GRID INTEGRATION OF ELECTROMOBILITY – POWER SYSTEM PLANNING PERSPECTIVE

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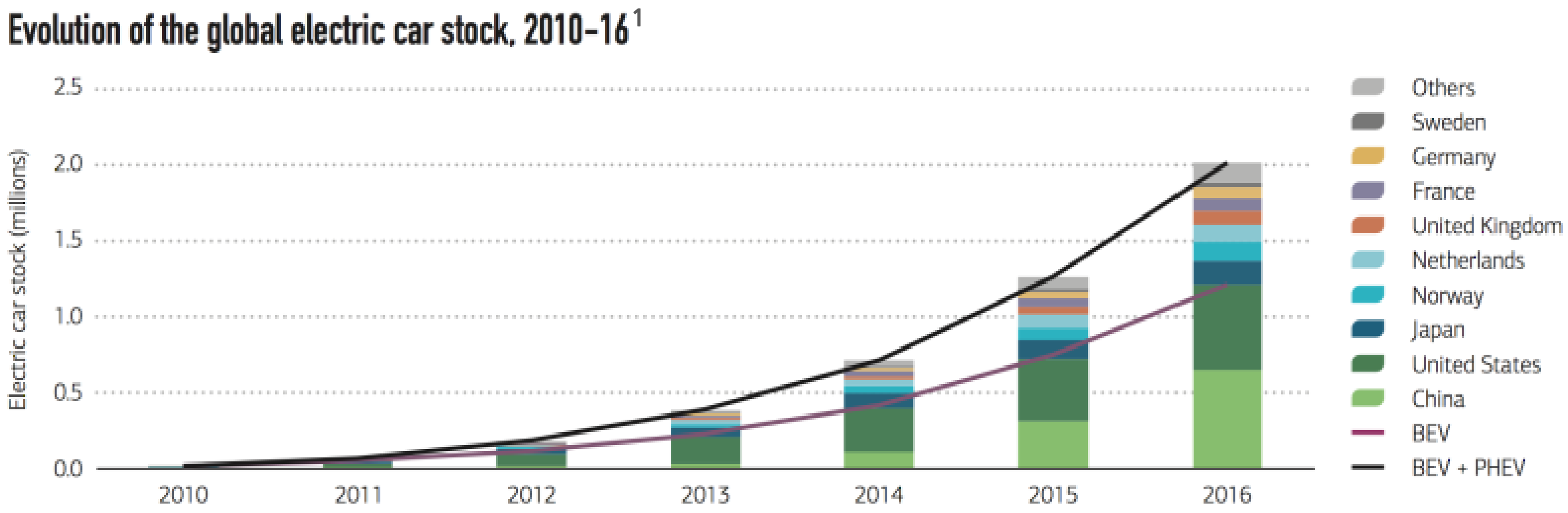
Motivation
Transition to Battery Electric Vehicles (BEVs)

- In the upcoming decades in many countries a **transition to battery electric vehicles** (BEVs) is expected
- The additional power flows could lead to **overloadings** and **voltage band violations**

Grid integration studies are important in order to assess:

- The hosting capacity for (additional) charging stations
- Necessary reinforcement and expansion measures + investment cost



[1] IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

Outline

- **Grid Integration Study in Germany (example federal state of Hesse)**
- Probabilistic Planning for Integrating Electromobility
- Project Outlook Charging Infrastructure 2.0

The Federal State of Hesse

- One of 16 federal states of Germany
- Covers nearly 6% of Germany’s area and comprises just over 7% of Germany’s residents
- Large cities: Frankfurt, Darmstadt, Wiesbaden (Capital)

Fraunhofer IEE

- Institute for Energy Economics and Energy System Technology
- Personal: approx. 360
- Annual budget: approx. 22.5 Mio EUR

www.iee.fraunhofer.de

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Considered Scenarios

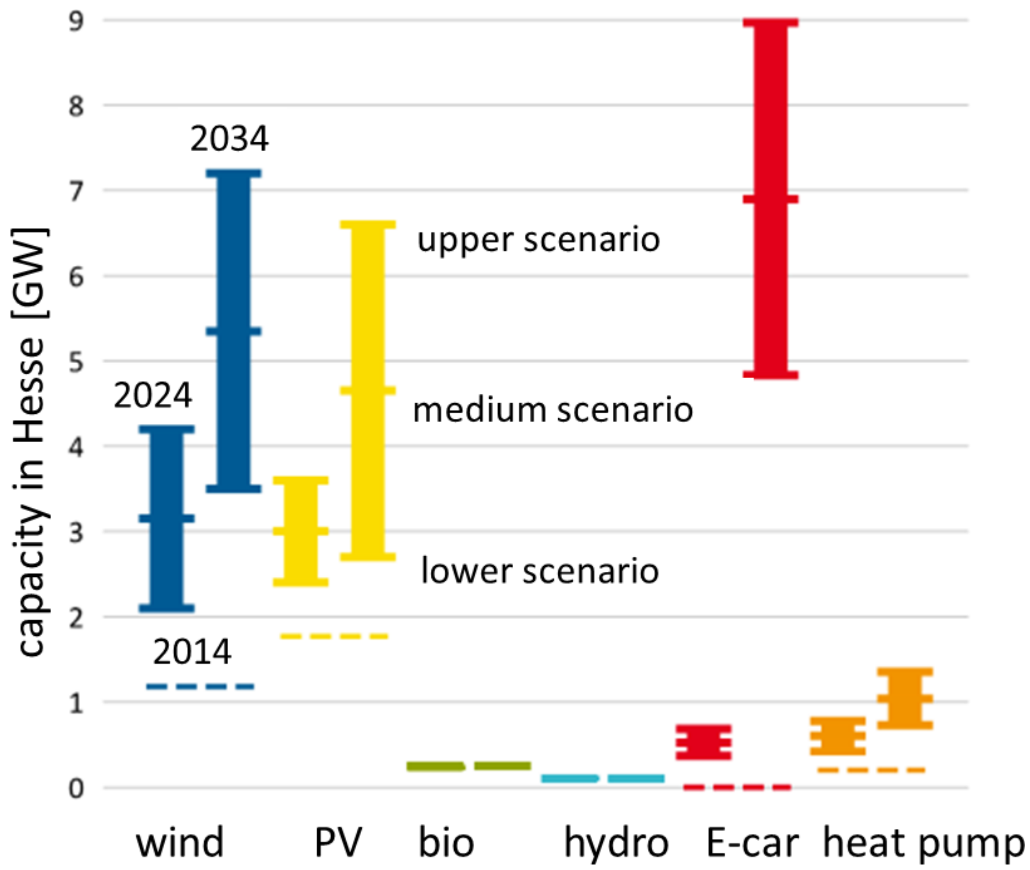
- Three scenarios model different rates of the "Energiewende" in Hesse

Generation

- Scenarios mainly dominated by wind and photovoltaic plants
- Only small development expected for bio gas and hydro power plants

Consumption

- Large increase in number of EV load points expected in 2034
- Conventional consumption decreases slightly, overall consumption increases slightly due to sector coupling
- Geographic shift due to demographic changes



