NEQUAL -WEB-BASED VOLTAGE QUALITY MONITORING IN SWITZERLAND

Jan MEYER
Etienne GASCH, Max DOMAGK
Technische Universitaet Dresden
Germany
jan.meyer@tu-dresden.de

Hansjörg HOLENSTEIN
Association of
Swiss Electricity Companies (VSE)
Switzerland
hansjoerg.holenstein@strom.ch

Stefan EGGER
St. Gallisch-Appenzellische
Kraftwerke AG (SAK)
Switzerland
stefan.egger@sak.ch

ABSTRACT

Measurements of voltage quality (VQ) are an inherent part of the work of a distribution system operator (DSO). Particularly monitoring compliance according to the European standard EN 50160 [1] plays an important role. Furthermore an increasing number of DSOs install Power Quality (PQ) monitoring systems for internal PQ assessment purposes. A continuous increase of measurement sites and measurement data is expected in the future, which could be additionally pushed by the availability of other intelligent devices with PQ functions, like energy meters.

Therefore the interest of DSOs in simple, comprehensive and unform methods for VQ analysis and reporting grows continuously. In order to satisfy these needs and to meet the demand of the Swiss regulatory authority for transparent and countrywide VQ statistics, the development of the web-based application NeQual was initiated by a working group of the Association of Swiss network operators (VSE).

After a brief discussion of the basic objectives for the NeQual development, the paper describes the basic functionalities of the application. The second part provides a short overview of the Voltage Quality in Swiss low voltage networks based on more than 700 individual measurements from the last seven years.

INTRODUCTION

In order to verify compliance with EN 50160 at a particular supply point, the DSO has to carry out a measurement for one week. If the measurement is finished, the DSO uses the native software provided by the manufacturer to download the data from the device and to generate an EN 50160 report. Generally reports of software from different vendors look different and results may not be easy comparable. Especially if one DSO owns measurement devices of different vendors, the use of different analysis software within one department is not acceptable. If the number of measured sites increases, the simple generation of multi-page reports per site and week is not feasible anymore and cannot provide an easy overall assessment of the PQ status of a network. Reporting multiple sites in a single comprehensive report or analyzing data from measurement devices of different vendors is often very difficult and time-intensive or impossible at all. Because most vendors use proprietary data formats, a comprehensive overall statistics today requires often a manual data export and consolidation in a third party application. If measurement data from different network operators has to be handled together (e.g. for benchmarking or overall statistics), a comprehensive protection of sensitive data, like DSO names or site addresses is of crucial importance, but often not possible in the vendor-specific software.

The above mentioned constraints have also been identified by the CIGRE/CIRED Working group C4.112 “Guidelines for PQ Monitoring”. More details can be found in [2, 3].

In order to overcome the current lacks in efficient processing and uniform reporting of larger amounts of PQ data from different DSOs, a new web-based reporting tool named NeQual was developed. Key requirements for the software development have been:

- Device-independent storage of measurement data from different DSOs
- Generation of reports according to EN 50160 in a standardized format and independent of the brand of the used measurement device
- Summary statistics for multiple measurement sites and weeks
- Simple to use and flexible accessibility without the need of installing additional software components
- High level of data security and anonymization

Last but not least also the costs for implementation and use of NeQual should be affordable also for small DSOs.

More details about future developments in PQ measurement can be found in [4]. Details about aspects of cost-efficient implementation of PQ monitoring systems are provided in [5].

NEQUAL APPLICATION

NeQual was developed in collaboration between VSE, the IT-company Oetiker & Partner AG, BCP AG and the Technische Universitaet Dresden. It consist of three major components:

I. Web-application for data import
II. Central data storage
III. Web-application for data analysis and reporting

NeQual does not need any local software installation on the computer. All applications run completely in the Internet-Browser. This way the data can also be accessed by tablets or smartphones. The general design of the

