INFLUENCE OF AGGREGATION INTERVALS ON POWER QUALITY ASSESSMENT ACCORDING TO EN 50160

Max DOMAGK, Jan MEYER
Peter SCHEGNER
TU Dresden - Germany
max.domagk@tu-dresden.de

Gerit EBERL
DREWAG Netz GmbH - Germany
gerit_eberl@drewag-netz.de

Thomas DARDA
ENSO Netz GmbH - Germany
thomas.darda@enso.de

ABSTRACT

EN 51060 [1] characterizes the product quality of electricity and is the most important standard for voltage quality assessment in Europe. The value of a particular continuous voltage quality parameter (e.g. unbalance) depends on several calculation parameters like aggregation interval and assessment quantile. Usually the EN 50160 assessment is based on 95-%-quantiles of the 10-minute-mean values for one week. The paper studies the impact of these calculation parameters and shall give an impulse for the on-going discussion of the pros and cons of their change in standards or regulation rules.

The analysis is based on a comprehensive database of more than 1000 measurement weeks in 14 different public low voltage grids in Germany. The main part of the paper studies systematically the impact of aggregation interval (1min, 10min, 30min), aggregation method (mean, max) and assessment quantile (95%, 99%) on the following voltage quality parameters: magnitude, selected harmonics, THD and unbalance.

INTRODUCTION

The voltage quality is quantified by a set of different parameters classified in continuous parameters (harmonics, unbalance, flicker, …) and events (dips, swells, interruptions, …). The assessment of the continuous voltage quality parameters depends on four different calculation parameters: aggregation interval, aggregation method, assessment quantile and assessment interval. EN 50160 [1] requires for most continuous parameters the 95-%-quantile of the 10-minute-mean values for one week. The main aim of EN 50160 is a description of the quality of electricity at the point of supply in European public distribution networks. In analogy to the compatibility levels in EMC coordination EN 50160 follows a probabilistic approach. The use of 10-minute-mean values addresses (thermal) long-term effects. The values in EN 50160 are not intended to be used for product design.

A change of aggregation interval and assessment quantile has been often proposed in the last years. Single measurements have shown differences between different aggregation intervals and respective bodies were concerned about the adequateness of the calculation parameters. Moreover in selected countries calculation parameters different to EN 50160 are already in use [2]. This paper considers the impact of the first 3 calculation parameters, while the assessment interval is fixed to one week.

The effect of the aggregation interval has already been analysed for measurements in Australian MV- and LV-grids [3]. This study has shown that shorter intervals than 10 minutes provide virtual no additional information. One intention of this paper is to verify this conclusion for LV grids in Europe.

The impact of aggregation interval (1min, 10min, 30min) and aggregation method (mean, max) on the time characteristic is exemplarily shown in Fig.1 for an unbalance measurement for one week. The aggregation interval has a visible impact on the time series for the mean values. A high aggregation interval usually results in a less dynamic time series with a smaller variation range. The

