Trend analysis for power quality parameters based on long-term measurement campaigns

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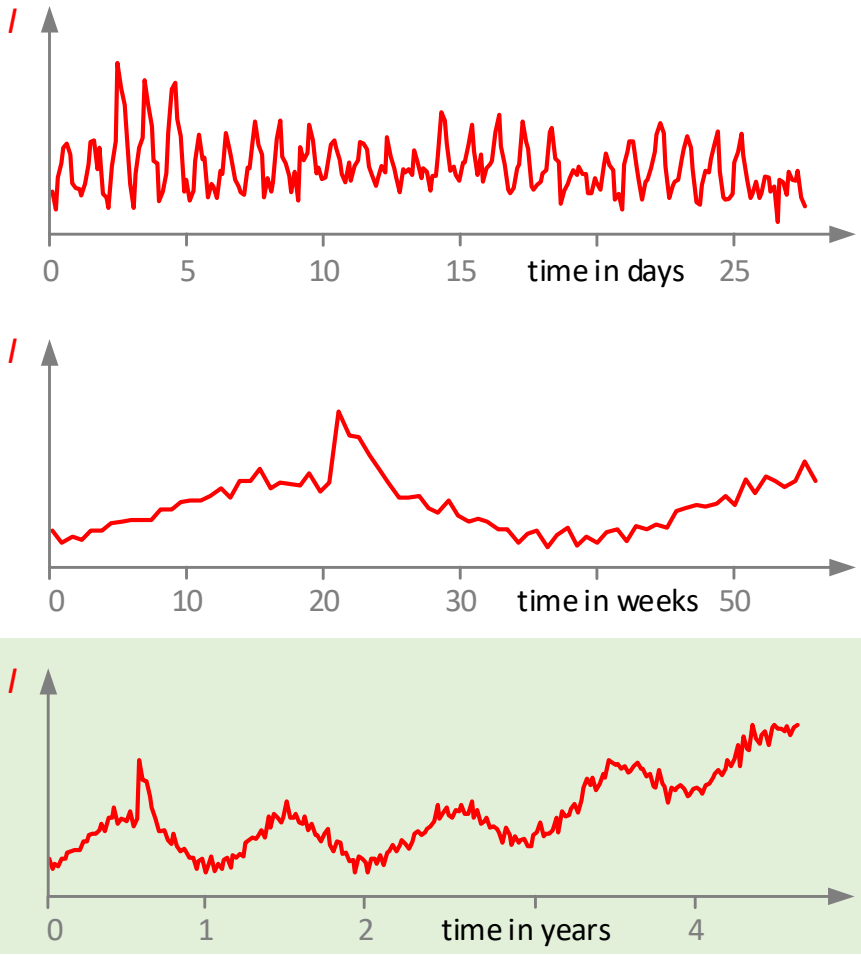
Introduction

Types of variation

- Variations of Power Quality due to set of complex impact factors (mostly electric environment)
- Short-term variations (days to weeks with daily and weekly cycles)
- Medium-term variations (weeks to months with seasonal effects)
- Long-term variations (months to years with **trend developments**)



Introduction

Analysis of trend developments

- Slow changing in PQ levels due to large scale replacement by new technologies
  - Consuming appliances (e.g. LED lamps, electrical vehicle chargers)
  - Generating equipment (e.g. PV inverters, wind turbines)

- Early detection of possible increases/decreases in PQ levels enables proactive and punctual actions
- Enables identification of possible trends for certain regions or sites within long-term measurements

Introduction

Analysis of trend developments

- Only few analysis methods for continuous PQ parameters
- Most of the methods apply linear regression without any pre-processing

- Development of robust methodology to process large amount of data
- Quantification based on easy-to-interpret indices
- Decrease the amount of „dark data“ and gain more insights

Methodology

Overview

- Step 0) Artificial extension of time series
  to use methodology for time series shorter than 2 years
- Step 1) Extraction of trend component
  by using time series decomposition to remove seasonal variations
- Step 2) Assessment of trend developments
  to quantify most recent increasing/decreasing tendencies

