Consequences on Grid Operation by Decentralized Renewable Power Generators

Consideration in the German Low Voltage and Medium Voltage Directive and related technical guidelines

UNIVERSITÄT PADERBORN
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2. Consideration of possible restrictions in the new directives for the low and medium voltage grid
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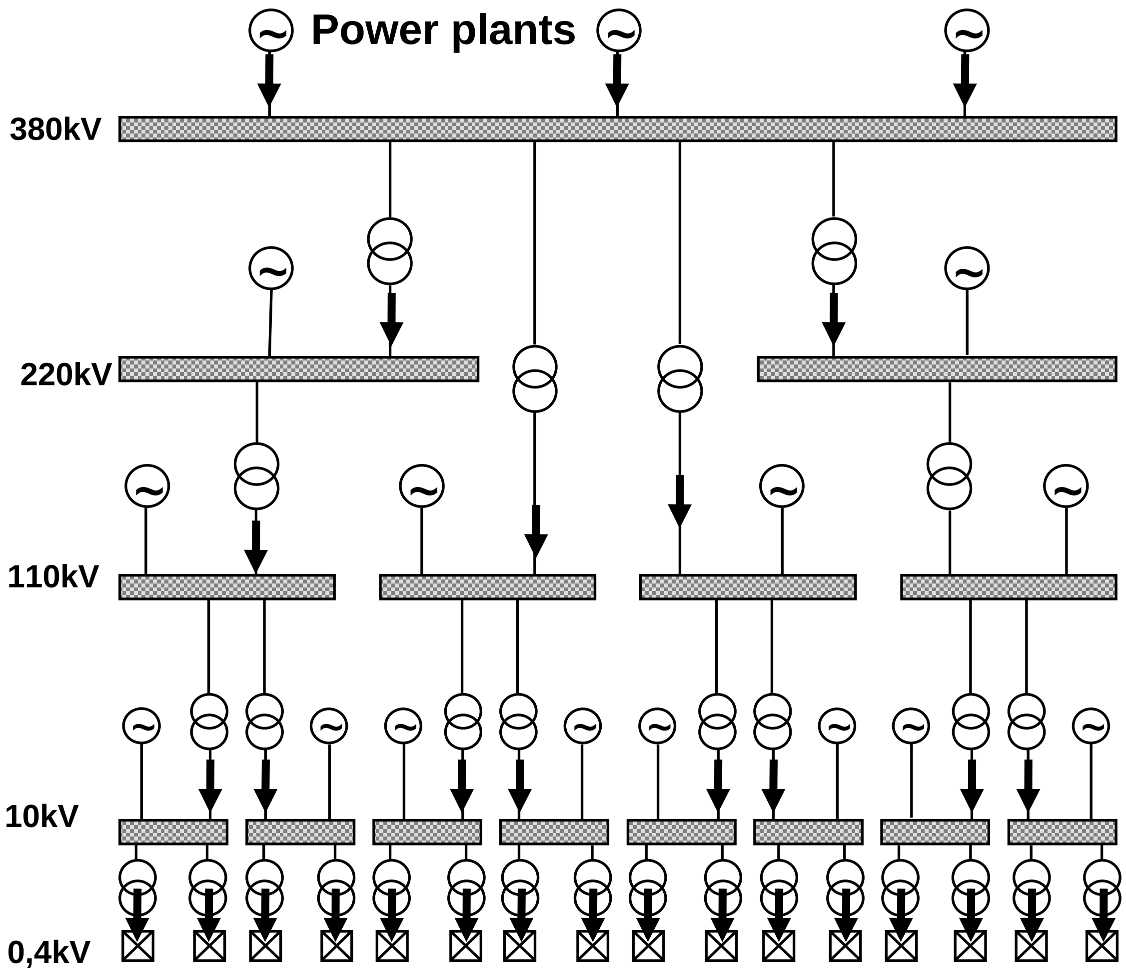
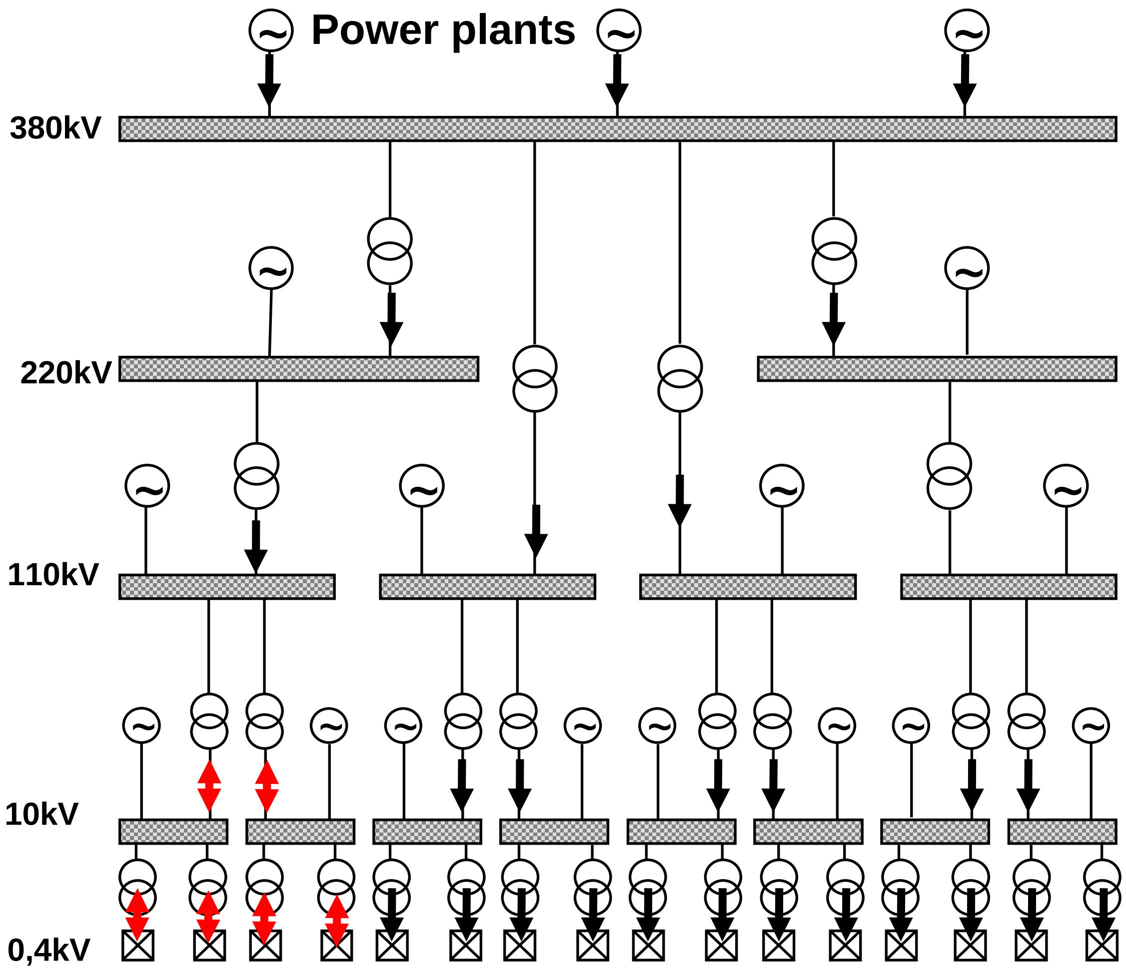
4. Are the possible restrictions reasonable? A closer look to different grid structures
5. Latest political corrections in the renewable energy sources act and its adequateness to react on the challenges – or: is energy planning allowed in

Electricity Transmission and Distribution, Yesterday



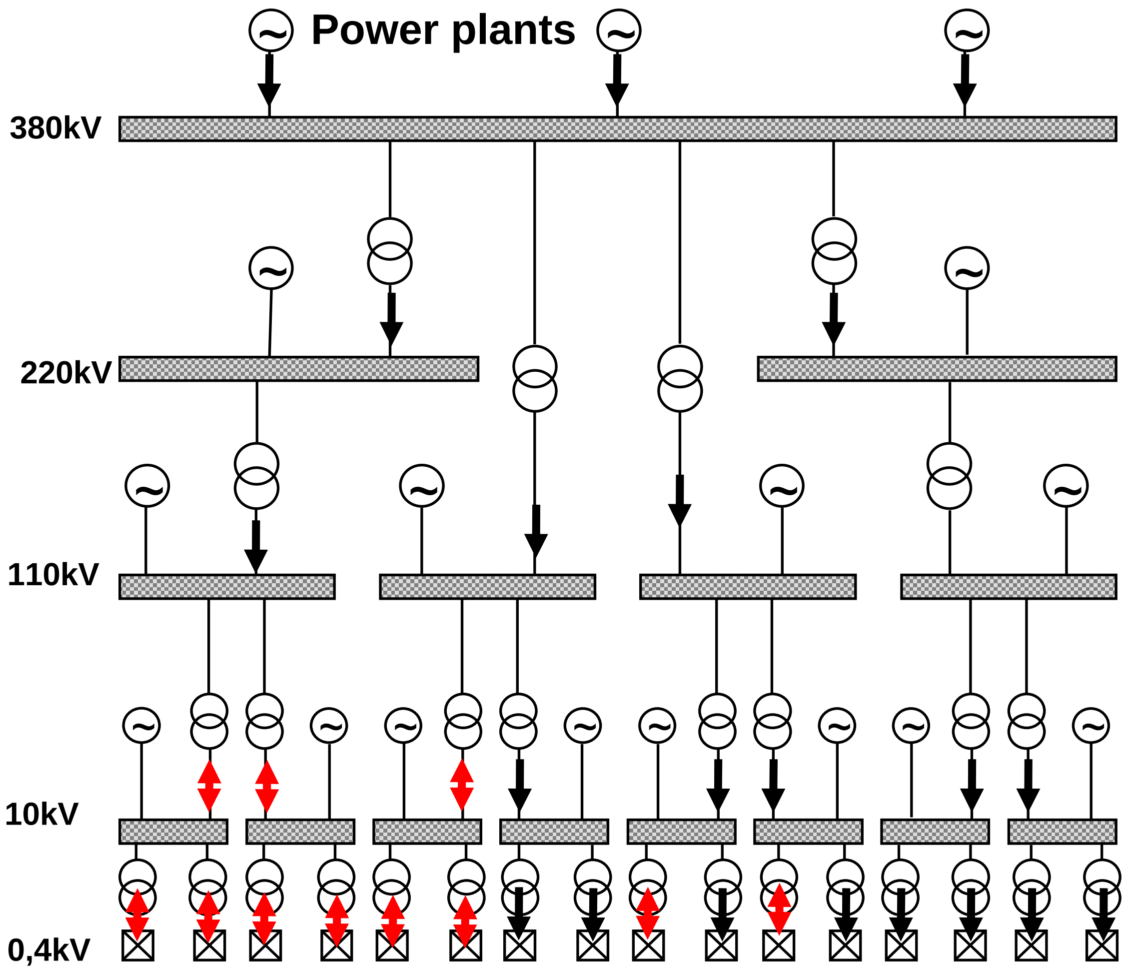
Electricity Transmission and Distribution, Today



- Generally, decentralized power generation unburdens the system!
- Lower loading of transmission and distribution equipment results in lower power losses and therefore in lower costs for grid operators

Are there other problems with decentralized generation and feeding into distribution grids?

Electricity Transmission and Distribution, Today



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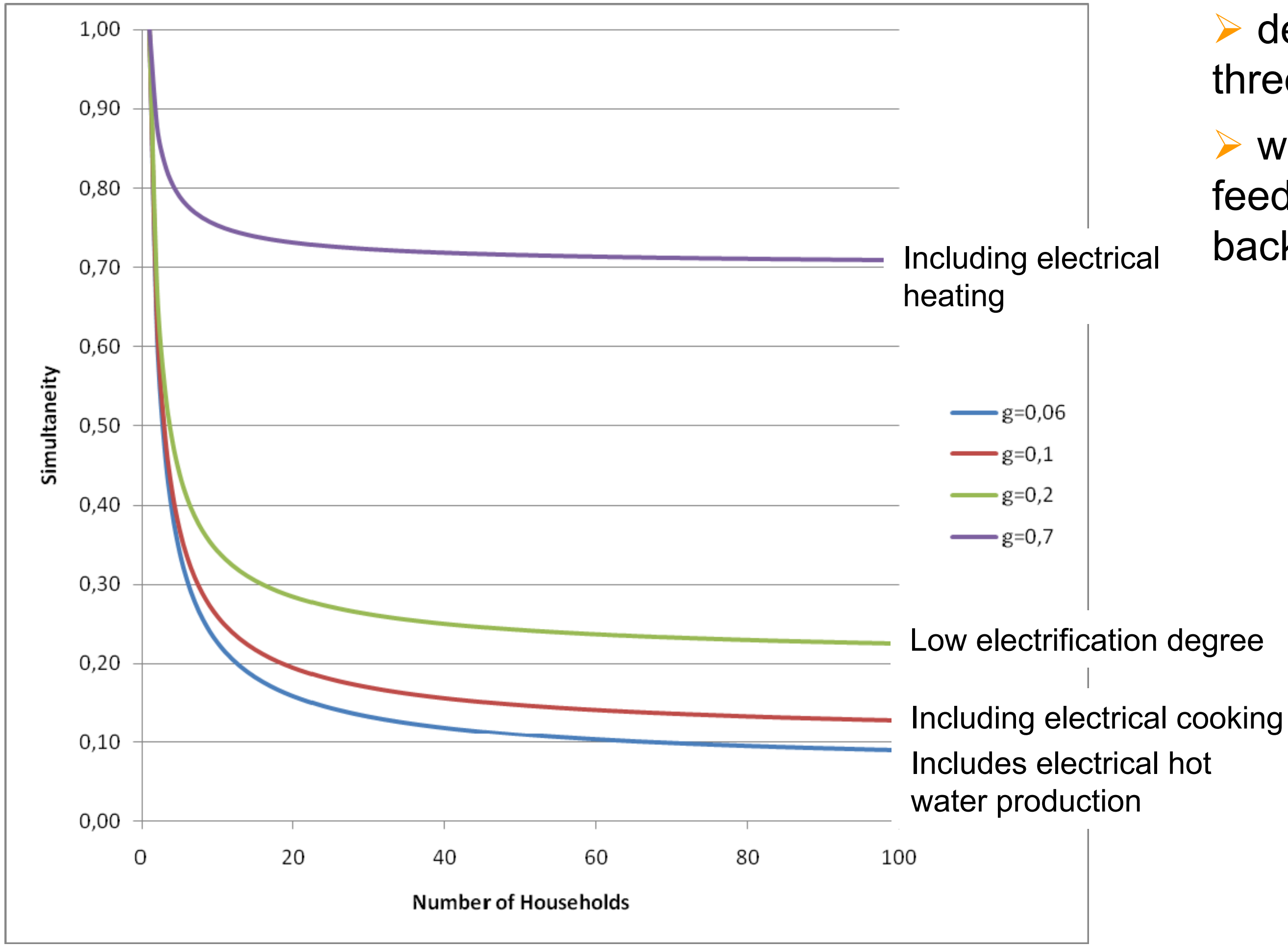
Are there other problems with decentralized generation and feeding into distribution grids?