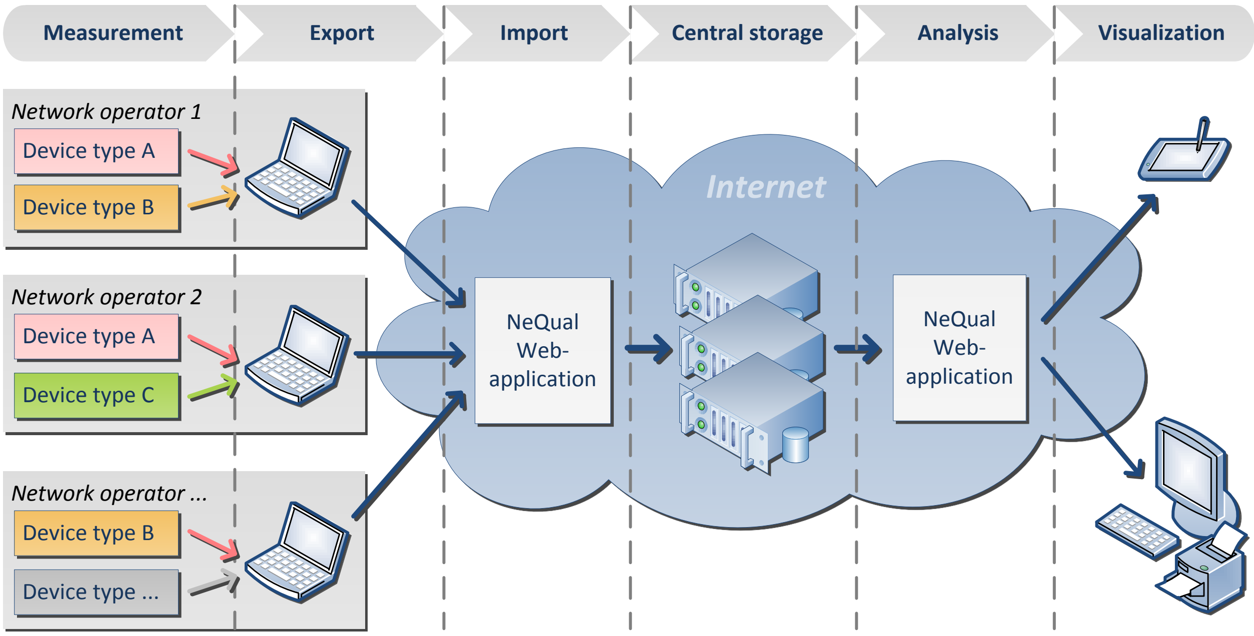


Figure 1 General design of NeQual

NeQual system is shown in Fig. 1.

After an EN 50160 measurement has been carried out by a DSO, it has to be exported in the format NeQual XML. This format was specifically developed for NeQual. The format specification is available to the public and several measurement devices support it already. In addition to the PQ parameters acc. to EN 50160 (voltage magnitude, unbalance, individual harmonics, THD, longterm-flicker, mains-signaling level), NeQual-XML supports current quality parameters and parameters describing the characteristic of the measurement site. These parameters include:

- Postal address
- Geographical coordinates
- Measurement reason (internal campaign, national campaign, troubleshooting, …)
- Area type (urban, rural, …)
- Consumer category (residential, commercial/industry, tourism, …)

This additional information allows more flexibility in filtering the measurement data for analysis. It becomes possible to analyze e.g. only residential sites or sites with a short circuit power below a defined threshold, like 570 kVA (reference short circuit power in public LV grids).

In order to upload the measurement data to the central storage, the user has to login to NeQual and run the data import application. Per definition each week measured at a particular site is threated in NeQual as one measurement. If e.g. three weeks at one site are uploaded, the import application splits it into three individual measurements.

