



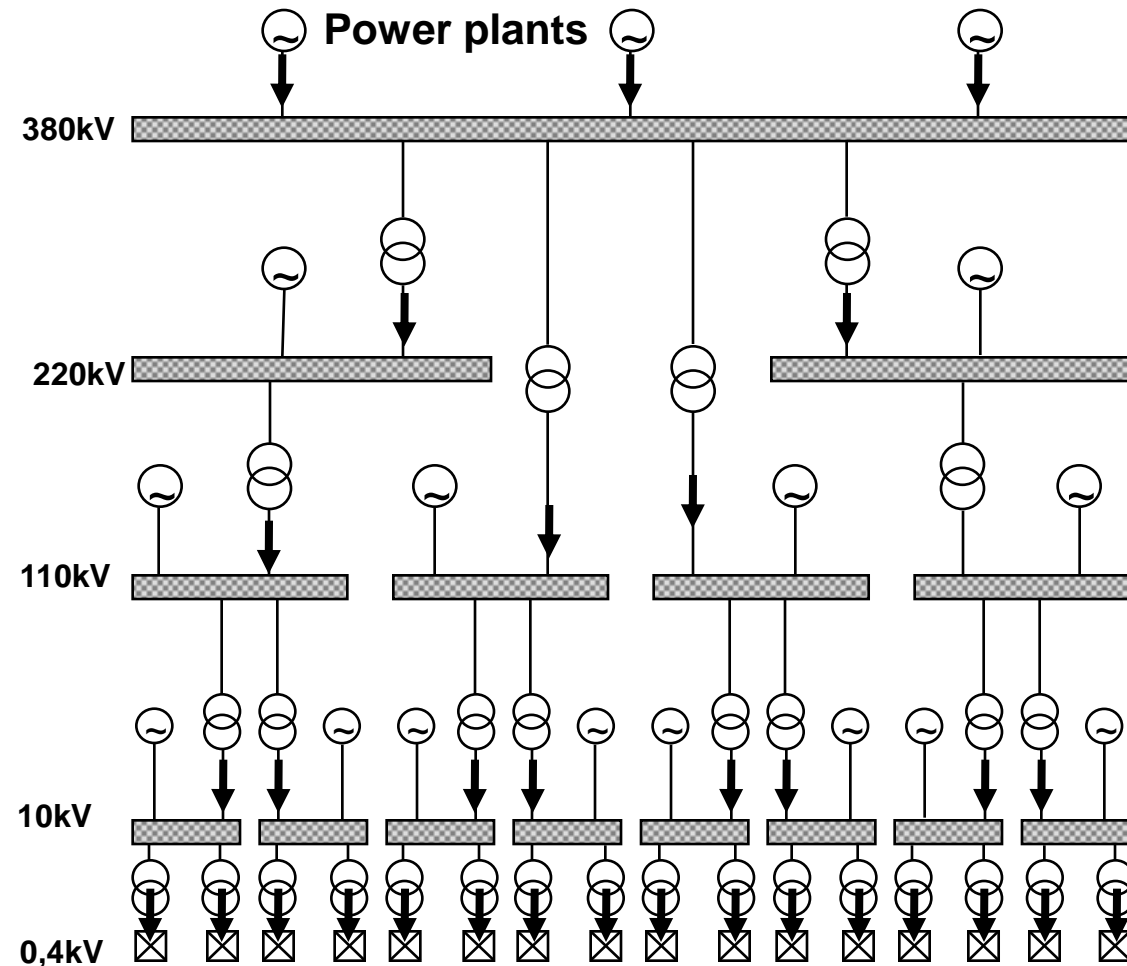
# Photovoltaic Systems in Low Voltage Distribution Grids – Limits and Perspectives with Smart Grid Technologies