Bottlenecks, Simultaneity



- detached house' fuse: three phase 63 A
- why can not all houses feed this power also backwards to the grid?

Simultaneity of Photovoltaic Power Systems is almost "1" (in a restricted area)

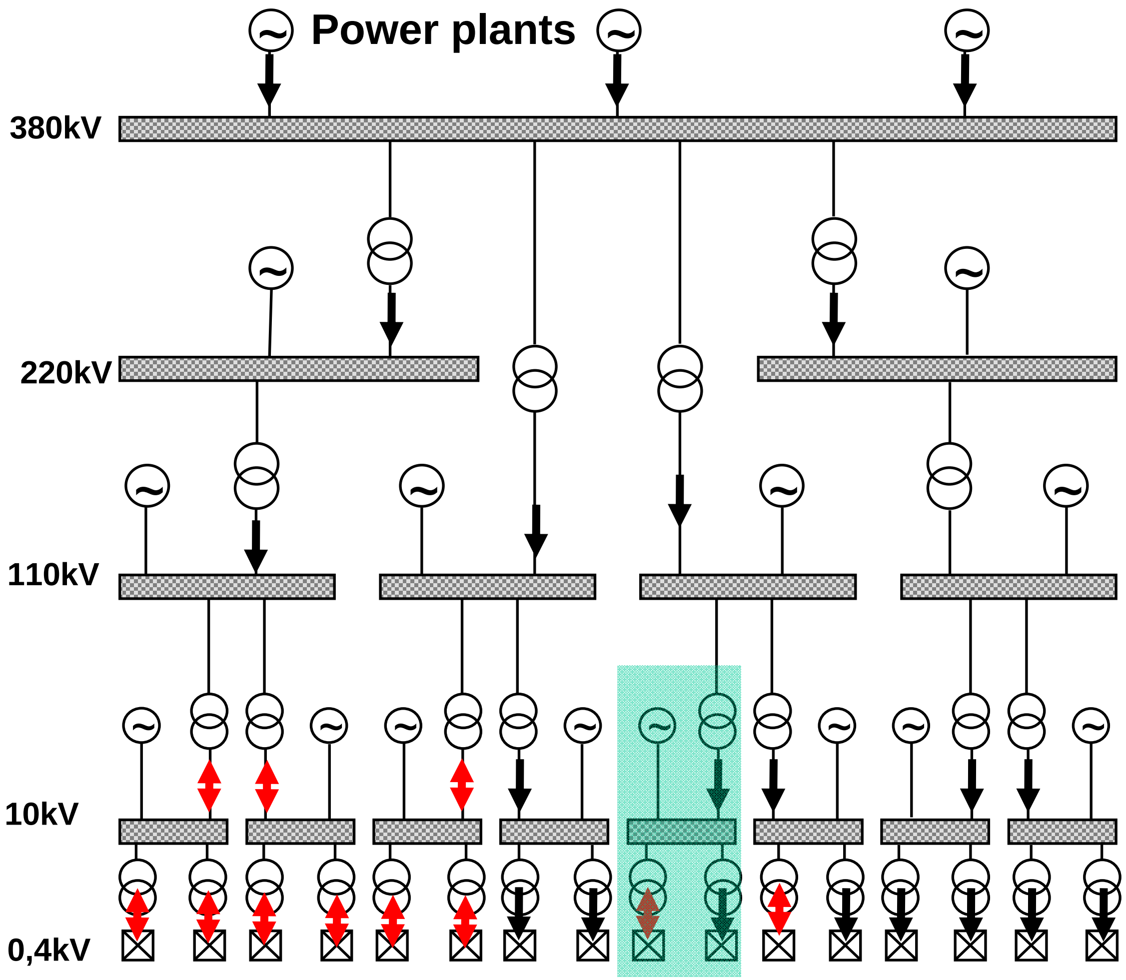
Bottlenecks, Simultaneity - Asset Loading

- Relevant assets are distribution transformers and cables
- A violation of defined loading limits either decreases the life time of the asset or even could destroy it.
- Electric currents cause losses in all assets and as a consequence they heat up.
- When the thermal load is too high aging is accelerated and life times decrease considerably (in case of short circuit currents to only few seconds).

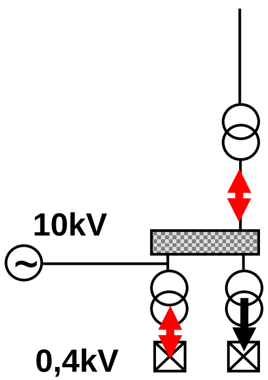
Bottlenecks, Voltage Limitations

- Voltage limits are defined in DIN-IEC 60038, VDE 0175 and DIN EN 50160.
- The voltage has to be kept within a limit of ±10% of the rated voltage
- In order to guarantee those norms different bodies have established further guidelines.
  - VDEW guidelines for parallel operation of electricity generation units in the low voltage grid. Although the voltage band allowed in low voltage grids is ±10% the guideline limits the contribution of decentralized generation with the criterion of ±2%.
  - in many other countries this is ±3%

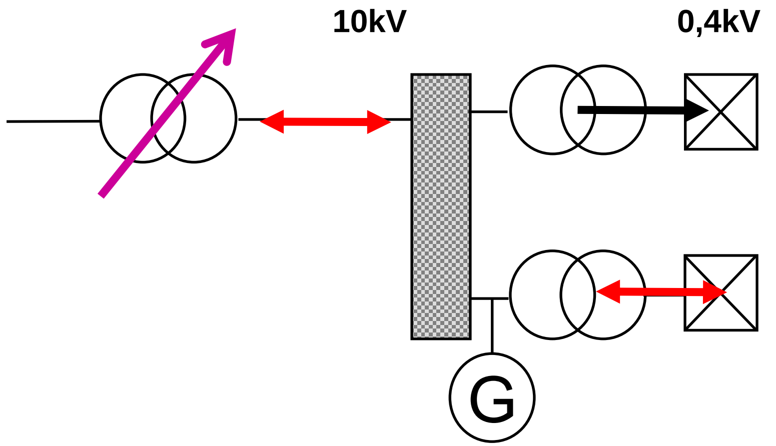
Bottlenecks, Voltage Limitations



Bottlenecks, Voltage Limitations

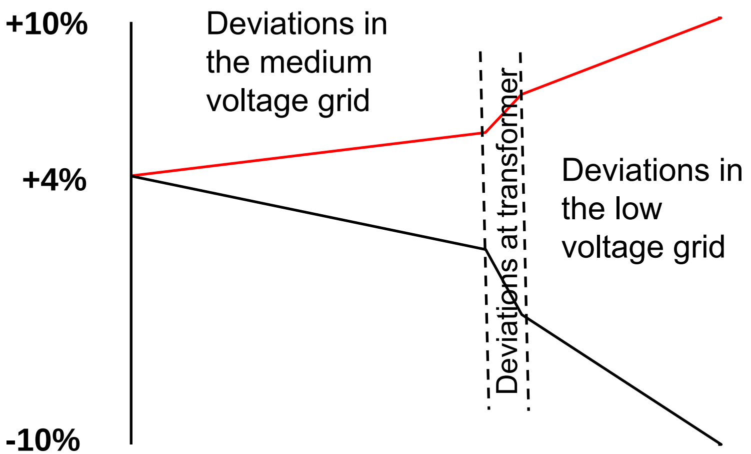


Bottlenecks, Voltage Limitations



Feeder 1:
high load, e.g.
electrical heating

Feeder 2:
high generation
Capacity, e.g. PV



When high to medium voltage transformer is at 104% the ±10% is kept with:

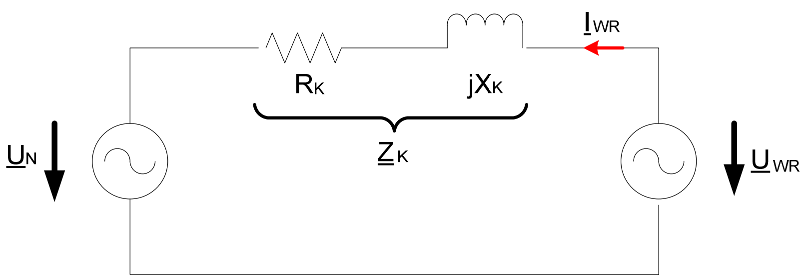
Highly loaded string:
- 5 % voltage drop in the low voltage grid
- 3 % in the distribution system transformer
- 5 % in the medium voltage grid
- 1 % safety reserve.

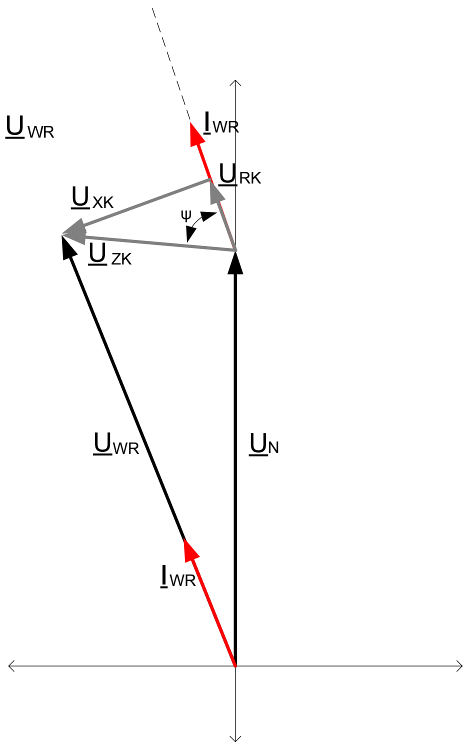
High feed-in string:
- 3 % voltage drop in low voltage grid including transformer
- 2 % voltage drop in medium voltage grid
- 1 % reserve.

Changes in Directives to cope with mentioned challenges

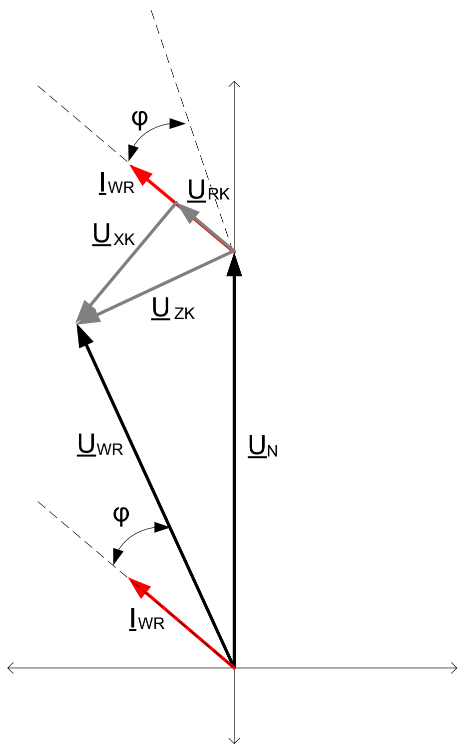
Technical solutions to overcome limitations, Voltage Violation

PV inverters can inject reactive currents in order to influence voltage and keep within the ±10% limit.



