

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

Max Domagk, Jan Meyer, Tongxun Wang, Dandan Feng, Wei Huang, Heiko Mayer, Simon Wenig, Marco Lindner, Jan-Hendrik Amrhein

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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

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# 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









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Slide 7

# 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 5 0
  (Differences compared to 0
  "true" trend components smaller
  the closer the duration is to 105 weeks)



### Methodology

### **Quantification of trend developments**

• Trend strength

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

• Seasonal strength

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

- 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



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### **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
- o 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

- o 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 (103, 105, ..., 119)



### **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  $\rightarrow$  threshold of 14 mV and 0.33 A

#### 3) Calculation of weekly 95<sup>th</sup> 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

## **Trend and seasonal strength**

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



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### **Analysis results**

### **Recent trend developments**

#### • Trend duration

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

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





-1.0	-0.5	0.0	0.5	1.0

DE12 -	-0.07	-0.05	-0.25	-0.08	-0.03	-0.01	-0.12	-0.11	0.06			
DE11 -	0.03	0	0.19	0.02	-0.01	0.01	0.01	-0.02	0.01			
DE10 -	0	0	0.23	0.14	0	0.07	0	-0.03	0.07			
DE09 -	-0.04	0	0.33	-0.06	0.01	-0.05	-0.04	-0.04	-0.05			
DE08 -	-0.03	0.01	0.39	-0.12	0	-0.06	0	-0.1	0.04			
DE07 -	0.03	0	0.78	0.2	0	0.19	0.1	0	0.02	94	2.8	2
DE06 -	0.02	-0.01	0.01	0.11	0	0.08	0.09	-0.02	-0.04	-5	-0.7	0
DE05 -	0.02	0	-0.19	-0.05	0	-0.03	-0.06	0	0	-18	-0.1	-0.2
DE04 -	0.02	-0.01	-0.72	-0.01	-0.01	0.06	-0.09	0	-0.01	57	1.9	0.3
DE03 -	0.03	0.02	-0.27	0	-0.01	-0.01	0	0.01	0	-16	0.1	-0.2
DE02 -	0.03	0.01	0.16	-0.07	-0.02	-0.05	-0.06	0.01	0	-26	1	
DE01 -	0.03	0.01	0.15	-0.07	-0.02	-0.05	-0.06	0.01	0	-20	0.8	
CN12 -	0.02	0	0.71	0.24	0.02	0.09	-0.02	0.03	-0.02	-20	1.4	1.2
CN11 -	0	-0.01	2.54	-0.43	0	-0.11	0.55	0.1	0.21	1	-2	-1.8
CN10 -	0.01	0	0	0.27	0.01	0.2	0.17	-0.12	0.09	14	-0.9	0.7
CN09 -	0	0.06	0.2	0.98	0.01	0.52	0.21	-0.02	0.02	188	0.3	2.2
CN08 -	-0.05	0.05	-0.32	-0.13	0.01	-0.07	0.08	_		-60	1.7	
CN07 -	0.05	0.07	0.27	-0.08	0.05	0.31	0.22	0.11	0.07	-73	0.3	-0.3
CN06 -	0.04	0.01	0.97	-0.1	0.03	-0.15	-0.2	0.03	-0.24	232	4.9	2.3
CN05 -	0.03	0.02	-0.35	0.92	0.02	0.62	0.42	-0.09	-0.01	61	0.4	0.1
CN04 -	0.07	-0.01	0.62	-0.08	0.08	-0.06	-0.38	-0.05	-0.03			
CN03 -	0	0.03	0	0.88	0	0.68	0.74	-0.13	0	-4	-1.3	4.1
CN02 -	-0.05	0.38	-0.44	1.73	-0.01	1.08	0.12	-0.12	-0.04	191	4.8	0.4
CN01 -	0.07	0	-0.63	2.72	-0.02	1.73	0.1	-0.1	0.22	169	10.6	-0.2
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DE06 -		-0.01		0.11								
DE05 -		0		-0.05								
DE04 -		-0.01		-0.01								
DE03 -		0.02		0								
DE02 -		0.01		-0.07								
DE01 -		0.01		-0.07								
CN12 -		0		0.24								
CN11 -		-0.01		-0.43								
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CN02 -		0.38		1.73								
CN01 -		0		2.72								
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2019

2020



2018

0.6

0.4

0.2

0.0

2017

Uplt in p.u.

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



% / y

0.5

-0.5

-1

-1.5

Voltage distortion

1.5

IFFF

# 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!

Max Domagk TU Dresden – IEEH +49 351 463 35223 max.domagk@tu-dresden.de

# Agenda



- Introduction
- Methodology
- Measurement data
- Analysis results
- Conclusion

## Methodology

### **Extraction of trend component**

14 I03 in A Time series decomposition based on 10 additive component model 9 2 Time series =0 + Seasonal component S<sub>t</sub> + Trend component T<sub>t</sub> 0 12 + Residual component  $R_t$ 10  $\infty$ Decomposition using STL method (Seasonal and Trend decomposition using Loess) 2 0 Two times exponential smoothing to remove seasonal component and ç extract trend component 2 3 4

time in years  $\rightarrow$ 

STL decomposition