Use Cases for Power Quality Data Analysis: Case Study for the Estonian Transmission System

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Agenda

Motivation

Use Cases for Power Quality Data Analysis

Case Study: Estonian Transmission System

- Use case 1: Compliance with limits
- Use case 2: Seasonal variations
- Use case 3: Trend identification

Conclusions

Motivation

- Recent developments (e.g. increase in renewables) can have a significant impact on Power Quality (PQ)
- Increasing number of PQ measurement campaigns to monitor networks
- Resulting in vast amounts of measurement data
- Measurement data contains valuable information that is often underutilized

Power Quality Data Analysis

- Various use cases with potential benefits
- Turning measurement data into actionable information
- Allowing a proactive management to ensure adequate PQ

Power Quality Data Analysis

Overview of use cases

Use case defines measurement requirements:

- **Measurement locations**
  - Single-point or multi-point measurements
  - Selection of locations
- **Measurement parameters**
  - Voltage quality parameters
  - Current quality parameters
  - Aggregation interval
- **Measurement duration**
  - Short-term (days to weeks)
  - Medium-term (months to years)
  - Long-term (multiple years)

#	Use Case	Minimum measurement duration	SP	MP
1	Events	Short-term	X	
2	Anomalies	Short-term	X	
3	**Compliance with limits**	Short-term	X	
4	Emission profiles	Short-term	X	
5	Correlation and propagation	Short-term		X
6	Model parameter identification	Short-term		X
7	Disturbance source identification	Short-term		X
8	**Seasonal variations**	Medium-term	X	
9	**Trend identification**	Long-term	X	
10	Trend forecasting	Long-term	X	

Case Study: Estonian Transmission System

Data set

Measurement campaign

- 15 sites in Estonian transmission system
- Up to 7.5 years of measurement duration
- 27 voltage quality parameters:
  - Unbalance (UNB),
  - Long-term flicker (Uplt),
  - Total harmonic distortion (Uthd) and
  - Harmonic voltages (U02-U25)
- 10 min aggregation interval
- Individual planning levels

Data pre-processing

1. Calculation of 95^{th} percentiles per week
2. Comparison with planning limits

Site	Voltage level	Nominal voltage in kV	Measurement duration in weeks	Available data in %
M01	EHV	330	340	96.2
M02	EHV	330	223	98.9
M03	HV	110	329	99.8
M04	HV	110	290	99.9
M05	HV	110	290	99.9
M06	HV	110	343	99.9
M07	HV	110	348	100
M08	HV	110	343	99.9
M09	HV	110	311	99.8
M10	HV	110	280	99.7
M11	HV	110	311	99.8
M12	HV	110	395	39.2
M13	HV	110	395	39.2
M14	HV	110	51	98.2
M15	HV	110	51	98.3

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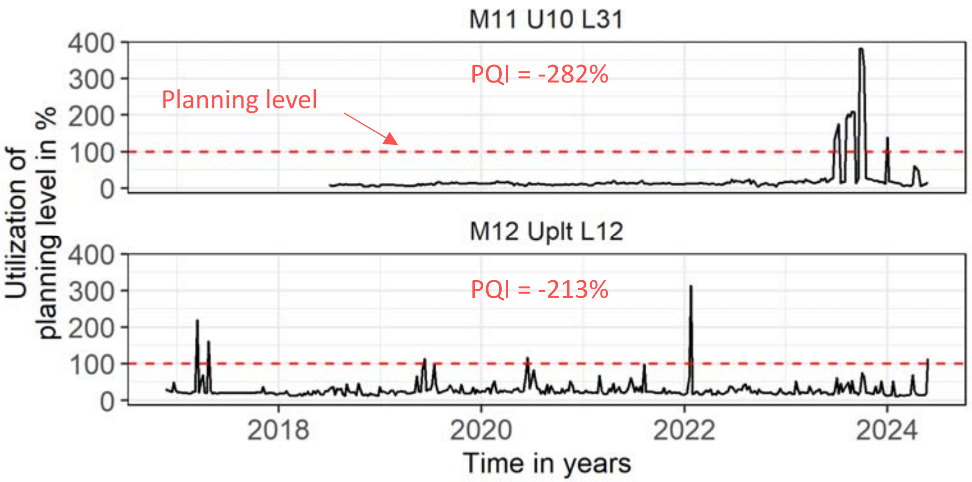
Use Case 1: Compliance with limits

- Comparison of weekly 95th percentiles for different parameters using normalized a Power Quality index (PQI)

$$\mathrm{PQI} = \left(1 - \frac{\text{value}}{\text{limit}}\right) \cdot 100\%$$