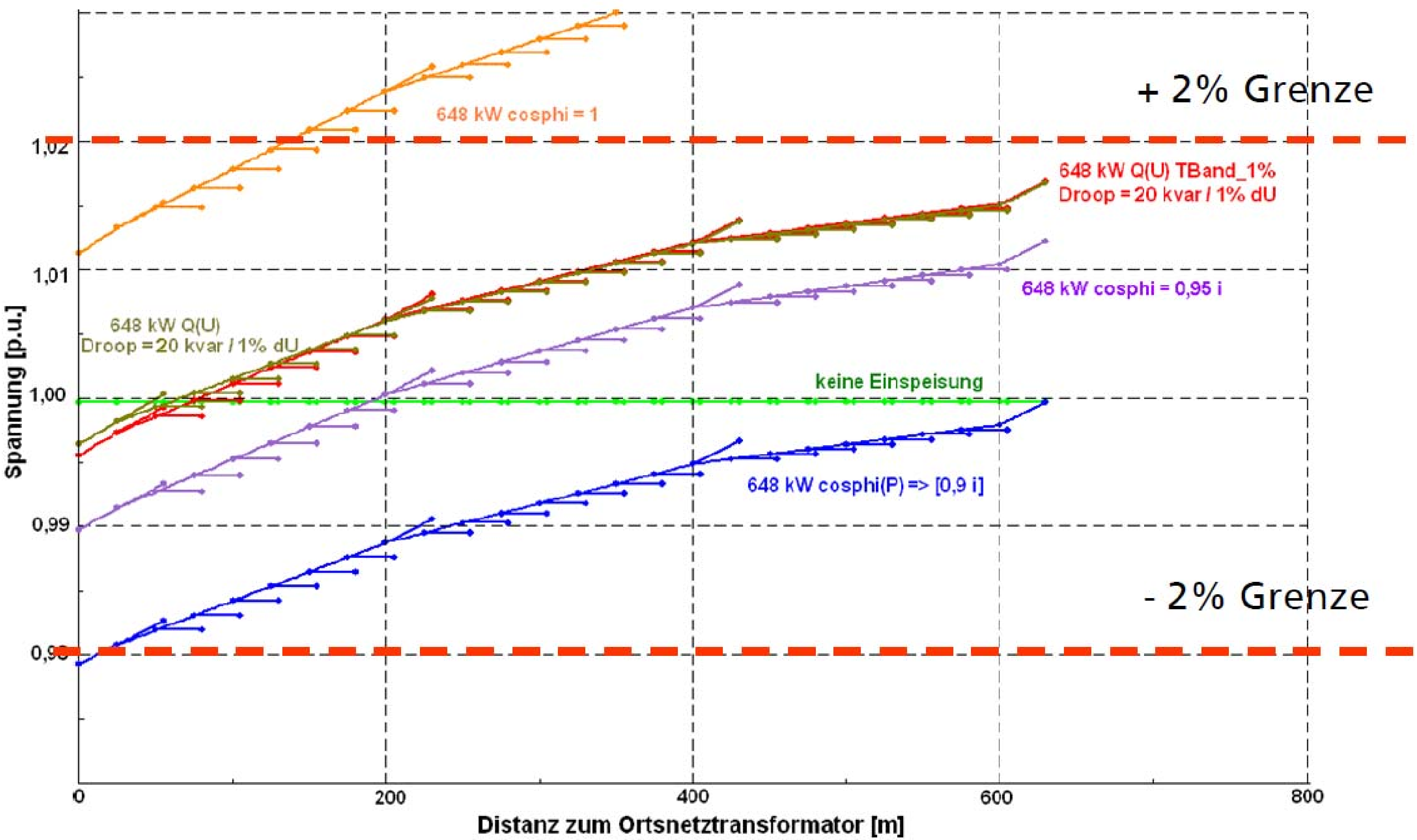


Active Power Feed-in



Reactive Power Feed-in

Technical solutions to overcome limitations, Voltage Violation



Source: Degner

VDE-AR-N 4105 with respect to voltage control

- For generation units with an

apparent power of

$$\sum S_{\max} \leq 3.68kVA$$

at point of grid connection:

- Within

$$\cos(\varphi) = 0.95_{underexcited}$$

to

$$\cos(\varphi) = 0.95_{overexcited}$$

but without any specification from

the grid operator

VDE-AR-N 4105 with respect to voltage control

- For generation units with an apparent power of

$$3.68kVA \leq \sum S_{\max} \leq 13.8kVA$$

at point of grid connection:

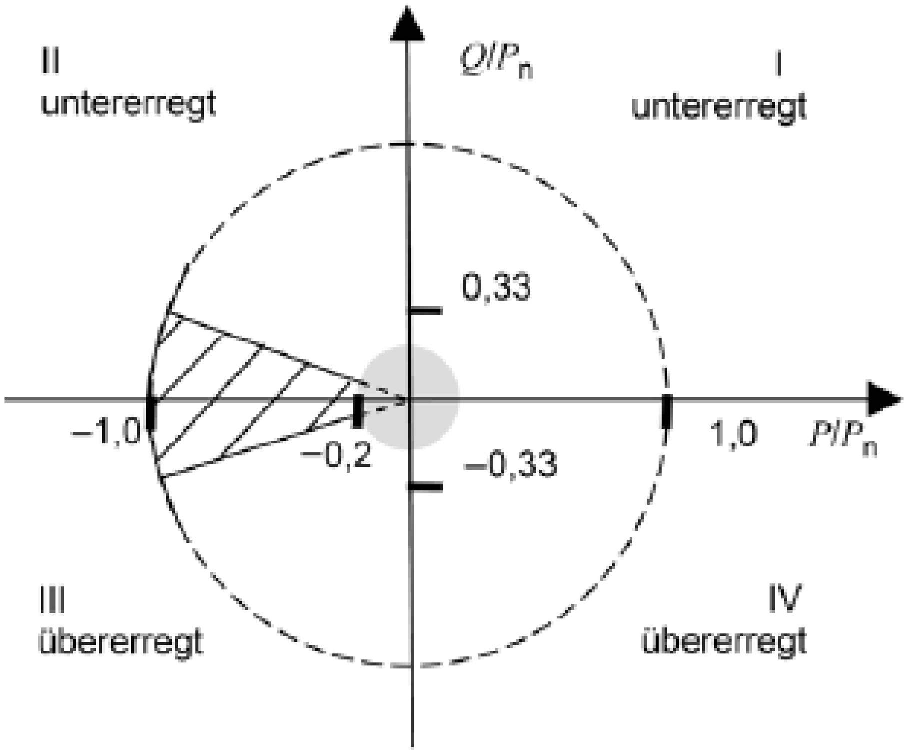
- Within

$$\cos(\varphi) = 0.95_{underexcited}$$

to

$$\cos(\varphi) = 0.95_{overexcited}$$

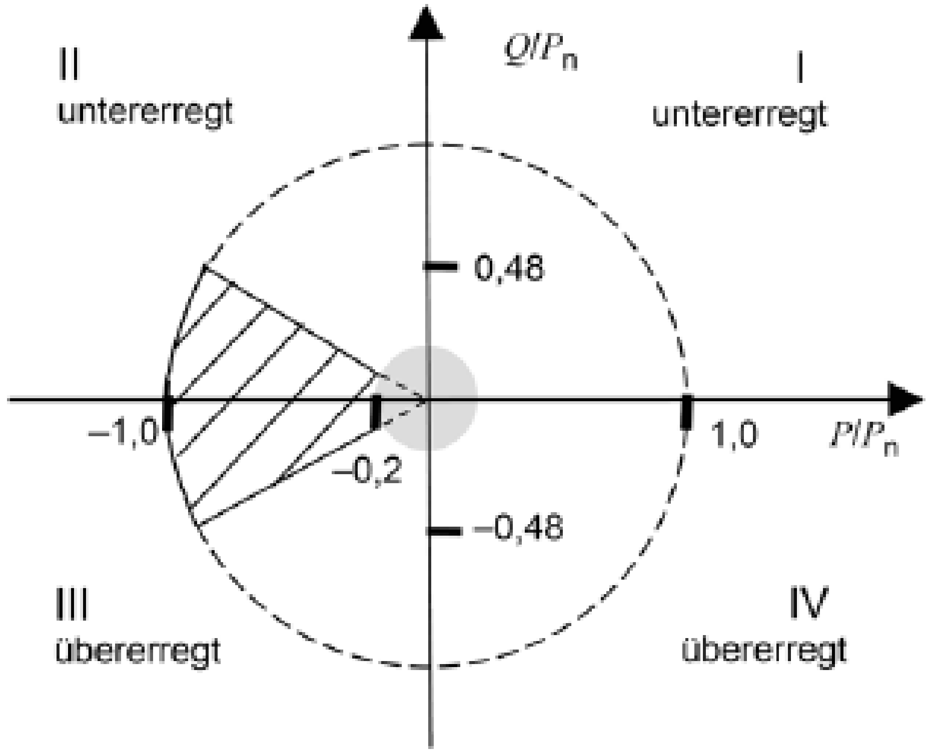
according to a characteristic curve provided by the grid operator (since 1st January 2012)



Source: VDE

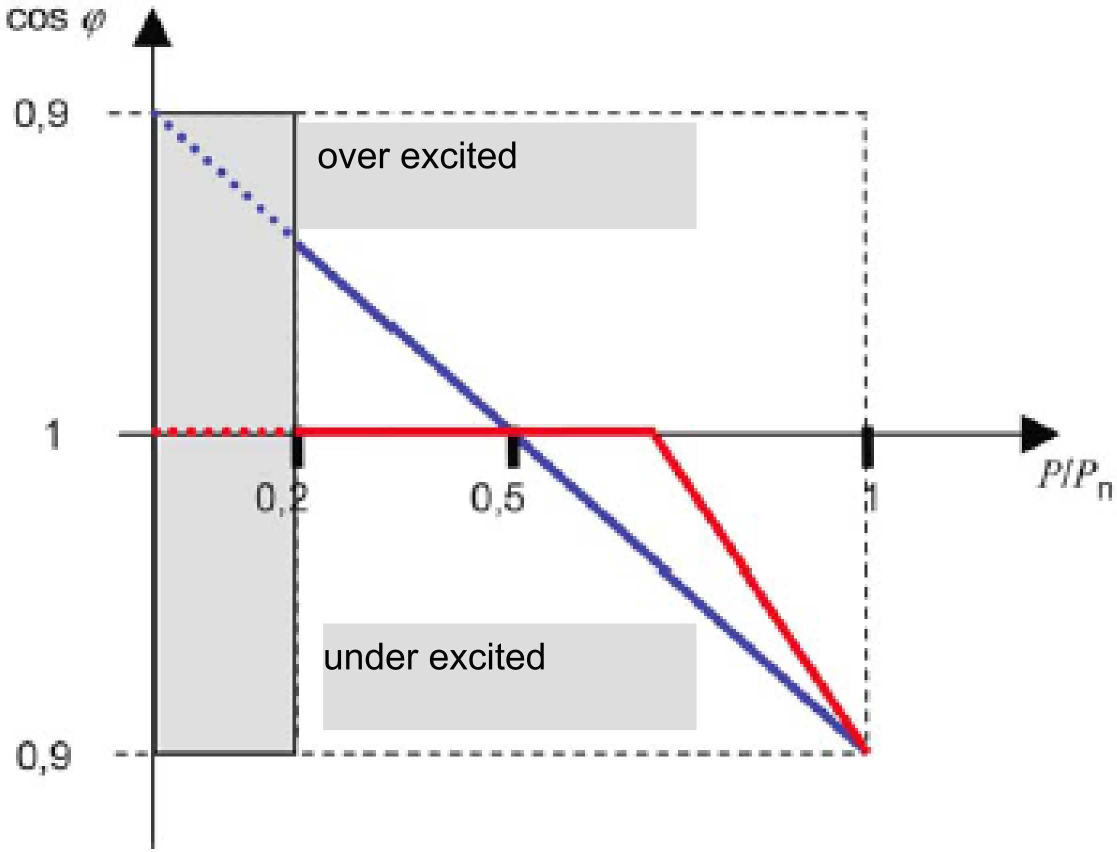
VDE-AR-N 4105 with respect to voltage control

- For generation units with an apparent power of $\sum S_{\max} > 13.8kVA$ at point of grid connection:
- Within $\cos(\varphi) = 0.90_{underexcited}$ to $\cos(\varphi) = 0.90_{overexcited}$ according to a characteristic curve provided by the grid operator (since 1st January 2012)