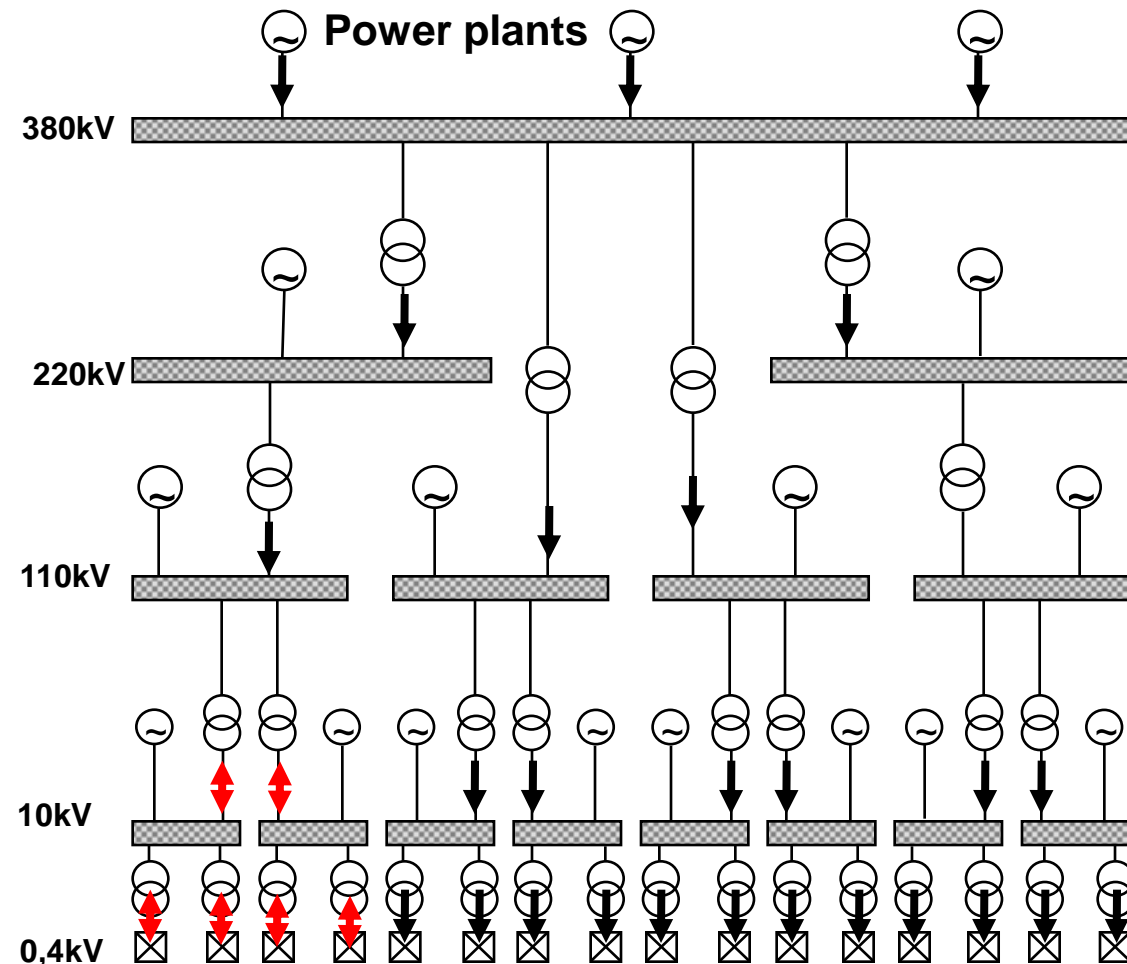
# Content

1. Electricity Grid Architecture and its suitability to absorb PV power
2. Technical guidelines, grid codes and limits that might be violated by PV systems
3. Technical (smart grid) solutions to overcome or at least to delay limit violations
4. Regulatory solution to avoid bottlenecks in the grid

# Electricity Transmission and Distribution, Yesterday



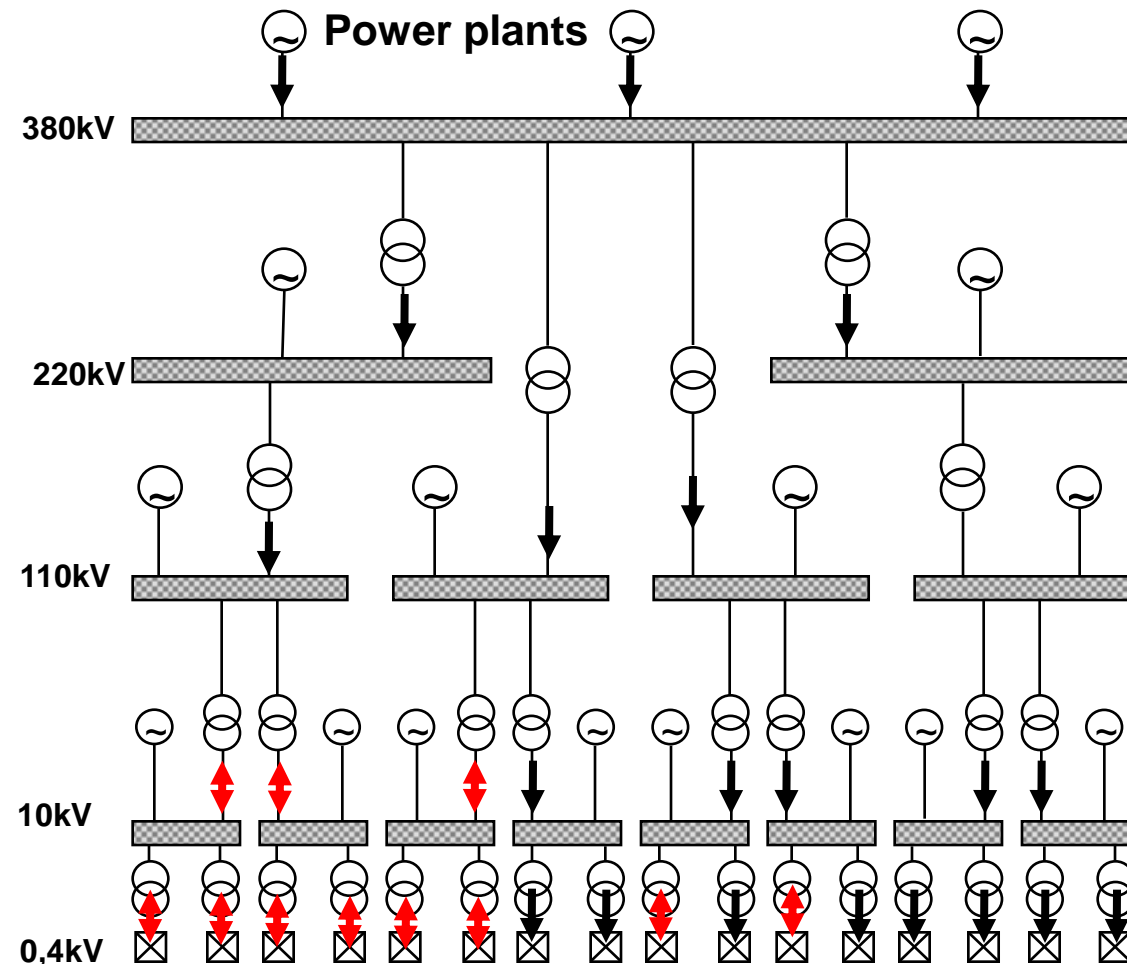
# Electricity Transmission and Distribution, Today



