Impact of BEV Charging on Typical Low Voltage Grids

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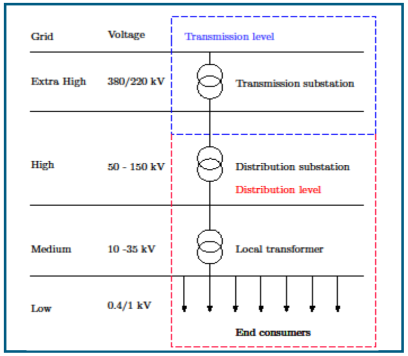
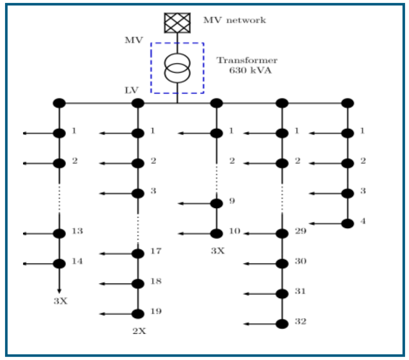
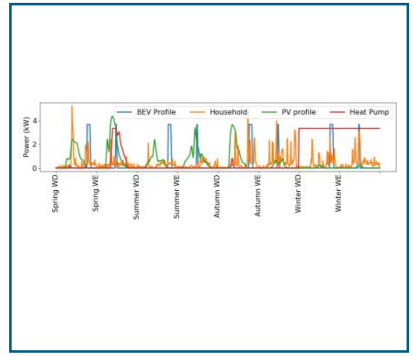
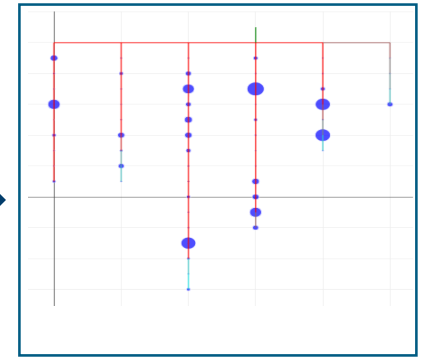
IEK-3: Institute of Techno-economic Systems Analysis

