

Higher integration of PV systems into existing low-voltage networks by probabilistic planning

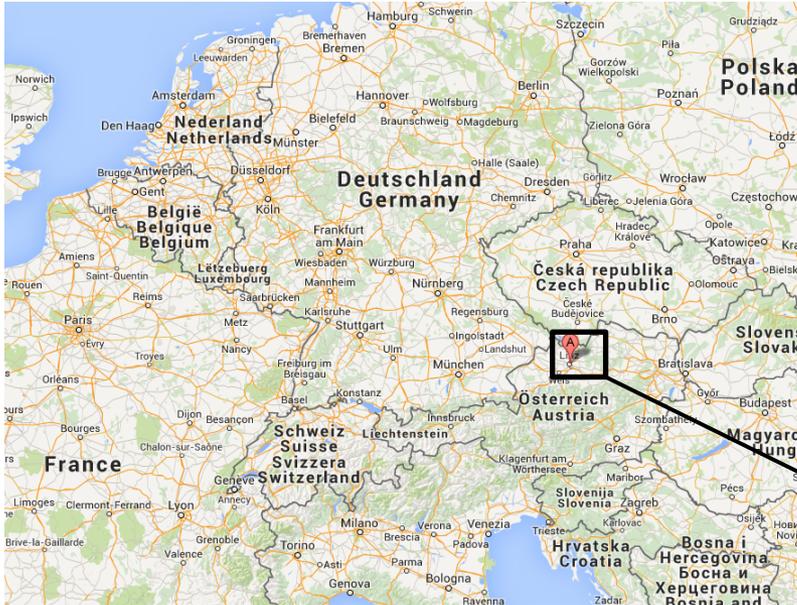
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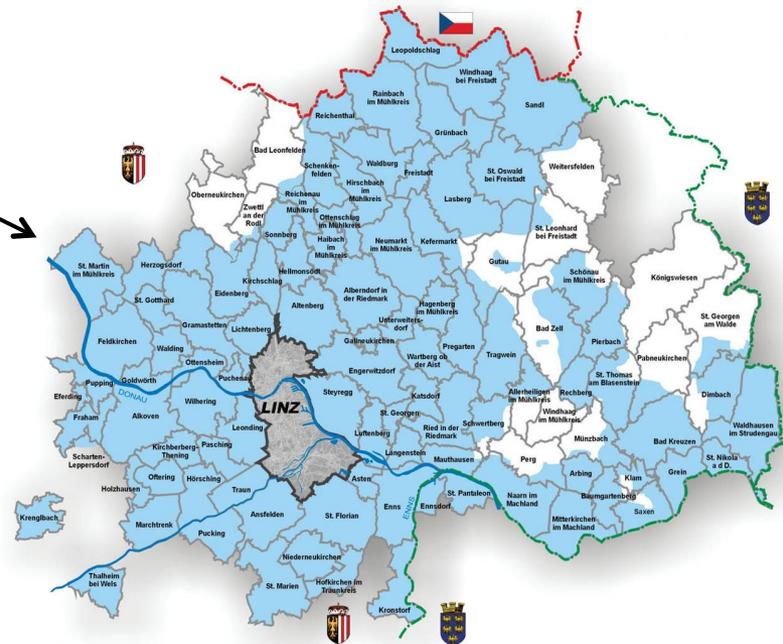
Agenda

- presentation LINZ STROM Netz GmbH
- framework for connecting distributed generation
 - general and economic frameworks
 - technical frameworks
- probabilistic planning approach
 - planning approaches
 - detailed probabilistic planning approach
 - simplified probabilistic assessment
- results from the field test area Prendt
 - reactive power control $\cos\phi(P)$, $Q(U)$
 - combined control $Q(U)$ and $P(U)$
 - not fed in energy
- conclusions

LINZ STROM Netz GmbH



- electricity grid for 82 communities (up to 110 kV)
- about 240.000 metering points



Framework for connecting distributed generation

- the objectives of the European Union are
 - to increase the energy efficiency
 - to increase the supply from renewable energy sources
- from an economic point of view of the customer, a feed-in
 - of 100% power
 - in 100% of the time (any time) is required
- feeding into the low voltage network represents for the distribution system operator (DSO) a major challenge
- according DACHCZ assessment rules, all feeders should not raise the voltage more than 3% in a LV-network
 - network, consumers and feeders share the available voltage range of +/- 10% Un (EN 50160: 100% of 10-min mean values have to be within +10%)
- if specified voltage limits according to TOR D4 and DACHCZ are reached or exceeded and to enable feeding into the low-voltage network and to guarantee the voltage quality, it is necessary
 - to invest into low-voltage networks
 - to limit the installed feed-in

Framework for connecting distributed generation

different optima: supplier \leftrightarrow DSO

supplier

- **full feed-in at any time**
- **maximum energy production** and thus to **optimize the profit**
- small or no grid connection costs

distribution system operator (DSO)

- efficient distribution network
- **network costs as low as possible**

to increase the total energy feeding

- to find a macroeconomic optimum $\text{supplier} \leftrightarrow \text{DSO}$
- **compromise** between **network investment** and **the volume supplied by the individual PV-generation**