- 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?

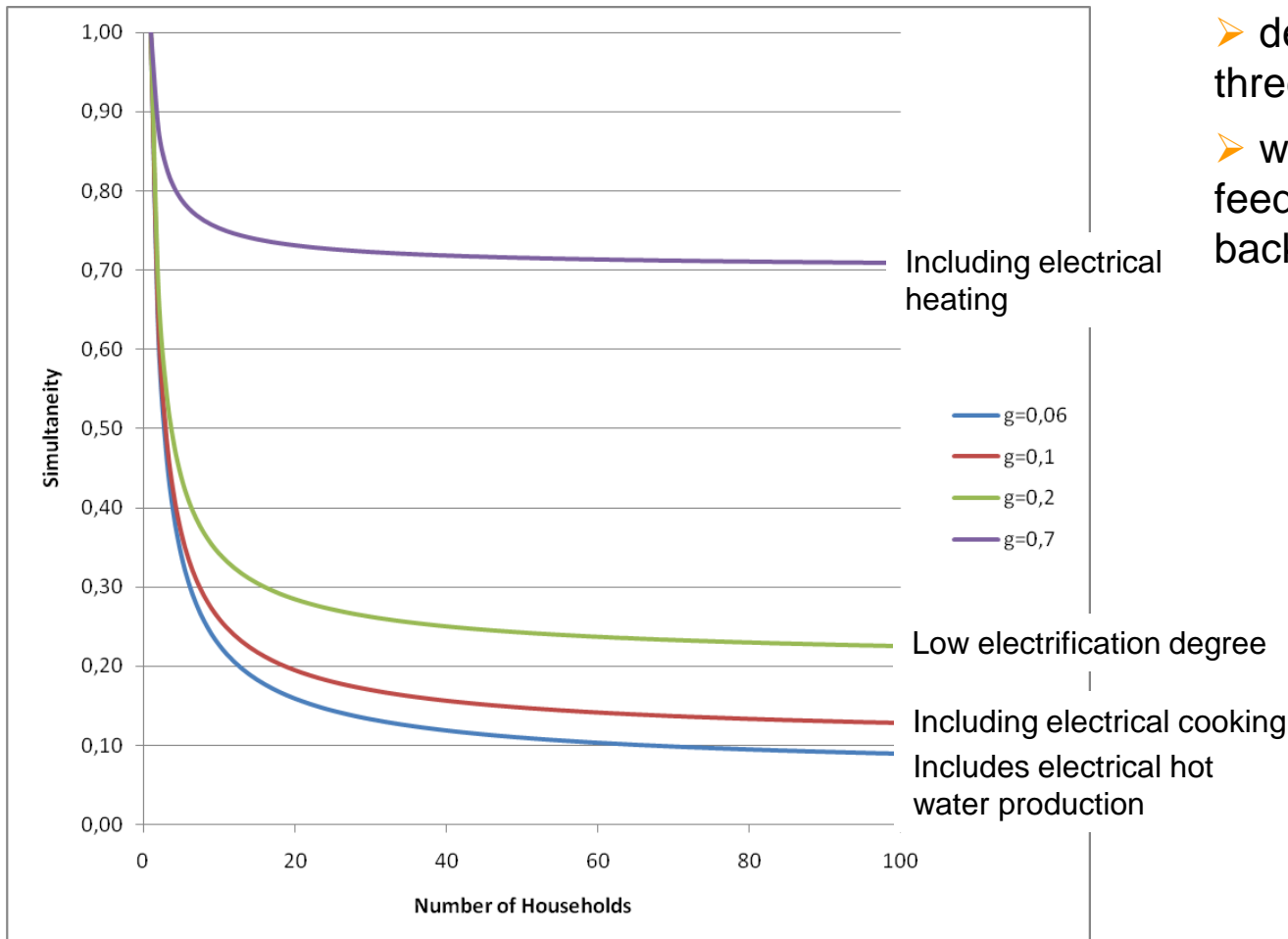
# Electricity Transmission and Distribution



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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