Approach







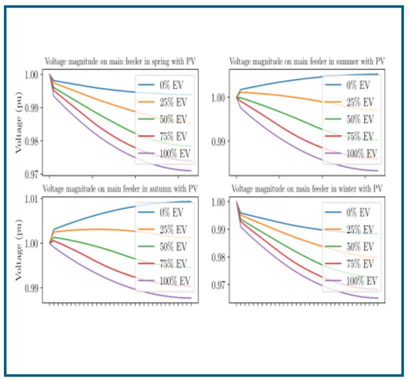


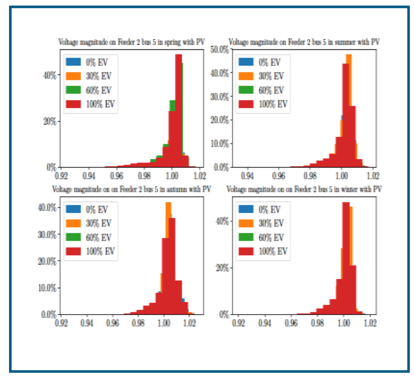
Distribution grid Germany

Typical networks in Germany

Load and generation profiles

Load flow calculations





Deterministic analysis

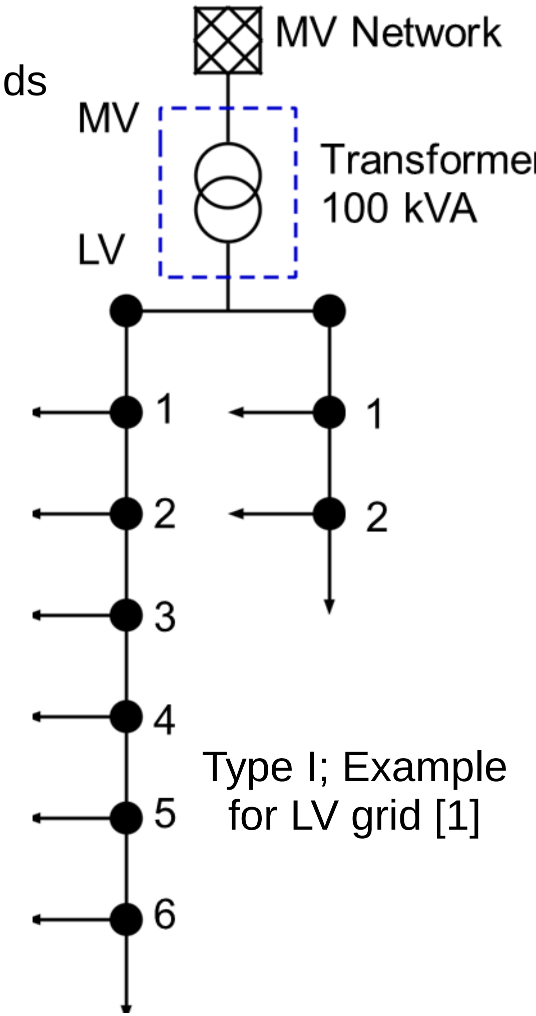
Probabilistic analysis

Typical Low Voltage Networks in Germany

- Simulations of standard or single real networks are not effective
- Use of typical networks to investigate general impacts on distribution grids
- Identified low voltage networks for Germany based on transformer ratings [1]:

Network	Type	Transformer	Households	Feeders
LV Type I	Country side	100 kVA	8	2
LV Type II	Village	160 kVA	14	2
LV Type III	Rural	400 kVA	52	6
LV Type IV	Sub urban	630 kVA	146	10

- Main feeder length with 10 different model classes [2]
- Around 87% are underground cables in LV networks
  => NAVY 4x150 mm^2 (275 A) cable was considered in the analysis
- Voltage limits (±10% for LV and MV) according to DIN EN 50160
- Transformer limit (100%)



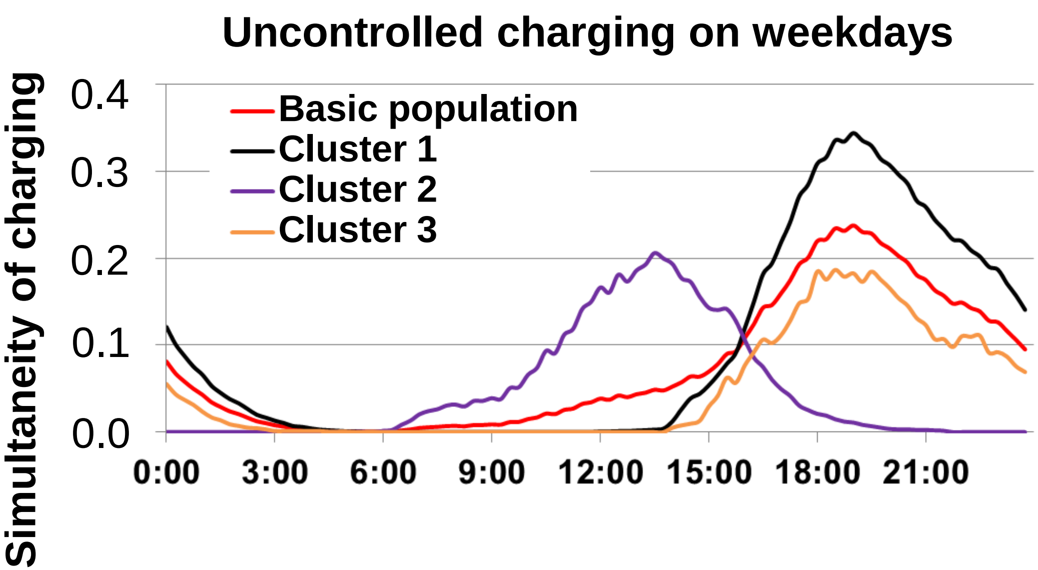
Type I; Example for LV grid [1]

[1] G. Kerber: Aufnahmefähigkeit von Niederspannungsverteilnetzen für die Einspeisung aus Photovoltaik-kleinanlagen. 2011. [2]. J. Büchner et al.: Moderne Verteilernetze für Deutschland“ (Verteilernetzstudie). 2014