Planning approaches

- conventional planning approach

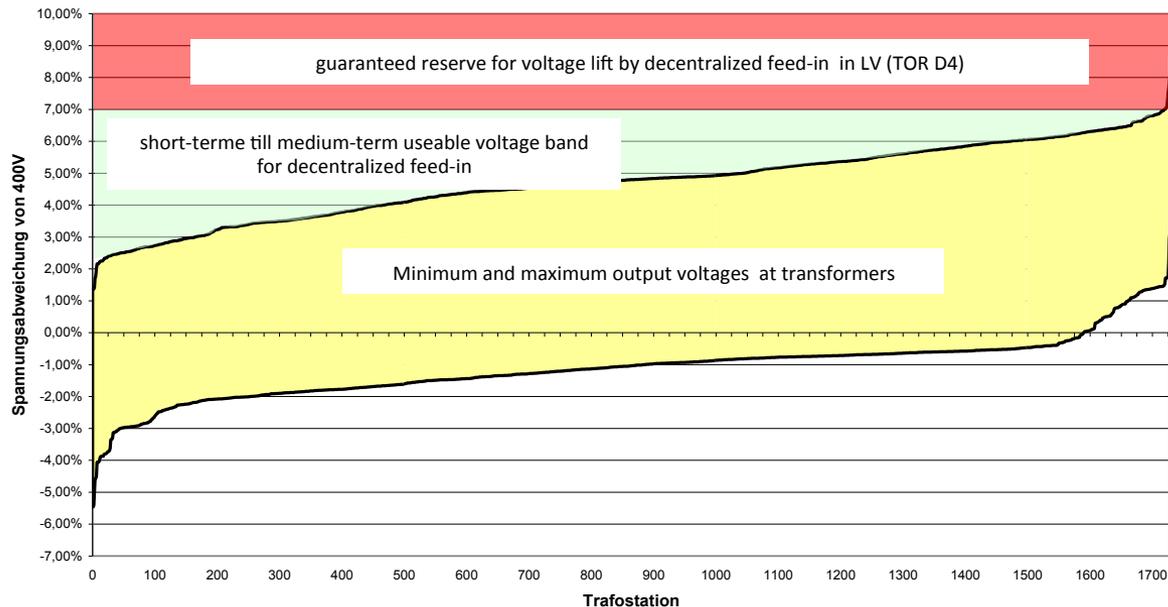
- in the conventional planning, it is assumed that the maximum power is fed at the worst operating condition in the distribution network
- calculation with the maximum possible output voltage at the MW/LV transformer (107%)
 - 3% voltage lift is reserved for suppliers
- calculation of the voltage lift according to the formulas of DACHCZ and TOR D4

$$d := \frac{\Delta S_a}{S_{kV}} \cdot \cos(\psi + \rho)$$

- only then is it possible to guarantee the 100% feed-in at any time
- networks with high integration of distributed generation, come quickly to the limits of the permissible voltage raise
- in fact, show current network conditions that critical voltage level rarely occur
 - a higher integration of decentralized feeders would be possible
 - currently assessment according to TOR or DACHCZ not taking into account existing network resources from the entire system

Use of real voltage band

Minimum and maximum voltages of transformers (incl. feed-in in MV)



- not all MV/LV transformers on the 400V-side are operated with $U=107\%$
 - depending on the voltage level in the MV network
 - depending on the transformer ratio
- in many local networks, there are therefore theoretically larger voltage reserves as 3% for the feed-in

Planning approaches

- probabilistic planning approach
 - this planning approach takes into account the static behavior of the parameters
 - voltage fluctuation at the MV/LV transformer
 - feed-in power
 - the aim of the planning approach is, to increase the installable feed-in power and to increase the amount of energy supplied
 - at low network costs and
 - low amount of not feed-in energy
 - the goal is only achievable if it is possible for the DSO to control or cut off the feed-in power for rare and short periods of time when needed

implementation of a probabilistic reduction factor “F”

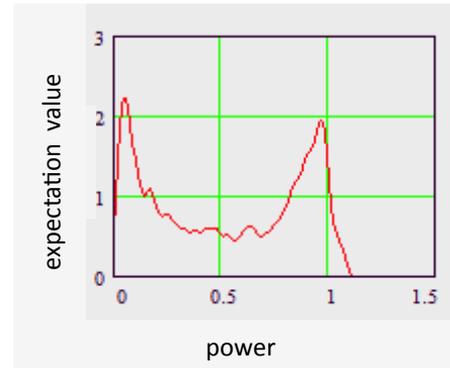
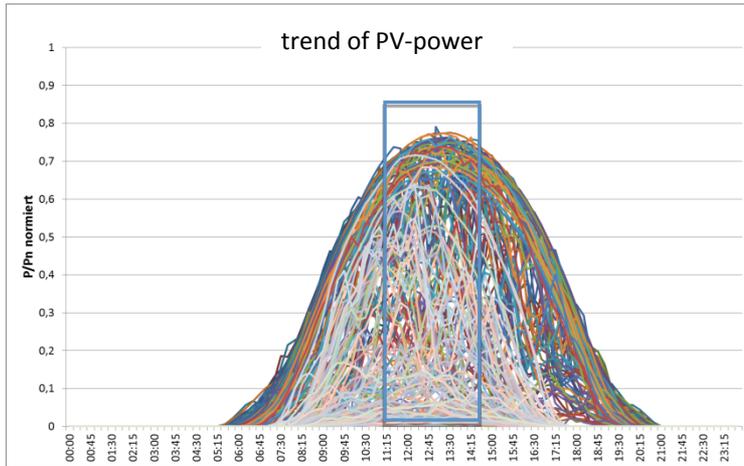
$$d := \frac{\Delta S_a}{S_{kV}} \cdot \cos(\psi + \rho) \cdot F$$

| | |
|--------------|---|
| d | <i>relative voltage change</i> |
| ΔS_a | <i>feed in power [kVA], for PV-system [kWp]</i> |
| S_{kV} | <i>short circuit power at connection point</i> |
| ψ | <i>grid angle</i> |
| φ | <i>angle of apparent power</i> |
| F | <i>probabilistic reduction factor</i> |

Simplified assessment procedure

Probabilistic assessment (methodology)

