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DRESDEN concept

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Analysis and Visualization of Large-Scale Power Quality Monitoring Campaigns

ICHQP 2024 Panel
Turning data into information: Recent developments and future needs in Power Quality data analysis
October 17, Chengdu, China

Agenda

Power Quality data analysis

Example use case: Correlation analysis

- Methodology and dataset
- Correlations between PQ parameters
- Correlations between measurement sites

Conclusions

Power Quality data analysis

Data amounts

- Measurement of PQ parameters (current and voltage) for one measurement site

Measured	every 10 min	per day	per week	per year
up to 2.5 kHz	**324**	**46.656**	**326.592**	**ca. 17 Mill.**
up to 150 kHz	**4767**	**686.016**	**ca. 5 Mill.**	**ca. 250 Mill.**

- Increasing number of large PQ monitoring campaigns in all voltage levels
- Resulting data amounts can often no longer be evaluated manually

Power Quality data analysis

Use cases / analysis goals

- Compliance with limits
- Anomaly detection
- Emission profiles
- Correlation and propagation
- Seasonal variations
- Trend identification
- Trend forecasting
- …

General analysis steps

1. Define use case / analysis goal
2. Data acquisition
3. Data pre-processing
4. Analysis methods
5. Visualization and knowledge extraction

Example use case: Correlation analysis

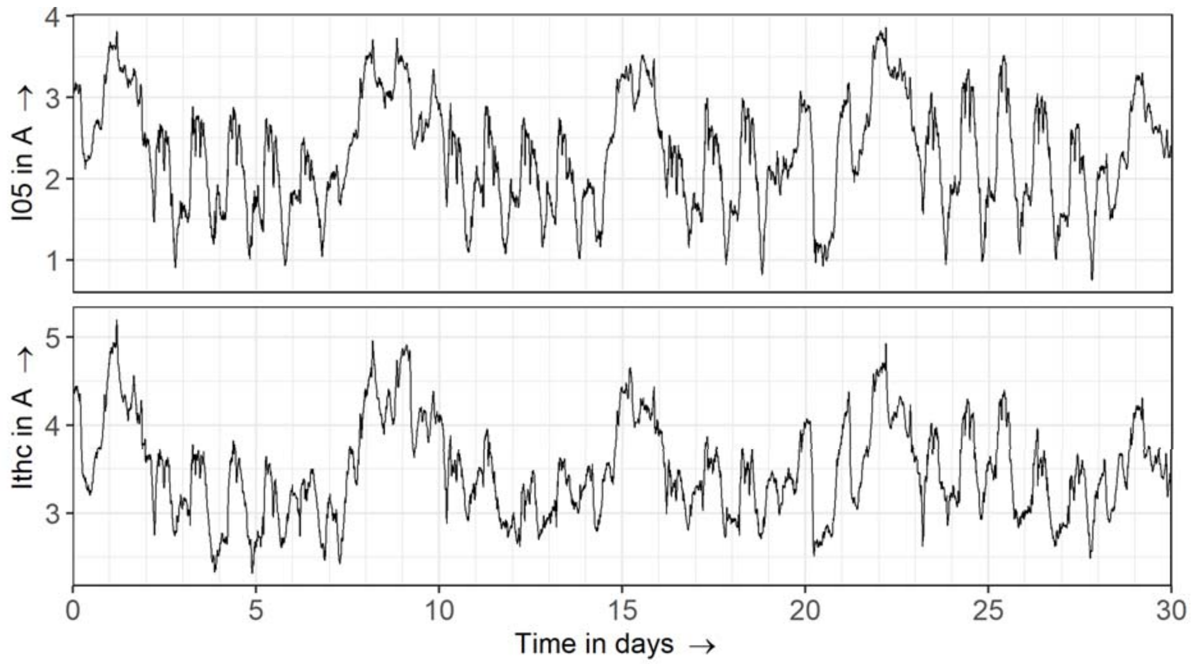
Correlation analysis

- Key for analysing relationships and dependencies in measurement data
- Can help to identify similarities in observed behaviour or asses propagation within the network