Charging Profiles: Clustering of Socio-demographic Groups

Development of a structure-recognizing cluster method

- Clustering into homogeneous groups regarding charging determining parameters
- Determination of a suitable number of clusters
- Analysis of the clusters with regard to socio-demographic similarities
- Possible analysis for future demographic trends or untypical distribution of groups



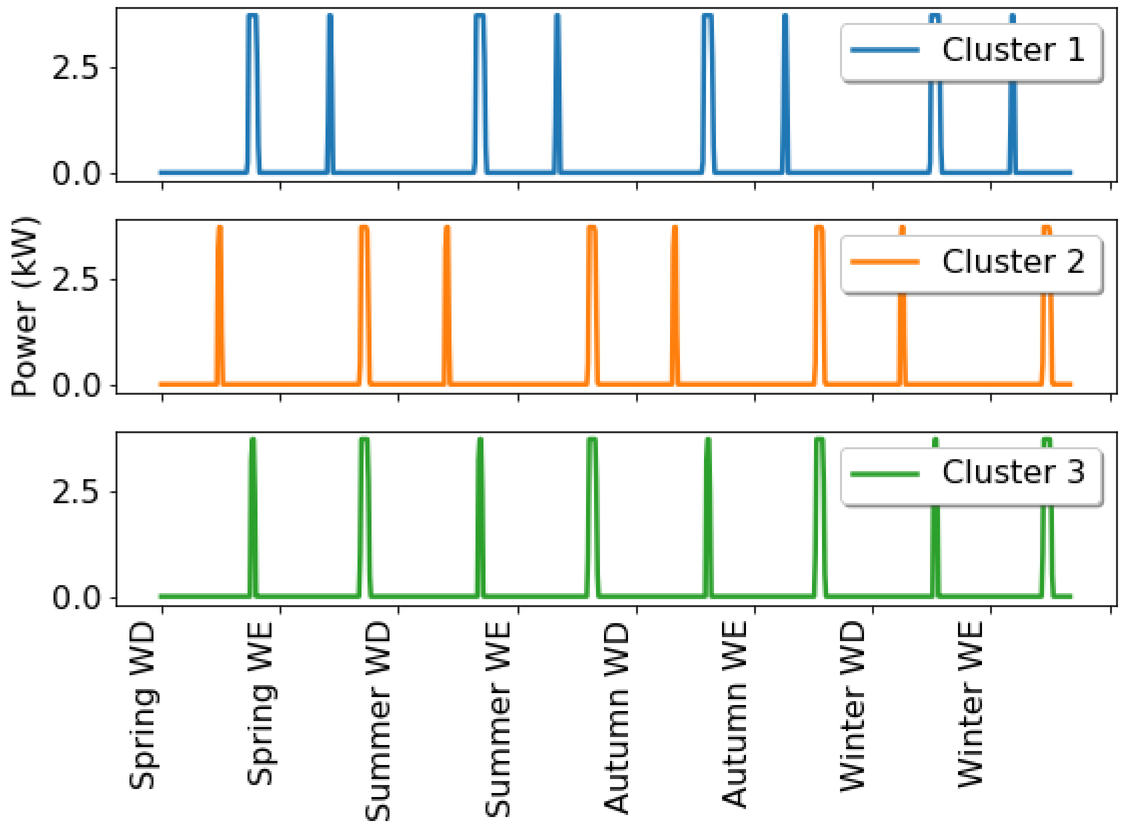
Socio-demographic Groups	Daily mileage [km]
Basic population	35.9
Education, full-time employed persons	46.8
Homemaker, pensioner, part-time employed persons	19.8
Students, others	20.9

[1] Linssen, J. (2018) : Modellierung zeitlich aufgelöster Ladeenergienachfragen von batterie-elektrischen Fahrzeugen und deren Abbildung in einem Energiesystemmodell, TU Dissertation Berlin

Demand Profiles: BEV Charging

Battery Electric Vehicles (BEVs)

- BEVs at home charging
- Assumed charging power: 3.7 kW (constant current)
- Time resolution of 15-minutes for four seasons on a typical day in the week and at weekends
- Three clusters with full-time employees (cluster 1), pensioners and housemakers (Cluster 2) and part-time employees (Cluster 3)
- Assumed BEV consumption:
  17.5 kWh/100 km
- Assumed daily traveling distance according to [1]