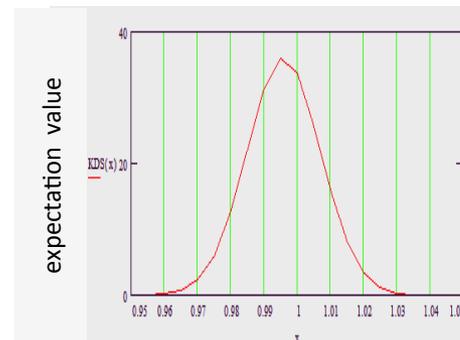
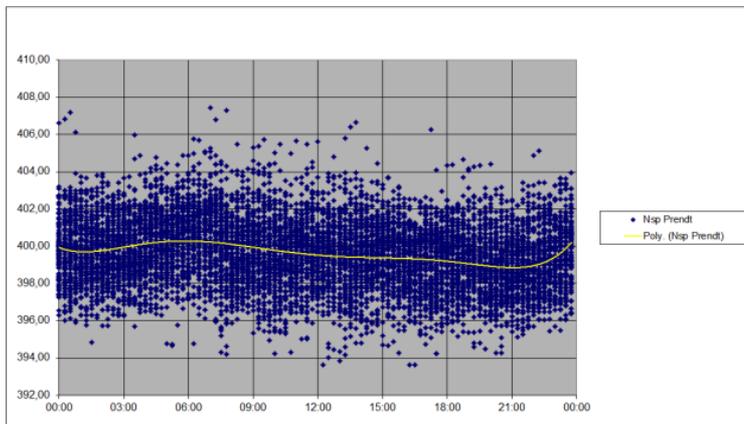
measured PV-Power (kW/kWp) und expectation of the power at noon



evaluation of the expected values via density estimation

$$f_n(x) := \frac{1}{n+h} \sum_{i=1}^n K\left(\frac{x-X_i}{h}\right)$$

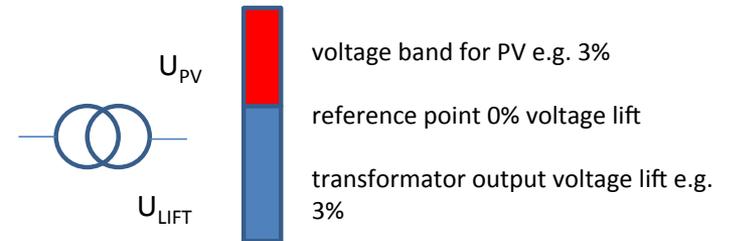
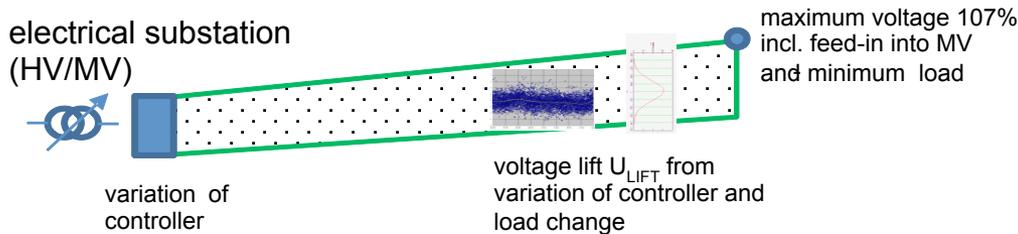
measured voltage at MV/LV transformer (June–September) and expected value of the voltage



$$K(u) := \frac{35}{32} (1-u^2)^3 \quad \text{Kernel (Triweight-Funktion)}$$

Source: <http://de.wikipedia.org/wiki/Kernel-Regression>

Probabilistic assessment (methodology)



$$\Delta U = \Delta U_{LIFT} + \Delta U_{PV}$$

ΔU resulting voltage lift
 ΔU_{Hub} variation of transformer output voltage from the reference point
 ΔU_{PV} voltage lift by PV

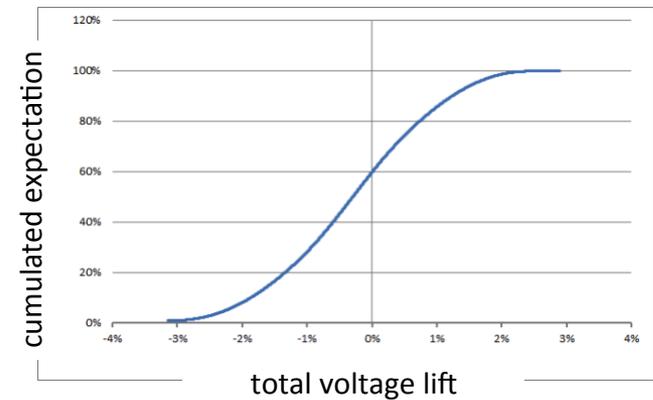
$$E = E_{LIFT} * E_{PV}$$

E total expectation value of resulting voltage lift
 E_{hub} expectation value of transformer output voltage
 E_{pv} expectation value of voltage lift by PV

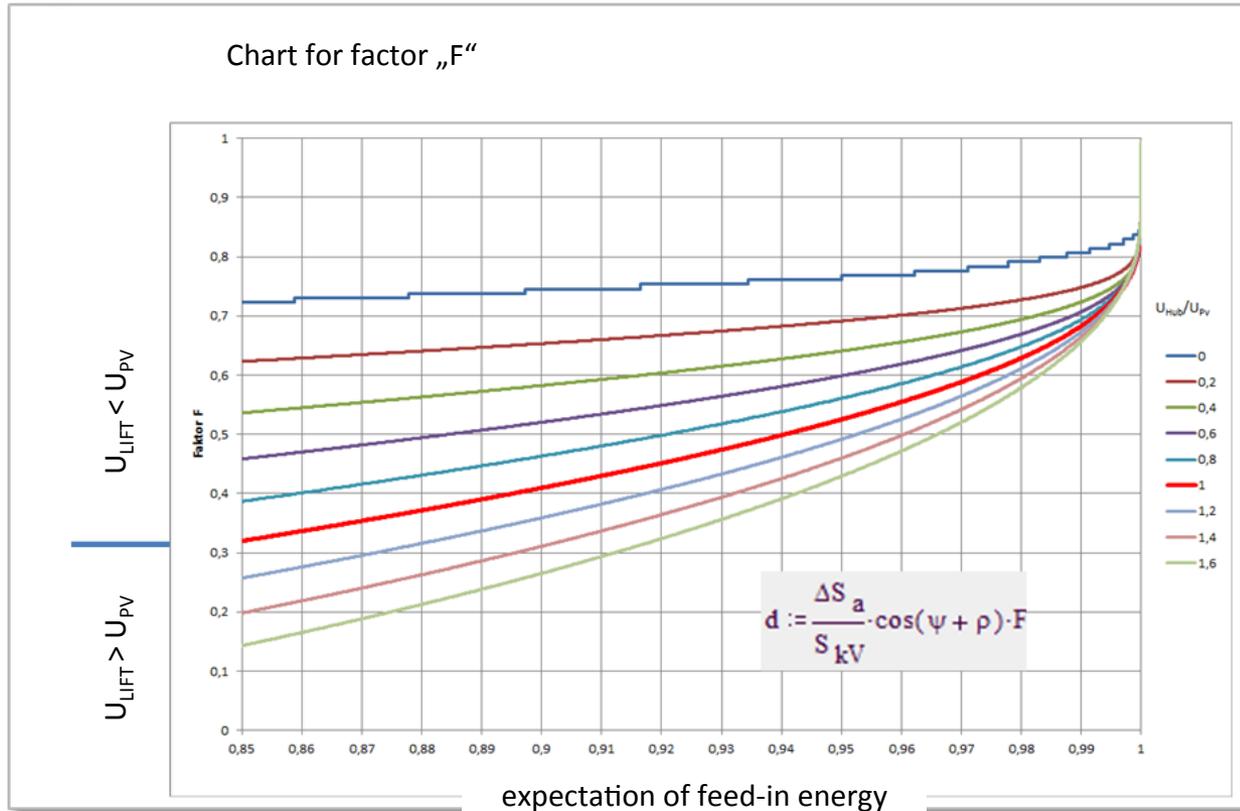
- the voltage values ΔU_{LIFT} and ΔU_{PV} are two independently occurring values
- total expected value is determined by multiplying the individual expected values