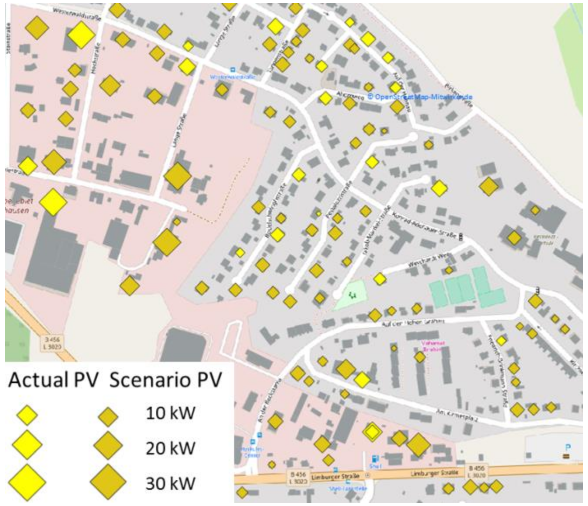
(Picture reprinted [translated] from [1])

[1] Braun et.al: Verteilnetzstudie Hessen, [Online]. Available: https://www.energieland.hessen.de/verteilnetzstudie_hessen

Source: https://www.energieland.hessen.de/verteilnetzstudie_hessen

Regionalization of the Scenario Prediction - PV

- State Hesse divided into ~3000 geographic patches
- Overall target capacities for PV given in the scenario is distributed among the patches
- Probabilistic distribution of roof-top PV plants within the patches onto houses
- Large on-ground PV plants are distributed near train rails and highways
- Wind plants distributed in designated priority areas



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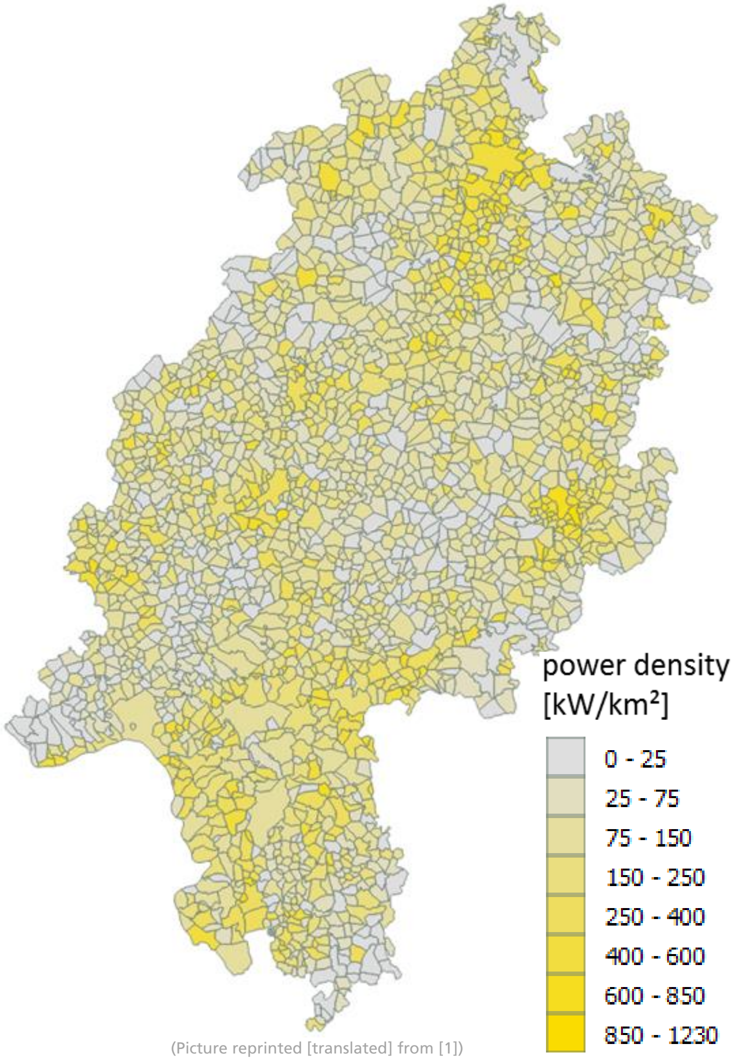

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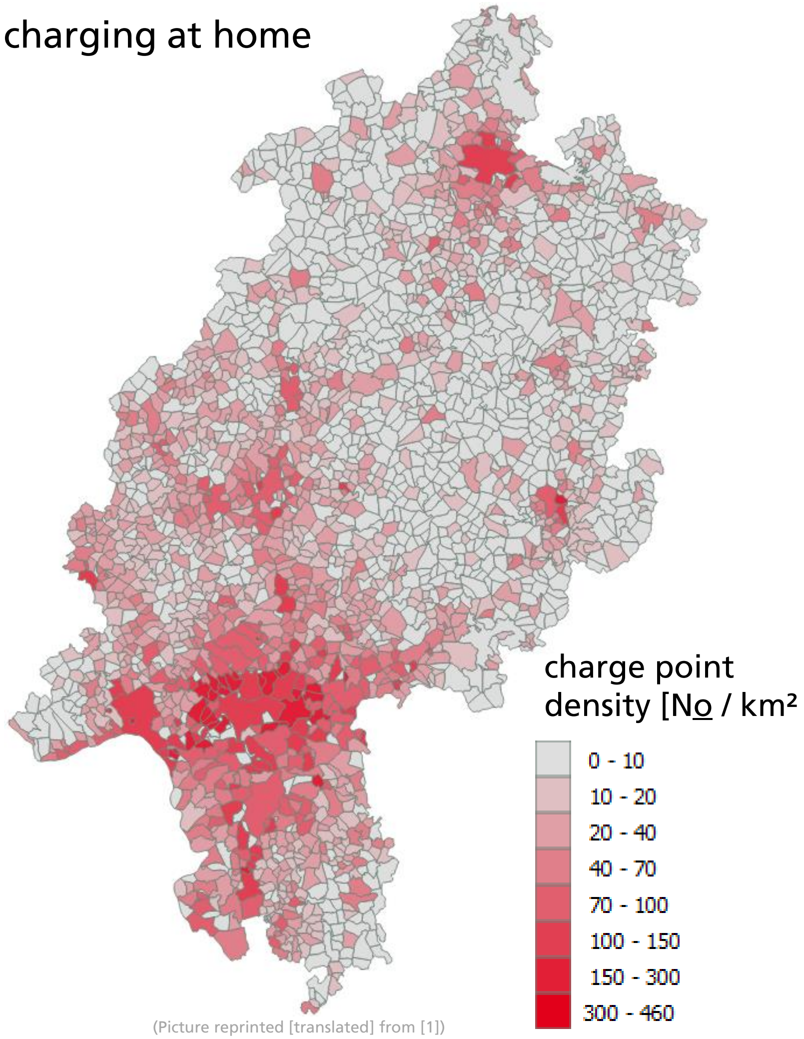
Regionalization of the Scenario Prediction - EV

- Two-step process:
  - 1) Regionalization of scenario predictions to municipalities
  - 2) Disaggregation to individual buildings/ charging points
  - Separate, statewide regionalization of long-distance traffic
- Four types of charging infrastructure: at home, at work, public and semi-public
- Consideration of OpenStreetMap and other geographical data for realistic placement of charging points

(Picture reprinted [translated] from [1])