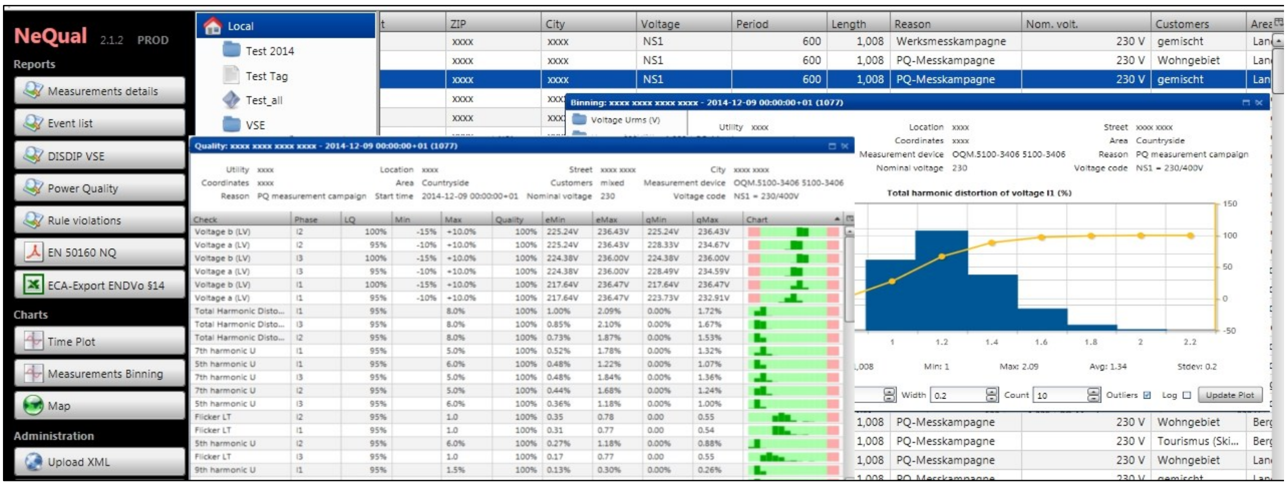
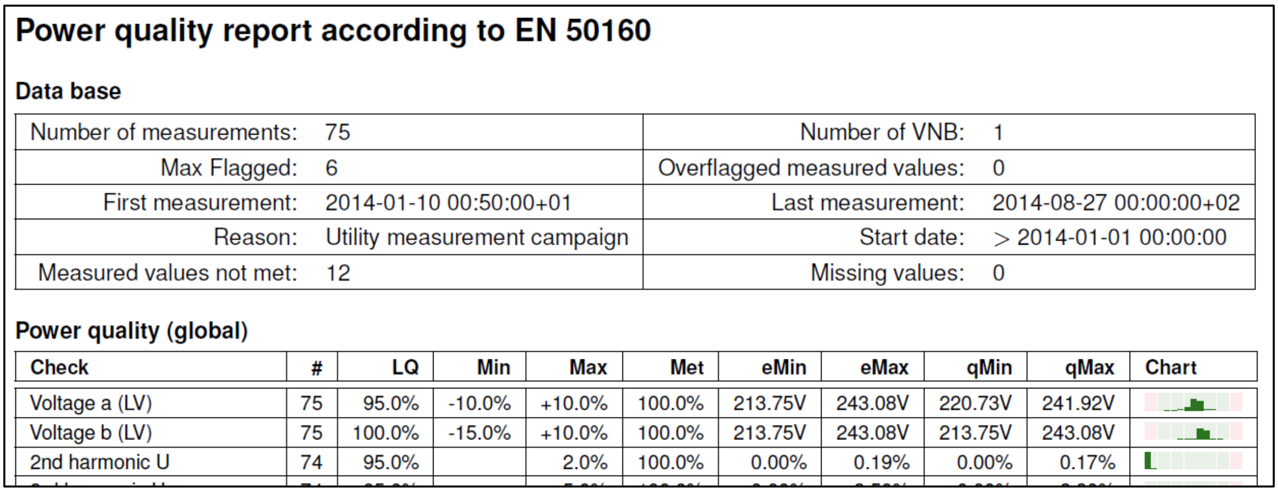


Figure 2 Example screenshot of the analysis application



Power quality report according to EN 50160

Data base

Number of measurements:	75	Number of VNB:	1
Max Flagged:	6	Overflagged measured values:	0
First measurement:	2014-01-10 00:50:00+01	Last measurement:	2014-08-27 00:00:00+02
Reason:	Utility measurement campaign	Start date:	> 2014-01-01 00:00:00
Measured values not met:	12	Missing values:	0

Power quality (global)

Check	#	LQ	Min	Max	Met	eMin	eMax	qMin	qMax	Chart
Voltage a (LV)	75	95.0%	-10.0%	+10.0%	100.0%	213.75V	243.08V	220.73V	241.92V	
Voltage b (LV)	75	100.0%	-15.0%	+10.0%	100.0%	213.75V	243.08V	213.75V	243.08V	
2nd harmonic U	74	95.0%		2.0%	100.0%	0.00%	0.19%	0.00%	0.17%	

Figure 3 Detail of a summarized EN 50160 report for 75 measurements

The analysis application provides features like data filtering, interactive visualization of measurement results and generation of reports according to EN 50160 (cf. to Fig. 2 and Fig. 3).