| U_{LIFT} | U_{PV} | | | |
|------------|----------|-----|-----|----|
| | 0% | 1% | 2% | 3% |
| 0% | 0% | 1% | 2% | 3% |
| -1% | -1% | 0% | 1% | 2% |
| -2% | -2% | -1% | 0% | 1% |
| -3% | -3% | -2% | -1% | 0% |

| U_{LIFT} | U_{PV} | | | |
|------------|----------|-------|-------|-------|
| | 0% | 1% | 2% | 3% |
| 0% | 0,021 | 0,022 | 0,021 | 0,061 |
| -1% | 0,071 | 0,077 | 0,071 | 0,207 |
| -2% | 0,071 | 0,077 | 0,071 | 0,207 |
| -3% | 0,021 | 0,023 | 0,021 | 0,061 |



Probabilistic assessment (methodology)

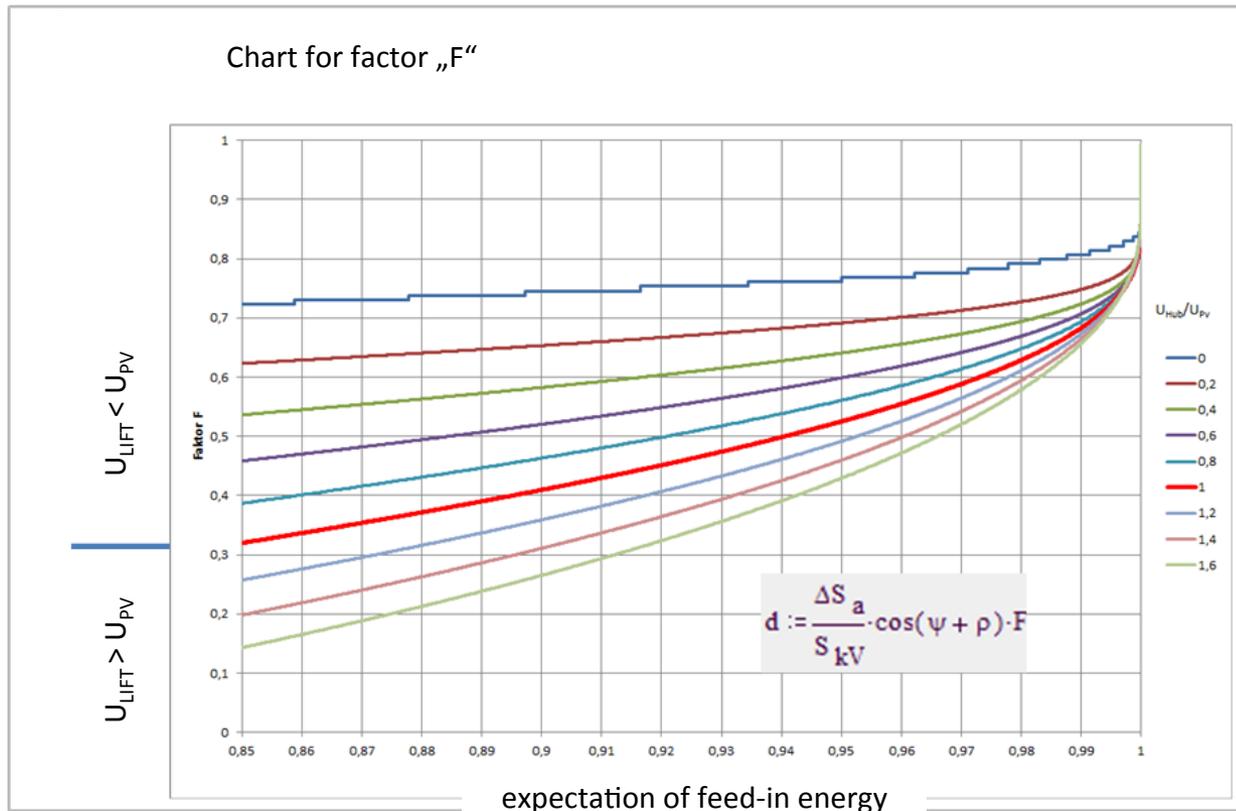


factor F is depending on ratio of U_{LIFT}/U_{PV}, so by the rated voltage on the MV/LV transformer and the allowed voltage-raising by PV-generation