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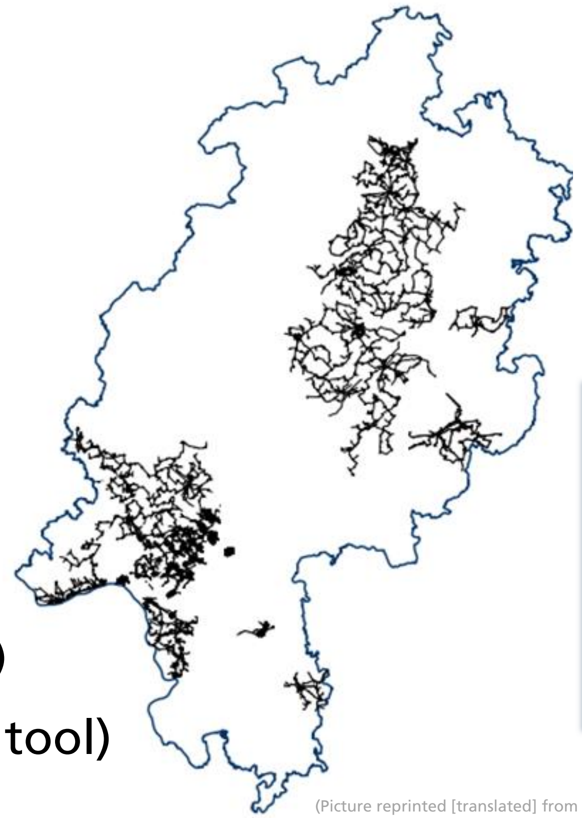
Grid Data

- Only models of real grids used
  - 80% of HV Level
  - 60 MV grids (6200 km lines, ~25% of Hesse)
  - 670 LV grids (2150 km lines, ~5% of Hesse)
- All models converted from source format (PowerFactory, Sincal, Neplan) to pandapower format
  - www.pandapower.org (open source)
  - www.pandapower.pro (professional tool)
- Adaption of all models to adhere the same modelling principles (e.g. naming conventions)



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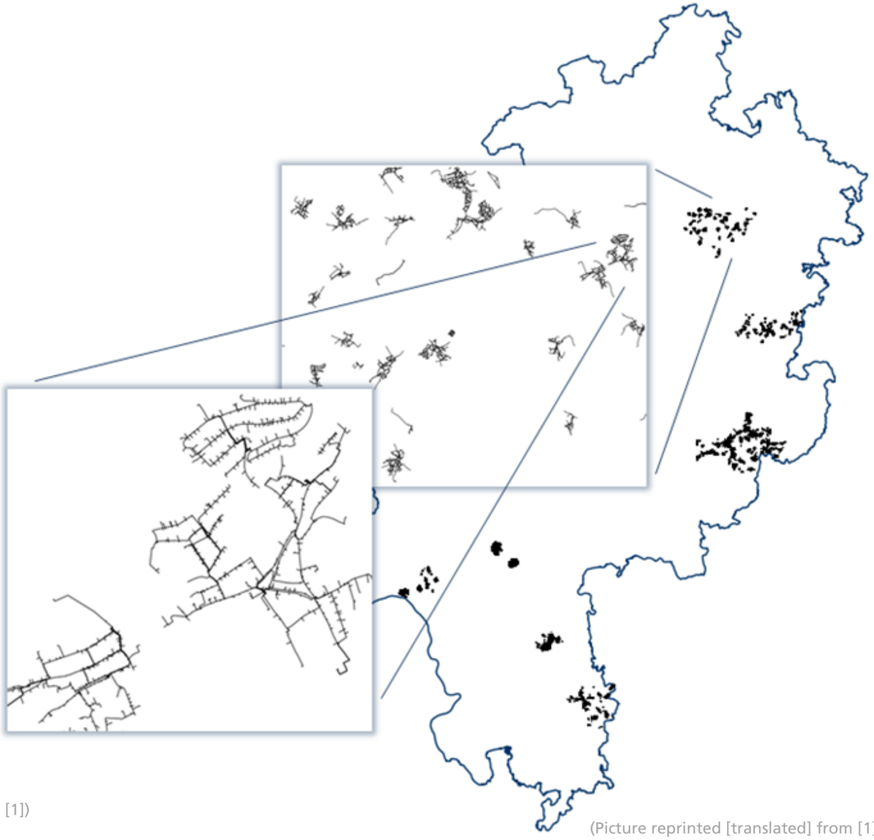

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[1]www.pandapower.org

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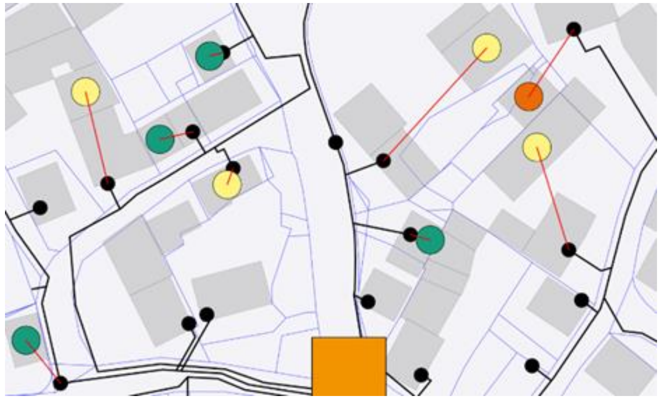
Implementation of Scenario Data into the Grid Models

- Regionalization step of scenario data provides geographic locations with associated rated power values
- Low-voltage level:
  - real estate data (blue lines in top figure) associated with grid connection points (black dots)
  - predicted DER (roof-top PV, EV charging stations and heat pumps) within a real estate is connected to connection point
- Medium-voltage level:
  - If low voltage grid data is available, it is used to assign DER to MV substations
  - Otherwise, real estates are assigned to substations using shortest distance



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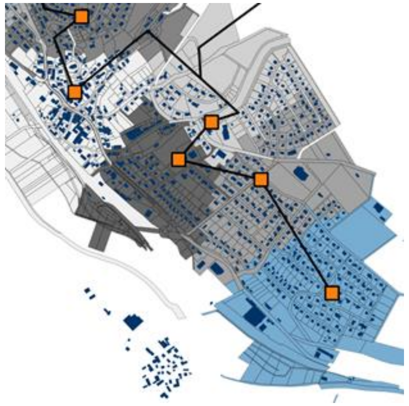

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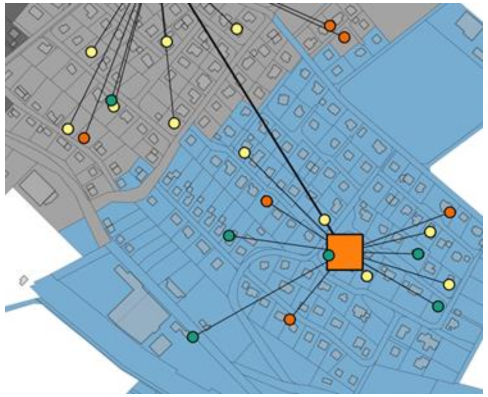

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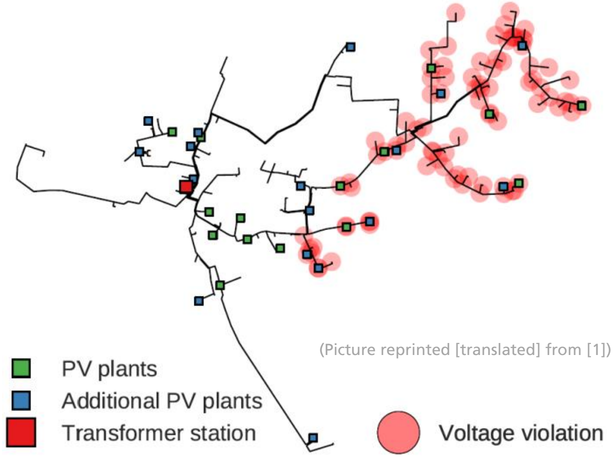
Low-voltage Level: Methodology