Source: VDE

VDE-AR-N 4105 with respect to voltage control

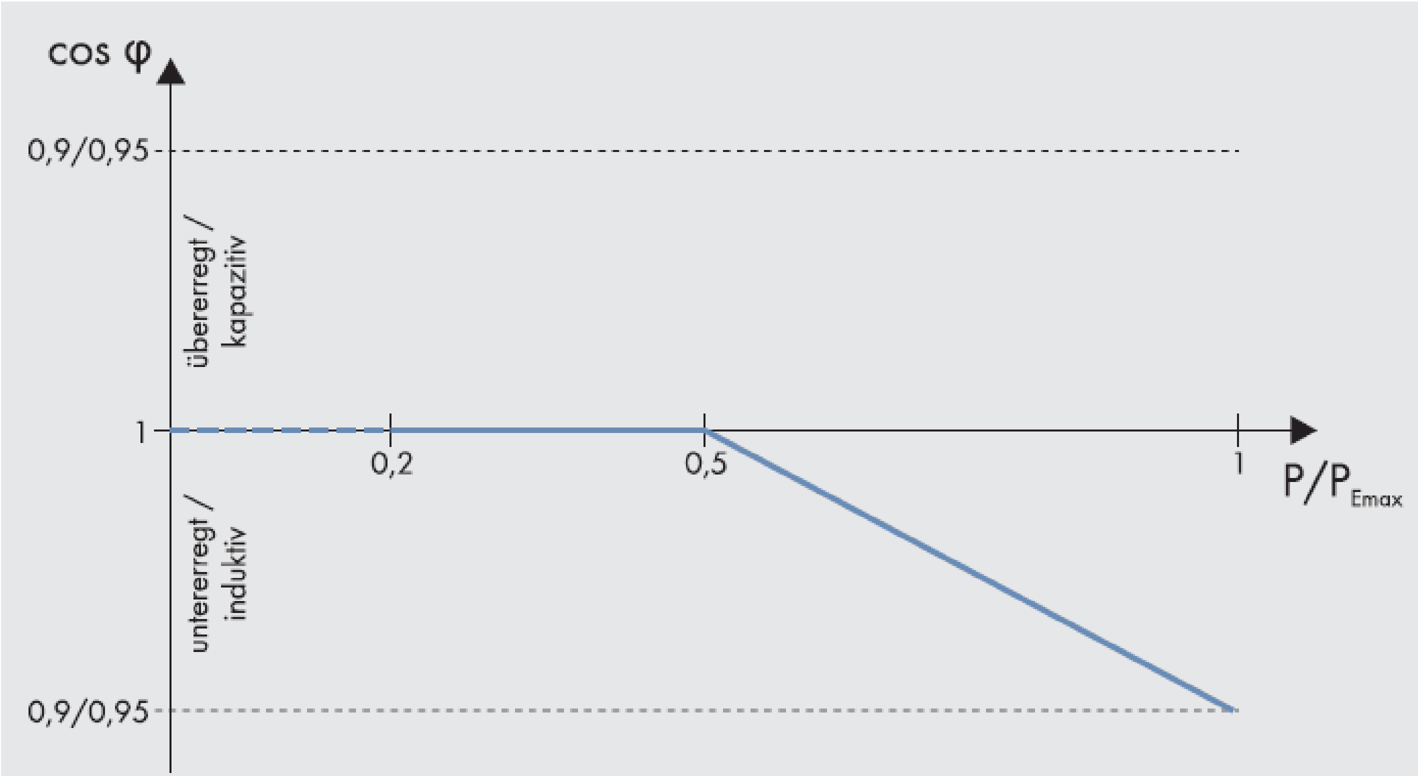


- Exemplary characteristic curves for the provision of reactive power

Source: VDE

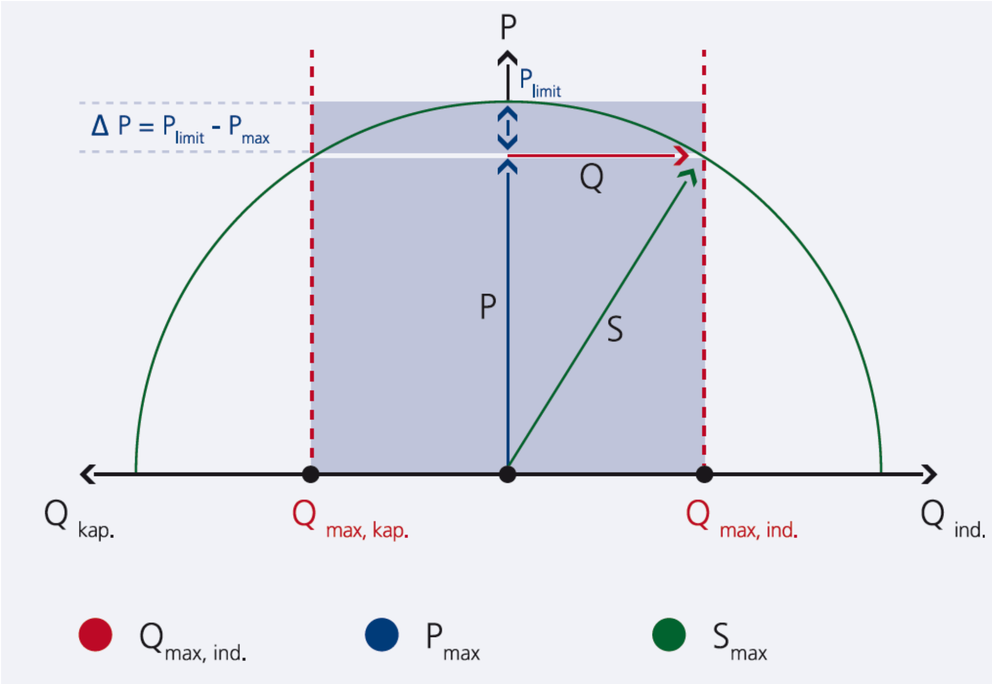
VDE-AR-N 4105 with respect to voltage control

- E.g. Factory settings of SMA inverters



Source: SMA

VDE-AR-N 4105 with respect to voltage control



- Over dimensioning required due to reactive power provision

$$S_{new} = S_{old} \cdot \frac{1}{\cos\varphi} = S_{old} \cdot \frac{1}{0.95} = 1.053 \cdot S_{old}$$

$$3.68kVA \leq \sum S_{max} \leq 13.8kVA$$

$$S_{new} = S_{old} \cdot \frac{1}{\cos\varphi} = S_{old} \cdot \frac{1}{0.90} = 1.11 \cdot S_{old}$$

$$\sum S_{max} > 13.8kVA$$

Source: KACO

VDE-AR-N 4105 with respect to asset loading and bottleneck problems

- Generation units need to be able to be operated with reduced power feed-in.
- Grid operators are allowed to decrease power feed-in or even to switch generation units off when one of the following circumstances appear:
  - danger of secure grid operation
  - bottlenecks / overload of grid infrastructure
  - danger of islanding
  - danger of static or dynamic grid stability
  - dangerous frequency increase
  - maintenance work or construction activities
- Practical implementation has been done via ripple control signals with four contacts. Each contact was representing a power level – 100%, 60%, 30%, and 0% of the nominal power.

VDE-AR-N 4105 with respect to asset loading and bottleneck problems

- For the resulting minor power generation the renewable energy sources act foresees a financial compensation.
- For new installations since 1st January 2012 this rule is now valid for all generation units, even those with a nominal power of less than 100 kW.
- For generation units with a nominal power of less than 30 kW it is possible to equip a photovoltaic power generator with an inverter that only supplies 70% of the photovoltaic DC generator.

Renewable Energy Sources Act with respect to asset loading and bottleneck problems

Generation units with a DC power of less than 30 kW:

- power is controllable remotely by the grid operator
- for this power class alternatively the generation unit operator can equip a photovoltaic power generator with an inverter that only supplies 70% of the photovoltaic DC generator.

Generation units with a DC power between 30 kW and 100 kW:

- power is controllable remotely by the grid operator
    - valid since 1st January 2012
    - for generation units installed between January 2009 and December 2011 this becomes valid with 1st January 2014

Renewable Energy Sources Act with respect to asset loading and bottleneck problems

Generation units with a DC power exceeding 100 kW:

- power is controllable remotely by the grid operator
- to call up the current electricity feed-in at any given point in time to which the grid system operator may have access
  - valid since 1st January 2012
  - for all other units installed earlier this becomes valid with 1st July 2012

Guidelines about generation units connected to the medium voltage grid

- Almost the same as in low voltage, but…

Guidelines about generation units connected to the medium voltage grid with respect to dynamic voltage control

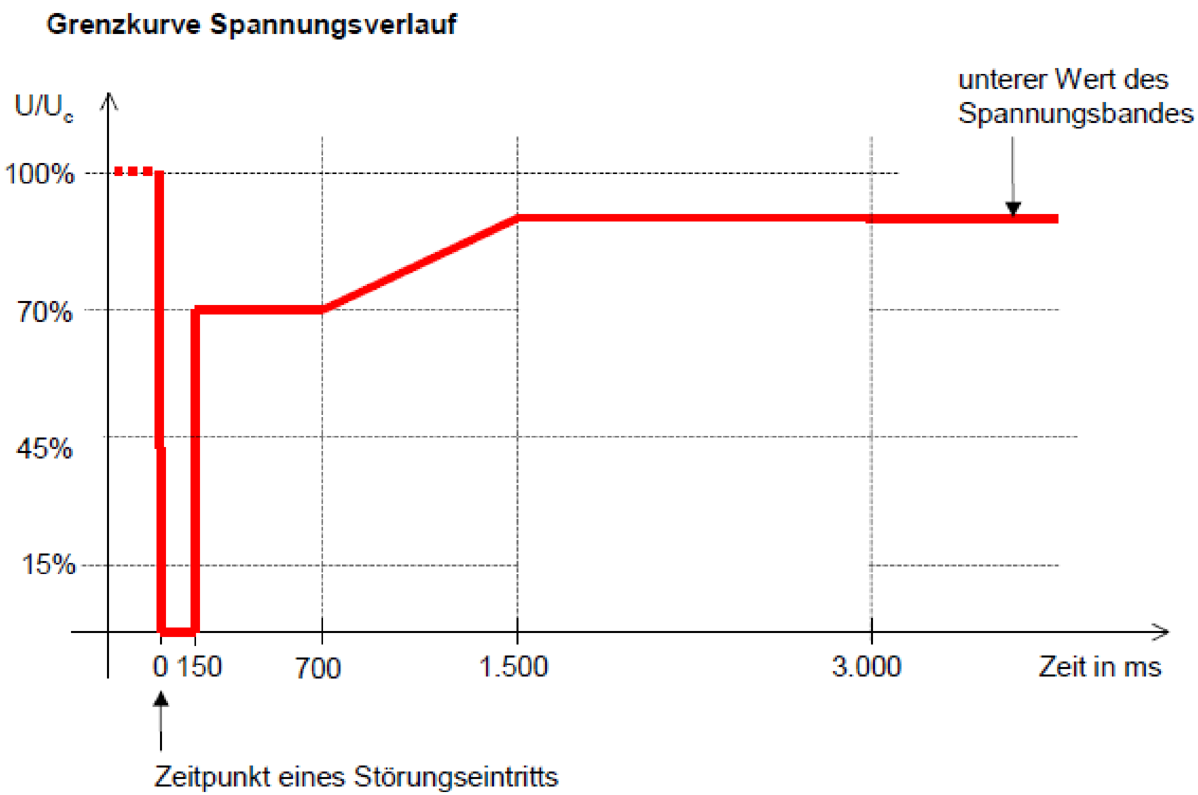
Even renewable power generation units connected to the medium voltage grid need to be able to:

- remain connected at the grid in case of grid faults
- support grid voltage during a grid fault by feeding reactive currents to the grid
- after clearing of the grid fault not to absorb more reactive power than before the fault

Guidelines about generation units connected to the medium voltage grid with respect to dynamic voltage control

Generation units connected to the grid via synchronous generators:

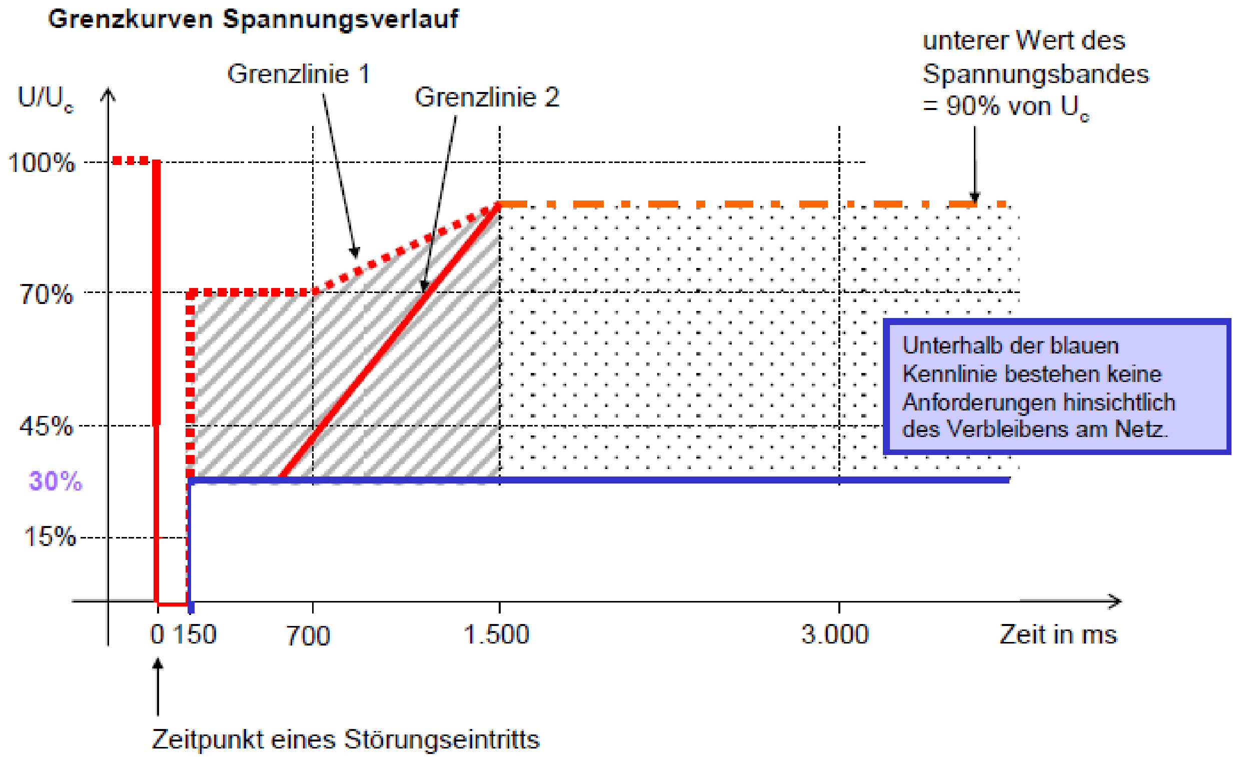
- above the red line generation units are not allowed to be disconnected



Guidelines about generation units connected to the medium voltage grid with respect to dynamic voltage control

