Impact of electric vehicle charging on low-voltage grids and the potential of battery storage as temporary equipment during grid reinforcement

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Research cooperation

Karlsruhe Institute of Technology

- Institute of Electric Energy Systems and High-Voltage Technology
- Field of research:
  - Integration of energy storage
  - Smart grids
  - Modelling of power grids
  - Inductive loading of electric cars

Netze BW

- Distribution grid operator in the region of Baden-Württemberg
- 110 kV, 20 kV, 0.4 kV
- 2.28 million clients
- Headquarter in Stuttgart

Structure

- Impact of electric vehicle charging on distribution grids
- Project schedule
- Simulations
- Capacity for electric vehicles in distribution grids
- Battery storage as temporary equipment during grid reinforcement

Impact of electric vehicle charging

- Share of electric vehicles will grow continuously over the next years
- Recharging of the vehicle battery at home is a main option
- A high number of comparatively small distribution grids exist
- First problems will arise at local accumulations of EVs which are not predictable

Target 1: Identification of crucial limits for the operation of distribution grids

- Grid expansion will be necessary (3 – 12 months)

Target 2: Investigate the usage of battery storage to bypass times of grid reinforcement

Project schedule

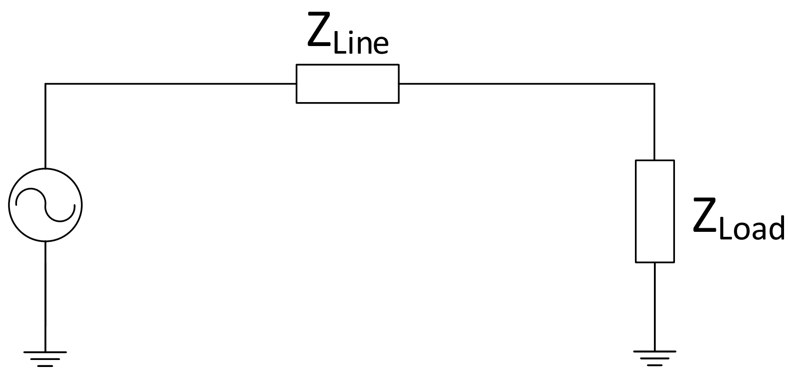
- Currently 1st step: Using a test grid with representative data from Netze BW distribution grids to develop a concept to investigate further grids
- 2nd step: Simulation with data from an existing grid
- 3rd step: Establish a field test in the simulated real grid to test the approach and validate the simulations
- 4th step: Decision about an extensive use of the idea in the Netze BW distribution grid

Limits for grid operation

- Three limits for the operation of the distribution grid have been verified during the power flow calculations:
  - Voltage drop from the LV bus bar to each point in the low-voltage grid has to be lower than 4% of the nominal voltage
  - Equipment may never be overloaded
  - The voltage unbalance has to be lower than 2%

Symmetric & asymmetric power flow calculations

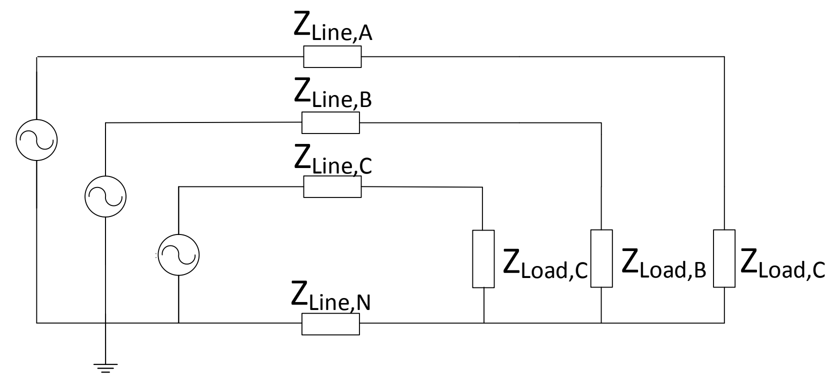
Symmetric power flow



- One-phase equivalent circuit
- Neutral line is neglected

- Used in grid planning processes by distribution grid operators

Asymmetric power flow



- Three-phase equivalent circuit
- Neutral line is not neglected

Capacity for electric vehicles in a test grid

- Order of the households with charging infrastructure:
  - Case I: Closest household to the bus bar to farthest
  - Case II: Farthest to closest household
- High penetration of charging infrastructure leads to violation of limits
  - In the used reference grid voltage sag is the limiting parameter