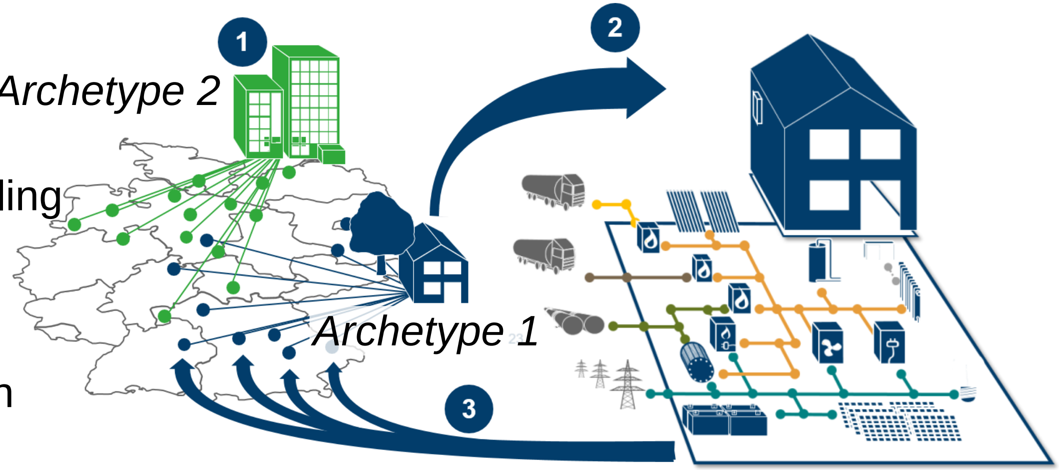


WD: weekday

WE: weekend

[1] Linssen, J. (2018) : Modellierung zeitlich aufgelöster Ladeenergienachfragen von batterie-elektrischen Fahrzeugen und deren Abbildung in einem Energiesystemmodell, TU Berlin Dissertation

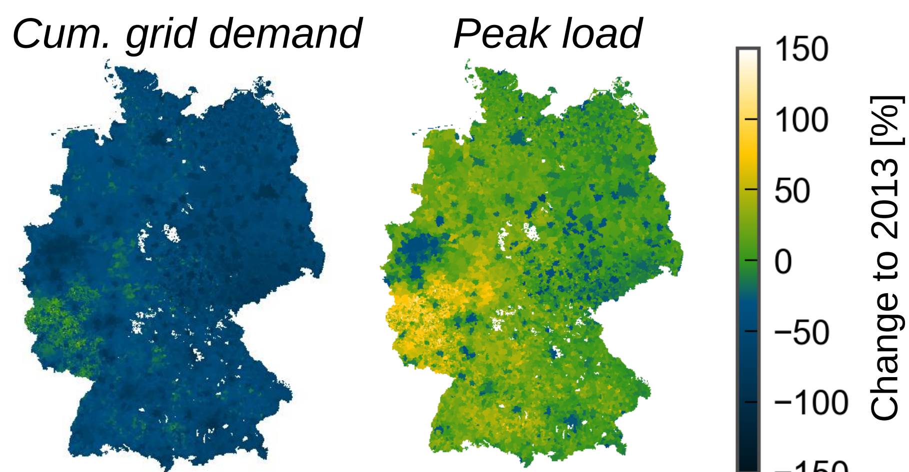
Model FINE-Residential: Demand Profiles Households



Model characteristics

- Parallel optimization[1,2] for cost minimal choice of efficiency measures, scaling and operation of technologies
- Aggregation of 200 spatially distributed archetype buildings [3] from census data on municipality level
- Aggregation of energy demand profiles to different nodes or regions and costs analysis