Each user is in general allowed to query all measurement data in the central storage. This enables a DSO e.g. to benchmark his data against other DSOs. However information about names and site addresses are only available for its own measurements. All measurements of the other DSOs are anonymized and read-only. This ensures security and anonymization of the data, which is essential for analyses including data from multiple DSOs. With the filtering functionalities of the analysis application it is possible to select a set of measurements, e.g. for defined time periods or a specific consumer category. It is also possible to select one single measurement, if e.g. a detailed EN 50160 report is required for a customer. If more than one measurement is selected, the analysis application generates a summary report for all measurements including the calculation of additional statistics, like histograms for the distribution of the 95th percentile for each PQ parameter or the number of missing/flagged data values (Fig. 2 and Fig. 3). Visualization within the application includes different kinds of tables, statistical charts and time plots as well as a geographical presentation of measurement sites.

SURVEY RESULTS 2008 – 2014

Available Dataset

As per October 2014 the central storage contained 754 measurements. Most of them (636) were collected between 2011 and 2014. The rest of the measurements dates back until 2008. Almost all of the measurements (97 %) are carried out in public LV grids, because most of the customers are located here.

For the further analysis only measurements in LV networks are considered. To ensure a reliable dataset representing typical VQ levels, troubleshooting measurements and measurements due to unknown reasons are excluded. Finally 707 measurements are left for the analysis.

Fig. 4 provides a chart of the annual growth of the number of measurements. The total number of measurements per month varies between about 20 and 50 except for February and August, where in each month almost 180 measurements have been performed. Reason for this is the national measurement campaign, which

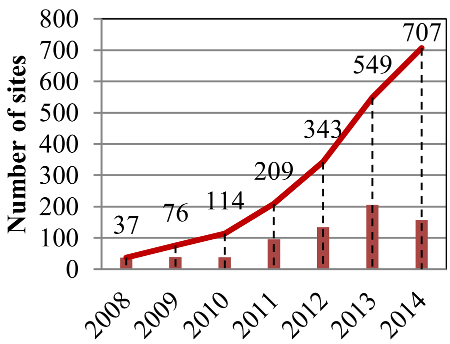


Figure 4 Annual growth of measured sites

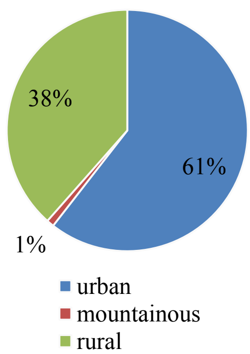


Figure 5 Distribution of supply areas

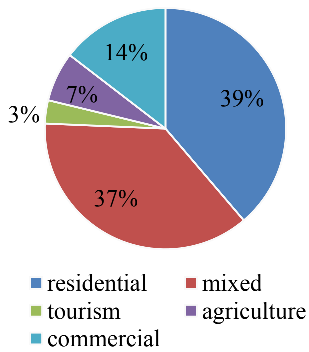


Figure 6 Distribution of consumer categories

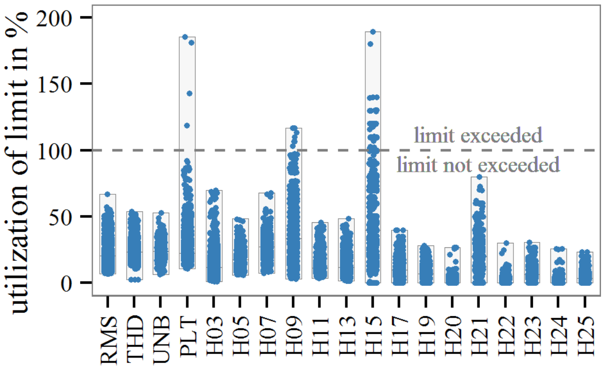


Figure 7 Overall performance of sites in urban areas

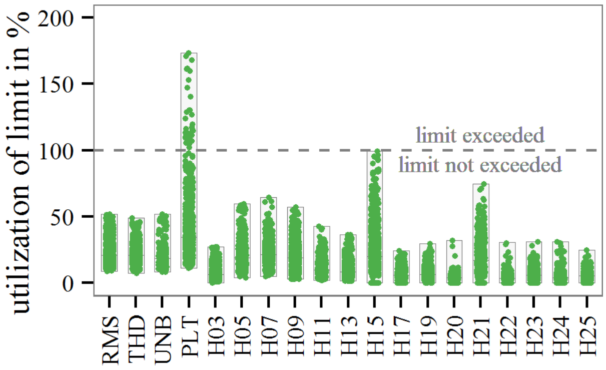


Figure 8 Overall performance of sites in rural areas

requires measurements to be carried out in those two months. This ensures a good representation in terms of possible seasonal variations between summer and winter.