Types of correlations

- Auto-Correlation
  between different time intervals (e.g. days) within one time series
- Cross-Correlation
  between PQ parameters of one site or between sites for one PQ parameter

PQ parameters of one measurement site



Example use case: Correlation analysis
Methodology

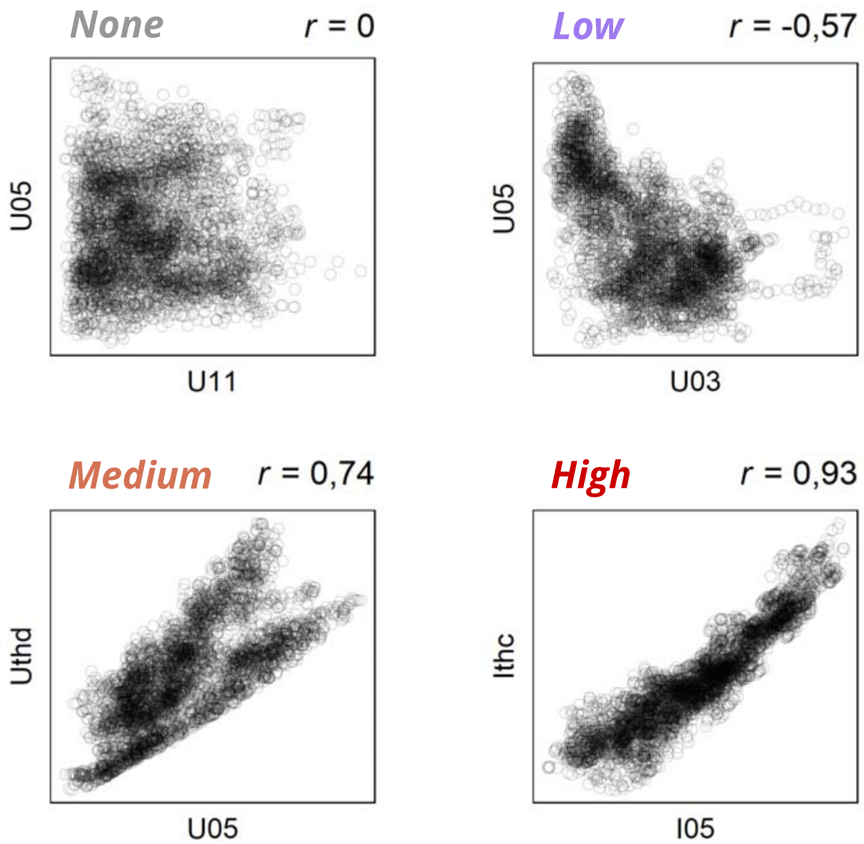
Spearman's correlation coefficient

- Measure of monotonic behaviour based on ranks
- Not limited to linear relationships

$$r = \frac{\sum_i \left(\mathrm{R}(x_i) - \bar{\mathrm{R}}_x\right)\left(\mathrm{R}(y_i) - \bar{\mathrm{R}}_y\right)}{\sqrt{\sum_i \left(\mathrm{R}(x_i) - \bar{\mathrm{R}}_x\right)^2}\sqrt{\sum_i \left(\mathrm{R}(y_i) - \bar{\mathrm{R}}_y\right)^2}}$$

Levels of correlation

- None $0 \leq |r| < 0.5$
- Low $0.5 \leq |r| < 0.7$
- Medium $0.7 \leq |r| < 0.9$
- High $0.9 \leq |r| \leq 1$



Example use case: Correlation analysis
Dataset

Measurement data

- Monitoring of German transmission system
- **85 measurement sites** in HV and EHV
  - 110 kV with 38 sites
  - 220 kV with 21 sites
  - 380 kV with 26 sites
- **20 PQ parameters**
  - RMS of voltage (Urms) and current (Irms)
  - Voltage unbalance (UNB)
  - Short-term flicker (Upst)
  - Distortion of voltage (Uthd) and current (Ithc)
  - Harmonics of voltage (U03-U15) and current (I03-I15)
  - In total 58 parameter-phase combinations
- 10 min average values for a duration of 30 days