Methodology

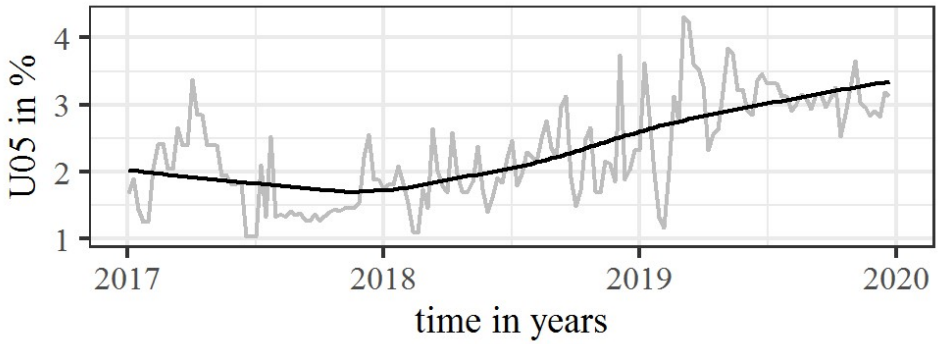
Extraction of trend component

- Time series decomposition based on additive component model

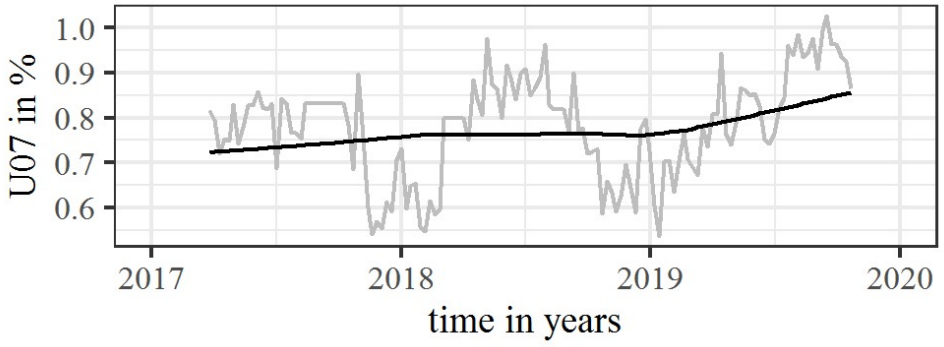
  Time series =
  + **Trend component** T_t
  + Seasonal component S_t
  + Residual component R_t

- Decomposition using STL method (Seasonal and Trend decomposition using Loess)
- Two times exponential smoothing to remove seasonal component and extract smoothed trend component

Chinese measurement CN01



German measurement DE07

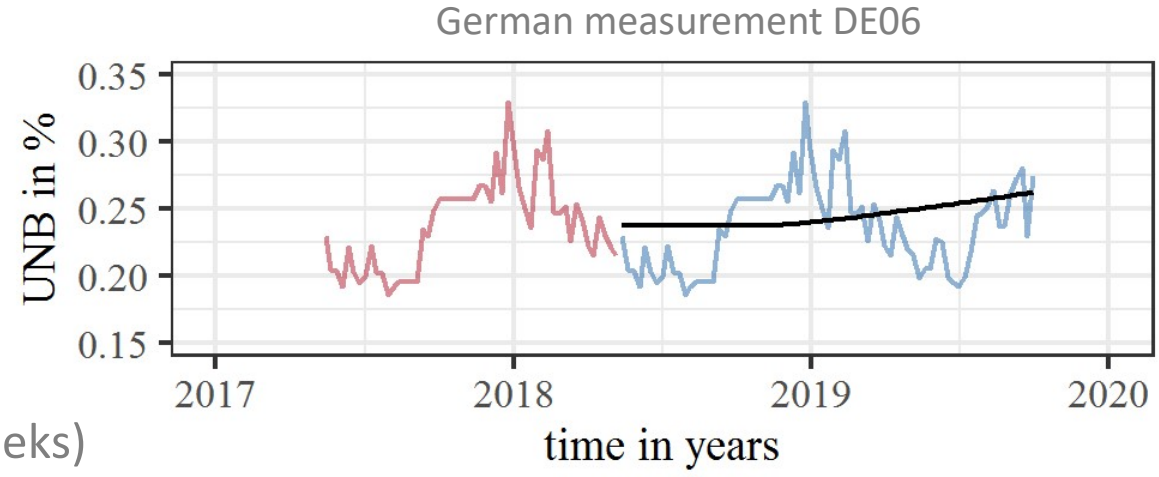


Methodology

Artificial extension of time series

- STL decomposition requires time series with 105 weeks
  (at least two periods of expected seasonal component)
- Artificial extension to apply STL for shorter durations of [53, 104] weeks

- Original time series (73 weeks)
- Artificially extended
  (repeated first full year)
- Resulting trend component
  (Differences compared to
  "true" trend components smaller
  the closer the duration is to 105 weeks)