Almost all measurements were performed in urban areas (60.5%) and rural areas (38.5%). Only 1 % of the measurements originate from mountainous areas that therefore seem to be underrepresented (Fig. 5).

The major consumer categories are residential customers and a mix of residential and commercial customers. Both represent almost equal proportions of a little bit less than 40 % of the measurements. The consumer categories tourism, agriculture and commerce present the remaining about 20 % (Fig. 6).

Analysis results

The following analyses are based on " PQ survey analysis tools", which has been developed in MATLAB and R. As the central storage provides a SQL-interface, the analysis tool can access the data directly, which increases speed and efficiency considerably. Due to the limited space, the following paragraphs present only a selection of the results. Moreover only continuous VQ parameters are considered, because comprehensive analysis methods exist already for events (e.g. DISDIP table).

In order to compare the different VQ parameters, the 95th percentiles are related to the limit according to EN 50160 and the utilization of the limit is shown. If the value is 100 %, the 95th percentile is equal to the respective limit. A 95th percentile of e.g. THD = 2 % results in a limit utilization of 25 % (THD_{lim} = 8 %). If the limit utilization is subtracted from 100 %, the resulting value corresponds to the remaining reserve to the limit. For THD = 2 % the reserve amounts 75 %.

Fig. 7 and Fig. 8 present the overall performance of measurements in urban areas and measurements in rural areas in separate plots. Each dot represents a single measurement. Even harmonics are not shown, because they have in virtually no measurement a reserve smaller than 50 %. Most of the other VQ parameters have a reserve between 10 % and 80 %. In rural networks most limit violations are observed for flicker, while in urban grids especially the zero-sequent harmonics H09 and H15 exceed the limit by up to 100 %.

Fig. 9 to Fig. 11 illustrates the development of the 15th harmonic voltage over the years, again separate for urban and rural areas. While in rural areas no increase of 15th harmonic voltage is observed, a considerable increase can be identified since 2010 for sites in urban areas. Not only the maximum 95th percentiles, but also the number of affected measurements has increased. In 2014 already 6 % of the measurements exceeded the limit. This requires further attention and should not be neglected. It has to be mentioned that the limit for the 15th harmonic voltage ($H15_{lim}$ = 0.5%) is very tight and it is suggested to start discussion in IEC 77A WG 8 about the compatibility levels of zero-sequent harmonics. On the

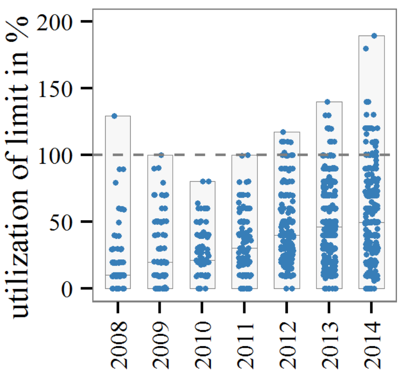


Figure 9 Development of the 15th harmonic voltage of sites in urban areas

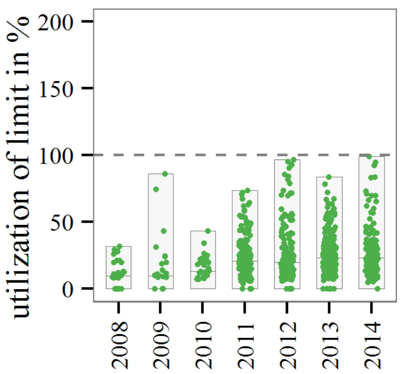


Figure 10 Development of the 15th harmonic voltage of sites in rural areas

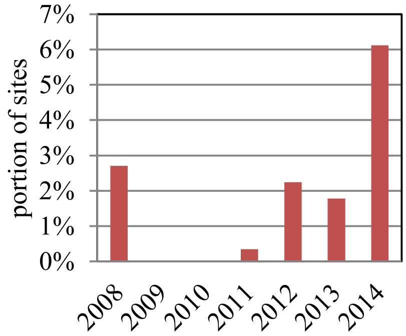


Figure 11 Percentage of measurements exceeding the limit

other hand it is important to wait with any modification of EN 50160, until a possible change of compatibility levels in IEC 61000-2-2 is finished.