Change of electricity load until 2050*



Highlights

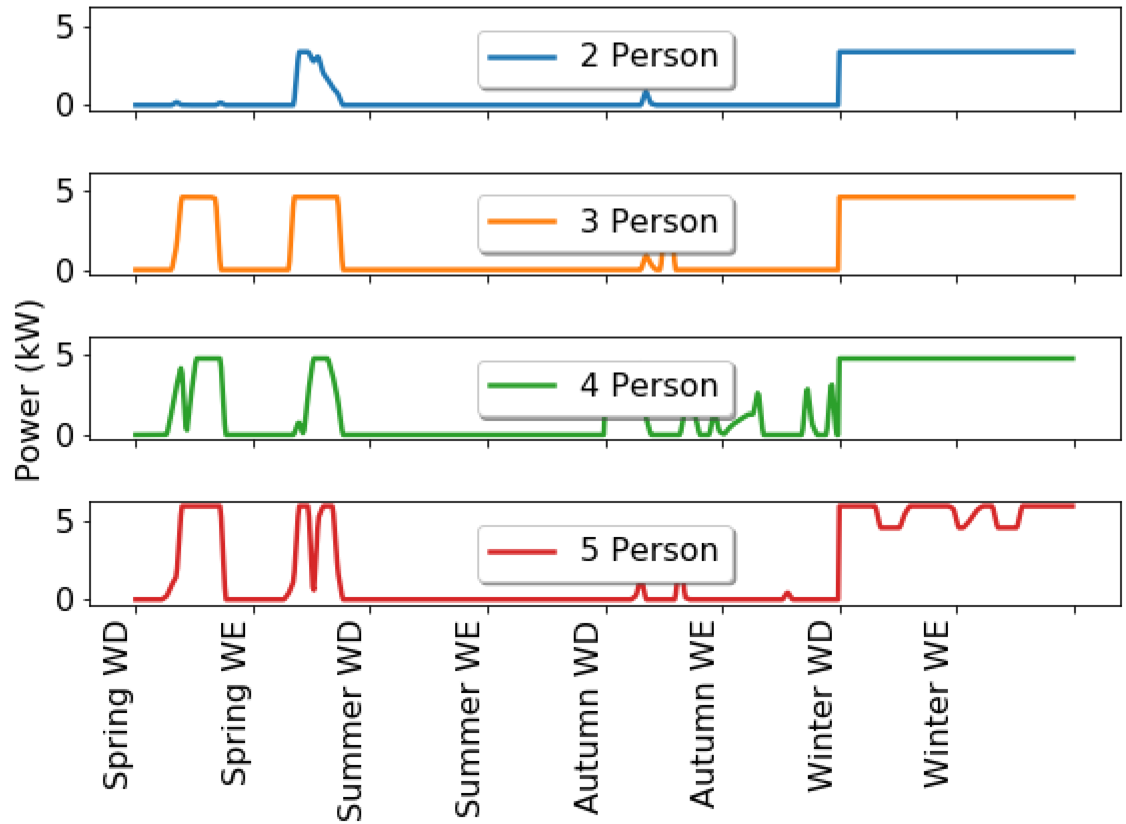
- Minimum cost scenarios[1] for energy supply in the residential sector
- Trends of supply and demand with high spatial and temporal resolution up to the year 2050

[1] Kotzur, L., et al., Impact of different time series aggregation methods on optimal energy system design. Renewable Energy, 2018. [2] Kotzur, L., et al., Time series aggregation for energy system design: Modeling seasonal storage. Applied Energy, 2018.
[3] Kotzur, L., et al., Bottom-up energy supply optimization of a national buildingstock, Dissertation RWTH Aachen

Demand Profiles for Heat Pumps

Heat pumps

- Model output of FINE-Residential
- Heat pump demand in residential households with two, three, four, five person households [1]
- Time resolution of 15-minutes for four seasons on a typical day in the week and at weekends
- Peak demand of 3.4, 4.6, 4.8, and 5.9 kW seen for two, three, four, and five person households
- Corresponding electricity demand profiles of households



WD: weekday

WE: weekend

[1]. Kotzur, L. (2018). Future Grid Load of the Residential Building Sector . RWTH Aachen, Dissertation