Correlations between PQ parameters

- 58 parameters = 1.653 unique correlations
- 1.653 x 85 sites = 140.505 correlations

Correlations between measurement sites

- 85 sites = 3.570 unique correlations
- 3.570 x 58 parameters = 207.060 correlations

Analysis of a total of 347.565 correlations

Correlations between PQ parameters
Results aggregation (1)

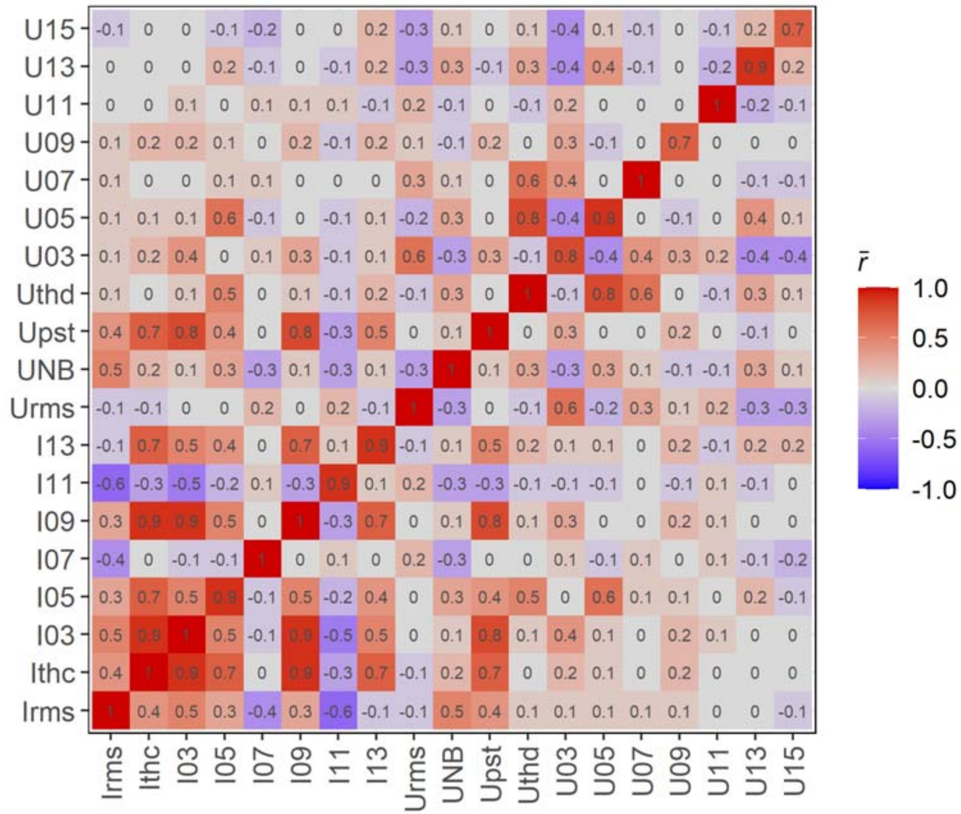
Averaging of correlation coefficients

- Up to 9 phase combinations between two parameters
  (e.g. Ithc L1/L2/L3 ~ I05 L1/L2/L3)
- Averaging reduces matrix by nearly a factor of 9
  (from 58^2 = 3.364 to 20^2 = 400 elements)
- Averaging using Fisher Z-transformation
  (otherwise too low averages due to value range [-1, 1])

- Analysing multiple matrices remains challenging
  (e.g. 85 matrices for all measurement sites)

→ Further aggregation of results necessary

Correlations between PQ parameters for one measurement site in 380 kV



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Correlations between PQ parameters
Results aggregation (2)

Aggregation of significant correlations

- Filtering of significant correlations (e.g. $|r| \geq 0.7$)
- Calculation of share across all matrices