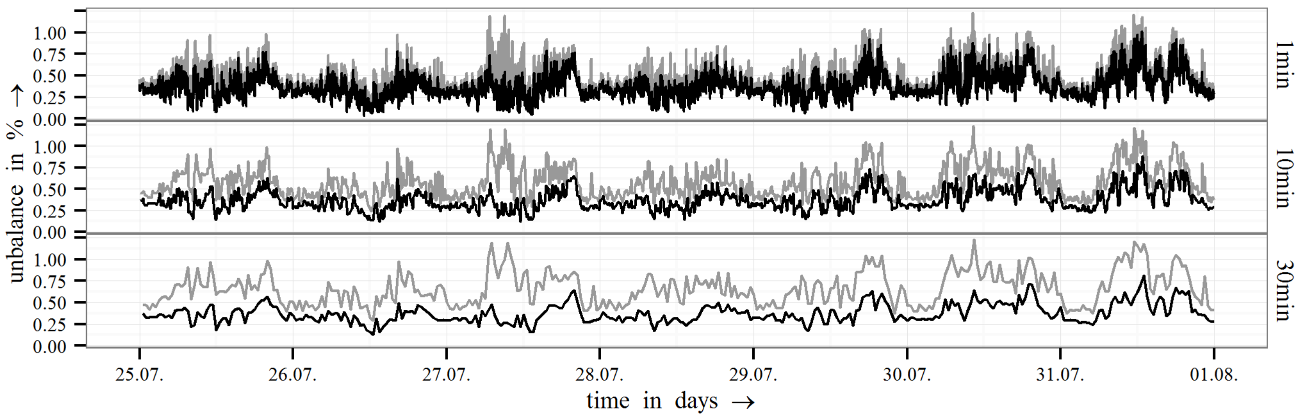


Figure 1 *Example week for the voltage unbalance with different aggregation intervals (1min, 10min and 30min) for maximum values (grey) and mean values (black) for of a grid with 26 office units and 6 shops*

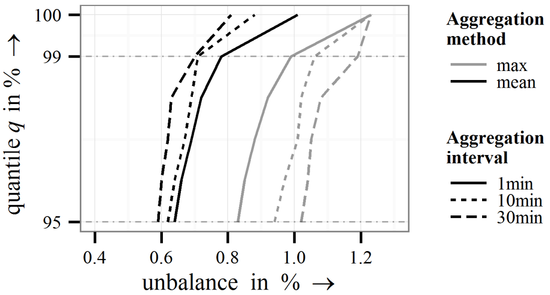


Figure 2: *Quantiles of different aggregations for example in Fig. 1*

maximum values maintain their high values in consequence of their aggregation method. The max values are not as robust as the mean values and are therefore not suitable for the assessment of long-term effects by continuous quality parameters, like they are needed for EN 50160 assessment. The general impact of the third parameter, the assessment quantile is discussed using Figure 2. It presents a part of the cumulative distribution function (cdf) for the example data. The robust 95-%-quantile and the more sensitive 99-%-quantile are highlighted. The values for these quantiles (see Tab. 1) show that higher aggregation intervals result in smaller quantiles for mean values, but higher quantiles for maximum values. The increasing variation, e.g. between mean and max values is characteristic for a decreasing robustness. The absolute deviation from the 95-%-quantile of 10-minute-mean values is used to quantify the influence in this paper (see Tab. 2).

Table 1: *95-%- and 99-%-quantiles for the unbalance in Fig. 2*

	Mean values		Maximum values	
Aggregation interval	95-%-quantile	99-%-quantile	95-%-quantile	99-%-quantile
1 min	0.64 %	0.78 %	0.83 %	0.99 %
10 min	**0.62 %**	0.71 %	0.94 %	1.06 %
30 min	0.59 %	0.70 %	1.02 %	1.19 %

Table 2: *Absolute deviations for the quantiles in Tab. 1 (reference: 95-%-quantile of 10-minute-mean values)*

	Mean values		Maximum values	
Aggregation interval	95-%-quantile	99-%-quantile	95-%-quantile	99-%-quantile
1 min	+0.02 %	+0.16 %	+0.21 %	+0.37 %
10 min	**ref.**	+0.09 %	+0.32 %	+0.44 %
30 min	–0.03 %	+0.08 %	+0.40 %	+0.57 %

MEASUREMENT DATABASE

Systematic measurements of power quality (voltage and current quality) have been carried out by the authors in cooperation with different DNOs over the last years. The analysis in this paper is based on 19 different sites in 14 individual LV grids. The measurement time per site ranges from 6 months up to 23 months. In total the measurement data consists of 1037 weeks for each voltage quality parameter.

Voltage quality parameters

The following set of continuous voltage quality parameters are analysed within this paper:

- **RMS** Magnitude (L1, L2, L3)
- **UNB** Unbalance
- **THD** Total harmonic distortion (L1, L2, L3)
- **H*n*** Harmonics of order n =3, 5, 7 (L1, L2, L3)

The assessment of the RMS is based on the relative deviation from the nominal voltage in per cent:

$$\mathrm{RMS} = \frac{|V_{\mathrm{RMS}} - 230\ \mathrm{V}|}{230\ \mathrm{V}} \tag{1}$$

Due to the 2 different limits in EN 50160 (±10% V_{RMS} for 95% of time and +10%/-15% for 100% of time) this value has to be processed slightly different for EN 50160 assessment. The main focus of this paper is the evaluation of the impact of the calculation parameters and therefor is the parameter according to equation (1) the most suitable one.