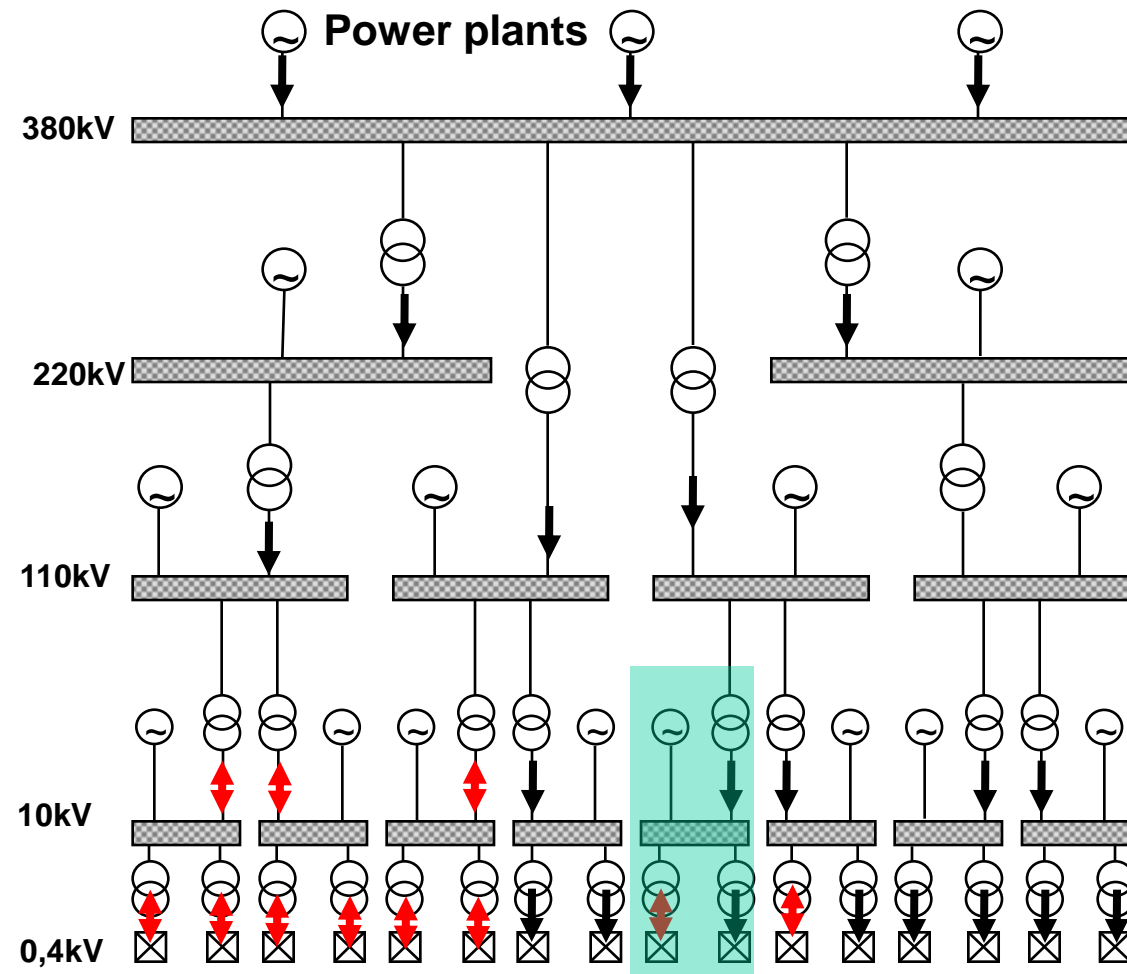
- Relevant assets are distribution transformers and cables
- A violation of defined loading limits either decreases the life time of the asset or even could destroy it.
- Electric currents cause losses in all assets and as a consequence they heat up.
- When the thermal load is too high aging is accelerated 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  $\pm 10\%$  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  $\pm 10\%$  the guideline limits the contribution of decentralized generation with the criterion of  $\pm 2\%$ .
  - in many other countries this is  $\pm 3\%$