- Similar approach to medium-voltage level
- Considered measures:
  - Replacing lines
  - Parallel lines between existing switch cabins
  - New switch cabins + parallel lines
  - Replacing transformer
  - Changing the fixed tap position of the transformers
  - New MV/LV substations



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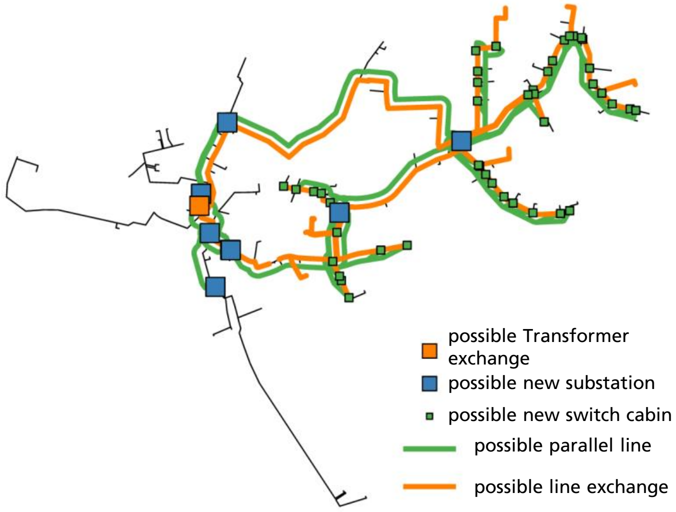

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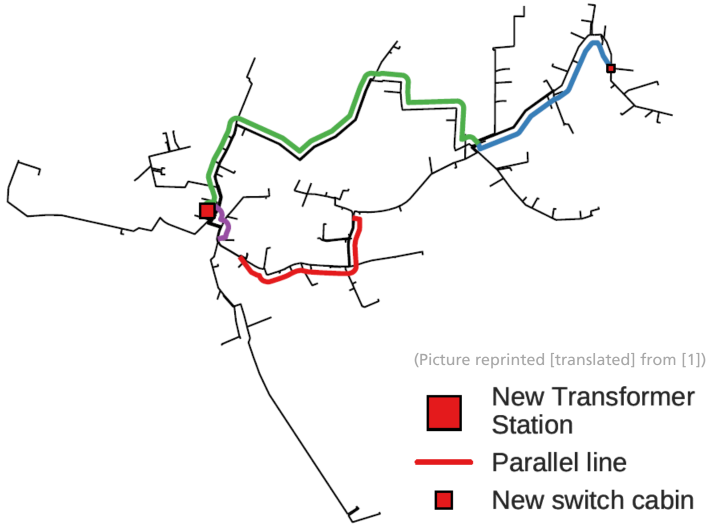

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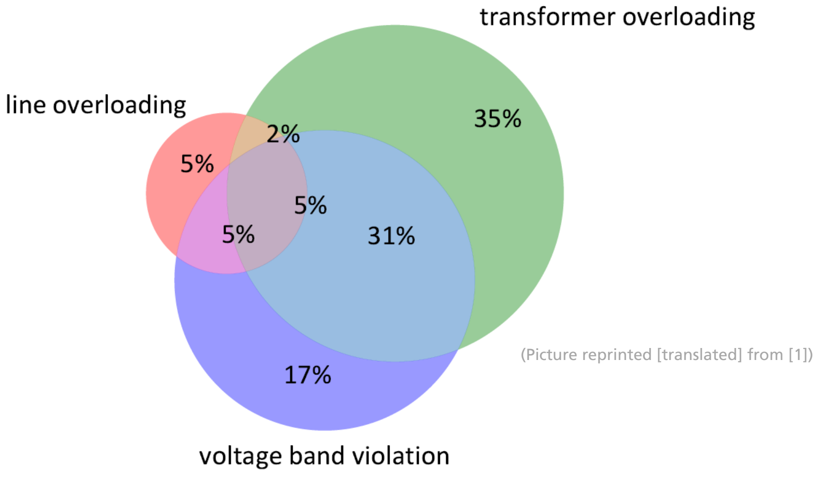
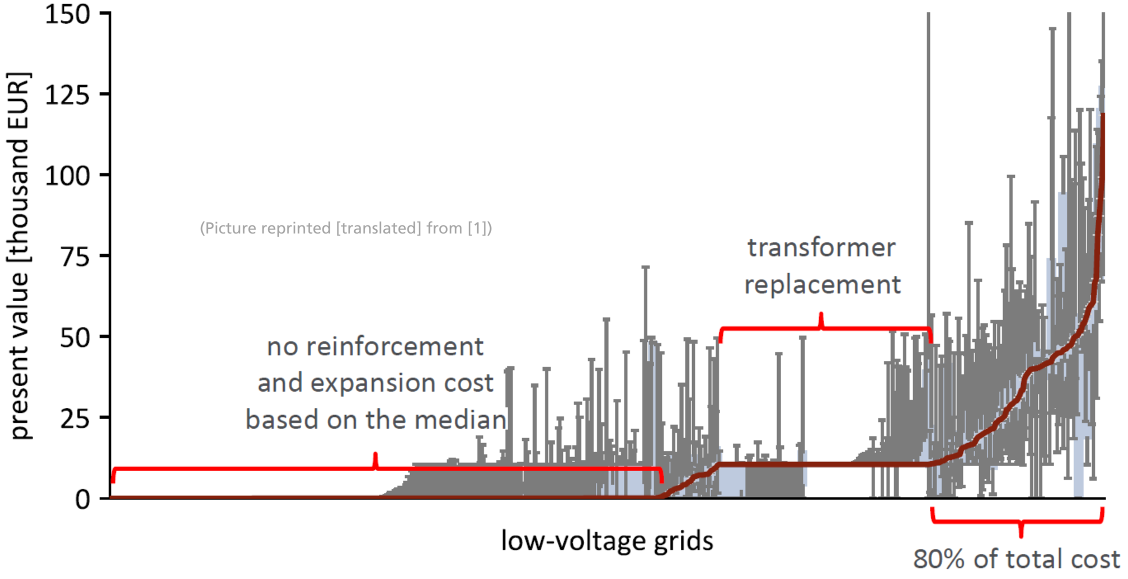
Low-voltage Level: Conventional Reinforcement

- In 30% of the analyzed LV grids no violations occur
- In 40% of the grids there is a chance that problems occur depending on the specific distribution of DER
- In the remaining 30% violations are very likely regardless of the distribution of new DER.
- 2024 mostly voltage violations dominate; 2034 transformer overloading is the most common violation type
- Line overloading plays only a marginal role
- 25% of the grids contribute to 80% of the overall reinforcement and expansion cost
- 2/3 of the cost relate to new transformers or new substations