Measurement sites

Power quality is mainly determined by consumer topology, generation topology and network topology. To represent the spectrum of typical grids as best as possible sites were selected based on a systematic analysis of the grid characteristics according to the above mentioned topologies. The consumer topology is separated into three main groups: residential areas (multi- or single-family houses), shopping centres and office districts. Generation topology is mainly represented by the total amount of installed decentralized generation and network topology by selecting both weaker (rural) and stronger (urban) grids. The 19 sites selected have the following characteristics:

Consumer topology:

- 8 sites with single-family houses (up to 83 houses)
- 7 sites with multi-family houses (up to 720 flats)
- 2 sites with shopping centers (electronic markets)
- 2 sites with offices (up to 26 office units)

Generation topology per site

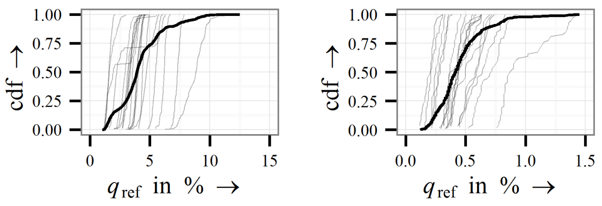
- 13 sites without generating installations
- 4 sites with total installed generation power < 50 kW
- 2 sites with total installed generation power > 50 kW

Network topology per site

- 9 sites with short circuit power < 10 MVA
- 10 sites with short circuit power > 10 MVA

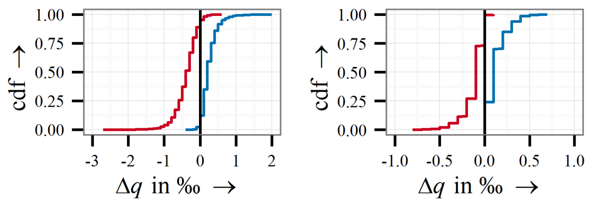
Reference data for the evaluation

The 95-%-quantiles of the 10-minute-mean values are calculated for each week and voltage quality parameter. These values are used as reference quantile q_{ref} for the evaluation of the impact of the different calculation parameters. Fig. 3 exemplarily shows the cdf of the calculated 95-%-quantiles for RMS according to equation



a) Magnitude (RMS) b) Unbalance (UNB)

Figure 3: *95-%-quantiles of the 10-minute-mean values; cdfs per sites (grey) and for all sites (black)*



a) Magnitude (RMS) b) Unbalance (UNB)

Figure 4: *Absolute deviations between 95-%-quantiles of 10-minute-mean values for 30 min (red) and 1 min (blue)*

(1) (Fig. 3 a)) and UNB (Fig. 3 b)). The figures show the individual per site distributions as well as the overall distribution.

INFLUENCE ON THE ASSESSMENT

The absolute deviation Δq is introduced to quantify the influence of the calculation parameters. It is defined as absolute difference between the reference quantile q_{ref} (95-%-quantile of 10-min-mean values) and another quantile q:

$$\Delta q = q - q_{ref} \qquad (2)$$

The quantile q represents the calculated value for the same voltage quality parameter and week as the reference quantile, but for the varied calculation parameters. In particular these are:

- Aggregation interval (1 min, 30 min)
- Assessment quantile (99 %)
- Aggregation method (maximum value)

To avoid any confusion while interpreting the tables, it should be explicitly mentioned that all deviations are absolute values.

Aggregation interval

Fig. 4 a) shows the distribution of the absolute deviations of different aggregation intervals exemplarily for the RMS. The results will be discussed in more detail.