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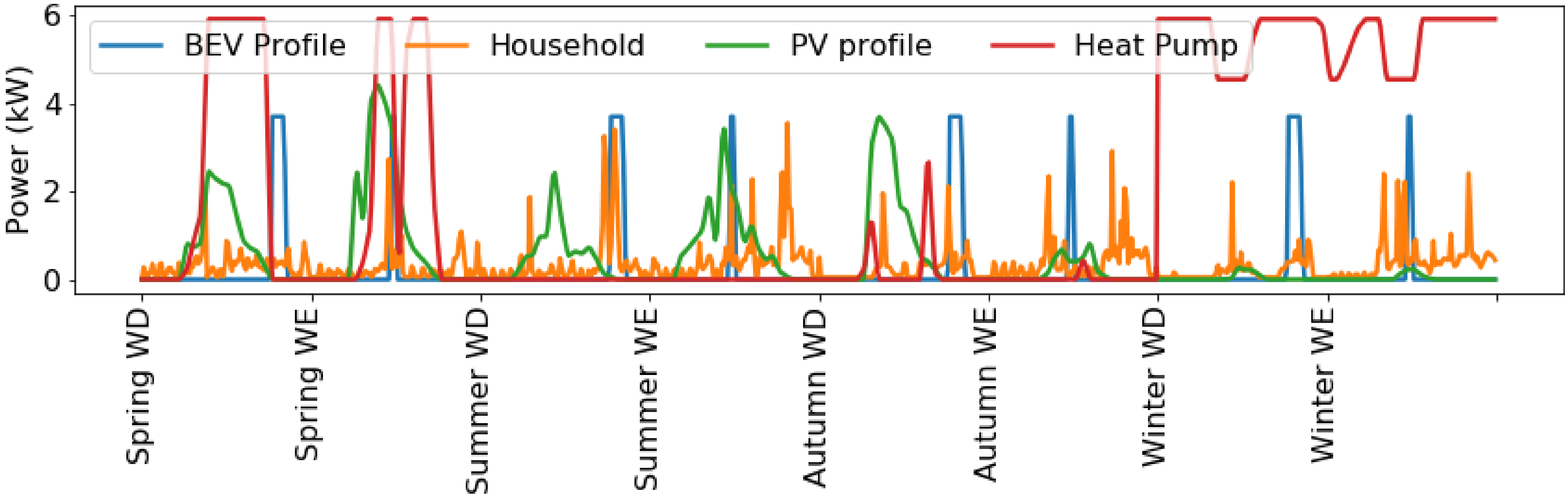
Electricity Demand Profiles



- Distributed demand with battery electric vehicles (BEVs) [1] and heat pump [2] in combination with household demand profiles [2]
- Modeling of four seasons with a typical day in the week and at the weekend (15 minutes time resolution)
- Distributed generation with solar rooftop PV (fixed generation capacity: 6 kW_{peak})
- In spring and summer time good matching of PV and additional demand; in autumn and winter mismatch of local generation and consumption resulting to high loads and simultaneity

[1] Linssen, J. (2018) : Modellierung zeitlich aufgelöster Ladeenergienachfragen von batterie-elektrischen Fahrzeugen ..., TU Berlin Dissertation
[2] Kotzur, L. (2018). Future Grid Load of the Residential Building Sector . Doctoral Thesis (submitted), RWTH Aachen.