Probabilistic assessment (methodology)

example

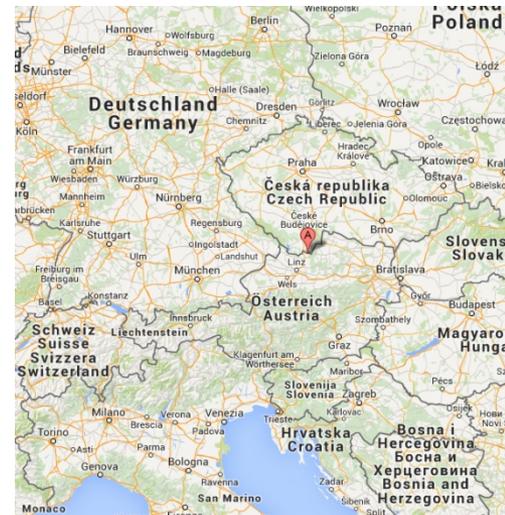
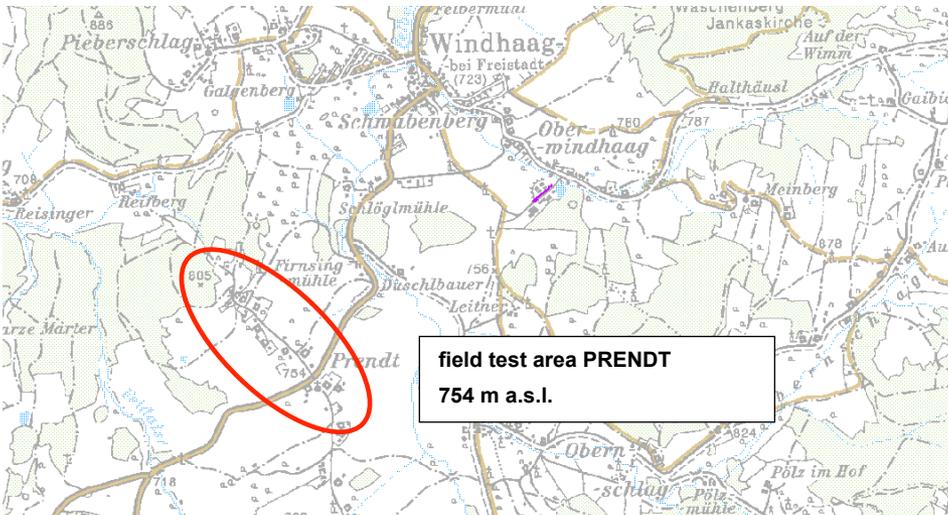
- maximum voltage in **MV-grid 107%**
- voltage lift (variation of controller) at **electrical substation (HV/MV) and at transformer station (MV/LV) 2%**
- **allowable voltage band** (planning value) for PV-feed-in in LV-grid **3%**; expectation value of 95%



- 30 kWp PV-feed-in 1 with CosPhi = 0,95 at connection point with S_{kV} = 570 kVA
ψ = 30°
- 30 kWp PV-feed in 2 with CosPhi = 0,95 at connection point with S_{kV} = 1200 kVA
ψ = 40°

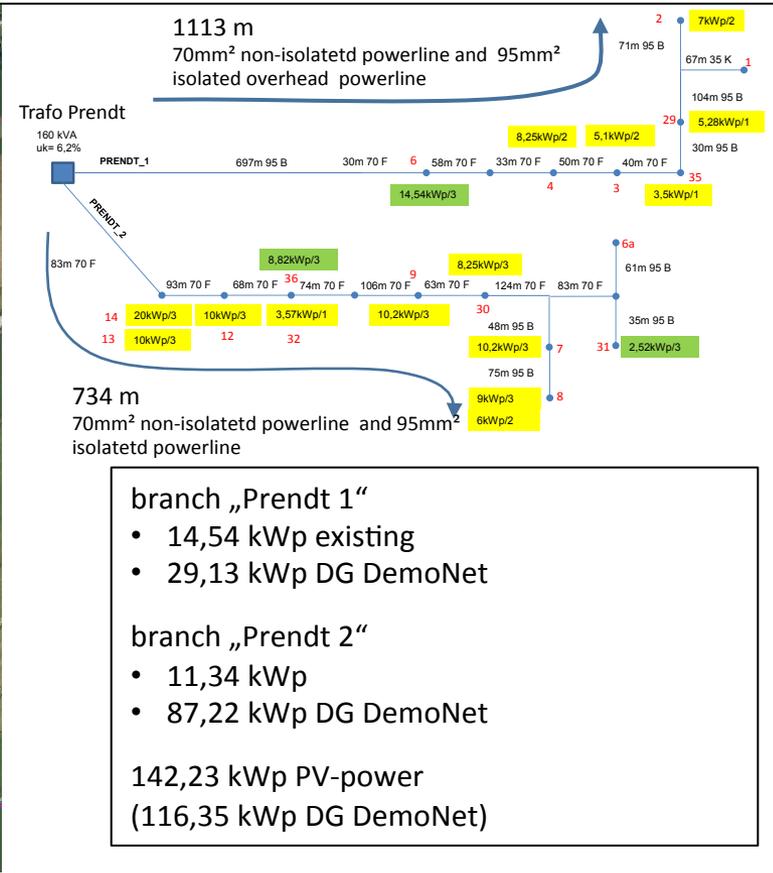
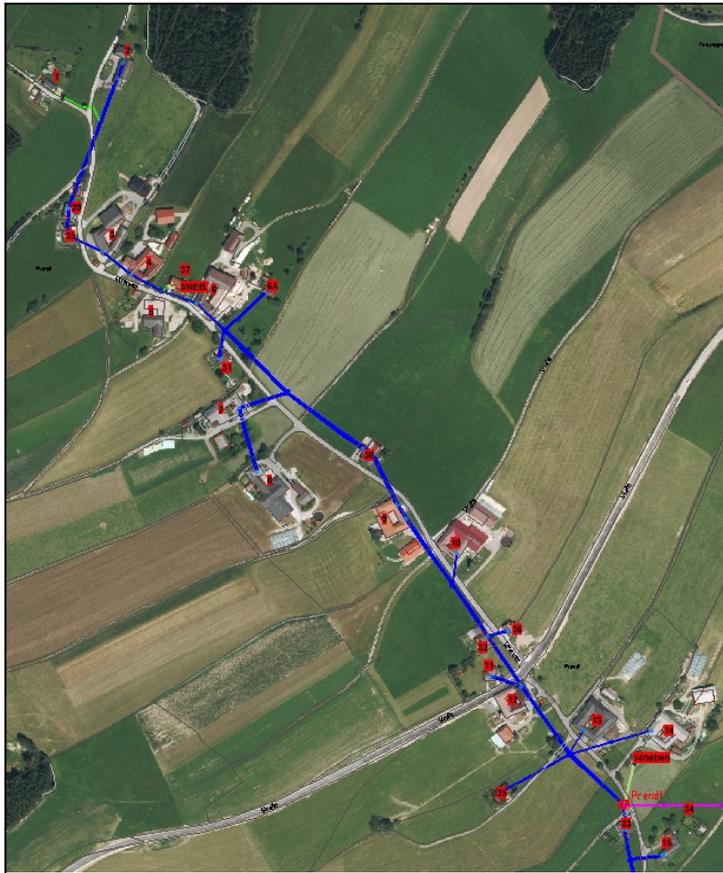
- U_{LIFT}/U_{PV} = 2% / 3% = 0,67
- factor **F = 0,6** (from line U_{LIFT}/U_{PV} = 0,6)
- d₁ = 30 kWp / 570 kVA * Cos(30 + 18) * 0,6 = 2,11%
- d₂ = 30 kWp / 1200 kVA * Cos(40 + 18) * 0,6 = 0,79%
- **d₁ + d₂ = 2,9%**
<3% (allowable voltage band for PV)
→ feed-in OK