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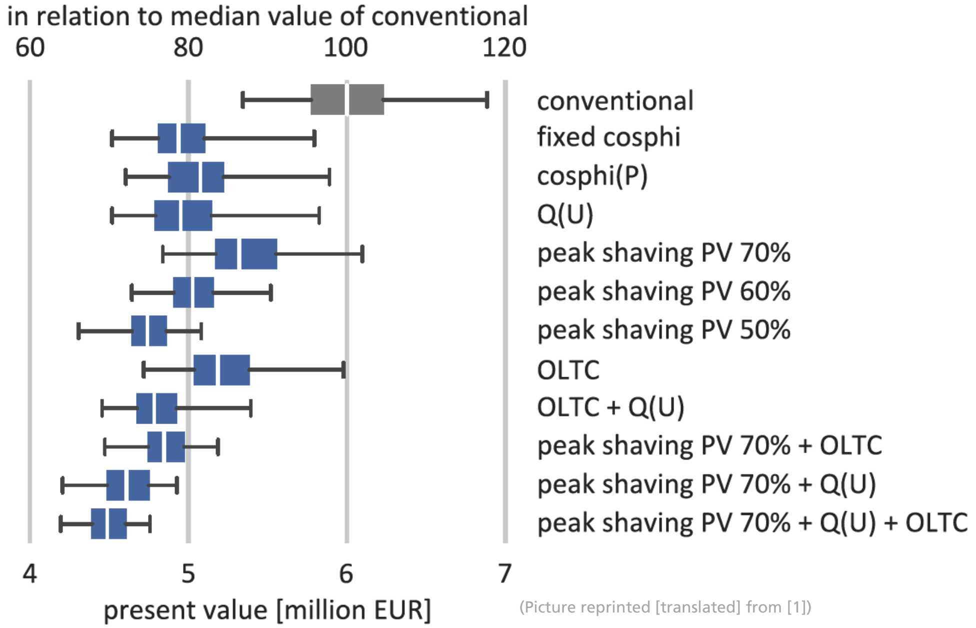
Low-voltage Level: Potential of Innovative Technologies

- Reactive power control technologies are able to decrease cost by around 20%
- MV/LV transformers with OLTC lead to savings of 18%(due to the additional investment cost, only applied in 18% of the grids where it leads to net savings)
- Peak shaving 70% leads to savings of about 15%
- Combination of voltage control with peak shaving leads to the highest overall savings of about 30%
- Grid friendly operation of prosumers potentially decreases investment cost by 35%.
  Market oriented behavior increases cost by 35%



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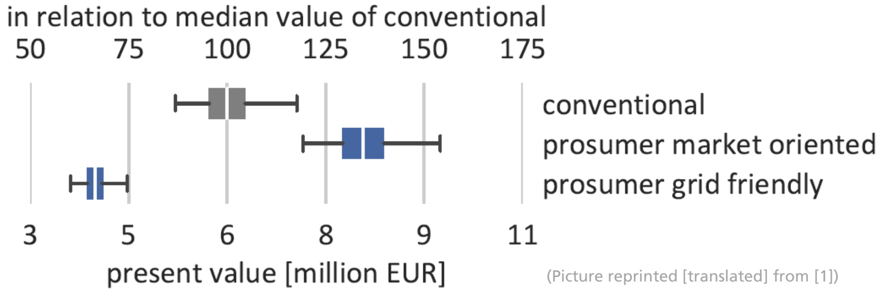

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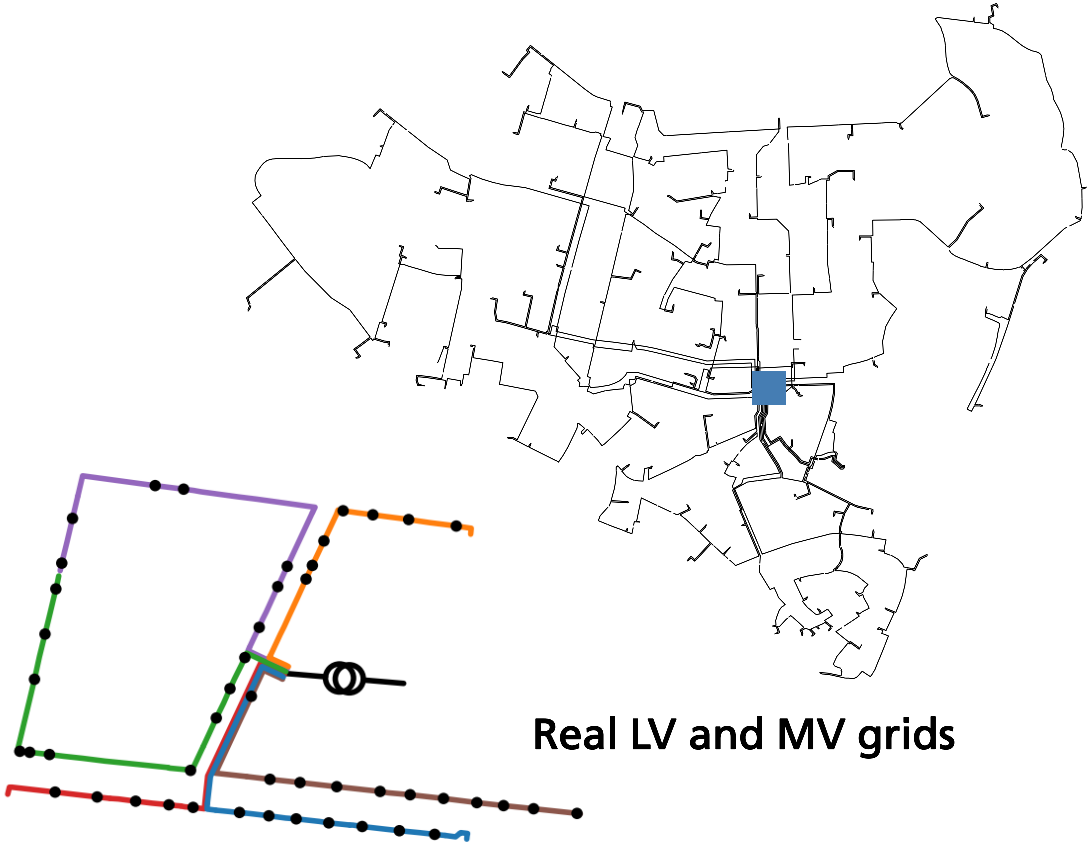
Outline