50% < PQI ≤ 100%
25% < PQI ≤ 50%
0% < PQI ≤ 25%
PQI ≤ 0%



PQ indices by parameter and site
(minimum aggregation of all weeks)

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12	M13	M14	M15
Uthd	68	84	51	58	58	53	16	44	-20	-46	50	4	-11	54	54
Uplt		71	41	58	58	-90	43	31	47	60	53	-213	-209	81	81
UNB	49	42	10	57	54	-77	52	50	55	52	66	50	35	67	64
U25	74	80	82	85	85	27	59	77	62	-30	91	81	78	97	97
U24	92	98	96	97	97	81	77	88	92	33	98			99	99
U23	60	82	84	93	94	30	48	64	64	-76	87	80	76	98	98
U22	94	96	97	98	98	74	76	87	93	33	95			99	99
U21	47	94	88	96	96	53	52	78	87	-54	80			97	97
U20	86	94	94	97	97	77	78	91	92	11	84			98	98
U19	84	97	88	96	96	51	48	81	89	-205	60	37	37	96	96
U18	81	97	97	98	98	88	87	94	95	36	71			98	98
U17	81	97	93	95	95	73	75	89	93	-48	29	20	21	97	97
U16	86	91	94	97	97	82	90	96	94	55	29			98	98
U15	-5	95	81	88	88	79	78	92	85	30	-28			92	92
U14	83	90	92	93	93	94	89	96	95	69	44			95	95
U13	63	91	75	77	77	73	85	92	77	37	33	49	44	84	85
U12	46	92	66	69	69	91	89	92	91	80	34			82	85
U11	32	71	80	82	82	81	89	90	81	69	55	57	51	94	93
U10	-12	43	-26	0	0	60	70	52	83	55	-282			17	2
U09	-13	92	87	89	89	88	94	92	90	95	87			86	87
U08	-29	-7	8	13	13	63	25	18	81	66	4			1	3
U07	10	70	69	69	70	82	70	67	-21	76	76	35	34	65	65
U06	5	17	34	37	38	39	24	12	-33	50	23			31	31
U05	39	39	60	66	66	56	14	49	34	64	66	21	20	68	68
U04	76	80	76	76	76	79	77	76	81	84	83			74	74
U03	51	62	71	79	79	72	69	73	72	78	75			79	79
U02	91	96	93	93	93	95	95	94	96	92	97			93	93

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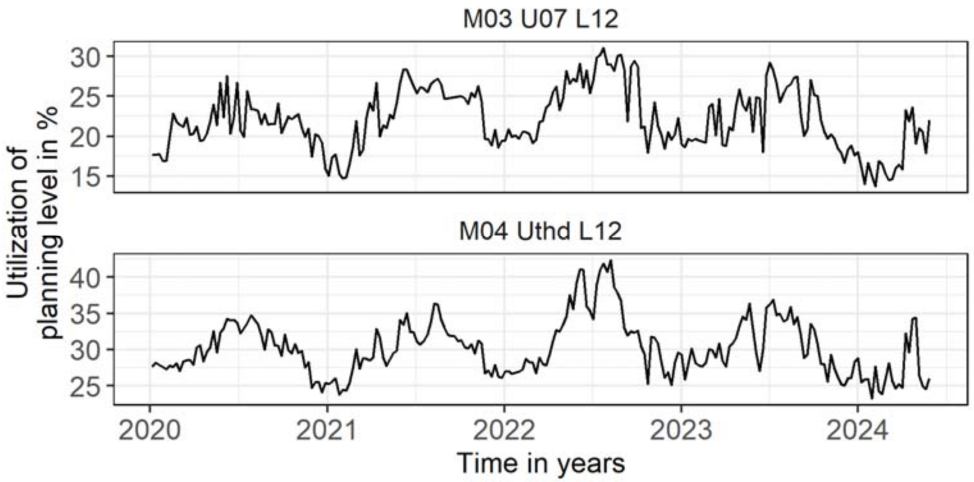
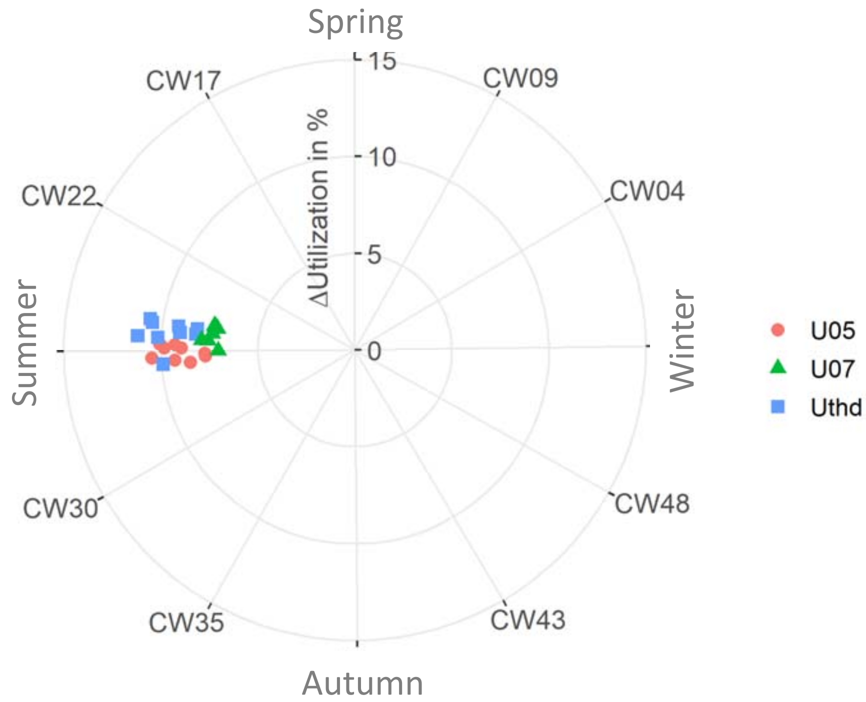
Use Case 2: Seasonal variations

