Integration of PV-Systems into German low-voltage grids

>> PV im urbanen Raum in Deutschland und Frankreich: Neue Modelle für eine intelligente Netzintegration (DFBEW, Intersolar 2018)

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- Based in Saarbrücken: ~ 55 staff
- Berlin office: ~ 3 staff
- Non-profit Ltd, main partner: Land of Saarland (~70%)
- Applied research and development
- 5 Departments
  - Energy markets
  - Material flow management
  - Infrastructure & municipal development
  - Technical Innovations
  - Environmental Psychology

The Study

- 3 Co-authors

- Interviews with 10 distribution grid operators (empirical approach)

- Large areal operators (urban and rural) with high RES-shares and PV-system shares

- „technical“ paper (Ger./Fr.)
  - What measures in construction and grid planning?
  - What changes in grid operation?

- „regulatory“ paper (Ger.)
  - Does the current regulation work?
  - What changes are desirable/necessary?

- In 2015 nearly 40 GW new PV-capacity
- Of this, 23 GW in low-voltage grids
- Mainly roof-top systems (residential and non-residential buildings)
- 90% of the systems smaller than 30 kW
- More than 800 distribution grid operators (DSOs) in Germany
- Following statements like „frequent measure“, „repeatedly utilized“ etc. refer to the number of interviewed DSO: n=10!

Grid Structure: Voltage Levels

- Grid levels are connected with „neighboring“ levels via transformers
- Voltage-ratio of transformers may be regulated for voltage control
- Exception: local distribution transformers between medium and low voltage level (fixed ratio)
- Local distribution transformer
  - Supply „normal“ consumer (housholds, business) in the local low voltage grid
  - „receive“ reverse flows in case of PV-feed-in exceed demand in the local low voltage grid

Voltage level	Nominal voltage	Grid categorie
Extra high voltage	220 kV, 380 kV	Transmission grid
High voltage	110 kV	Distribution grid
Medium voltage	20 kV	
Low voltage	400 V (0,4 kV)	

Grid Structure: Grid Topologie Low Voltage Grid

- Radial grid: single power lines lead from the local distribution transformer (LDT) to the consumer

- Ring grid: power lines leads as a closed ring back to the LDT (sometimes more than one LDT in the ring); consumers connected to Ring
  - Open ring: two power lines (=radial grid); may be switched together as a ring

- Connected lines: several lines and several LDT‘s may be connected (as a ring or as a line)

- Maintain voltage range (+/- 10% at nominal low voltage level)
  - Consumption („Load“) lowers voltage
  - Decentral feed-in raises voltage

- Avoid thermal overload (current intensity) of operating equipment
  - Load raises thermal load
  - Decentral feed-in raises thermal load

	Measure (overview)	Maintain Voltage range	Avoid thermal overload
1.	Classic grid extension	X	X
2.	Intelligent equipment	X	
3.	Grid optimization	X	(x)
4.	Grid operation and planning		

- Replacement of local distribution transformer (LDT)
  - When PV-capacity addition is high, LDT is often first bottle neck (thermal overload)
- Segmentation of local low voltage grid
  - When PV-capacity addition is very high and replacement-option of LDT exhausted
  - relatively complex, also affects medium voltage grid
  - Installation of second LDT, segmentation of local low voltage grid
  - Also relief for power lines of local low voltage grid, also helps with voltage range
- Laying parallel cables
  - Parallel cables from LDT to cable distribution box, in sum larger cross-section
  - Frequent measure, helps avoiding thermal overload and maintaining voltage range
- Increasing cross section
  - Replacement usually at the end of lifetime
  - Use larger cross sections (150-300 mm2)

- Voltage regulator (booster transformer)
  - Automatic voltage control in *one* line of local low voltage grid
  - So far mainly in individual cases or pilot projects
  - Suitable for long lines (large voltage differences between LDT and consumer or feed-in point)

- Voltage-regulated local distribution transformer (V-rLDT)
  - Voltage-ratio changes automatically (conventional LDT is fix, may be changed stepwise by hand)
  - Prevents exceeding the allowed voltage range in the event of feed-in at the end of long lines
  - Mainly pilot projects (only one DSO with a rollout-concept)

- Individual tap changing of conventional local distribution transformer (LDT)
  - Manual change (on site) of voltage ratio, lowers voltage in local low voltage grid
  - Limited by load situation, as load lowers voltage
  - Repeatedly utilized, in one case on a seasonal basis (lowering voltage in summer)

- Wide-area control
  - Changing voltage ratio between high and medium voltage grid
  - Lowers voltage for the whole supply area of a transformer substation
  - Also limited by load situation (see above) but dynamically adjustable
  - Inexpensive measure, repeatedly utilized

3. Grid Optimization (cont‘d)

- Reactive power feed-in through PV-inverters
  - Allows to exceed voltage range at feed-in point
  - Especially suitable for long lines
  - (almost) no individual specifications by DSOs; usage of industrial standards

- Changing grid topology
  - Closing of open ring grids: changes radial into ring grid, lowers resistance
  - Relocation of separation points (in case of 2 LDTs): distributes reverse flows more evenly
  - In individual cases; seen as temporary measure

- Grid monitoring
  - No real time data for operational services (voltage, current intensity) in low voltage grids
  - No planning for grid-wide measurement in low voltage grids
- Feed-in management
  - For low voltage grids (according to EEG 2012): simplified feed-in management / automatic curtailment
  - In individual cases
- Improved grid planning
  - Different approaches
  - Partly general admission for PV-systems of less than 10 kW
  - Partly usage of simulation programs also for low voltage grid, partly only in case of high PV-share
  - Partly different interpretation of Norms

Conclusions

- Grid optimization (set 3)
  - In many cases the most economical first measure
  - once potential is exhausted, more measure necessary

- Classic grid extension (set 1)
  - follows as main set of measures once potential of grid optimization is exhausted
  - Necessary to avoid thermal overload (current intensity)

- Intelligent equipment (set 2)
  - Economical only in single cases (necessary for voltage control)

- Planning and Monitoring (set 4)
  - Monitoring is considered sufficient on the medium voltage level
  - Some improvements in grid planning, different progress

- Specific grid structure: short lines, very high density of connections (consumers)

- PV-capacity additions in urban areas rather low so far…
  - Largest PV-capacity additions so far in areas with single-family houses in Southern Germany
  - Roof-top space in urban areas is limited; still, existing potential rarely used so far
  - Future PV-Systems on walls? Windows?
  - Landlord-tenant-problem; contracts for tenant according to §23b Abs. 2 EEG? (Mieterstrom?)

- Driver for urban grid expansion?
  - New PV-capacity or the rise of electric mobility? That is, new feed-in or new consumers?
  - Or do both together alleviate the grid? Open research question

Thank you for your attention!

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