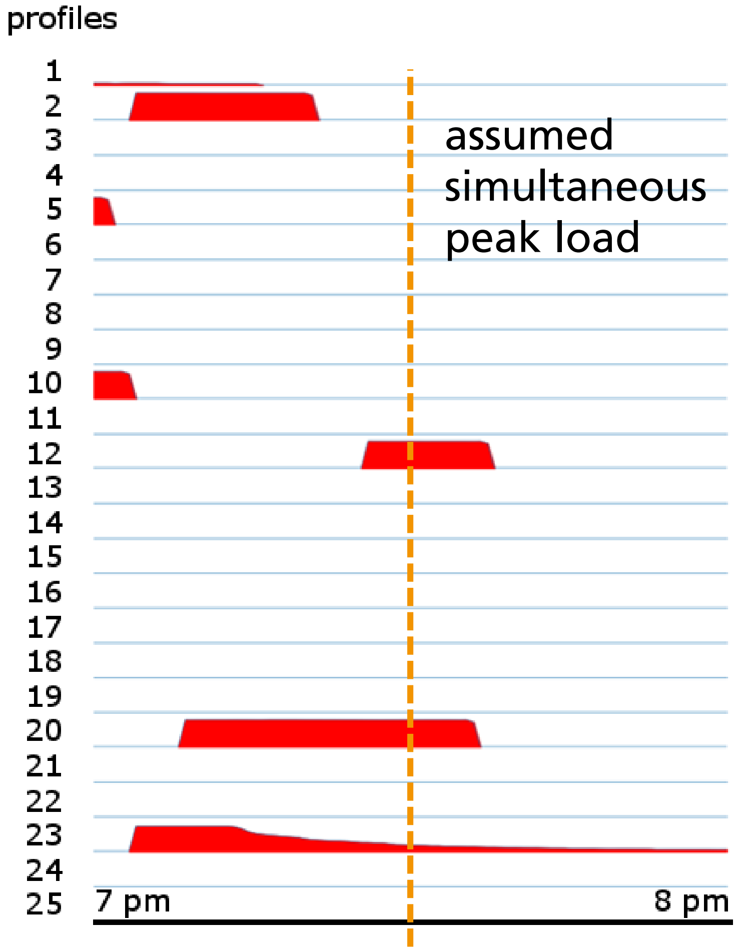
- Grid Integration Study in Germany (example federal state of Hesse)
- **Probabilistic Planning for Integrating Electromobility**
- Project Outlook Charging Infrastructure 2.0

Method for conducting grid integration studies in the context of Electromobility

- Detailed comparison of **simultaneity factors** vs. a **probabilistic distribution approach** based on BEV charging profiles
- Application on **real medium- and low-voltage grids** provided by the German DSO Stadtwerke Kiel
- Demonstration of different BEV **charging infrastructure concepts**
- Evaluation of grid integration cost with an **automated grid reinforcement and expansion approach**
- All calculations and analyses are performed with pandapower



Modelling of BEV Charging



Simulated BEV charging profiles with consideration of:

- Usage behaviour of BEV owners (time of day, time spans, travelled distance, …)
- Technical specification of common BEV models (battery capacity, energy consumption per km, …)
- BEV market shares in Germany
- Charging behaviour of lithium-ion batteries (charging speed dependence on state of charge)

→ 10.000 BEV charging profiles generated

→ Here, all charging points have an assumed rated power of 22 kW (other rated powers are possible)

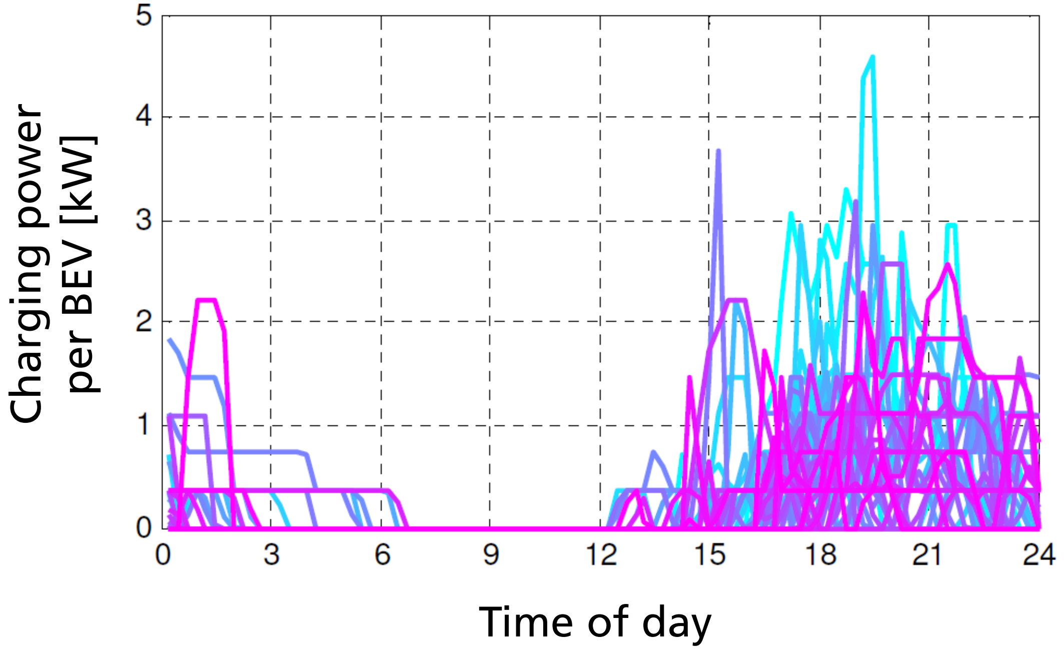
Charging Infrastructure 2.0 – Probabilistic Planning of EV Charging Infrastructure

- In the absence of market induced effects it is very unlikely that all EVs in a grid **charge at the same time** with their rated power

- Common method: usage of **simultaneity factors** in order to **scale down** power consumption per BEV according to the number of simultaneously charging vehicles

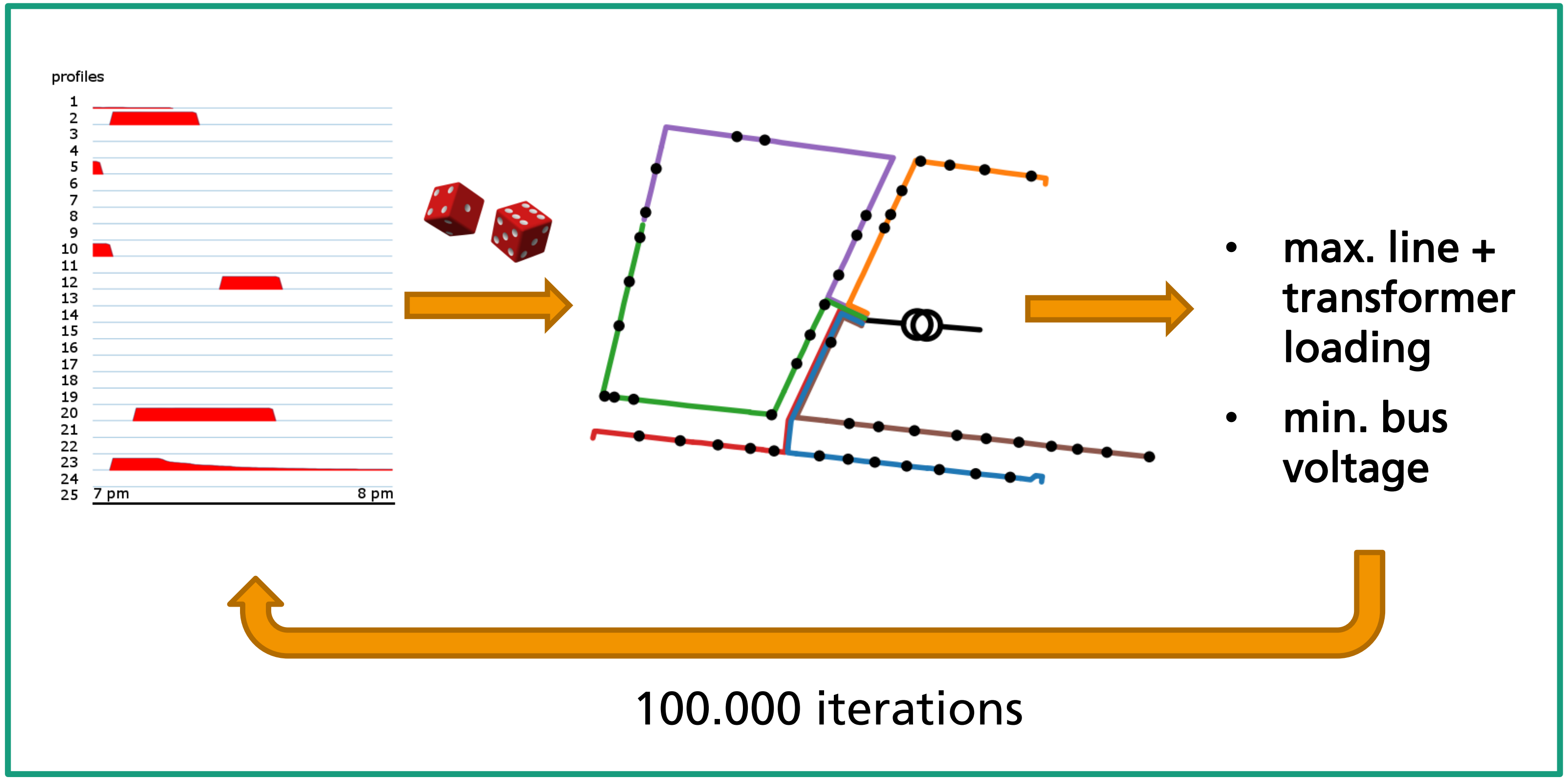
- Suitability for small numbers of vehicles is **questionable** → Comparison with a **probabilistic method** for assessing realistic worst-case values