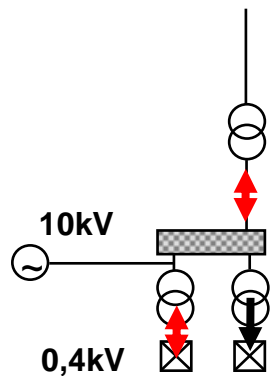


# Bottlenecks, Voltage Limitations



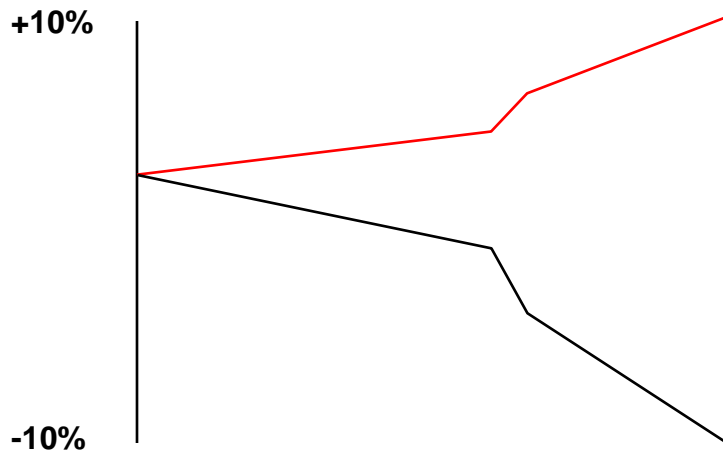
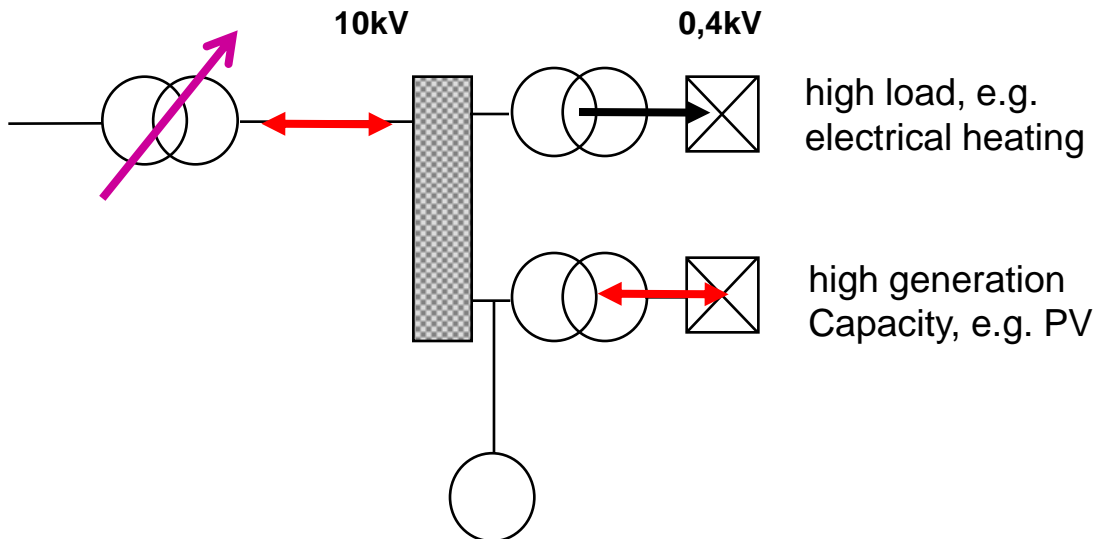


# Bottlenecks, Voltage Limitations





# Bottlenecks, Voltage Limitations



When high to medium voltage transformer is at 104% the  $\pm 10\%$  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.

# Technical solutions to overcome limitations, Voltage Violation

## Introduction

The evaluation of typical grids has shown that the “voltage violation” problem is seldom the case – and when then it is more of a theoretical nature:

- The  $\pm 2\%$  criterion or the  $\pm 3\%$  criterion, respectively, was derived from a situation when one grid string was loaded with its peak and therefore the medium voltage needed to be set to a maximum allowed. At the same time in another grid string it is assumed that there is no or minimum load but maximum feed-in from PV systems. This is not a very probable assumption.
- [Scheffler 2002] reports that load caused voltage drops normally are of a maximum of 2 % and this only in case of grid sections that are far away from transformation station and only in case that storage heating systems cause a high load. And that is normally during night where the power injection from PV is zero.
- Before European and international harmonization of norms low voltage grids have been designed for a voltage deviation of  $\pm 5\%$ . Therefore, the today's  $\pm 10\%$  should leave a large safety margin.



## Technical solutions to overcome limitations, Voltage Violation

Solution “Voltage Violation” 1: voltage and/or current are measured at every low voltage transformer. From this information one can draw conclusions on the line loading and take adjustments on the high voltage to medium voltage transformer stations in order to keep all areas within a grid in its required limits. Those transformers can change their transformation ratio on load whereas low voltage transformers only can be adapted under no load condition in fixed steps

*smart*



## Technical solutions to overcome limitations, Voltage Violation

*smart*

**Solution “Voltage Violation” 2:** Information about voltage can be gathered even from the distributed inverters of PV plants. On basis of that information again action can be taken in the medium voltage transformer station.

*not smart*

**Solution “Voltage Violation” 3:** completely without communication the problem is solved decentralized by PV inverters themselves. For safety reasons PV inverters contain security devices that measure among other parameters grid voltage. When the  $\pm 10\%$  criterion is violated they can automatically reduce power injection or switch off. Additional expenditure compared to today’s inverter design would be minimal.

A problem could be more the social compatibility because always those inverters need to reduce power injection first that are located at the end of a grid string.

Another problem is the legal boundary condition of the renewable energy act that guarantees that renewable electricity plant operators have the right to feed-in their generated electricity.