Field test area Prendt

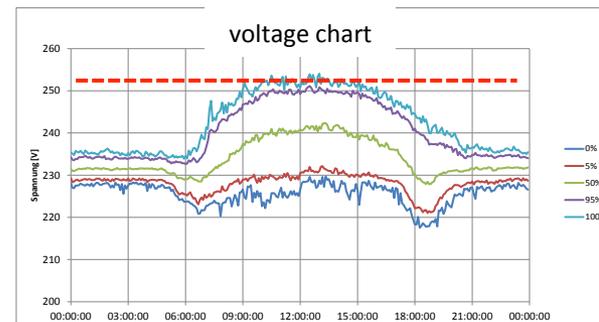
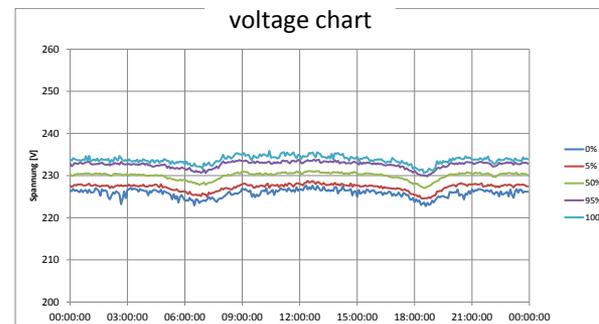
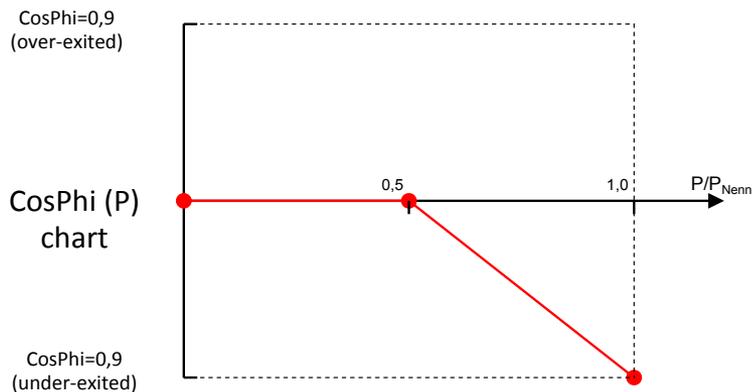


Field test area Prendt

in the framework of the research project "DG DemoNet smart LV grid"
the probabilistic planning approach has been tested



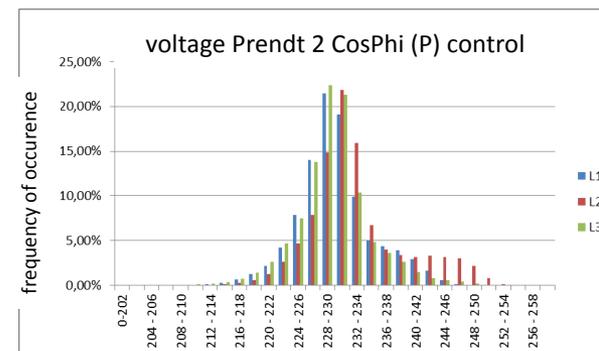
Results field test area $\text{Cos}\varphi(P)$