Charging profiles of 10 BEVs [2]



[2] reprinted [translated] from: A. Probst, Auswirkungen von Elektromobilität auf Energieversorgungsnetze analysiert auf Basis probabilistischer Netzplanung

Charging Infrastructure 2.0 – Probabilistic Planning of EV Charging Infrastructure

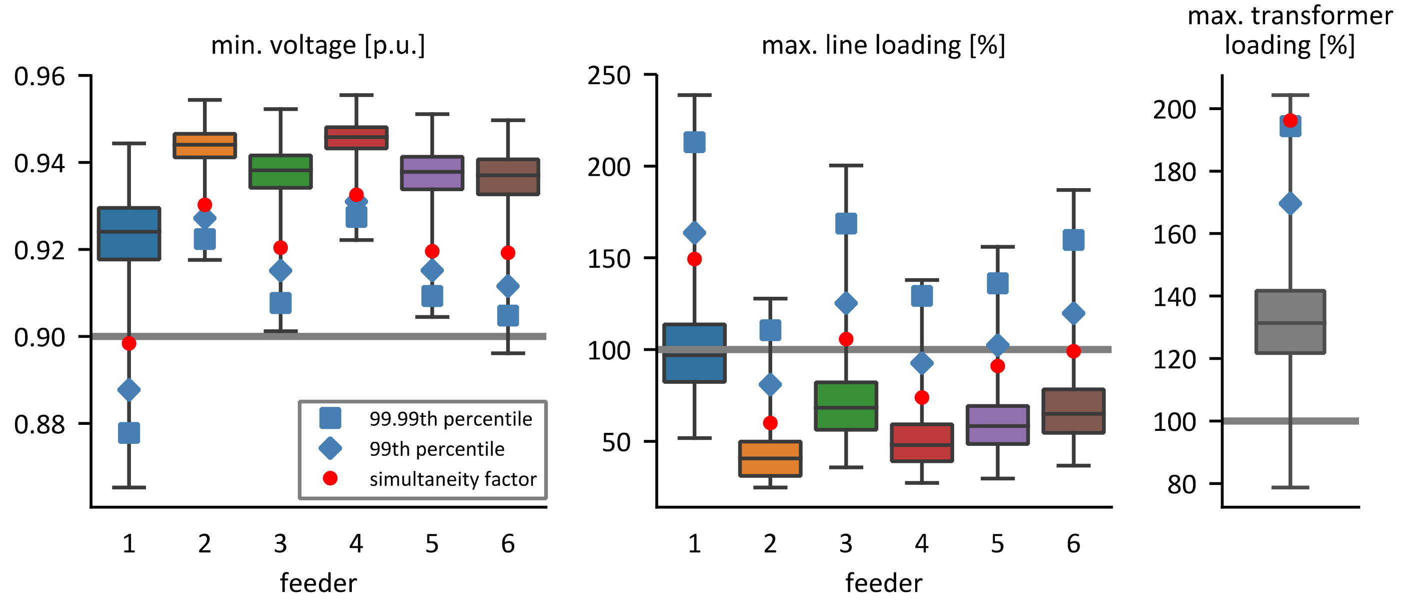


Worst-case scenario of 100.000 iterations:

1) Randomly chosen charging profile for every charging point in the grid (positions of charging points are fixed)
2) Power flow calculation
3) Analyses of line/transformer loading and bus voltages

Charging Infrastructure 2.0 – Probabilistic Planning of EV Charging Infrastructure

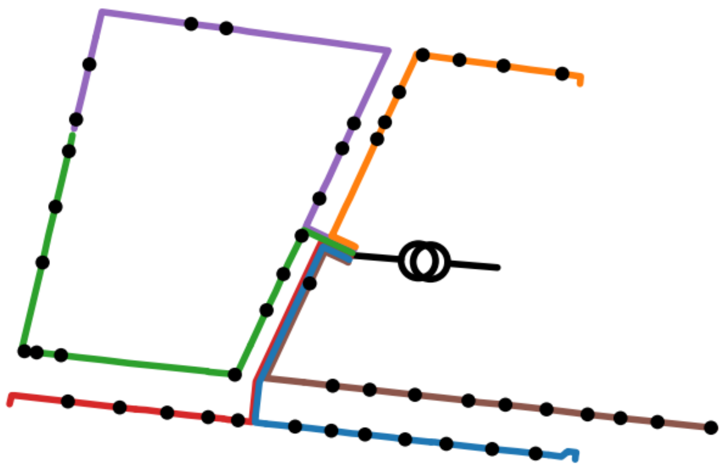
LV grid - min. voltages/ max. loadings in 100.000 BEV distributions



- Simultaneity factor approach **underestimates** min. bus voltages / max. line loadings in all six feeders compared to probabilistically determined worst-case grid situation
→ probabilistic approach preferable method for **small numbers of charging vehicles** (e.g. in LV grids)
- Max. transformer loading: **Simultaneity factor value matches the probabilistic value** → well suited for **larger numbers** of vehicles (MV/LV transformers, MV grids)

Exemplary LV grid

- Urban area
- Supplies ~500 households
- Six feeders
- 48 to 116 BEVs per feeder