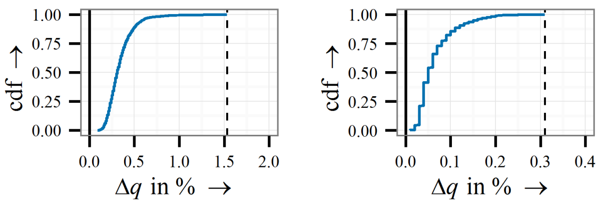
Changing the interval for the RMS from 10 minutes to 1 minute results in higher quantiles ($\Delta q > 0$ %) for 88 % of the weeks. 2 % of the weeks have slightly lower quantiles ($\Delta q < 0$ %), while 10 % of the weeks are almost equal. The positive deviation is larger than the negative one due to the decrease of the aggregation interval. The maximum positive deviation is $\Delta q_{max} = +0.2$ %, the maximum negative deviation amounts $\Delta q_{min} = -0.04$ %. An increase of the aggregation interval to 30 minutes results in lower quantiles for 89 % of the weeks and slightly higher quantiles for 5 % of the weeks. For 6% of the weeks the quantiles of the different aggregation intervals are equal. In contrast to the above the negative deviation is larger than the positive one. It ranges from $\Delta q_{min} = -0.27$ % to $\Delta q_{max} = 0.06$ %. For all analysed weeks, the highest influence by changing aggregation interval on the assessment for the RMS is an absolute deviation of less than ±0.3 %. The effect on the assessment is even smaller than ±0.1 % for most of the weeks (90 %). Compared to the first limit range according to EN 50160 of ±10 % the difference is almost negligible. Fig 4 b) presents the UNB, which shows qualitative a similar behaviour as the RMS. The highest absolute deviations are smaller than ±0.1 % for both aggregation intervals. The majority of all deviations is below ±0.05 %. Tab. 3 summarizes the deviations for all voltage quality parameters. For each voltage quality parameter the absolute deviations in per cent are given for the minimum and maximum deviation Δq_{min} and Δq_{max}, the lower quantile $\Delta q_{0.05}$, the median $\Delta q_{0.50}$ and the upper quantile $\Delta q_{0.95}$. The quantile range $r_{0.9}$ contains 90 % of the deviations of all weeks ($r_{0.9} = \Delta q_{0.95} - \Delta q_{0.05}$) and is for almost all values equal or below 0.04 %. The low ranges indicate that the influence of aggregation interval for almost all analysed weeks and sites can be neglected. Therefore a shorter aggregation interval of 1 minute does not give any further insight to the analysed measurement data. In contrary, the increase of the aggregation interval to 30 minutes would give almost the same results compared to the 10-minute aggregation interval.

Table 3: *Absolute deviations for aggregation intervals (reference: 95-%-quantile of 10-minute-mean values)*

Δq in %	Interval	Δq_{min}	$\Delta q_{0.05}$	$\Delta q_{0.50}$	$\Delta q_{0.95}$	Δq_{max}
RMS	1 min	-0.04	0.00	0.02	0.06	**0.20**
UNB	1 min	0.00	0.00	0.01	0.04	**0.07**
THD	1 min	-0.02	0.00	0.02	0.02	**0.05**
H03	1 min	-0.02	0.00	0.00	0.01	**0.02**
H05	1 min	-0.02	0.00	0.01	0.03	**0.07**
H07	1 min	-0.02	0.00	0.01	0.02	**0.03**
RMS	30 min	**-0.27**	-0.06	-0.04	0.00	0.06
UNB	30 min	**-0.08**	-0.04	-0.01	0.00	0.01
THD	30 min	**-0.07**	-0.02	-0.01	0.01	0.03
H03	30 min	**-0.06**	-0.01	0.00	0.00	0.02
H05	30 min	**-0.07**	-0.03	-0.01	0.00	0.04
H07	30 min	**-0.05**	-0.02	-0.01	0.00	0.03

Assessment quantile

The second calculation parameter, which can influence the assessment of a voltage quality parameter, is the quantile that is selected for the assessment itself. The 99-%-quantile has by definition higher values and is more sensitive to extreme values than the 95-%-quantile. The aggregation method for mean values will be used to compare these.



a) Magnitude (RMS) b) Unbalance (UNB)

Figure 5: *Absolute deviations between 99-%-quantile and 95-%-quantiles of 10-minute-mean values*

Fig. 5 a) exemplarily shows the absolute deviations of 99-%-assessment quantile for the RMS. The minimum difference to the reference quantile is $\Delta q_{\min} = +0.09$ %. For the majority of the measured weeks the 99-%-quantile is not more than 0.59 % higher compared to the respective 95-%-quantile. Only for very few weeks the deviation exceeds this value. The maximum deviation is $\Delta q_{\max} = +1.53$ %. Although the 99-%-quantile is more sensitive the deviation from the reference is very small.