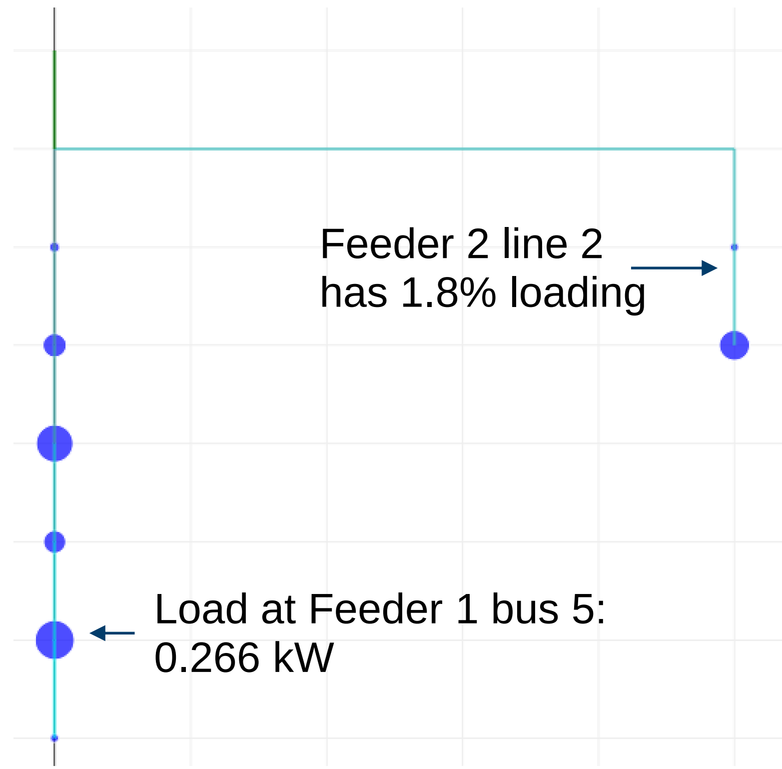
Load Flow Simulation

- Load flow simulations performed using PyPSA [1]
- Static and symmetric power flows; linear optimal power flow (Newton-Raphson algorithm)
- 10 model classes for LV networks which represents main feeder lengths [2]
- Variations of penetration of BEV, PV and heat pumps in different households (2 to 5 persons)

Approaches:

- Deterministic approach with fixed network and load configurations
- Probabilistic approach: with probabilistic assignment of BEV, PV and heat pumps to different households applied on typical grids

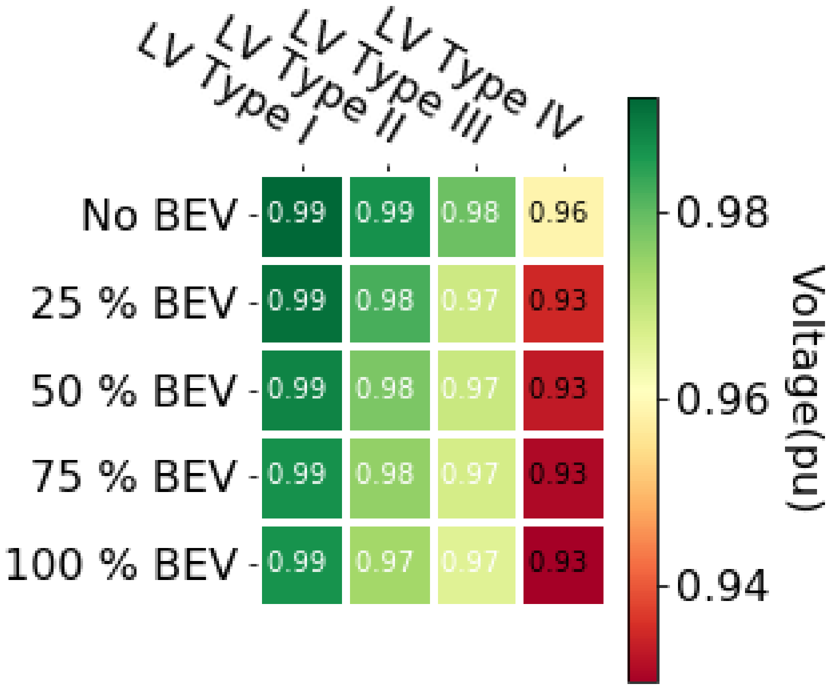
Load distribution and line loading for LV Type-I [3]; Example for Offpeak situation