Generation units connected to the grid, else than via synchronous generators:

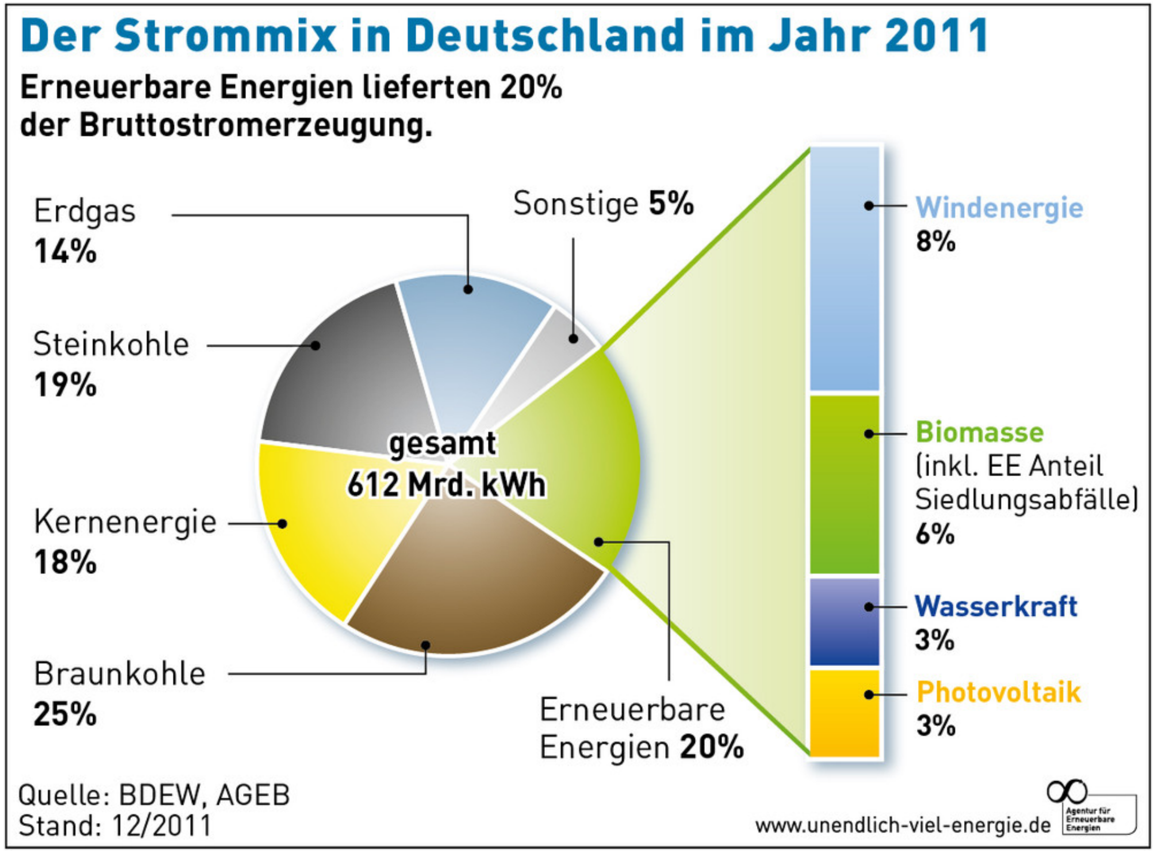
- above the red line generation units are not allowed to be disconnected



Frequency Control in low voltage grids ???

… but first a look to success of decentralized power generation

Power Generation Mix in Germany 2011

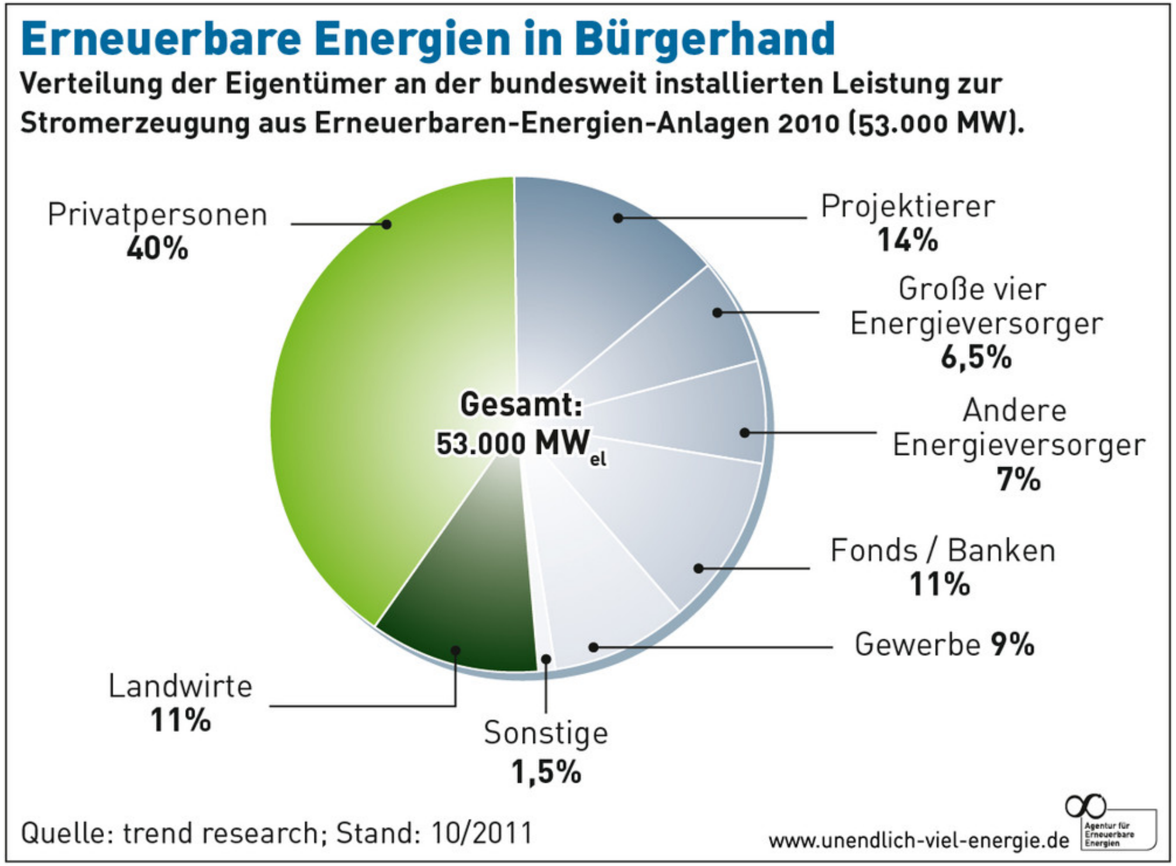


- 20 % Renewable Power
- 8 % Wind Power
- 6 % Bio-Energy
- 3 % Hydro Power
- 3 % Photovoltaics

Power Generation Mix in Germany 2011

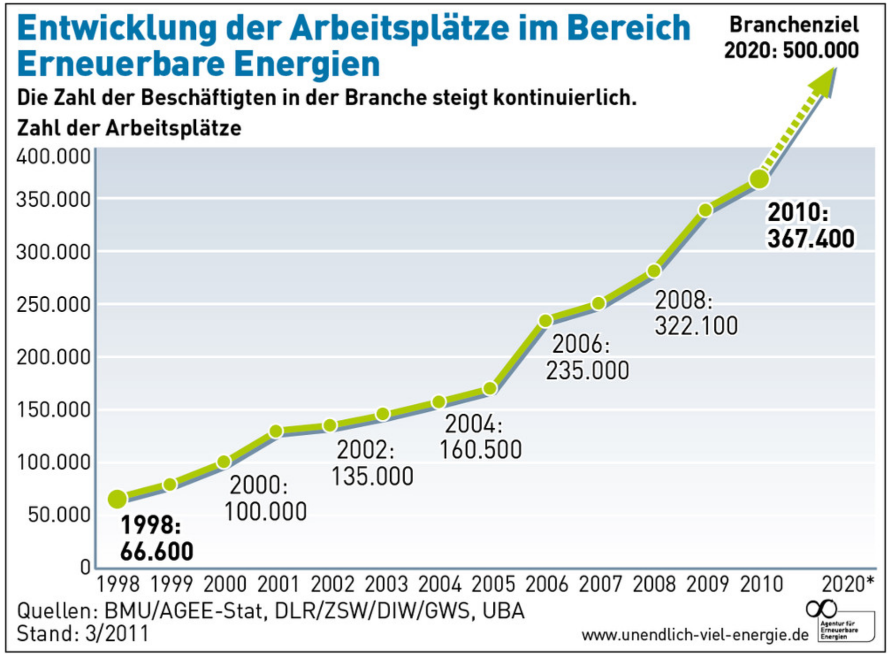
- Renewable Energy Act triggered enormous private investments in power generation capacities
- many of them are small scale units installed in the distribution grids
- comparable capacity increases are almost impossible with large centralized units in a comparable time scale
- this brought mayor changes in several parts of society …
- … but for sure also in grid management

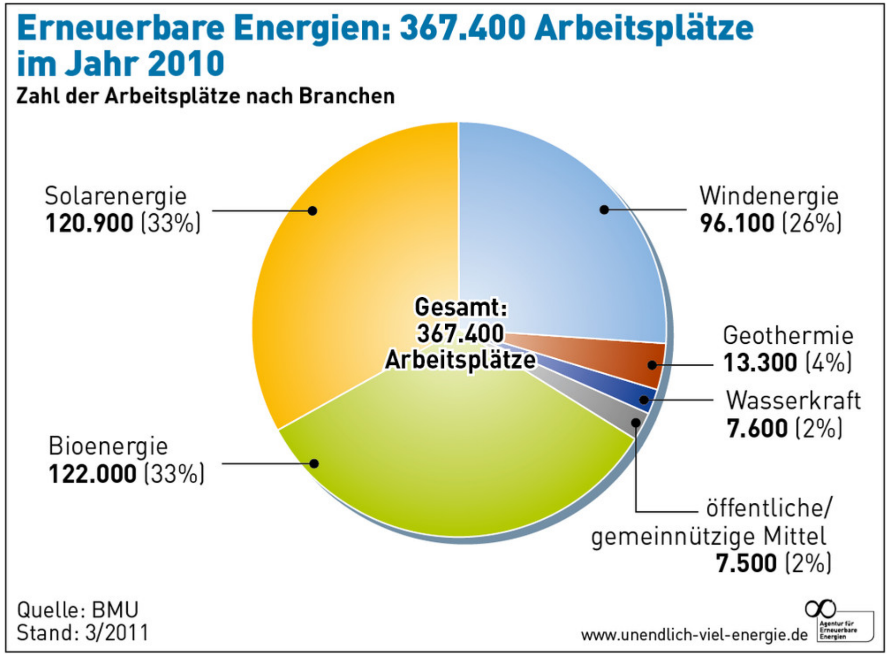
Ownership of renewable power generation capacity



- 53 GW renewable generation power
- more than half are private investments
- 40% private persons
- 10% farmers
- only 13% utilities