Outline

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CHARGING INFRASTRUCTURE 2.0

Optimizing grid expansion and operation for the integration of electric vehicles

Continental The Future in Motion

thüga

Stromnetz Hamburg

SWM Stadtwerke München

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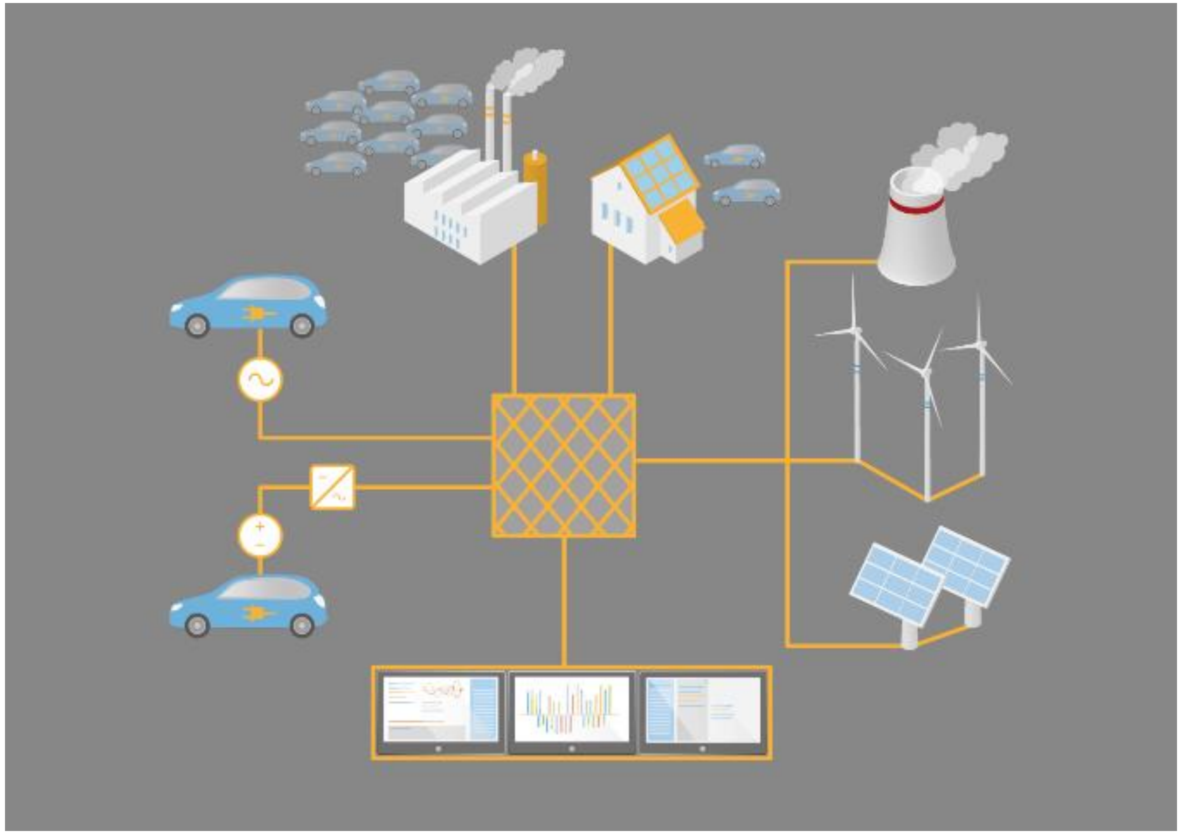

CHARGING INFRASTRUCTURE 2.0

Outline

STATUS QUO

- Energy systems require the integration of e-mobility on a large scale.
- Various actors and technical components are involved
- This complex system cannot be analysed from the perspective of single components alone.

PROJECT USE

- Help stakeholders to provide individual solutions that are coordinated and economically optimal.
- Integrate requirements from vehicle owners, car and charging component manufacturers, grid operators and energy service providers.

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Project roadmap

Detailed **scenarios** for energy production and demand down to single customer level and individual locations

New approaches for **grid operation** (beeDIP) and **energy management**

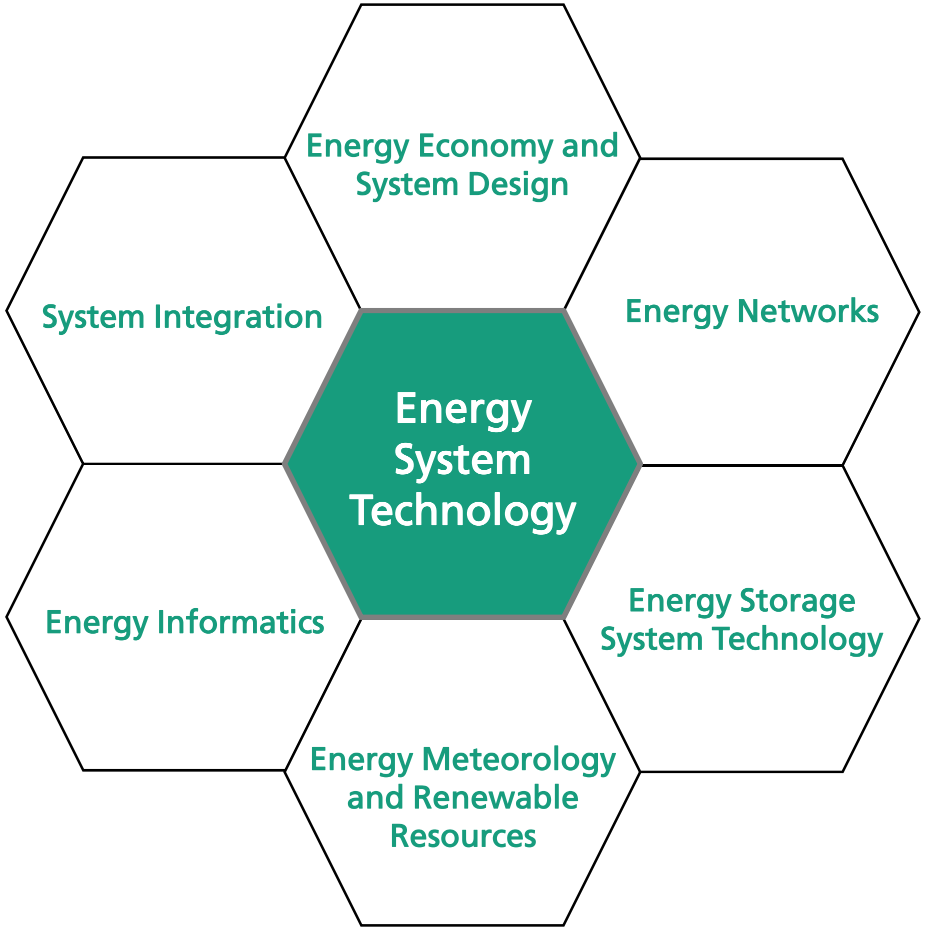
Blueprint for EV Integration studies

Heuristic **grid planning tools** (pandapower Pro) to find optimal grid reinforcement and expansion measures.

Field-tests of charging hardware, grid planning tools and operation software with several DSOs.

Costs and benefits of different options predicted and combined into a **multi-factor evaluation** on a regional level.

Energy system technology to realize the 'Energiewende'



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Fraunhofer IEE– Business Field Grid Planning and Operation

- Techno-economic studies for analyzing, planning, operation, control, stability of power systems
- Automated planning tools
  www.pandapower.pro
- Operational tools (algorithms for ancillary services, hardware/software test platform)
  www.iee.fraunhofer.de/beeDIP
- (Co-simulation) test platforms for operational solutions
  www.opsim.net/en
- Multi-energy system planning and operation (power, heat, gas)
- Microgrid/ hybrid system test bench and PHiL tests

Energiemanagement und Betrieb elektrischer Netze

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Department e²n

Energy Management and Power System Operation

- Development of models, methods, algorithms and tools for analysis, operation and control, and design of the future decentralized power system with high share of renewable energies. e.g. www.pandapower.org
- Multi-Objective/Perspective/Level Optimisation of the power system
- Simulation of the power system over time scales and system levels.
- Resilient Control Design incl. power system stability, network restoration, microgrid structures

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