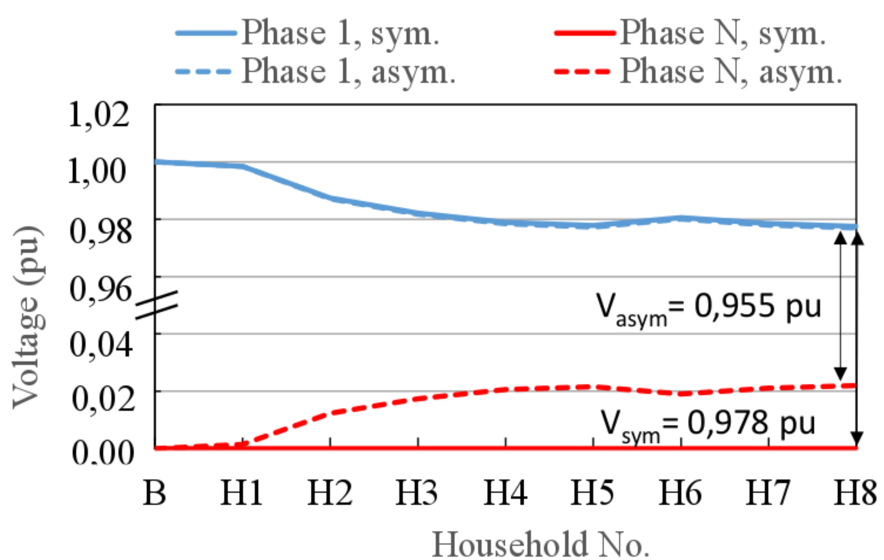
Case I:	Chargeable EVs	Max. Utilization	Min. Voltage (pu)	Max. Unbalance
1ph, 3.7 kW	7	50.6 %	0.961	0.63 %
1ph, 4.6 kW	5	45.7 %	0.966	0.54 %
2ph, 7.4 kW	7	50.6 %	0.962	0.64 %
3ph, 11 kW	8	56.1 %	0.978	0.00 %
3ph, 22 kW	7	92.5 %	0.964	0.00 %

Case II:	Chargeable EVs	Max. Utilization	Min. Voltage (pu)	Max. Unbalance
1ph, 3.7 kW	5	38.9 %	0.962	0.61 %
1ph, 4.6 kW	4	38.7 %	0.961	0.64 %
2ph, 7.4 kW	5	38.8 %	0.963	0.62 %
3ph, 11 kW	8	56.1 %	0.978	0.00 %
3ph, 22 kW	6	81.2 %	0.961	0.00 %

Errors by neglecting asymmetries

	Charged EVs	Max. Utilization	Min. Voltage (pu)	Max. Unbalance
1ph, 3.7 kW, asym.	8	56.9 %	0.955	0.71 %
1ph, 3.7 kW, sym.	8	56.1 %	0.978	0.00 %

- Voltage unbalance can not be verified using a symmetric load flow calculation
- Significant differences regarding the voltages in the grid, because power flow over the neutral line is neglected



Possibilities for distribution grid operators

- Conventional grid extension
  - Lasts approximately 3 – 12 months
- Controllable distribution transformer
  - Can be useful to reduce voltage sag, but not to prevent overloading & asymmetries. Therefore only helpful under special circumstances.
- Load management
  - No regulatory framework and not always beneficial for the distribution grid
- Battery storage
  - Task: Compensate the power used in the charging process directly
  - Recharging of the batteries in low load times
  - Universal solution
  - Fast installation possible

Battery Placement

- Decentral battery storage
  - Using a battery storage in each household that connects new charging infrastructure which leads to a violation of limits
  - Power and energy requirements of the battery storage depend on the power and energy of the charging process
  - Storing of batteries for a fast installation necessary
- Central battery storage
  - Using one battery storage in each distribution grid
  - Power and energy requirements of the battery depend on future charging infrastructure installations
  - Placement like conventional grid infrastructure

Distributed approach

- The point of installation depends on the order of installation of charging infrastructure in the grid
- Rated power of the required battery storage is maximum the power of the charging process

Case I:	Chargeable EVs	Storage Placement	Rated power of energy storage
1ph, 3.7 kW	7	-	-
1ph, 3.7 kW	8	H8	2.9 kW

Case II:	Chargeable EVs	Storage Placement	Rated power of energy storage
1ph, 3.7 kW	5	-	-
1ph, 3.7 kW	6	H3	1.7 kW
1ph, 3.7 kW	7	H3 H2	1.7 kW 3.7 kW
1ph, 3.7 kW	8	H3 H2 H1	1.7 kW 3.7 kW 3.7 kW

Centralized approach

- Rated power depends on the position of the central battery storage
- Positions far away from the MV/LV transformer are beneficial regarding the rated power

	Storage placement	Rated power of energy storage
1ph, 3.7 kW	H1	Not possible
1ph, 3.7 kW	H2	6.5 kW
1ph, 3.7 kW	H3	4.2 kW
1ph, 3.7 kW	H4	3.4 kW
1ph, 3.7 kW	H5	3.4 kW
1ph, 3.7 kW	H6	3.3 kW
1ph, 3.7 kW	H7	2.9 kW
1ph, 3.7 kW	H8	2.9 kW

Conclusion & Outlook

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- Conclusion
  - Crucial limits for the operation of distribution grids regarding EV charging have been verified
    - In the used test grid voltage sag was the major issue
  - Battery storage has been identified as possible temporary equipment during grid extension
    - Simulations have shown that they are able to ensure the operation of the distribution grid in compliance with the given limits
    - Two different approaches are presented: A centralized approach using one battery storage and a second approach using several decentralized battery storages

- Outlook
  - A distribution grid for a field-test is searched at the moment
  - Further simulations with this real grid will be performed

Thank you for your attention!