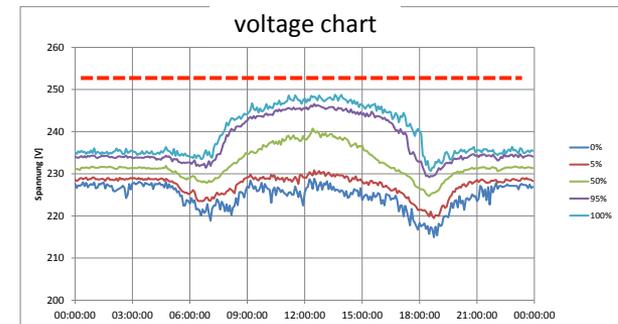
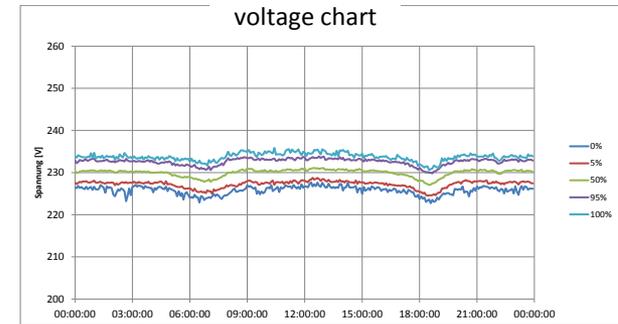
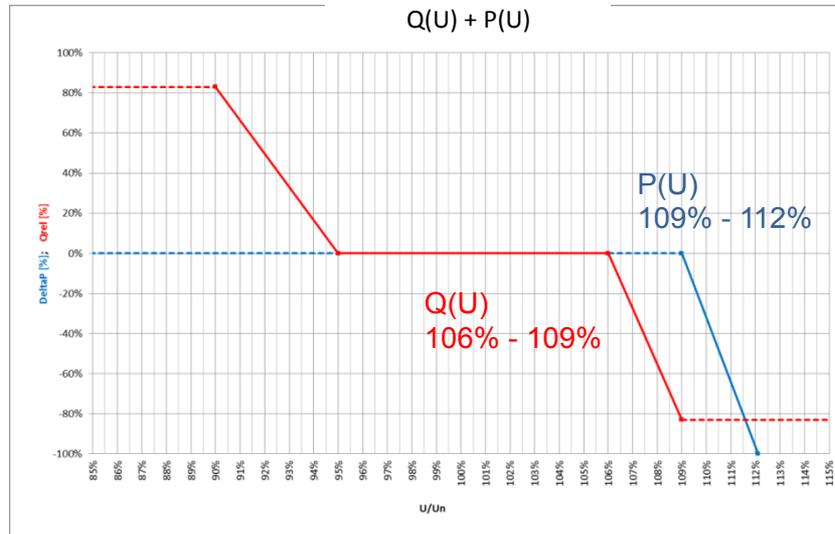
conventional assessment with $\text{CosPhi}=1 \rightarrow \Delta U = +9\%$

measured maximum voltages (100% und 95% quantile)

| | transformer station | | Prendt 2 | | ΔU [%] |
|--------|---------------------|----------|----------|----------|----------------|
| U Q95 | 101,7% | 233,91 V | 109,2% | 251,16 V | 7,5 % |
| U Q100 | 102,5% | 235,75 | 110,5% | 254,15 V | 8,0 % |



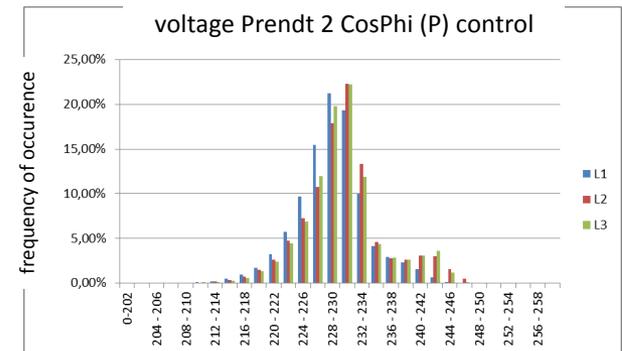
Results field test area Q(U) + P(U)



conventional assessment with $\text{Cosp}=1 \rightarrow \Delta U = +9\%$

measured maximum voltages (100% und 95% quantile)

| | transformer station | | Prendt 2 | | ΔU [%] |
|--------|---------------------|----------|----------|----------|----------------|
| U Q95 | 101,7% | 233,91 V | 107,2% | 246,56 V | 5,5 % |
| U Q100 | 102,5% | 235,75 V | 108,2% | 248,86 V | 5,7 % |

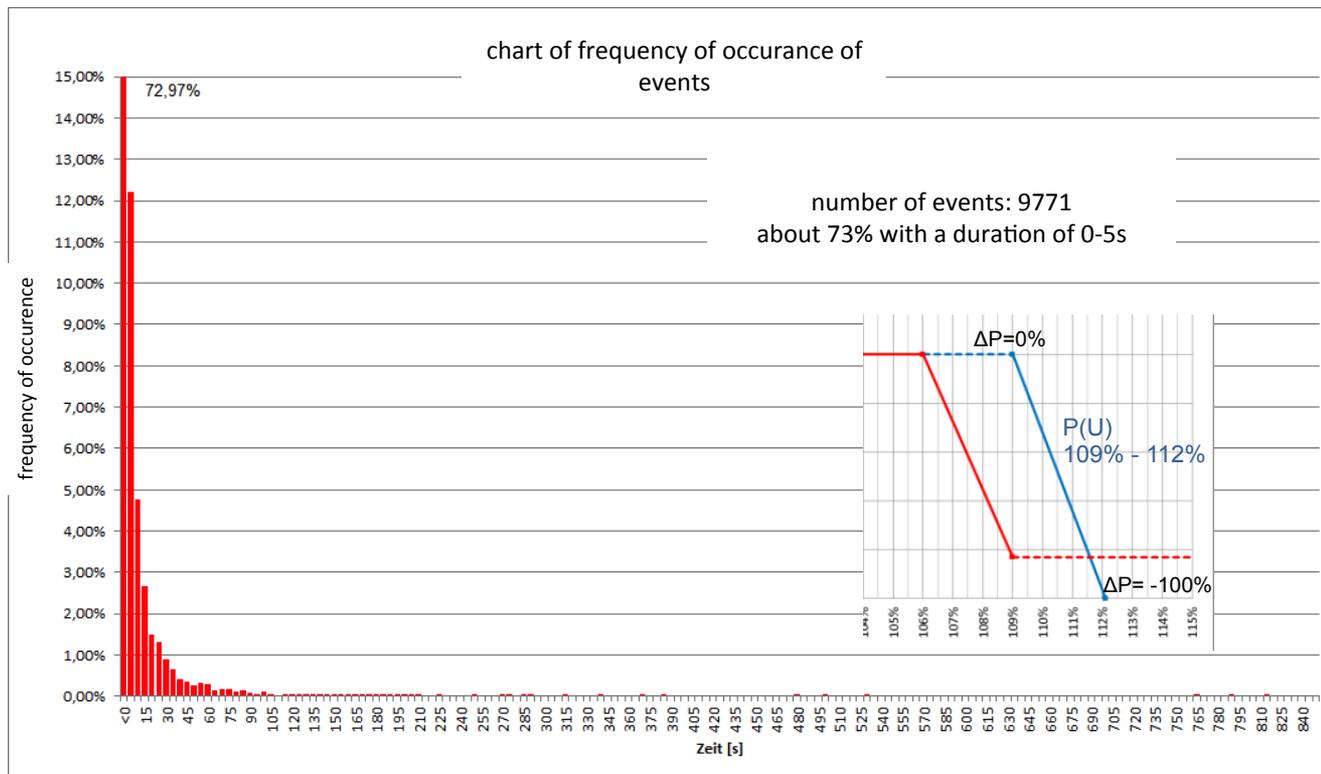


Results field test area Q(U) + P(U)

In Prendt 2, a Fronius datalogger was installed by the customer.