Methodology

Quantification of trend developments

- Trend strength

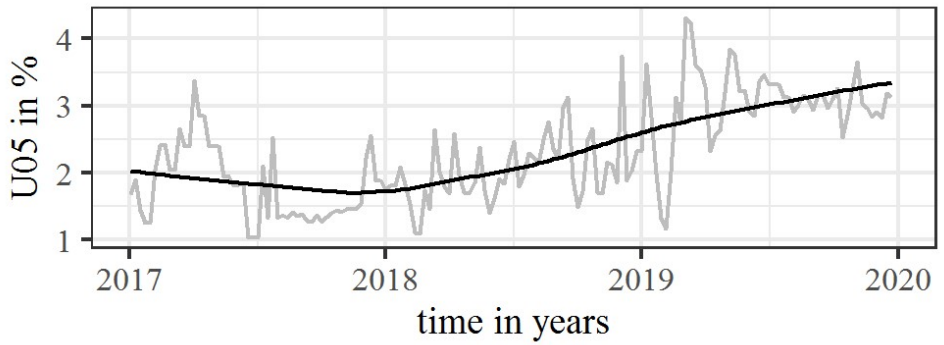
$$f_{\mathrm{T}} = \max\left(0, 1 - \frac{\mathrm{Var}(R_t)}{\mathrm{Var}(T_t + R_t)}\right) \quad = 0.66$$

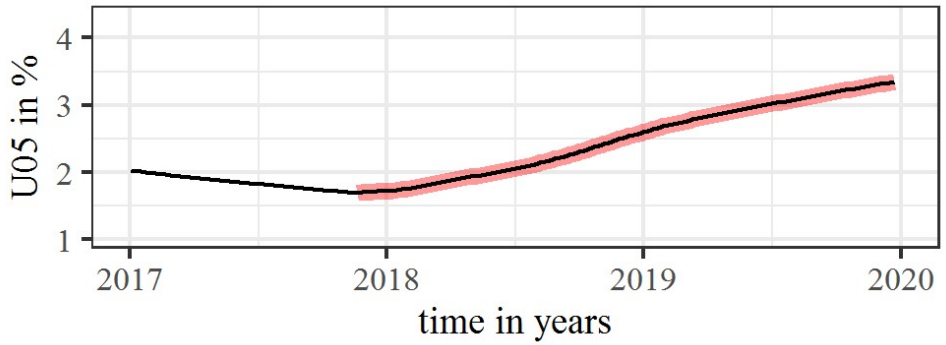
- Seasonal strength

$$f_{\mathrm{S}} = \max\left(0, 1 - \frac{\mathrm{Var}(R_t)}{\mathrm{Var}(S_t + R_t)}\right) \quad = 0.38$$

- Recent trend development
  (after most recent turning point if present)
  - Absolute trend gain *G* = +1.65 %
  - Trend duration *d* = 110 weeks
  - Average trend gain *g* = *G*/*d* = +0.78 %/y

Chinese measurement CN01





Measurement data

Measurement sites and PQ parameters

24 measurements within **110 kV with durations up to 3 years** (62 w up to 157 w)

12 Chinese measurements (CN)

- Aggregation interval of 3 min
- Different cities in East China
- Electrified railway, microfabrication and municipal electricity

12 German measurements (DE)

- Aggregation interval of 10 min
- Central and Southern Germany
- Renewable energy, municipal electricity and rural areas

Fixed PQ instruments complying with **IEC 61000-4-30 class A**

Voltage quality parameters

- RMS (Urms)
- Unbalance (UNB)
- Long-term flicker (Uplt)
- Total harmonic distortion (Uthd)
- Harmonics (U03, U05, …, U25)

Current quality parameters

- RMS (Irms)
- Total harmonic current (Ithc)
- Harmonics (I03, I05, …, I19)

Measurement data

Data pre-processing

1) Aggregation of Chinese measurements to 9 minutes

2) Uncertainty assessment of harmonics
   - Especially triple order harmonics (h = 3, 9, …, 21) with low amplitudes close to measurement noise
   - Determination of uncertainty threshold for maximum amplitude error of 10 %
   - Laboratory measurements for German PQ instruments → threshold of 14 mV and 0.33 A

3) Calculation of weekly 95th percentiles
   - Every full calendar week (from Monday to Sunday)
   - Requires at least 95 % of measured values available (up to 8.5 h missing values)

4) Impute missing weeks
   - Replace missing weeks with last calculated weekly percentile