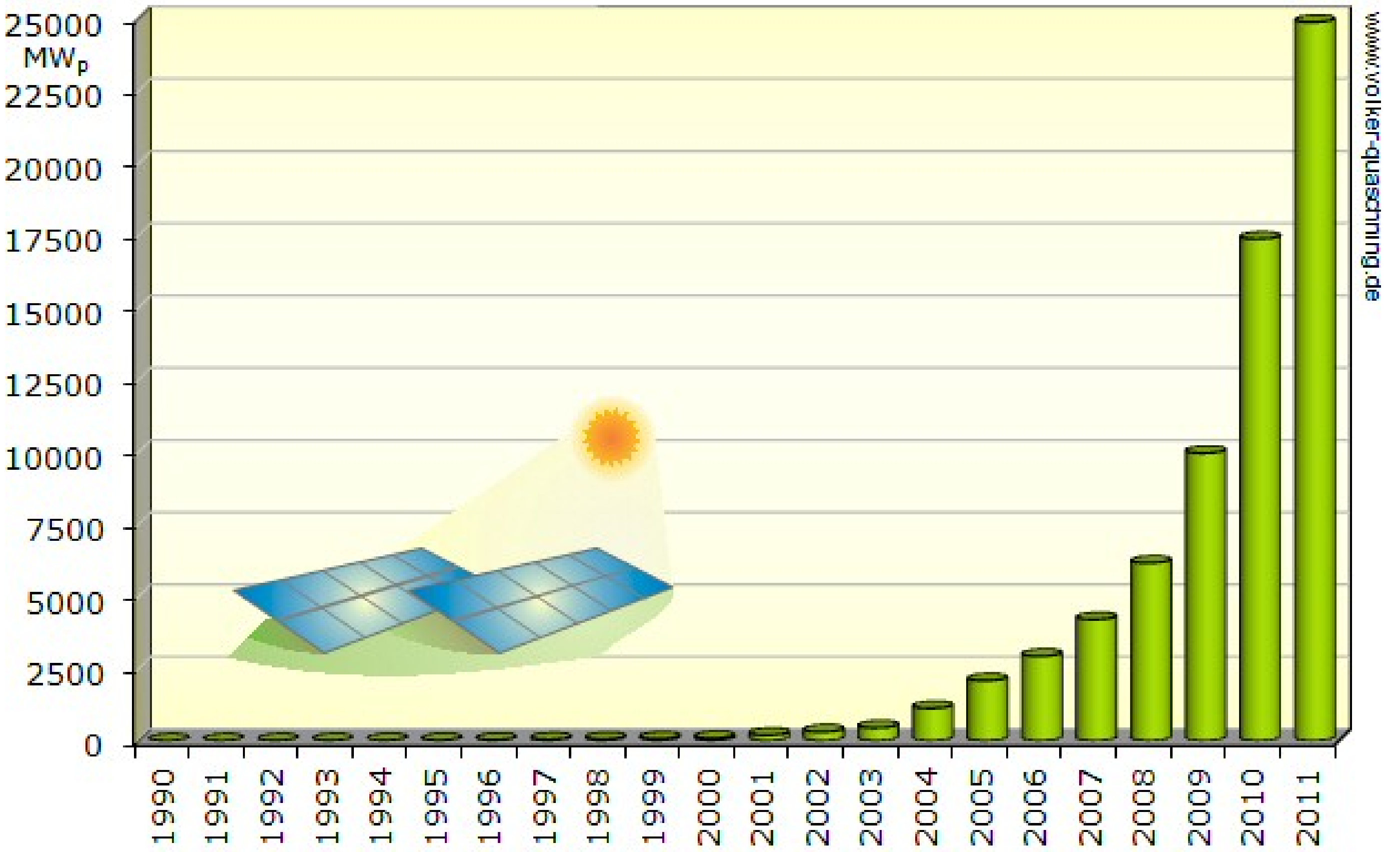
Job creation in renewable power sector





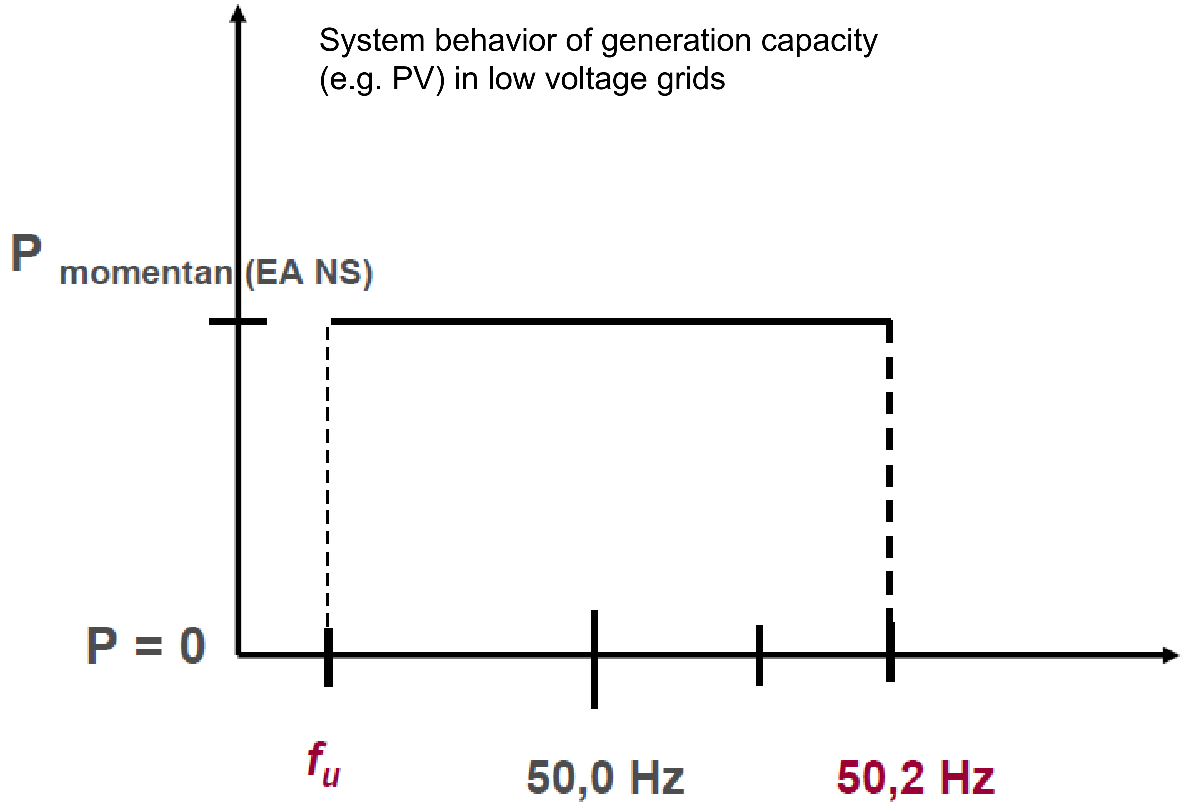
- more than 300.000 new jobs since the year 2000
- more or less equally distributed in wind power, bio energy and photovoltaics

Photovoltaics in Germany

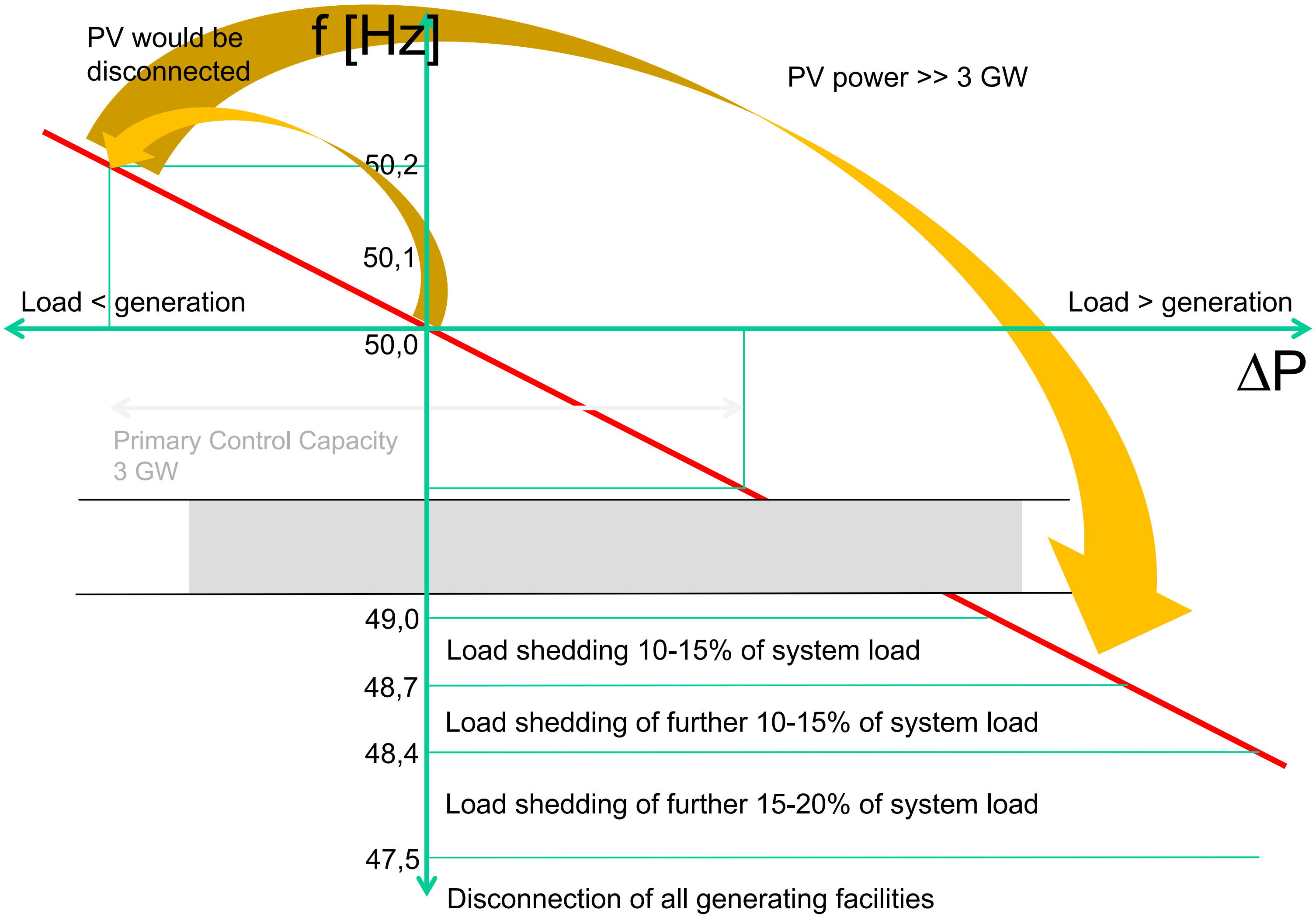


- two times Itaipú distributed in about one million small scale installations all around the country

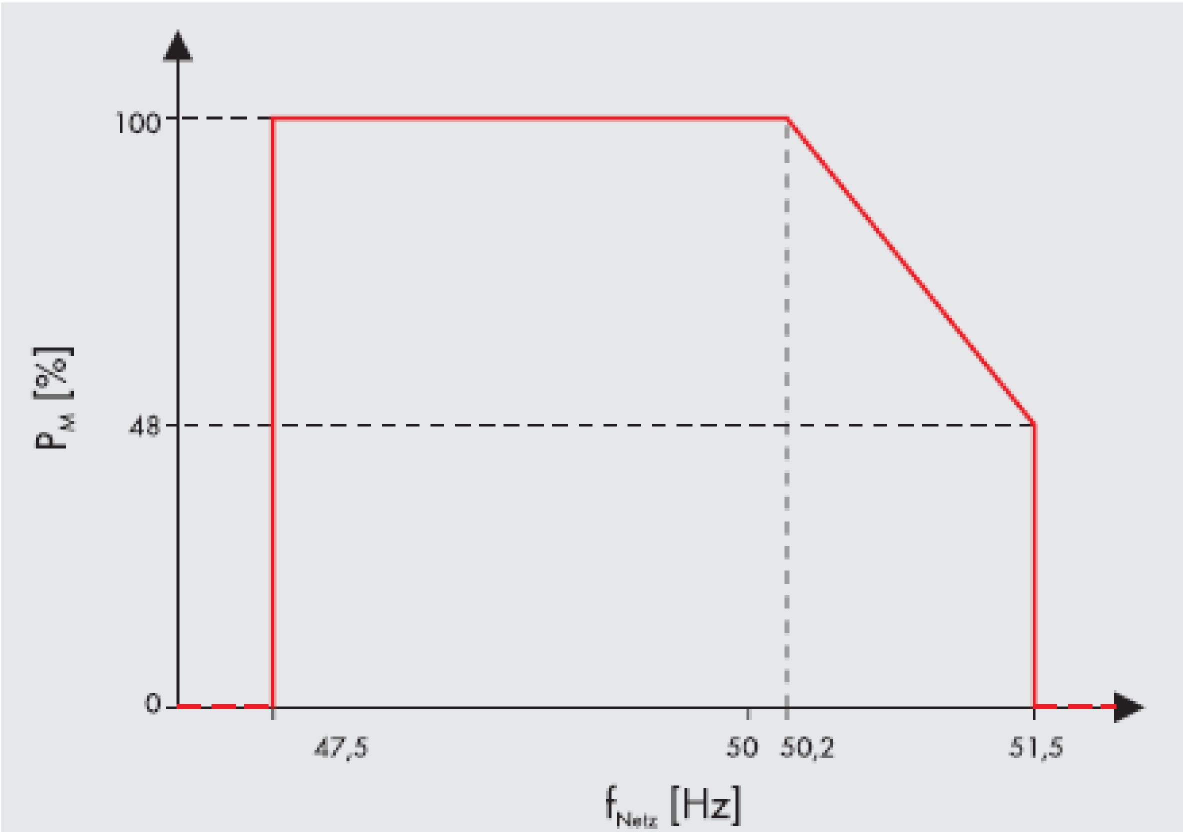
Reaction to frequency changes – old version



50.2 Hz problem



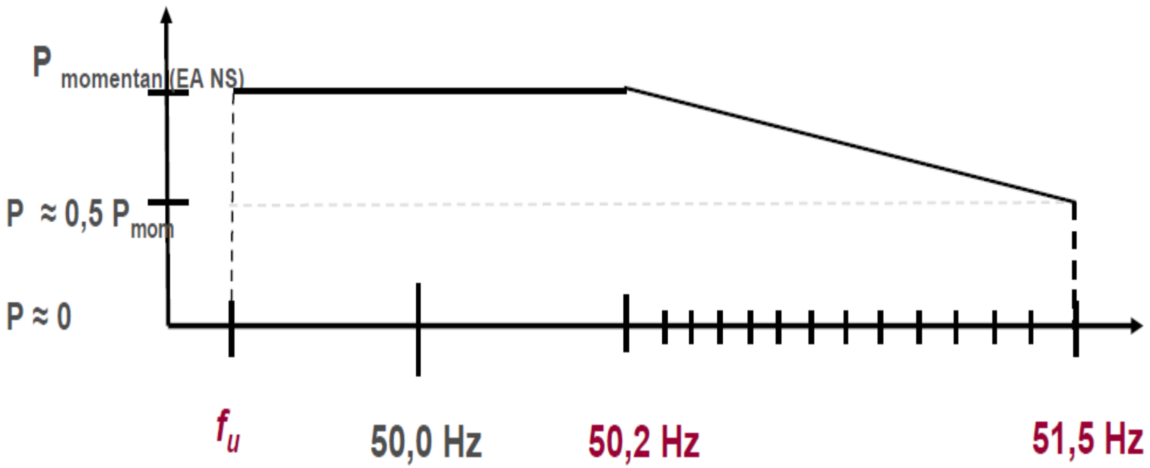
VDE-AR-N 4105 with respect to frequency control