- Quantification of seasonal variations by analysing spectral components of time series
- Component with period of 52 weeks (“fundamental”)
  - Amplitude indicates size of variations
  - Phase angle represents calendar weeks with highest levels



Polar plot of seasonal variations



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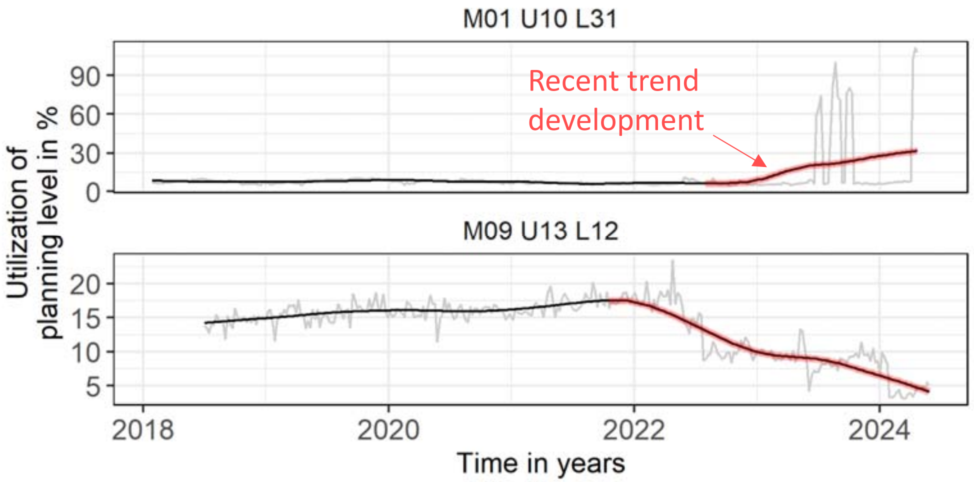
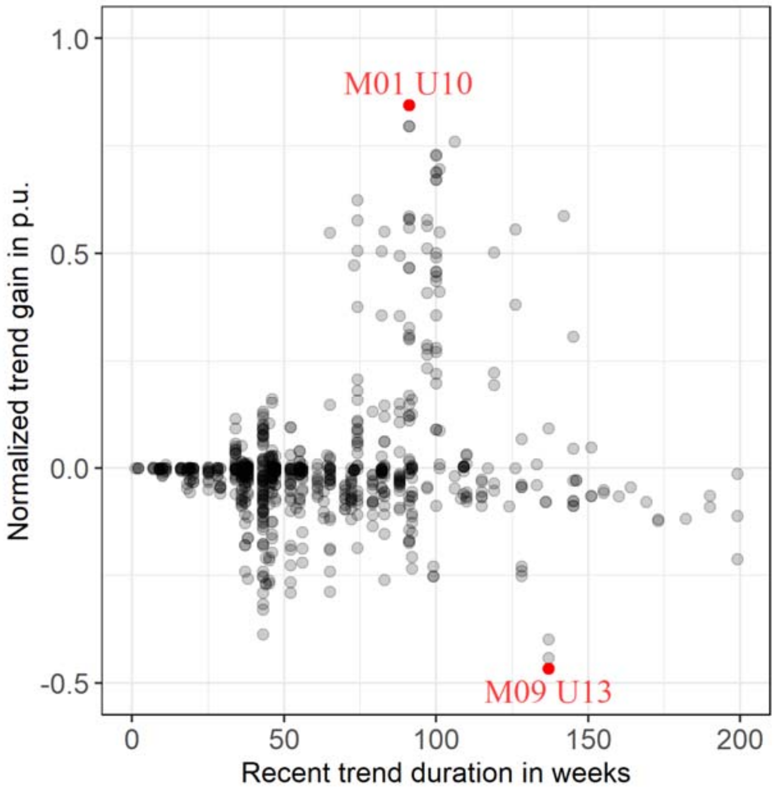
Use Case 3: Trend identification (1)

