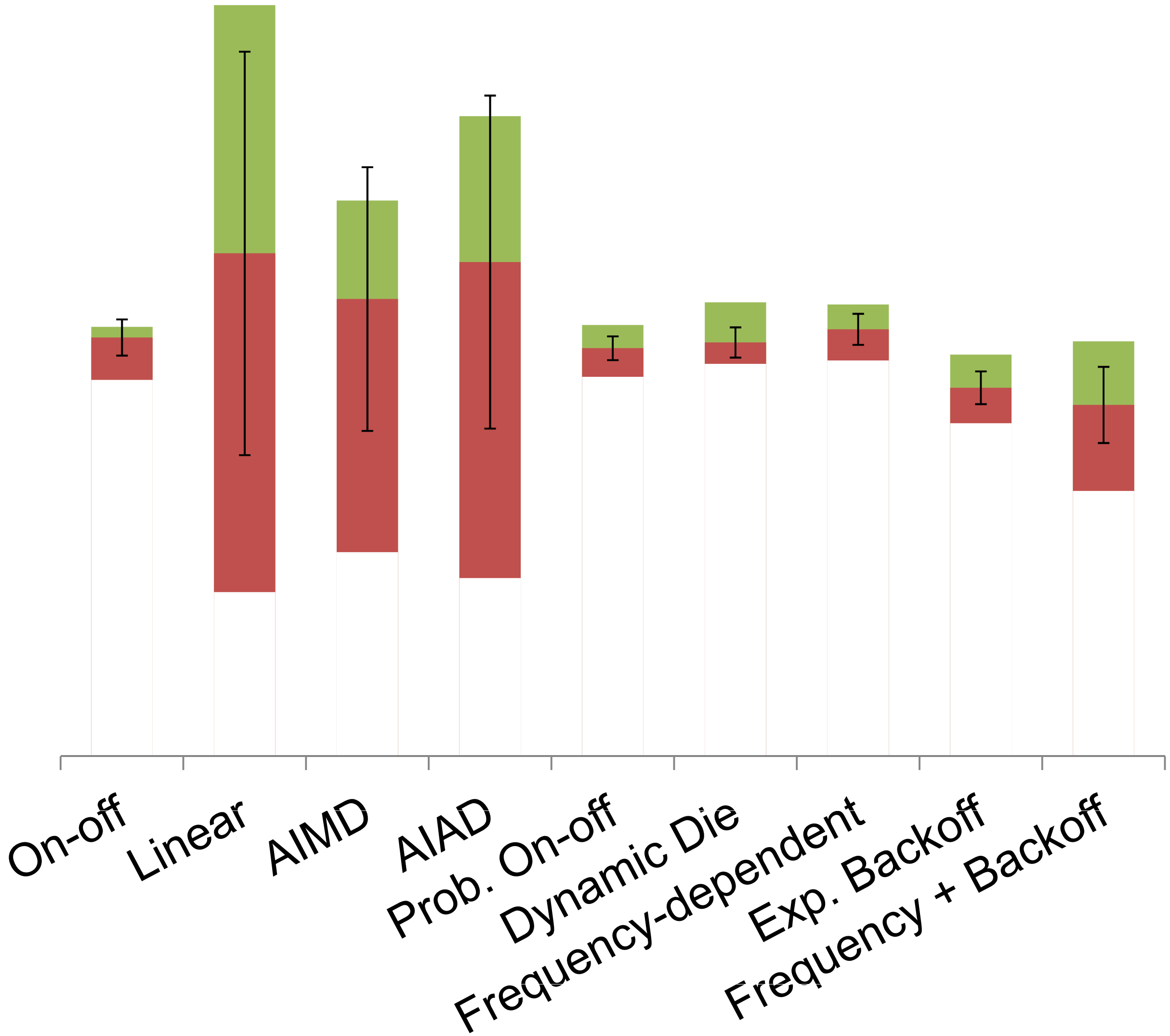
Where do these numbers come from?

- 32 photovoltaic microgenerators.
- Decide upon observed frequency every 20 sec.
- Time points initially picked uniformly.
- Linear impact on frequency.
- Reaction delay is 0, 10 or 20 seconds.

- Background frequency generated by random walk.
- All modelled in Modest.
- 10000 simulation runs of modes discrete event simulator.

Fairness

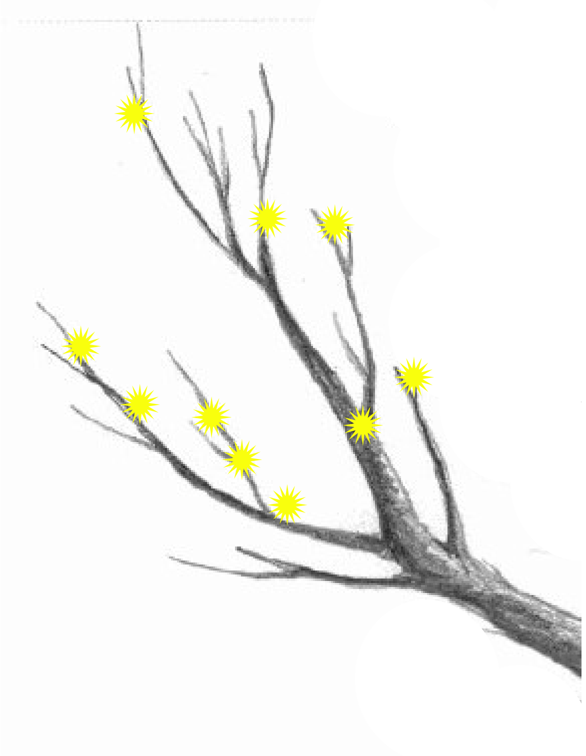
Max/min/
average
output
per generator:



What remains to be done?