- After generation units have been disconnected or had to reduce active power feed-in due to over frequency the feed-in power is not allowed to be increased before the grid frequency has decreased to values less or equal to 50.05 Hz

Source: SMA

Medium Voltage Directive with respect to frequency control



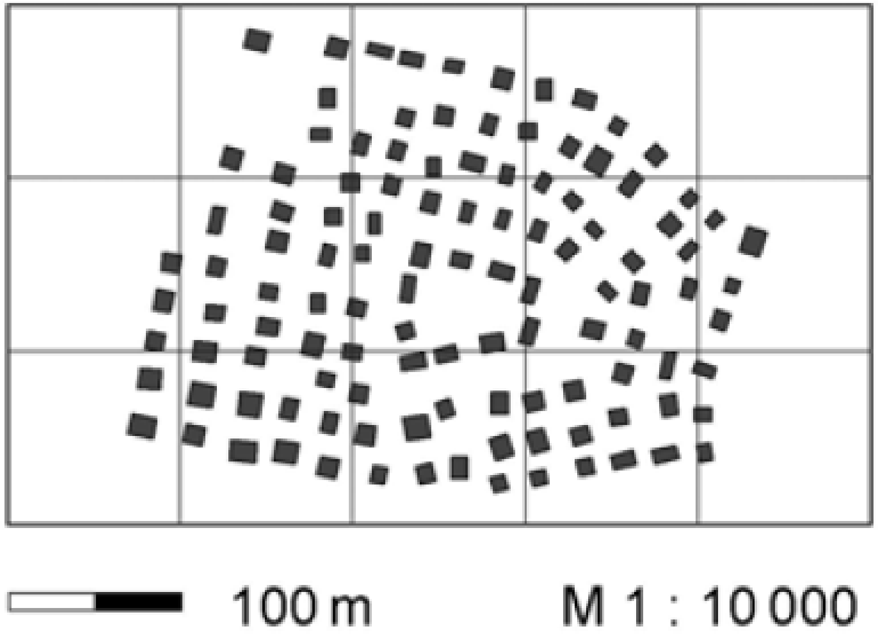
- After generation units have been disconnected or had to reduce active power feed-in due to over frequency the feed-in power is not allowed to be increased before the grid frequency has decreased to values less or equal to 50.05 Hz

- To help grid operators to restore the grid after a black-out generation units with a nominal power above 1 MW need to be reconnected with a ramp function. An increase of feed-in power is limited to 10% of the nominal capacity per minute.

Source: SMA

Are grid limitations real or only a threat?

1. Detached housing areas (high density)

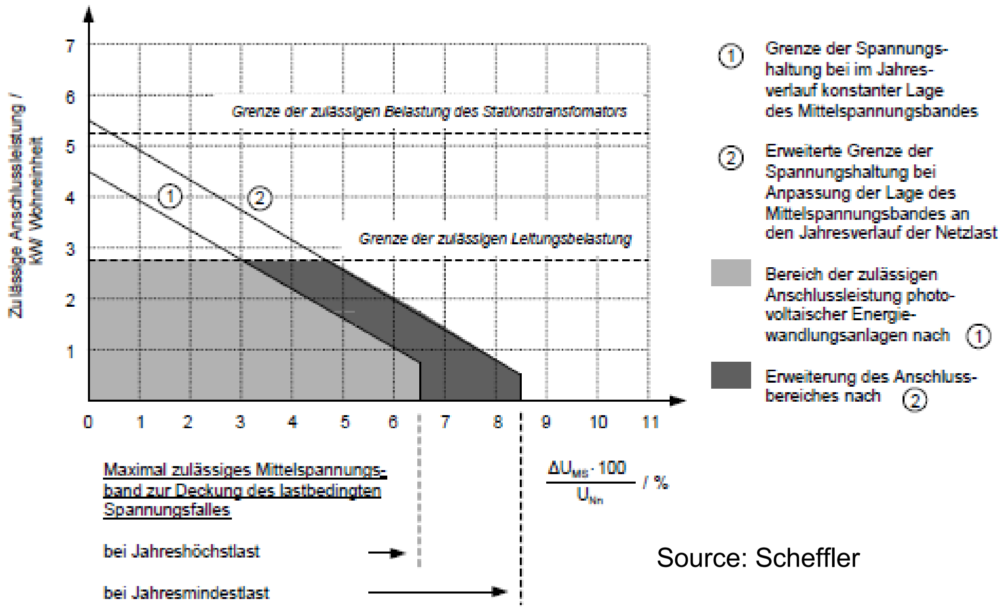


Source: Scheffler

- Suburb structure mostly located at the border areas of cities.
- Electricity supply is done by cables. ,
- Number of accommodation units: 176
- Peak load quotient per accommodation unit: 2.0 kW

The boundary conditions are the following: Medium voltage grid: 20 kV; Short circuit power 116 MVA; Grid impedance angle 39°; Transformer apparent power: 630 kVA; Cables: NAYY 4x150 mm²; I_{max}=265 A; House connections: NAYY 4x25 mm²; I_{max}=90 A; 1,15 accommodation units per house connection (85 % detached houses; 15 % two family houses)

1. Detached housing areas (high density)

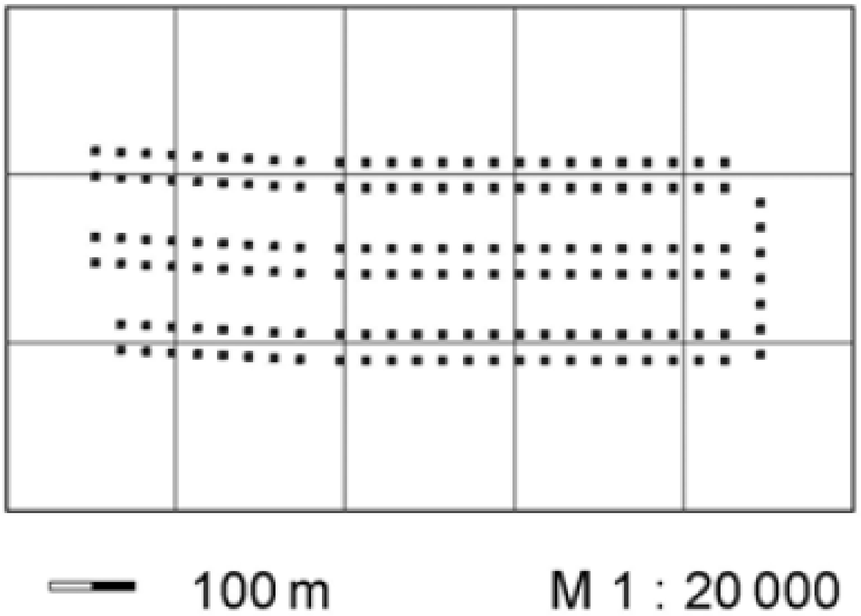


Source: Scheffler

- With an installed PV capacity of 5.32 kW_p per accommodation unit the transformer is at its loading limit.
- Cables are already at their limit with an installed capacity of 2.83 kW_p.
- Limitations due to voltage deviations are given according to the fluctuation range within the medium voltage grid. In case the medium voltage band would be ±6.6% the PV capacity would be limited to only 0.7 kW_p per accommodation unit. Bigger variations of the medium voltage band are not allowed due to the voltage limit in the low voltage grid during peak load condition.

- In case the medium voltage is controlled in a way that according to the load the minimum voltage is kept the possible installation area is increased to the dark grey area
- With a medium voltage band of ±3.0% the maximum capacity that is limited by cable loading can be installed.
- This is only about 30 % of the suited roof area but nevertheless the installed capacity would be almost 500 kW_p in this small neighborhood.

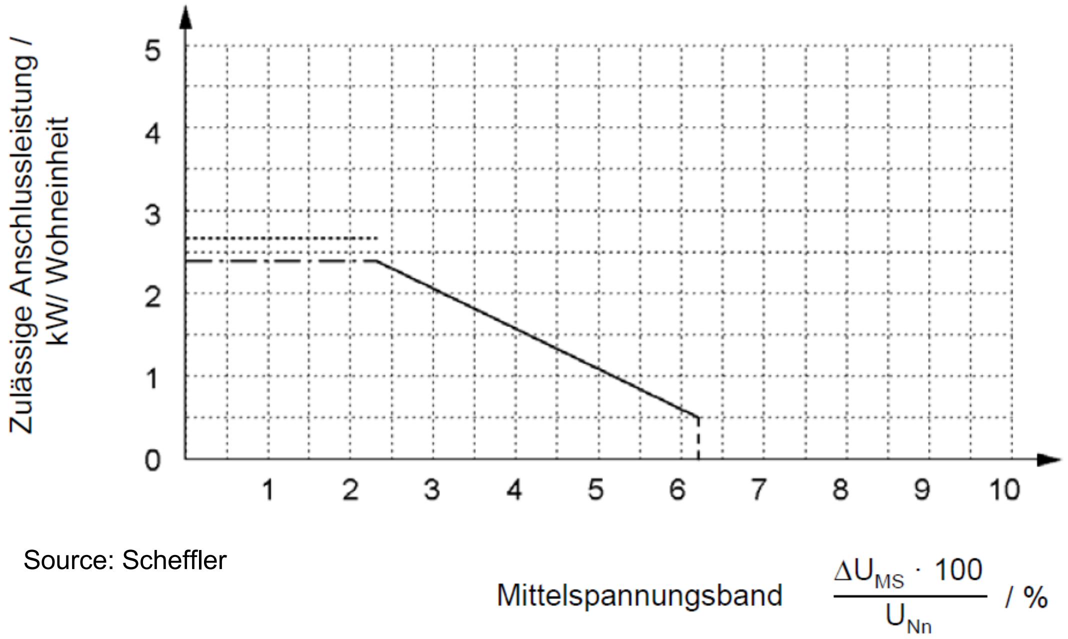
2. Single and two family houses areas (low density)



Source: Scheffler

- similar structure like the one described before
- suburb structure mostly located at the border areas of cities
- lots of land are bigger than in the one described before what results in a lower density
- Electricity supply is mostly done by cables, sometimes by overhead lines
- The exemplary grid is a single fed mesh network and operated as radial distribution system arranged as insulated overhead line.

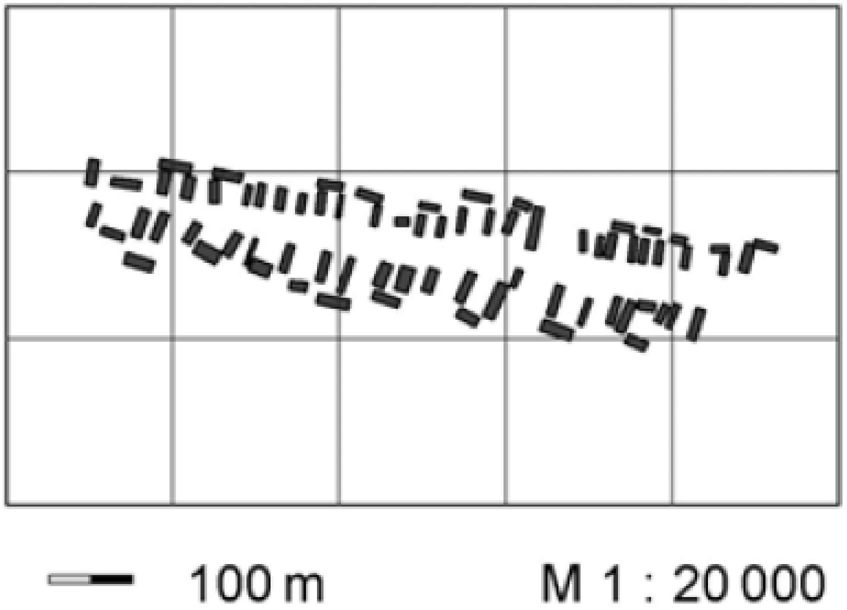
2. Single and two family houses areas (low density)



Source: Scheffler

- the limitation in the single and two-family houses area is limited by the cable capacity, too
- The capacity limit here is lower because of the lower population density and therefore bigger cable lengths and was determined to be 2.4 kW_p per accommodation unit
- This is the relevant limit when the medium voltage band is less or equal to ±2,3% of the nominal voltage
- With reduced PV capacities the medium voltage band can be increased up to ±6,2% before the voltage drop according to peak load is the limitation
- With the 2.4 kWp per accommodation about 50 % of the theoretical potential can be accessed.

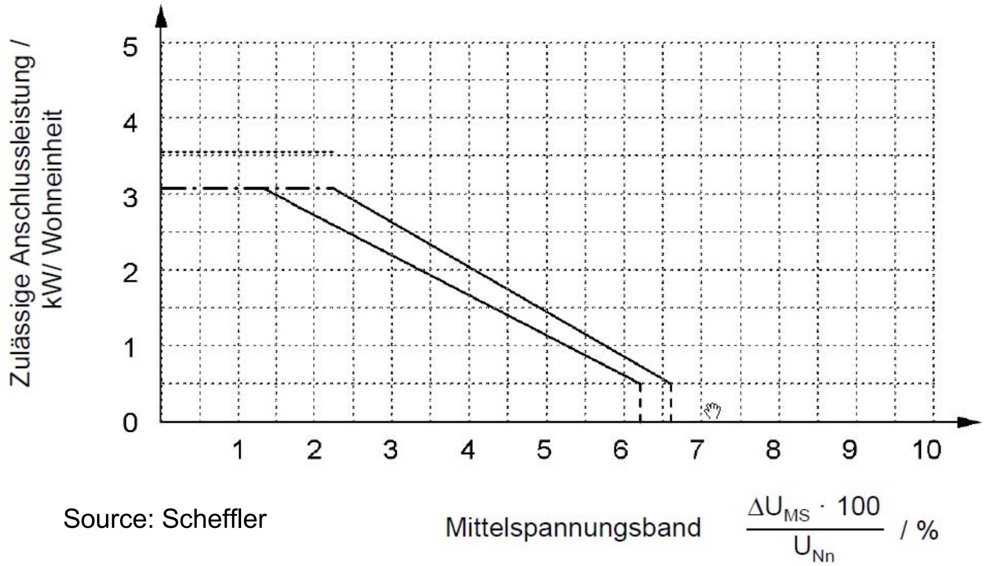
3. Villages including courtyard houses areas



Source: Scheffler

- This grid example is typical for rural areas
- Electricity supply is mostly done by cables, sometimes by overhead lines
- The grid type is a radial distribution system
- In the exemplary grid about 15 % of the houses include agricultural holdings
- Into the investigations a line tap of 800 meters behind grid string number two is assumed.