In order to quantify the VQ reserve in a simple and comprehensive way, the PQ index system described in [6, 7] is applied to all 707 measurements. Tab. 1 shows for each year and each VQ parameter the measurement with the minimum VQ reserve. E.g. for unbalance UNB in 2013 none of the almost 200 measurements (cf. to Fig. 4) had an unbalance reserve of less than 51 %. Based on the limit of UNB_{lim} = 2 % this means all measurements have a 95th percentile lower than UNB = 1 %. Depending on the VQ reserve the following color code is used:

- Reserve higher than 50 % - green
- Reserve between 0 % and 50 % - yellow
  Reserve lower than 0 % (limit exceeded) - red

Tab. 1 Overview of VQ indices

	2008	2009	2010	2011	2012	2013	2014	
RMS	54	54	55	50	33	49	43	33
THD	62	65	71	54	48	49	46	46
UNB	64	54	54	53	49	51	47	47
PLT	-43	-13	22	-62	-71	-86	-76	-86
H03	67	62	73	67	30	36	43	30
H05	63	73	70	55	40	41	43	40
H07	53	65	69	36	43	32	48	32
H09	45	23	43	40	-7	-7	-17	-17
H11	54	79	68	58	61	62	57	54
H13	70	65	59	52	57	56	57	52
H15	-30	0	20	0	-18	-40	-90	-90
H17	73	60	82	76	68	68	65	60
H19	75	73	77	73	70	77	74	70
H20	78	94	93	88	68	73	73	68
H21	53	41	56	50	27	40	20	20
H22	79	95	91	89	70	70	80	70
H23	87	73	86	77	77	69	73	69
H24	82	95	76	85	70	72	69	69
H25	89	83	87	75	80	77	79	75
	-43	-13	20	-62	-71	-86	-90	**-90**

Last column and last row represent aggregated values for PQ parameter and year respectively. E.g. the lowest reserve for H03 over all years amounts 30 %, while the lowest reserve in 2010 over all VQ parameters amounts 20 %. The change of color from green via yellow to red indicates a significant decrease of reserve, which is clear to observe for 9th and 15th harmonic voltage.

CONCLUSIONS

This paper presents the web-based application NeQual for reporting voltage quality according to EN 50160. The application is independent of the vendor of measurement equipment and easy accessible by all participating DSOs via Internet. It can visualize large data sets and generate uniformly formatted and comparable voltage quality reports. Each DSO is able to benchmark its own data with those from other DSOs. The Association of Swiss Electricity Companies (VSE) uses NeQual to generate an annual voltage quality statistics, which could also be reported to the regulatory authority.

The analysis of more than 700 measurements in low voltage grids collected during the last seven years has shown that in most of the cases the limits according to EN 50160 are not exceeded and quality reserves of 50 % and more are common. However the often advanced opinion that voltage quality has no problems at all is not supported by this study. A general slight trend to lower reserves can be negated. A considerable amount of limit violations occurs for flicker and selected zero-sequent harmonics. However during the last three years a significant increase of 9th and 15th harmonic voltage was observed, but limited to urban areas only. The 15th harmonic voltage in 2014 exceeded the limit according to EN 50160 already at 6 % of the sites (10 % of the sites in urban areas). This issue requires further attention, because a similar increase of zero-sequent harmonics has been observed in several German measurement campaigns as well.

Since 2014 NeQual is also used in Austria in order to simplify the reporting to the regulatory authority. For further information or to receive the NeQual XML specification, please visit the website of VSE (http://www.strom.ch).

REFERENCES

[1] CENELEC EN 50160: Voltage characteristics of electricity supplied by public electricity networks, 2010.

[2] CIGRE Report 596: CIGRE/CIRED Joint Working Group C4.112, "Guidelines for Power Quality Monitoring", October 2014.

[3] J. Milanovic et.al., "International Industry Practice on Power-Quality Monitoring", IEEE Transactions on Power Delivery 29/2, 2014.

[4] F. Zavoda et. al., "CIGRE/CIRED/IEEE Working Group C4.24 – Power Quality in the Future Grid – Status Report", *this conference*

[5] J. Meyer et. al., "Contemporary and future aspects of cost effective power quality monitoring — Position paper of CIGRE WG C4.112", *Electric Power Quality and Supply Reliability Conference*, Estonia, 2012

[6] J. Meyer et.al., "Efficient Method for Power Quality Surveying in Distribution Networks", *18th CIRED*, Italy 2005.

[7] E. Gasch et.al., "Efficient Power Quality Anaylsis of Large Data Amounts – Case Study for a Distribution Network Operator", *this conference*