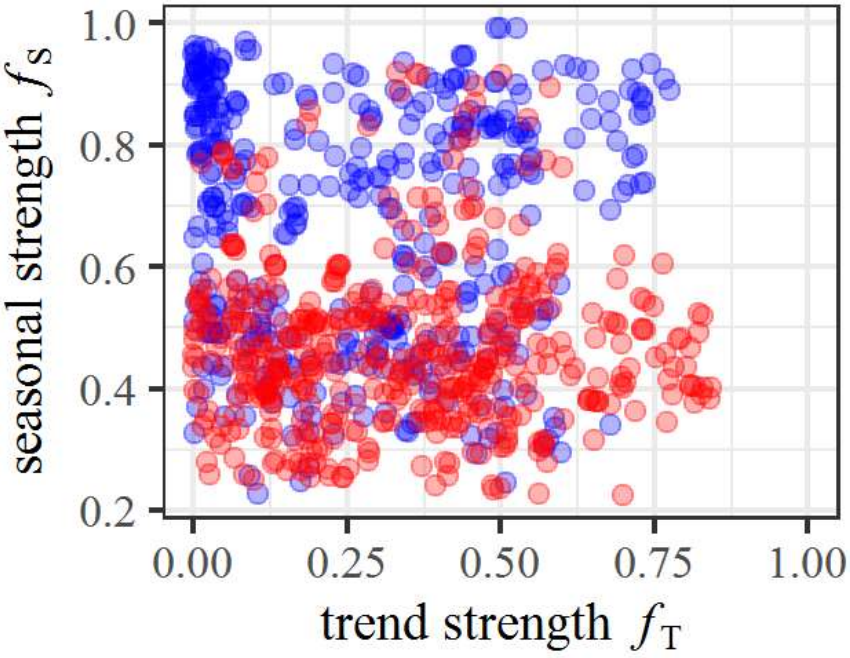
5) Select suitable time series
   - Duration of time series > 52 weeks
   - Maximum single gap of missing weeks ≤ 10 weeks
   - Total percentage of missing weeks ≤ 20 %

→ 847 time series available for analysis

Analysis results

Trend and seasonal strength

- Trend strength
  - Varies between 0.0 (no trend developments) and 0.8 (strong trend developments)
  - Most German sites low to no trends
  - Some Chinese sites strong trends
- Seasonal strength
  - Most German sites with higher seasonality ($f_S > 0.6$)
  - Most Chineses sites with lower seasonality ($f_S < 0.6$)



Analysis results

Recent trend developments

- Trend duration
  - Most recent trend developments last almost 1 year or longer (75 % with more than 40 weeks)
  - Some sites with durations up to 3 years

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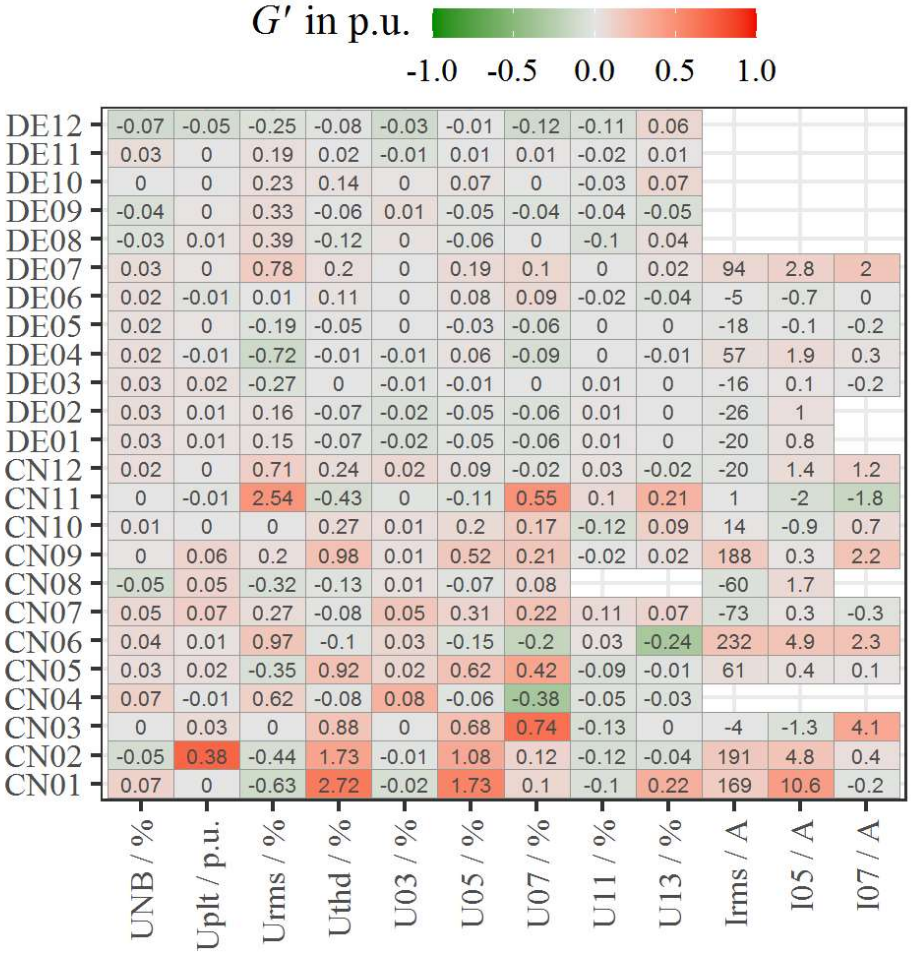
- Absolute trend gain
  - Most trend developments almost zero or very low
  - 25 % decreasing and 33 % increasing tendencies
  - Some sites with very high increases (CN02 for Uplt and CN01/CN02 for Uthd)