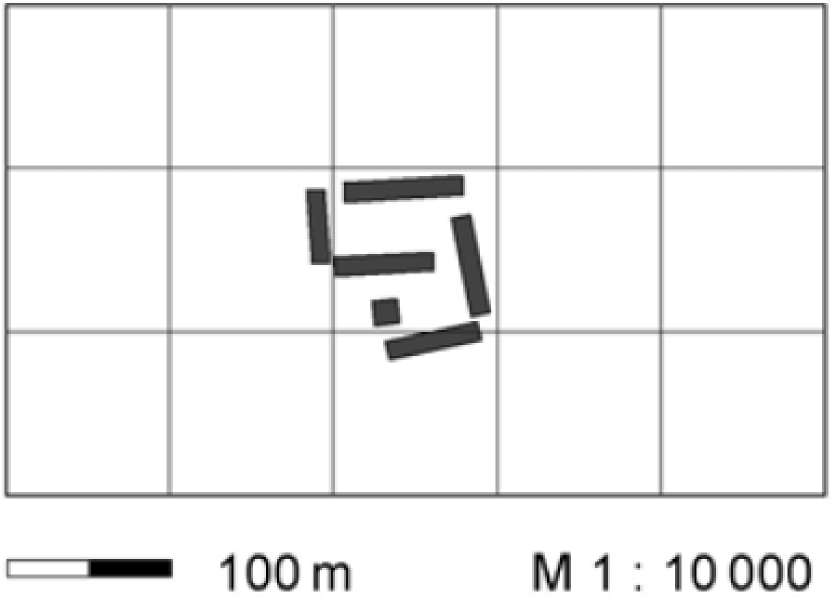
3. Villages including courtyard houses areas



Source: Scheffler

- The maximum PV capacity again is limited by the cable capacity and should not exceed 3.1 kW_p per accommodation unit
- Due to the wide-stretched grid topology and the resulting voltage drops the installed capacity decreases already with a medium voltage band bigger than ±2,5%
- The theoretical PV capacity potential can only be used by 20 %.

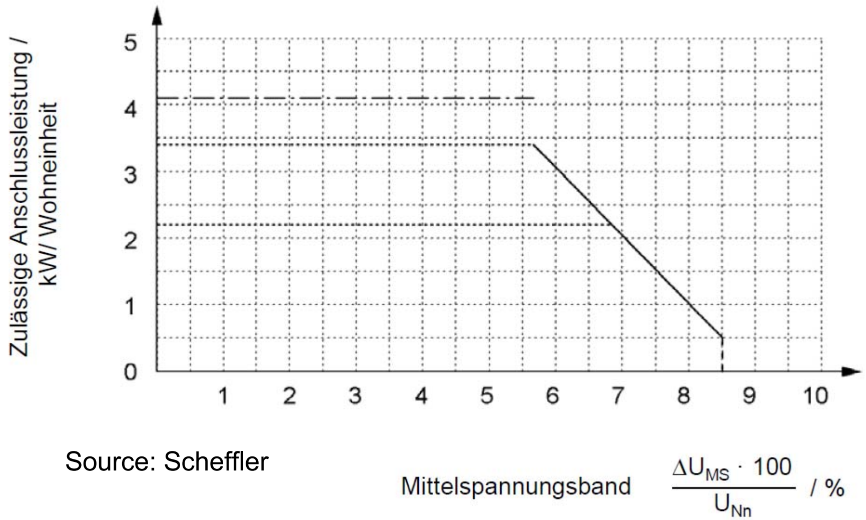
4. Row of multistory buildings areas



Source: Scheffler

- This area type is typically located at the border of large and small cities and sometimes in newer city centers
- They are supplied by cables
- Because of the building sizes each building typically is supplied via a single grid string
- At grid string seven a school is connected to

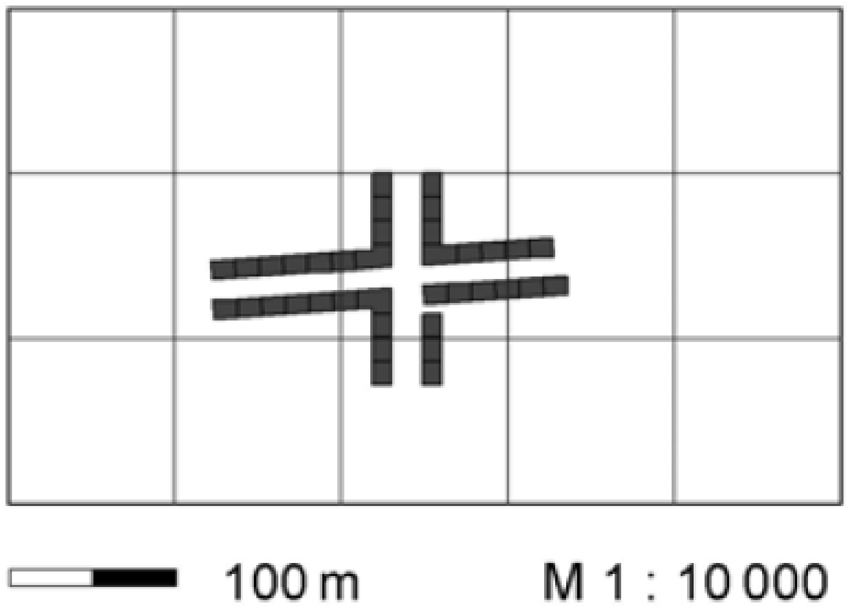
4. Row of multistory buildings areas



Source: Scheffler

- maximum capacity is limited by the transformer loading when the capacity has reached 2.2 kW_p per accommodation unit
- The small dimension of the grid area is the reason why voltage drops are not significant
- limitations start when the medium voltage band exceeds ±6,7%
- Load justified limitations even start not until a band of ±8,5%
- An increase of the transformer rated power from 400 kVA to 630 kVA increases the capacity limit to 3.4 kW_p per accommodation unit
- The allowed low voltage band of ±8,5% is never violated
- As the limit is always given in kWp per accommodation unit and those buildings contain many units the roof potential can be exploited by 100 % (even facades could be equipped with PV).

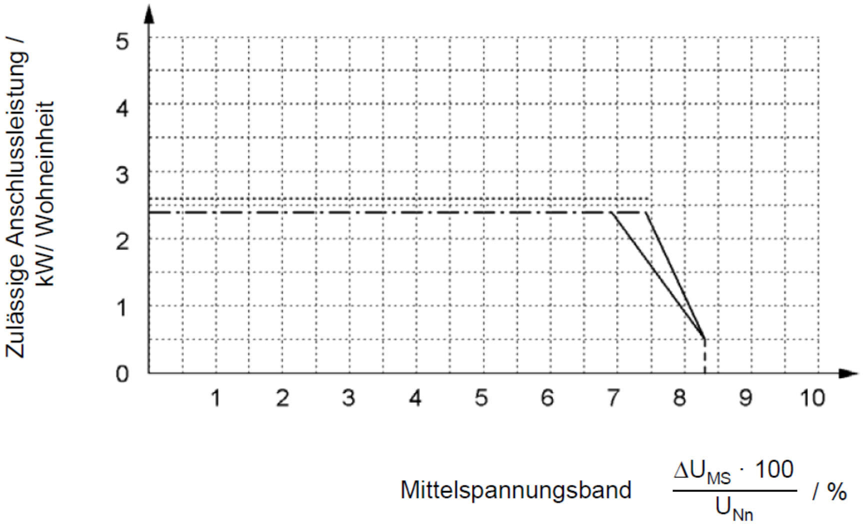
5. Block of buildings / city blocks



Source: Scheffler

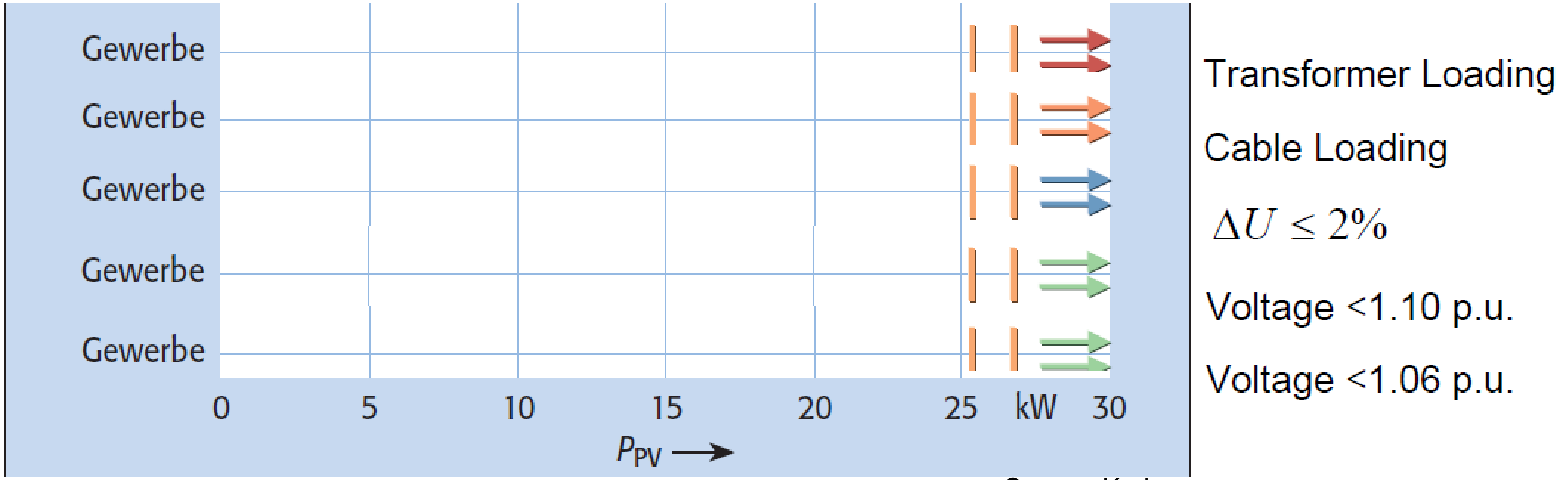
- This area is typical for city centers
- These areas are supplied via cables, have high load densities and line lengths are limited
- The exemplary grid supplies 36 buildings
- The mesh grid is fed by several transformers. Via opened section points it is operated as a radial distribution system

5. Block of buildings / city blocks



- installation capacity is limited by the loading of cables to 2.4 kW per accommodation unit
- Due to the limited line lengths the voltage drops are small and a limitation by voltage is only valid for a medium voltage band exceeding ±7%
- Available roof area is small compared to the number of accommodation units. Therefore, the theoretical potential can be completely used.

6. Other Areas, Industry



Source: Kerber

Results:

- the building capacities often exceed 100 kWp, the investigated 30 kWp always can be installed
- In industrial areas there are no existing grid limitations

Summary for investigated Settlement Areas

- Limitations are given in rural areas and pure residential suburbs
- within cities, city centers, multistory building areas and industry areas almost now limitations are existing

Berlin: where is photovoltaics?

Hamburg: where is photovoltaics?

Munich: where is photovoltaics?

Cologne: where is photovoltaics?

Residential Areas …

… and Farm Houses

Latest changes to the renewable energy sources act

- Feed-in tariffs should be reduced dramatically, they should be:
  - 19.5 €ct/kWh for installations up to 10 kWp; (this would be significantly less than electricity end users pay for electricity; less than net metering)
  - 16.5 €ct/kWh for installations up to 1 MWp, and
  - 13.5 €ct/kWh for installations up to 10 MWp
- Starting from May 1st every month feed-in tariffs will be lowered by 1% per month
- With the euphemism "market integration" is meant that for installations up to 10 kWp only 80 % of the electricity generated is paid for. For larger installations the fraction paid for is 90 %. The rest should be consumed by the plant owner itself or should be sold on which market ever.

Regulatory Solution to avoid Bottlenecks in the Grid

City centers:

- PV can hardly be found
- extremely strong and meshed grid infrastructure
- high loads at peak PV feed-in

But:

- Installations preferably in more weak grid areas
- disconnection because of grid bottlenecks – not because the electricity is not needed!
- only 80% of electricity generated is paid for – even in cases when electricity is needed and can be transmitted!
- financial compensation of electricity that could not be transmitted.

- Do we need incentives for city centers?
- And restrictions for (very, very) rural areas?
- Is **energy planning** allowed to be considered in Germany?
- With **energy planning** the grid could absorb then forecasted PV electricity generation of 52 GW in 2020 without any grid enforcements

Thank you very much

for your attention