The distribution of the deviations for UNB (Fig.5b) shows a similar behaviour and no significant deviations between 99-%-quantiles and reference quantiles.

Tab. 4 gives an overview of all analysed voltage quality parameters. It shows that the main parts of the deviations (95% of all weeks) are in most cases below 0.3 % higher than the respective 95-%-quantile. Higher deviations are very rare and do not exceed +1 % except for RMS. Due to the higher sensitivity of the 99-%-quantile, the $q_{\max}$ should be interpreted carefully.

Table 4: *Absolute deviations of the 99-%-quantile (reference: 95-%-quantile for 10-minute-mean values)*

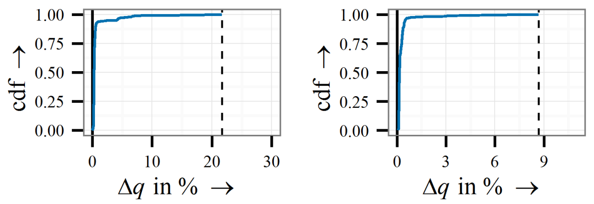
Δq in %	$\Delta q_{\mathbf{min}}$	$\Delta q_{\mathbf{0.05}}$	$\Delta q_{\mathbf{0.50}}$	$\Delta q_{\mathbf{0.95}}$	$\Delta q_{\max}$
RMS	0.09	0.17	0.31	0.59	**1.53**
UNB	0.01	0.03	0.05	0.16	**0.31**
THD	0.00	0.05	0.05	0.20	**0.34**
H03	0.00	0.03	0.05	0.15	**0.34**
H05	0.02	0.05	0.11	0.23	**0.81**
H07	0.03	0.05	0.08	0.19	**0.73**

Aggregation method

As third parameter the aggregation method is considered. Each 10-minute-value represents according to 61000-4-30 the maximum 10-cycle-value of the respective 10-minute-interval. Therefore it is not robust and subsequently not suitable for assessing long-term effects. The parameter can e.g. be useful in solving customer complaints.

Table 5: *Absolute deviations for maximum values (reference: 95-%-quantile for 10-minute-mean values)*

Δq in %	$\Delta q_{\mathbf{min}}$	$\Delta q_{\mathbf{0.05}}$	$\Delta q_{\mathbf{0.50}}$	$\Delta q_{\mathbf{0.95}}$
RMS	0.01	0.19	0.30	3.94
UNB	0.07	0.10	0.15	0.49
THD	0.05	0.10	0.49	2.40
H03	0.03	0.06	0.10	0.41
H05	0.05	0.10	0.63	1.33
H07	0.06	0.10	0.17	0.89



a) Magnitude (RMS) b) Unbalance (UNB)

Figure 6: *Absolute deviations between 95-%-quantiles of 10-minute-maximum values and 10-minute-mean values*

Fig. 6 exemplarily shows the absolute deviations between the 95-%-quantiles of both aggregation methods (maximum and mean) for RMS and UNB. Both plots show a similar behaviour. Tab. 5 shows a summary of the deviations. Due to the non-robustness the maximum deviation $\Delta q_{\max}$ is not meaningful and therefore not presented. For 95 % of the weeks the maximum value is less than 4 % higher than the respective mean value.

SUMMARY

Based on a comprehensive database of more than 1000 measurement weeks from 19 sites in different public LV grids the influence of the 3 major parameters (aggregation interval, assessment quantile, aggregation method) on the calculation of selected continuous voltage quality parameters was analysed. For the analysed measurement data no significant influence of the calculation parameters on the results could be identified. Compared to the reference (95-%-quantile of the 10-minute-mean) for the considered grids no additional information can be obtained by changing the calculation parameters. The almost negligible maximum absolute deviation of about 0.3% that has been observed for different aggregation intervals confirms the results of a similar study in Australia.

At least based on the results of this study the choice of 95-%-quantile and 10-minute-mean values seems to be adequate for voltage quality assessment. The research results do not give any evidence for changing these parameters. However, a further verification of the results for LV grids with significant different structure is recommended. Special care should always be taken to the representativeness of the data.

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