## Technical solutions to overcome limitations, Voltage Violation

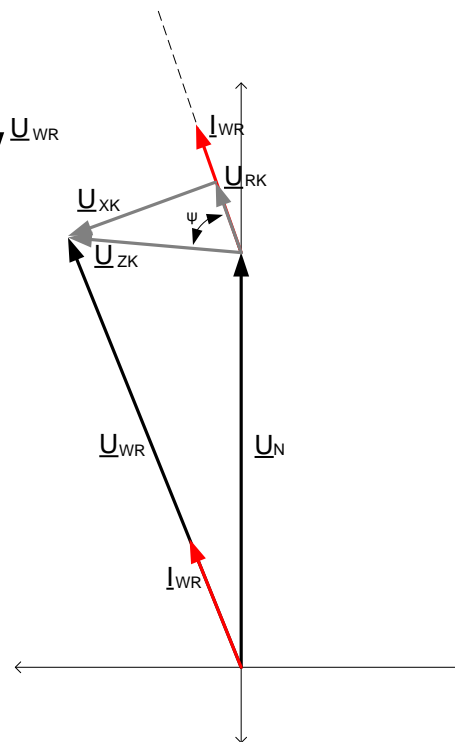
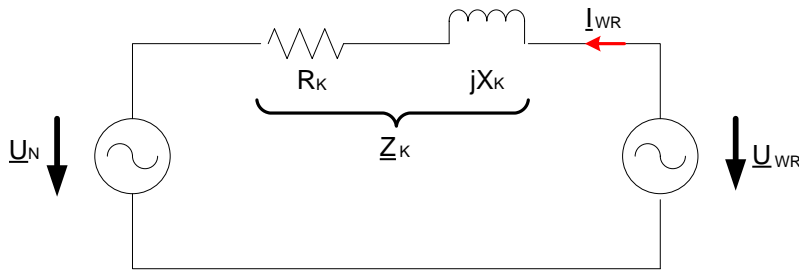
Smart

Solution “Voltage Violation” 4: Not only in the low voltage grid but also in the medium voltage grid an increasing number of renewable energy generators are installed - mainly wind power generators. Those generators have excellent abilities in order to influence the voltage level in the medium voltage grid. According to “Systemdienstleistungsverordnung” those generators are obliged to perform voltage regulation. In advanced grid management structures this ability can be applied in order to also improve the voltage in low voltage grid.

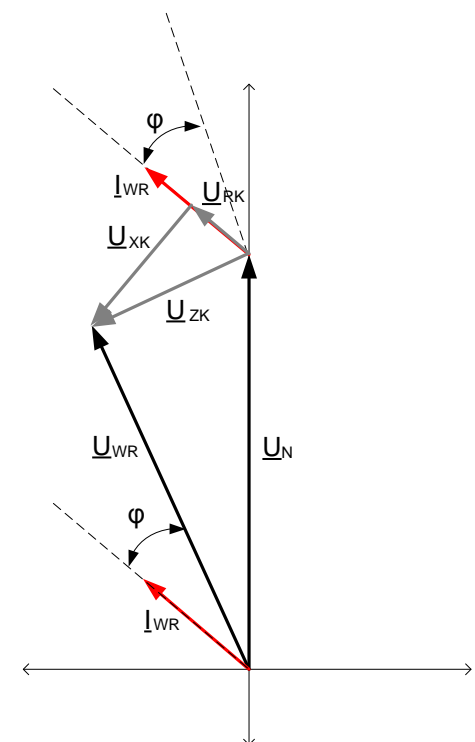


# Technical solutions to overcome limitations, Voltage Violation

**Solution "Voltage Violation" 5:** PV inverters can inject reactive currents in order to influence voltage and keep within the  $\pm 10\%$  limit.