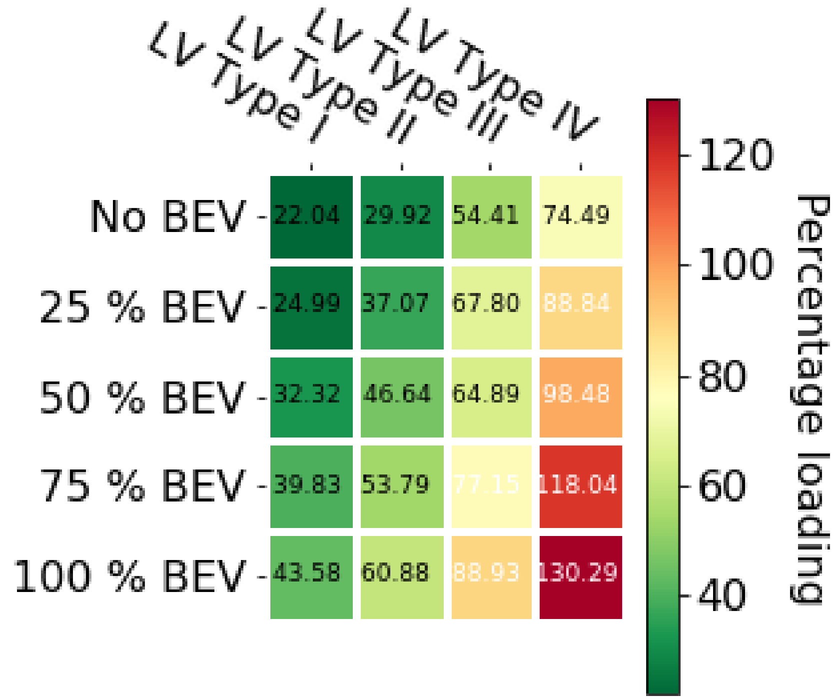
[1] T. Brown, J. Hörsch, and D. Schlachtberger: PyPSA: Python for Power System Analysis. 2017 [2]. J. Büchner et al.: Moderne Verteilernetze für Deutschland“ (Verteilernetzstudie). 2014 [3] G. Kerber: Aufnahmefähigkeit von Niederspannungsverteilnetzen für die Einspeisung aus Photovoltaikkleinanlagen, 2011.

Deterministic Analysis: Voltage Drop and Transformer Loading

- Analysis of LV networks: fixed penetration level for PV (30%) and heat pumps (30%)
- Load flow simulations with fixed network configurations



Minimum voltage magnitude (pu) depending on BEV penetration



Maximum transformer loading depending on BEV penetration

Probabilistic Analysis: Transformer Loading

30% Heat Pump

BEV [%]	0	30	60	100	0	30	60	100	0	30	60	100	0	30	60	100	0	30	60	100
PV [%]	10	10	10	10	30	30	30	30	50	50	50	50	60	60	60	60	70	70	70	70
LV Type I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LV Type II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LV Type III	0.00	0.00	0.02	2.02	0.00	0.00	0.02	1.92	0.00	0.00	0.02	1.88	0.00	0.00	0.02	1.89	0.00	0.00	0.02	1.83
LV Type IV	0.00	0.05	3.91	29.28	0.00	0.07	3.92	28.03	0.00	0.06	3.82	27.23	0.00	0.06	3.74	27.04	0.00	0.06	3.84	26.84

20
10
0

Probability of transformer loading violations

30% Solar PV

%

BEV [%]	0	30	60	100	0	30	60	100	0	30	60	100	0	30	60	100	0	30	60	100
HP [%]	10	10	10	10	20	20	20	20	30	30	30	30	40	40	40	40	50	50	50	50
LV Type I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LV Type II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LV Type III	0.00	0.00	0.03	1.94	0.00	0.00	0.02	1.94	0.00	0.00	0.02	1.92	0.00	0.00	0.02	1.94	0.00	0.00	0.02	1.92
LV Type IV	0.00	0.07	3.96	27.98	0.00	0.05	3.95	27.97	0.00	0.07	3.92	28.03	0.00	0.06	3.92	28.01	0.00	0.06	3.81	28.03

20
10
0

Probability of transformer loading violations

Summary

- Stress to distribution grid significantly depends on future consumer/ prosumer behavior and their simultaneity
- Main problems due to new consumers like BEV in distribution grids: voltage and transformer limit violations
- Low risks concerning voltage and transformer limit violations in the typical LV network type I, II, and III; LV network type IV turns out to be the critical network
- Congestions caused by BEV and heat pump operating together when limited solar PV generation is available
- Smart charging BEV can avoid grid violations but with some impacts on full usability of vehicles

Next steps

- From typical networks for distribution in Germany to synthetic networks for selected countries in Europe
- Use of open data sources for generating synthetic distribution grid topologies
- Coupling of distribution grid model with the transmission grid model Europower

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Acknowledgement to the Systems Analysis Team

Thank you for your attention!