This data logger recorded the control actions ('events' for 223 days) of the P(U)-Control in the following form:

- timestamp of the control action
- duration of the activation
- minimum and maximum voltage of the activated phase(s) (1s-value)



Results field test area

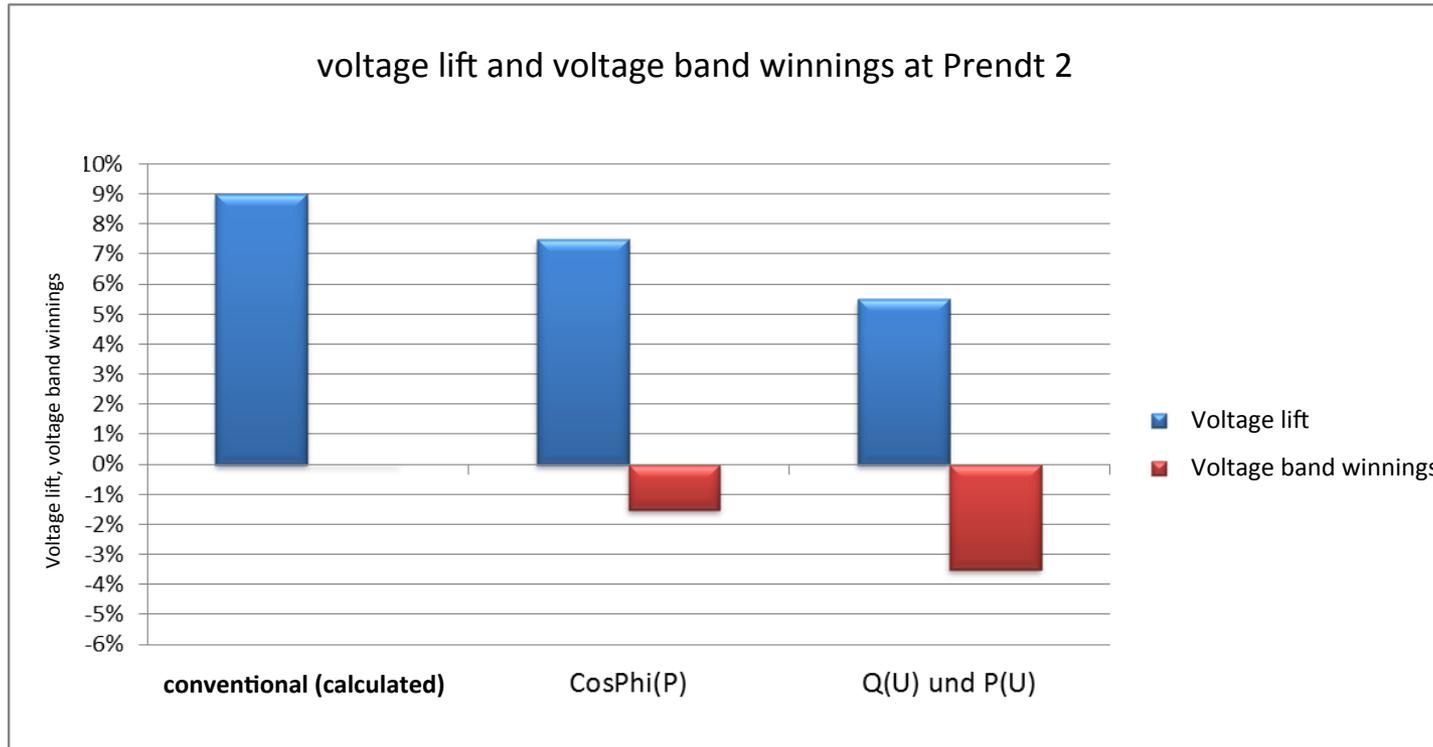
| | loss of yield [kWh] | | | loss of yield [%] | | |
|--------------------------|---------------------|------|------|-------------------|-------|-------|
| | 100% | 50% | 25% | 100% | 50% | 25% |
| expected power reduction | | | | | | |
| >0 s | 133,6 | 66,8 | 33,4 | 2,62% | 1,31% | 0,66% |
| >5 s | 104,1 | 52,0 | 26,0 | 2,04% | 1,02% | 0,51% |

In the power inverter recorded voltages (1 s values) show, that during the control actions the voltage values are less than 109%.

If we now assume that such control interventions take a very short time (compensation of voltage spikes when devices are powered on) and takes into account the control curve to estimate the power reduction, the result is a yield loss of 0.176% at 15.83 h control intervention time.

**not feed-in energy amount is very low
in the range between 0.18% - 1.31%**

Results field test area



Conclusions

- probabilistic planning approach represents a **very effective method for improved evaluation of network capacity** for decentralized PV feed-in
- while **conventional assessment always assumes worst-case assumptions**, the presented probabilistic planning approach takes into account the static behavior of the voltage on the MV/LV transformer and the feed-in power
- it is shown that the **worst-case assumptions only occur with low probability**
- if it is possible for the distribution system operator (DSO) to cut-off or control the feed-in power (P(U)-control) of one or more feeder as needed for **rare short periods** of time when the upper voltage limit is reached, an increase of installed PV feed-in is possible
- both the results of the probabilistic planning approach and the results of the field tests show that a **doubling of installed photovoltaic capacity in existing low voltage networks is possible with a small amount of not feed-in energy**

Thank you for your attention!

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