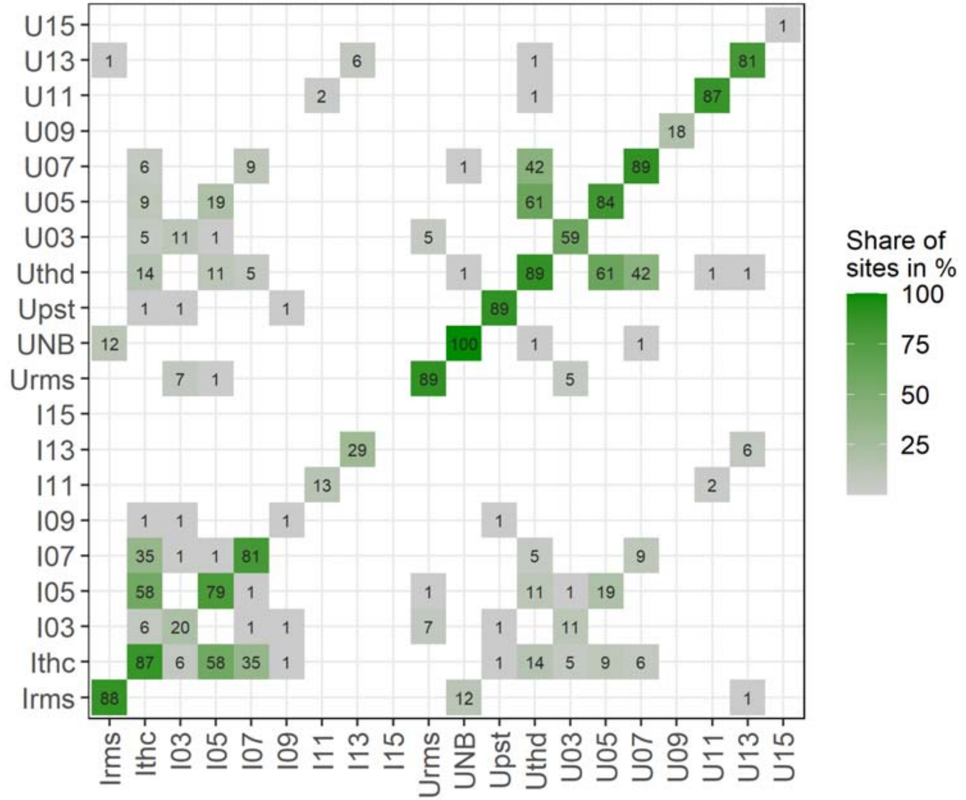
Visualization of matrices

- Very large matrices may be difficult to interpret
- Various visualizations available for distance matrices

→ Calculation of distance matrix from the matrix of significant correlation shares:

$$D_{ij} = \begin{cases} 100 - S_{ij}, & \text{for } i \neq j \\ 0, & \text{for } i = j \end{cases}$$

Share of significant correlations (|r|>0.7) between PQ parameters across all sites