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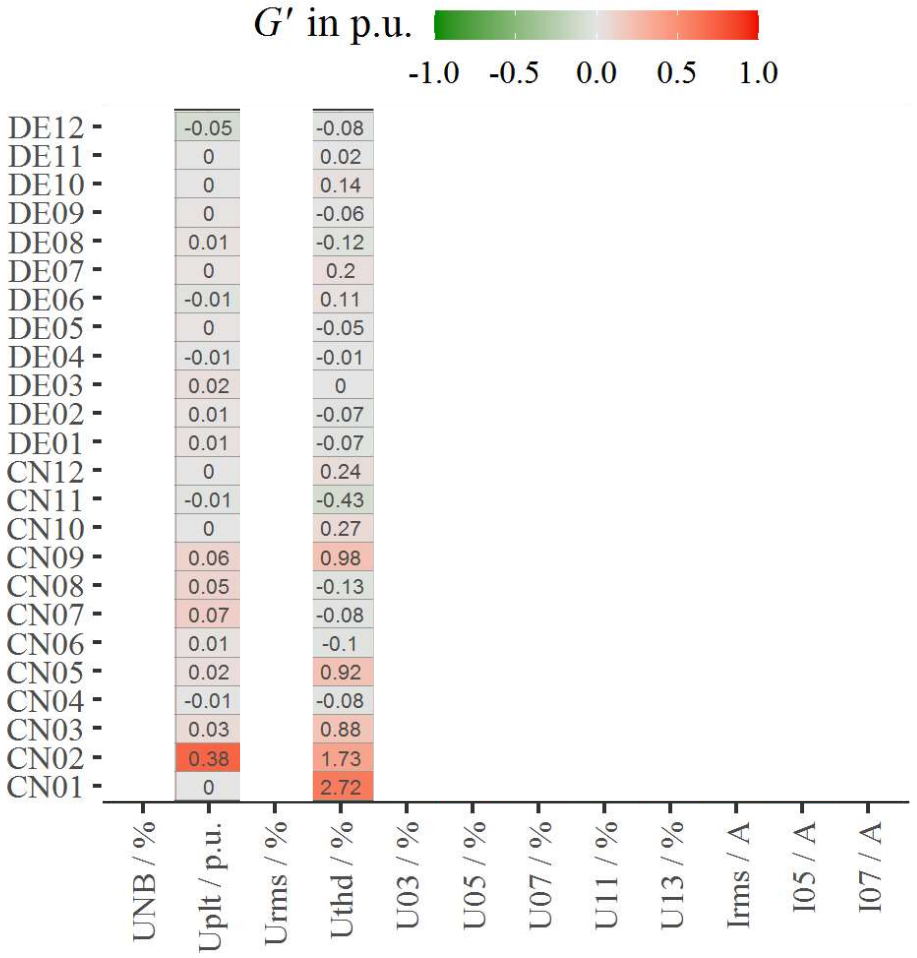