Active Power Feed-in

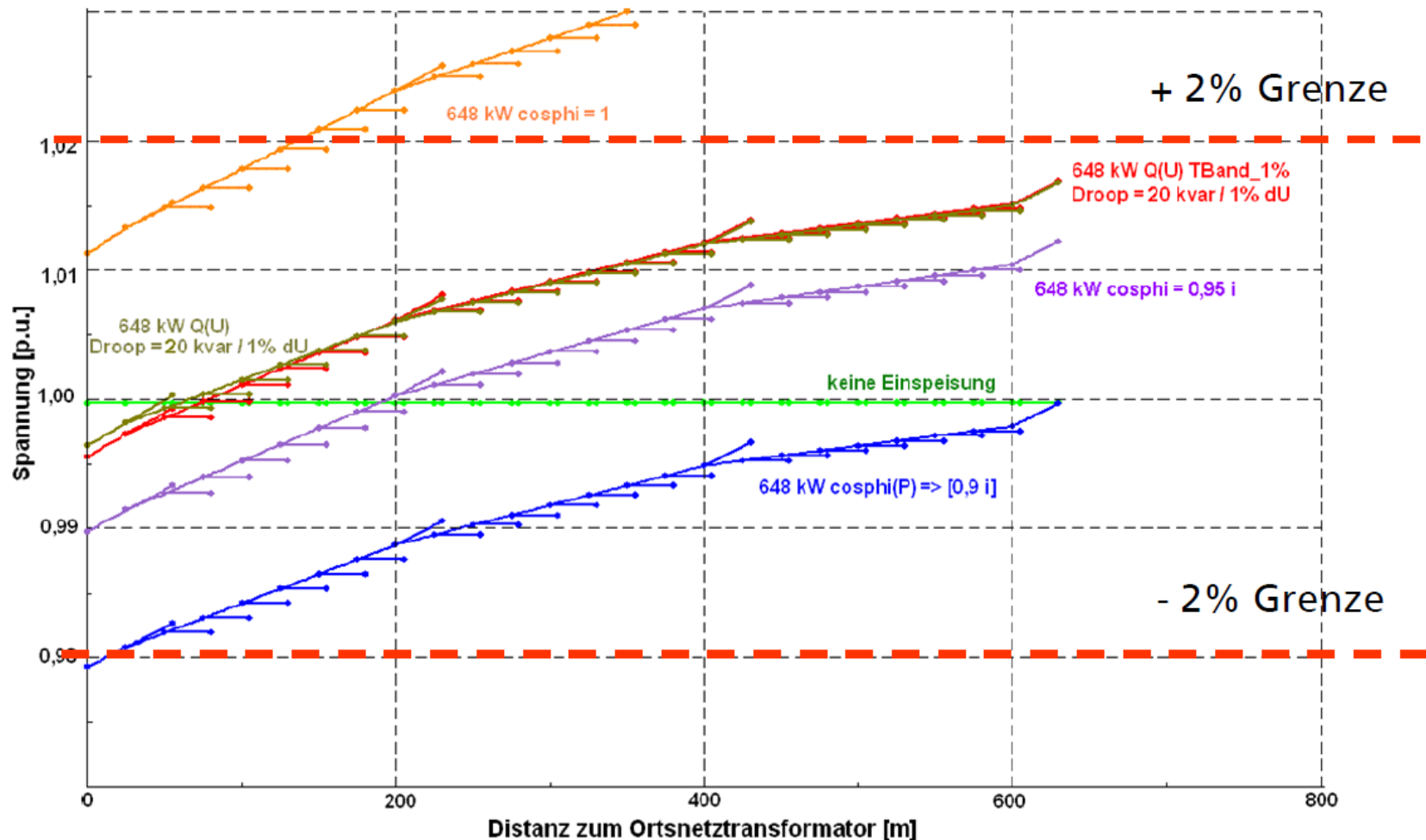


Reactive Power Feed-in

*smart* or *not smart*



# Technical solutions to overcome limitations, Voltage Violation





## Technical solutions to overcome limitations, Asset Loading

not  
smart

Solution “Asset Loading” 1: in case of a too small transformer a second one can be installed in parallel or it could be exchanged by one with a higher rated capacity.

In case the loading of cables is the problem it is not that easy just to lay a second cable as this action comes along with costly ground work apart from the pure cable cost. Therefore other actions need to be undertaken first.

smart

Solution “Asset Loading” 2: The current at the transformer could be measured. In case the current from the low voltage side to the medium voltage side is too high PV inverters could reduce power injection. This solution requires a communication infrastructure.

This measure could significantly increase the potential PV capacity as the theoretically assumed minimum load during maximum feeding-in is not very probable. And times with peak injection also are of short duration. Therefore, this measure probably only seldom need to be applied.

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Solution “Asset Loading” 3: grid load is generally of ohmic-inductive nature. When inductive power is provided via the low voltage transformer means an additional load also to the cables. PV inverters can supply a reactive power in order to make a decentralized compensation. This reduces the load on the line and additional active capacity could be installed. This also reduces line losses at the same time.



## Technical solutions to overcome limitations, Asset Loading

„Smart“  
Smart

Solution “Asset Loading” 4: Alternatively to the communication solution described beforehand power factor could be controlled decentralized to “1” at the injection point. Here, a communication with e.g. a smart meter would be necessary that measures  $\cos(\varphi)$ .

Solution “Asset Loading” 5: Again with communication at least with the low voltage transformer or even with PV inverters the medium voltage could be adopted in a way that low voltage is at its maximum allowed. With the same power injected the current is decreased when the voltage is increased.

## Technical solutions to overcome limitations, Advanced

- In low voltage grids the relation of resistance load per unit length to reactance load per unit length is around 2.5.
- Due to this fact in opposite to high and medium voltage grids active power has a bigger influence on voltage drop than inductive power.
- Therefore, grid management via active power management is more effective than reactive power management.
- Active power management not only controls voltage but at the same time also the loading of cables and transformers.