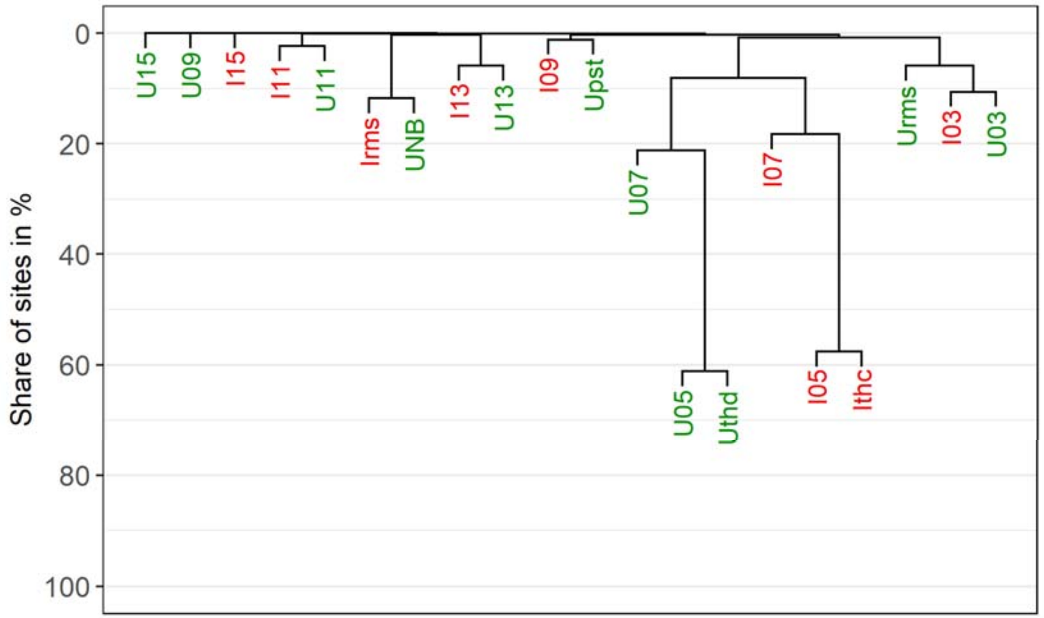


Correlations between PQ parameters
Visualization (1)

Dendrogram of clustering

- Clusters merged step-by-step based on similarity/distance
- Tree-like diagram showing hierarchical relationships between elements
- Height of branch indicates the level of similarity

Dendrogram of clustering based on the share of significant correlations



Correlations between PQ parameters
Visualization (2)

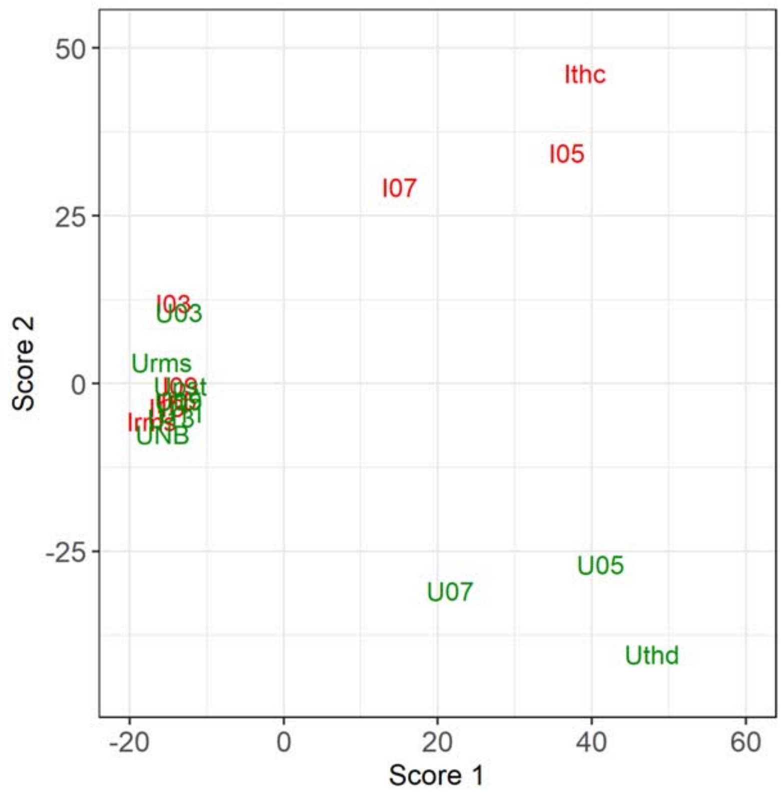
Dendrogram of clustering

- Clusters merged step-by-step based on similarity/distance
- Tree-like diagram showing hierarchical relationships between elements
- Height of branch indicates the level of similarity

Multidimensional scaling (MDS)

- Technique for dimension reduction
- Visualizes distances between elements in lower-dimensional space
- Preserves relative distances to reflect similarities