- Extraction of trend component using time series decomposition
- Quantification of recent trend developments using:
  - Trend gain (increasing/decreasing tendencies)
  - Trend duration (after last turning point)



Overview of trend gain and duration



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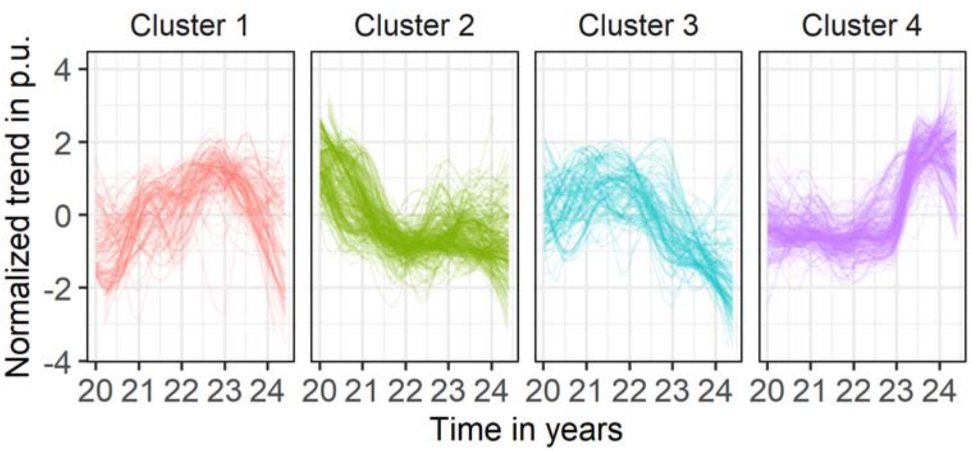
Use Case 3: Trend identification (2)

- Multivariate analysis of trend components
- Clustering using k-means to group similar developments
  - Clusters 1 to 3 with recent decreasing tendencies
  - Cluster 4 with significant increasing tendencies



Resulting cluster assignments

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10
Uthd	4	1	1	1	1	2	2	2	4	1
Uplt				2	2	2	2	2	2	
UNB	1	2	3	1	1	4	4	4	2	4
U25	1	2	2	3	3	2	2	2	2	2
U24	4	2	2	2	2	2	2	2	3	2
U23	2	2	2	2	2	2	2	3	2	3
U22	4	1	2	2	2	2	2	3	3	2
U21	3	2	2	2	2	2	2	3	3	2
U20	2	1	2	2	2	2	2	3	3	1
U19	3	2	2	1	1	2	1	3	3	1
U18	4	2	2	2	2	2	1	3	3	1
U17	2	2	2	2	2	2	1	3	3	1
U16	4	3	2	2	2	2	1	1	3	1
U15	4	2	2	2	2	3	1	1	3	4
U14	4	4	2	2	2	4	1	1	3	4
U13	3	1	2	4	4	2	1	4	3	4
U12	4	4	4	4	4	4	4	4	3	4
U11	2	1	2	3	3	2	4	1	3	1
U10	4	1	4	4	4	4	4	4	3	4
U09	3	3	2	4	4	2	1	2	4	4
U08	4	4	4	4	4	4	4	4	2	4
U07	1	2	1	3	3	3	3	3	4	3
U06	4	4	4	4	4	4	4	4	4	4
U05	4	1	1	1	1	2	2	2	4	2
U04	4	4	4	4	4	4	4	4	4	4
U03	2	2	2	2	2	2	2	2	2	2
U02	4	2	4	4	4	4	2	2	2	4

Conclusions

- PQ measurements are necessary to monitor recent changes in the energy sector
- Use cases are important in the proper design of PQ monitoring campaigns
- PQ data analysis can reveal valuable insights

- Case study of the Estonian transmission system:
  - Compliance with limits most of the time, exceedance only in certain weeks (0.4% of all weeks)
  - Seasonal variations for THD, 5th and 7th harmonic with higher levels observed in summer
  - Recent trend developments show mostly stable or decreasing tendencies, though some parameters with recent increases (e.g. lower even harmonic orders for nearly all sites)

- Future work will address:
  - Automated data pre-processing (including data validation, data imputation)
  - Further development of multivariate analysis methods for PQ measurement data

Thank you for your attention!

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