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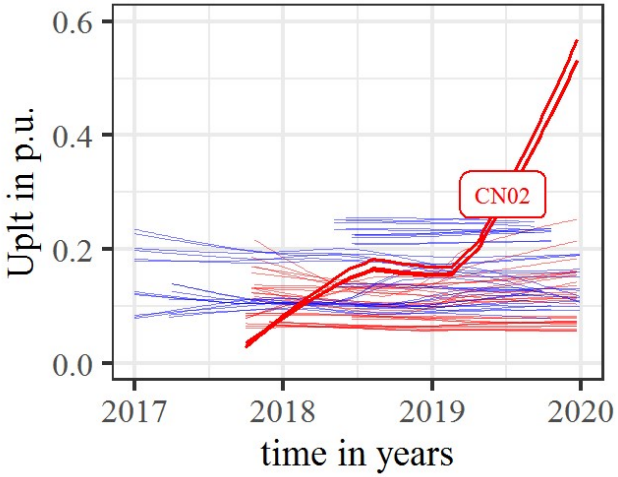

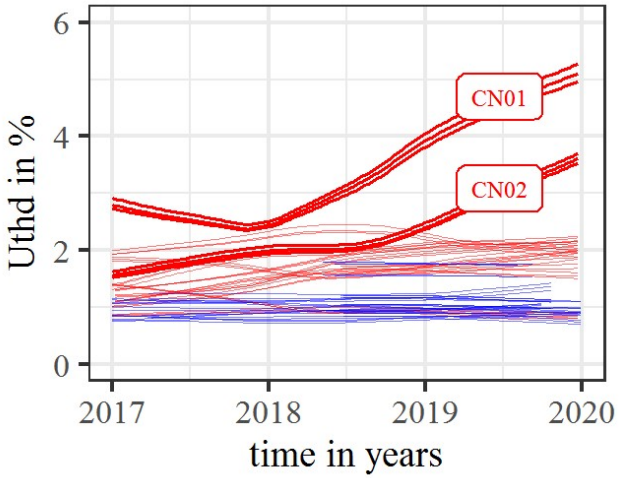

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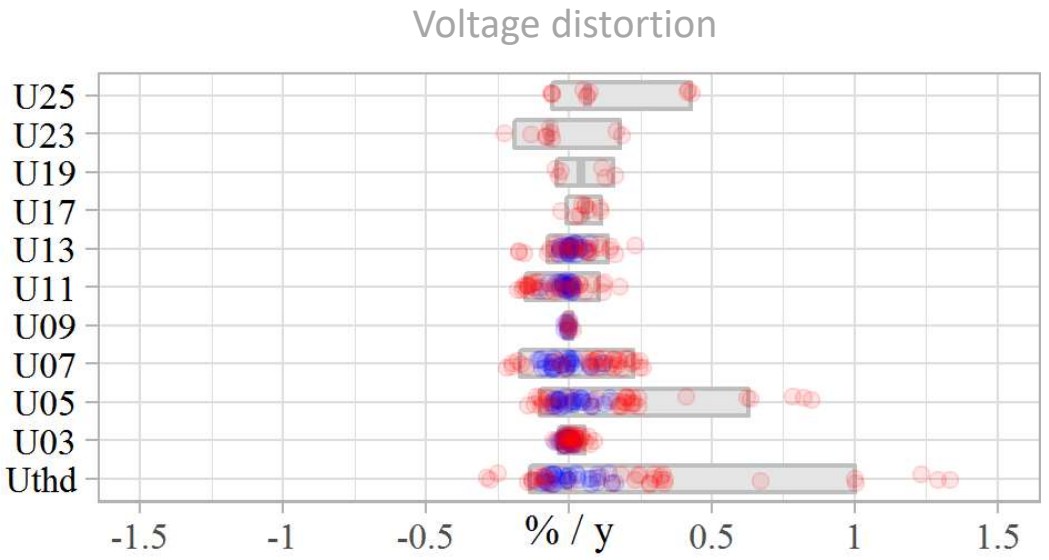
  - 25 % decreasing and 33 % increasing tendencies
  - Some sites with very high increases (CN02 for Uplt and CN01/CN02 for Uthd)
- Average trend gain
  - Recent trends for voltage distortion mostly lower than ±0.25 %/y
  - All German sites with low to no changes
  - Two Chinese sites with higher increases (CN01/CN02 for Uthd, U05 and U25)



Conclusion

- Methodology to analyse trend developments in long-term measurements
- Extraction of trend component using STL decomposition
- Artificial extension for the application of measurements < 2 years
- Quantification of trend developments with easy-to-interpret indices

- Analysis of German and Chinese measurements shows qualitative differences
- Most of recent trend developments show low to no increases/decreases and last more than one year
- Two Chinese sites with very strong increases for flicker and voltage distortion

Thank you for your attention!

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Agenda

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- Methodology
- Measurement data
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