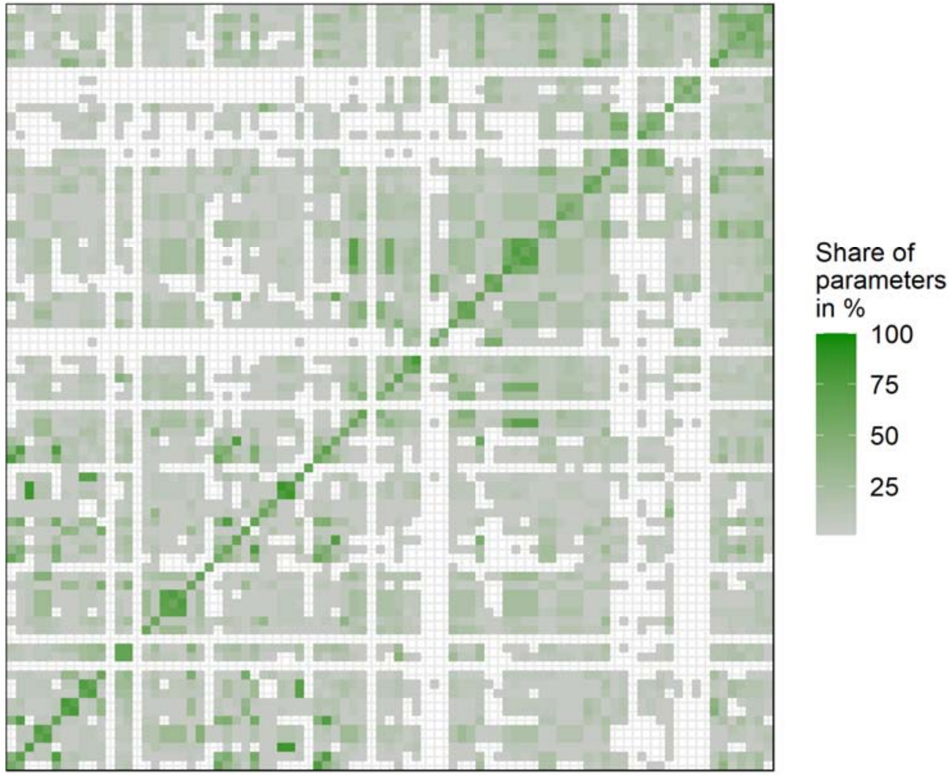
2D scatterplot using MDS based on the share of significant correlations



Correlations between measurement sites
Results aggregation

- Difficult to interpret holistically due to large number of individual elements
- Still, some observations:
  - Some sites with no correlations
  - Many sites with few correlations (ca.10 %)
  - Few sites with many correlations (up to 85 %)