- A lot.

- Team up with
  - design space explorators
  - machine learners
  - domain experts
  - decision bodies
  - patent fanatics



- Consider voltage instead of frequency
  - spatial layout can become important (dependent on setup)

- Develop good abstractions

- Increase awareness

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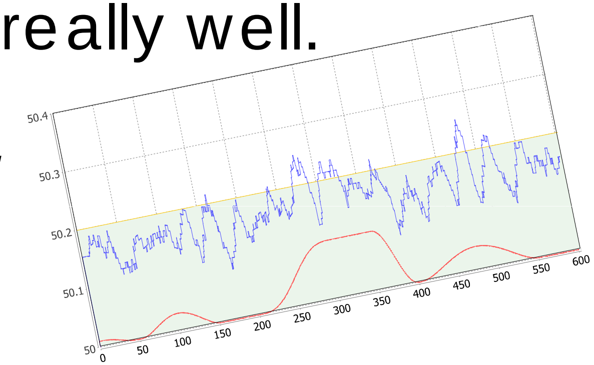
Conclusion

Photovoltaic microgeneration creates new challenges.

Formal models help evaluate new approaches soundly.

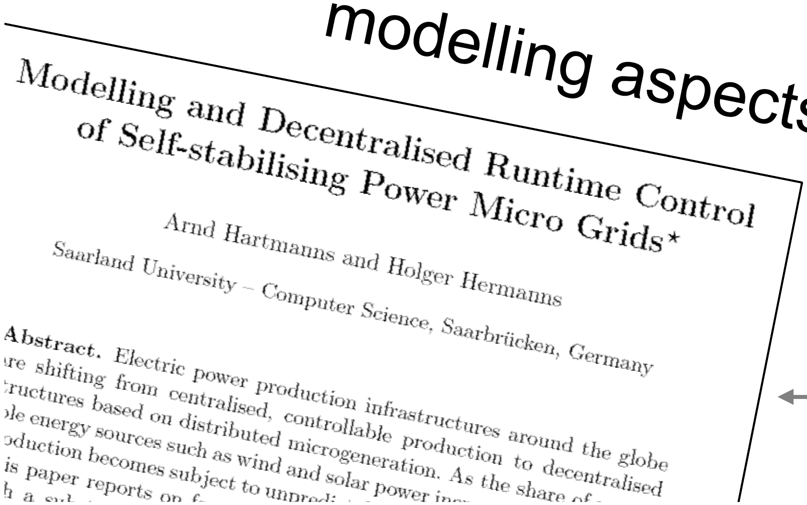
Some of the new control strategies work really well.



Bonus: No privacy concerns!

inspiration from computer networks

modelling aspects



Modelling and Decentralised Runtime Control of Self-stabilising Power Micro Grids*

Arnd Hartmanns and Holger Hermanns

Saarland University – Computer Science, Saarbrücken, Germany

Abstract. Electric power production infrastructures around the globe are shifting from centralised, controllable production to decentralised structures based on distributed microgeneration. As the share of renewable energy sources such as wind and solar power increases, production becomes subject to unpredictable ...

simulation study

Proceedings of the 2012 Winter Simulation Conference
C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, eds.

A Comparative Analysis of Decentralized Power Grid Stabilization Strategies*

Pascal Berrang, Arnd Hartmanns, and Holger Hermanns

Saarland University – Computer Science

ABSTRACT

This paper reports on formal behavioural models of power grids with a substantial share of photovoltaic microgeneration. Simulation studies show that the current legislatory framework in Germany can ... frequency oscillations. This phenomenon is indeed recognized by the German Federal Net... ... the national power grids, and new regulations are currently ... the currently valid proposal, and compare it with ...

WSC 2012 →

← ISoLA 2012

Epilogue

A broader perspective

On the long run,

the power grid stability problem will be

a major concern on all layers

of the grid hierarchy

What is needed, is a grid managment operating

- **highly local,**
  - **highly automatic,**
    - **highly decentralized, and**
      - **highly flexible**

New operational principles for power grids

Grid neutrality: There is no discrimination in the way the grid shares its capacity among its users.

Grid fairness: Ideally, the grid is fair in the sense that if *n* users are sharing a grid path, then on average each user can use about *1/n*-th of the capacity.

Scalability: Distributed, decentralized control is a prime means to assure scalability, together with hierarchy.

Privacy: End user privacy is protected by decentralized decision making based on public global information and private local information.

Intelligent edges, dumb core: Intelligence resides in the edges of the grid, i.e. is embedded into the end user appliances. The core of the grid is barely smart.

New operational principles are old!

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An internet analogy!

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Turning the power grid into a power web

This is a **vision**.

Caution:

The protocols and techniques
driving the web have been developed
at a time when no one cared.

This time things are different:

The transformation must be done
while our society relies on it
if it is to be done at all.

Go!

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