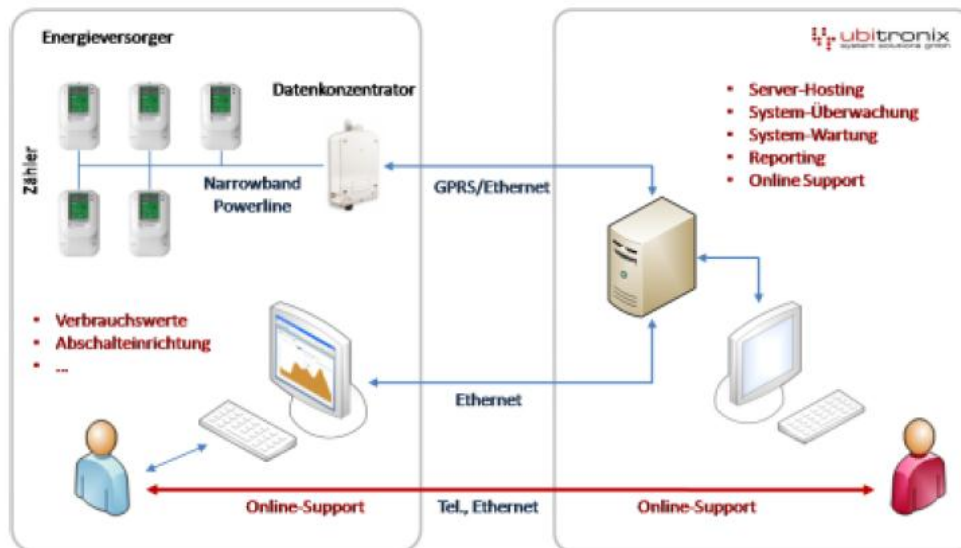


# Solutions for higher installed capacities, Advanced Solutions

Smart

Active power management solution 1: By demand side management respective load shifting in combination with smart metering loads can be shifted to times of high solar irradiation and therefore consume the power generated at the place or close to the place of generation.

By this, both voltage increase and line overloading is prevented.



Source: Ubitronix





## Solutions for higher installed capacities, Advanced Solutions

smart

Active power management solution 2: Mobile battery storage in electrical vehicles. Batteries can be charged when solar power generation is high. With so-called plug-in-hybrids also a discharge in case of a power need could be realized.



Source: Stadtwerke Düsseldorf





## Solutions for higher installed capacities, Advanced Solutions

smart

Active power management solution 3: Stationary battery storage. Batteries can absorb excess power generation when the grid is overloaded. They can be discharged in a high load and low power generation condition.

smart

Active power management solution 4: An increased number of buildings are heated with heat pumps. When heating systems are equipped with (cheap) heat storages heat pumps need not be operated in times of heat demand but can be operated when solar power generation is highest and therefore avoid overvoltage and cable overloading. The same could be realized with cold storages and air conditioning units.

smart

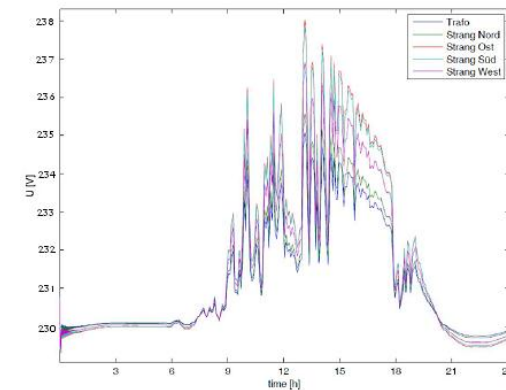
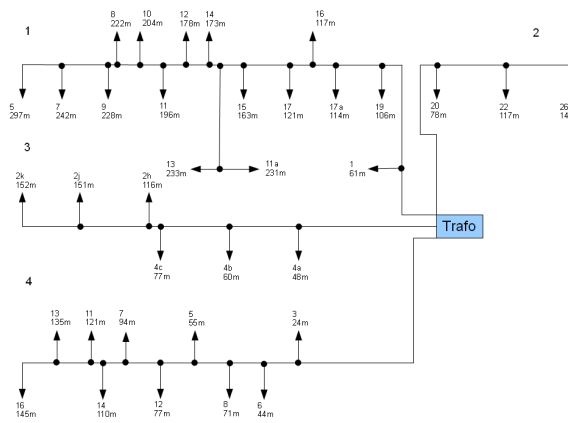
Active power management solution 5: Finally, also direct electrical heating can be applied in times of too high solar power generation. With a heating rod hot water tanks can be heated in times additional loads are required for grid management.



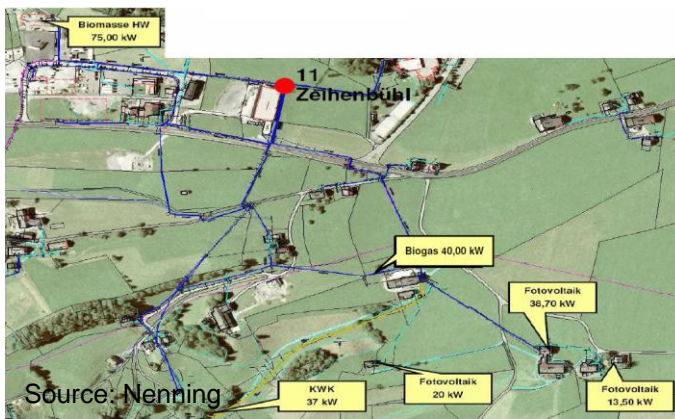
# Regulatory Solution to avoid Bottlenecks in the Grid

Investigation Results in Cologne and close to:

- limitations almost do not exist in urban areas!



- rural, agricultural dominated areas



- photovoltaic plants
  - 13,5 kW<sub>p</sub>
  - 20 kW<sub>p</sub>
  - 38,7 kW<sub>p</sub>
- other distributed generation (biogas combined heat and power)
  - 152 kW
- Overloaded grid infrastructure





# 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



München



Berlin

- Do we need incentives for city centers? And restrictions for (very, very) rural areas?
- Is energy planning allowed to be considered in Germany?



Thank you very much  
for your attention