Share of significant correlations (|r|>0.7) between sites across all parameters

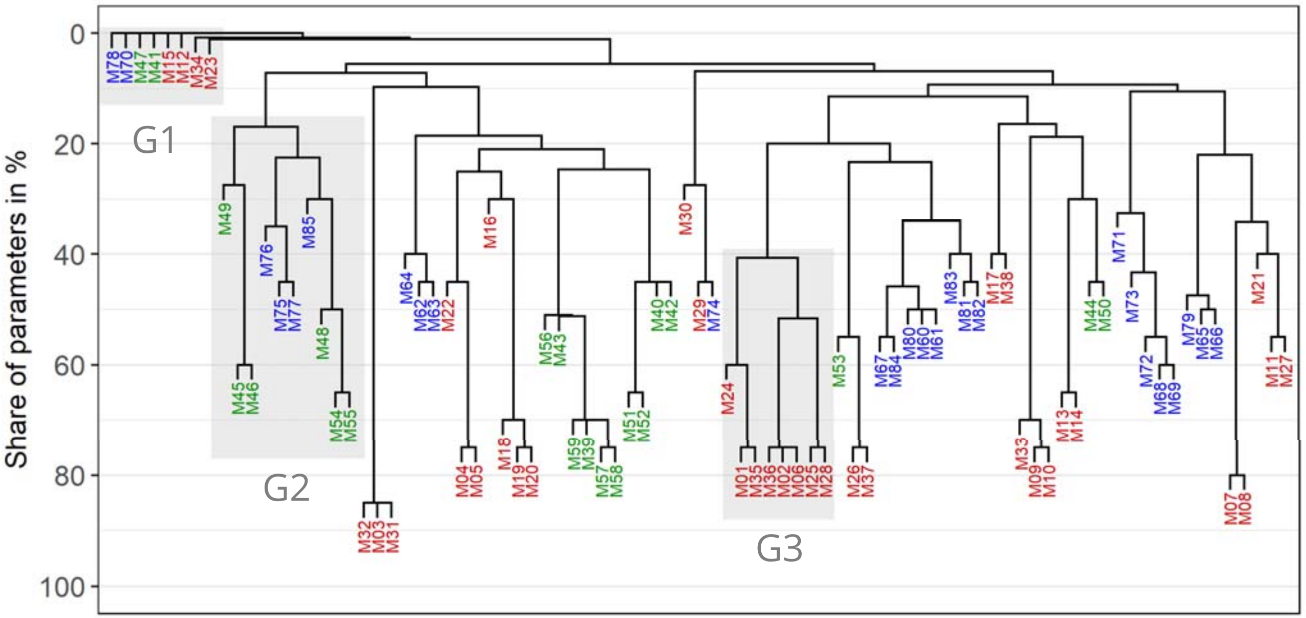


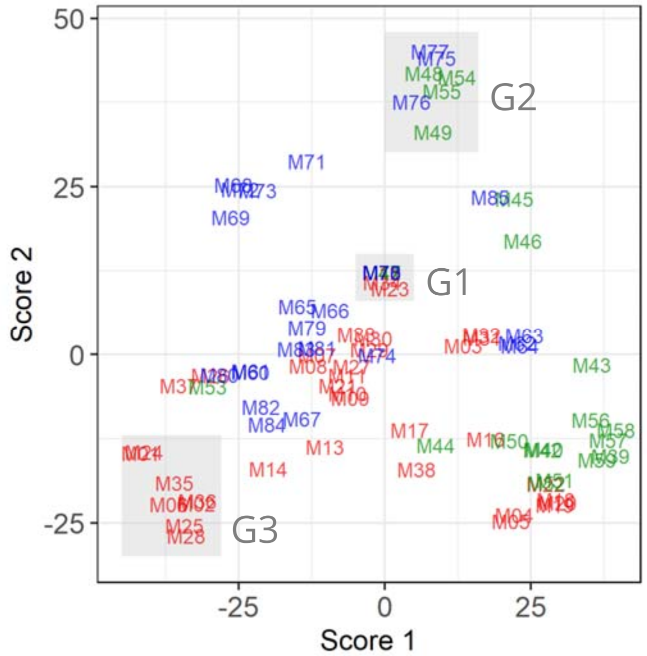
Correlations between measurement sites

Visualization (1)

- Combination of dendrogram and 2D scatterplot allows to identify different groups

- G1 = Sites that do not or barely correlate
- G2 = EHV sites partially correlated (ca. 20% - 60%)
- G3 = HV sites highly correlated (ca. 40% – 80%)



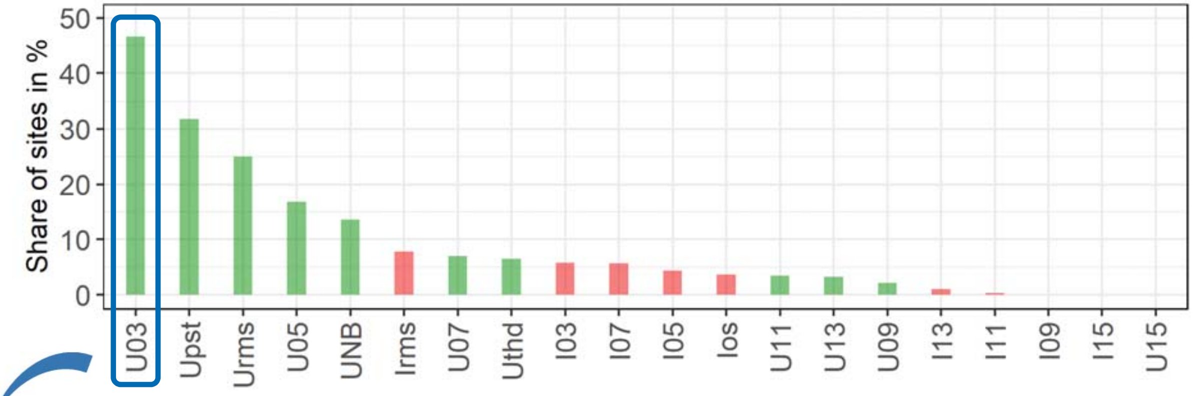


Voltage level: 110 kV, 220 kV, 380 kV

Correlations between measurement sites
Visualization (2)

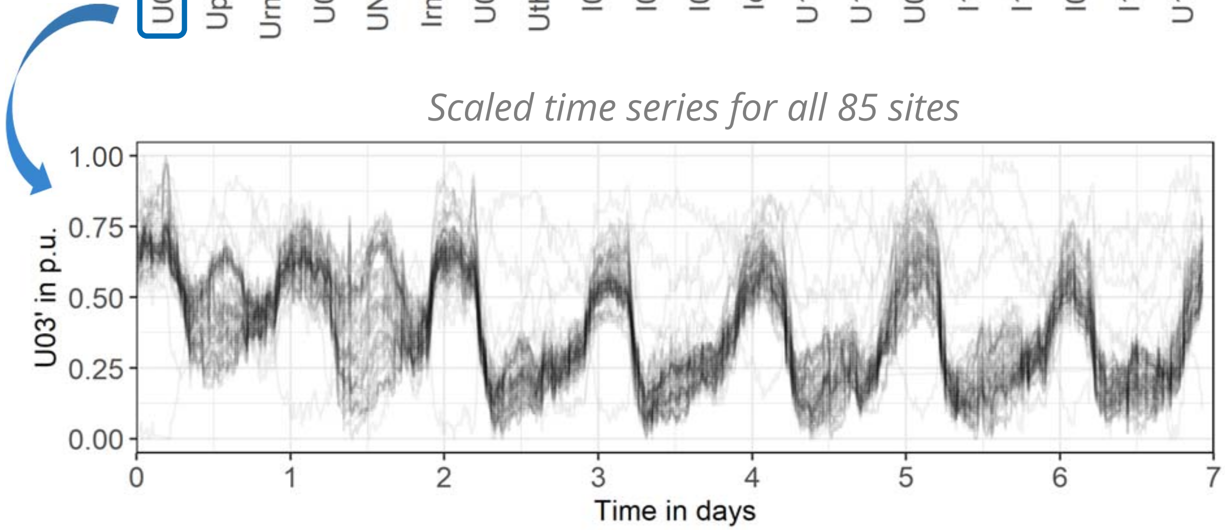
- Most correlations between sites for 1 or 2 parameters
- Highest share of correlations between all 85 sites for:
  - 3rd voltage harmonic (U03) and
  - Short-term flicker (Upst)

Share of correlations with |r|>0.7 between sites



- 3rd voltage harmonic with distinctive daily pattern across all voltage levels
- Possible harmonic sources:
  - Converters
  - Transformer magnetization
  - Corona discharges

Scaled time series for all 85 sites



Conclusions

Power Quality data analysis

- Robust and reliable methods are essential for an automated application
- Results aggregation and visualizations are key for:
  - Extracting actionable insights and
  - Making data accessible to non-experts

Future research needs

- Advanced multivariate analysis methods for large-scale PQ monitoring campaigns (e.g. clustering approaches and dimension reduction)
- Automated data pre-processing:
  - Data validation (e.g. measurement errors, measurement uncertainty)
  - Data imputation (e.g. handling of missing values)

Thank you for your attention!

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