EFFICIENT METHOD FOR POWER QUALITY SURVEYING IN DISTRIBUTION NETWORKS

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INTRODUCTION

In the future the importance of methods for an overall power quality rating of distribution networks will increase continuously. Utilities become more and more interested in knowledge about the average levels of power quality as well as the distances between actual levels of power quality and corresponding limits in their distribution networks. Reporting power quality in accordance with DIN EN 50160 leads to simple qualitative results only. However the measurement data contain much more information about the time- and site-dependent behaviour of power quality. Therefore enhanced quantitative calculation methods are needed for additional in-detail-analyses of the measurement data. The results can be reasonably used e.g. for estimating an overall performance of power quality, benchmarking power quality between networks or planning purposes. The paper describes a method of power quality surveying in distribution networks by several performance indices. Their values are direct proportional to the actual reserve of power quality at the measured sites. Considering statistical aspects already during the measurement site selection results in performance indices, that give a good estimation of average power quality levels in the analysed distribution networks.

Finally the paper applies the new method to different medium voltage networks of two German distribution system operators (DSO A and DSO B).

SELECTING MEASUREMENT SITES

The medium voltage networks of many DSO's, including the DSO's A and B considered in the paper, consist of more than 1000 PCC. Due to disproportional high efforts in time and money it neither makes sense, nor it is realizable to perform measurements at all PCC. Generally the measurements have to be limited to as few as possible sites and should require as few as possible manpower for analysing and reporting. In terms of statistics all PCC, that should be considered by a survey (i.e. a complete distribution network or parts of it), present a statistical population. A sample of measurement sites is drawn from the population. The performance indices, calculated for the sampled sites, represent the performance indices of the underlying population with a certain probability of error. The quality of the performance indices mainly depends on the way of site selection and the number of selected sites. A simple method of site selection samples measurement points completely stochastic from all PCC of the population (see Fig. 1.a). PCC with well-known, serious power quality problems have to be left out, because these "worst-case" sites don't represent average power quality levels. These sites don't belong to the assumed population and has to be considered separately. Generally the origin of power quality disturbances strongly depends on topological parameters of network and consumer structure and consumer behaviour. Differences in structure and behaviour lead to different grades of power quality. Especially in case of small sample sizes and inhomogeneous structures a comparatively high probability exists that the completely stochastic drawing of sites doesn't cover all the different structures in a right manner (see Fig. 1.b - C and D). An enhanced sampling method considers this disadvantage by clustering the complete population in several parts by taking the different structures into account. The clustering may include following structural parameters:

- network structure (meshed, ringed, radial)
- consumer structure (household, industry, mix of both)
- network size (large, medium, small)
- cabling ratio (high, medium, low)

Some steps are presented in detail in the following chapters of the paper. It should be pointed out, that only the use of statistical methods for several of the above mentioned steps lead to good and reliable results.
HANDLING MEASUREMENT DATA

Measurement campaigns usually result in a huge amount of data. This data has to be organized in an efficient way. Fig. 2 shows the modular designed software system IMEDA, especially developed for the analysis of survey measurements. A database server running Oracle® is accessed via ODBC from client computers where management software and analysis software are installed. The management software automatically imports all raw data of the measurement devices into the database. That way different data formats of the devices are converted into a unique format and can be accessed by standard SQL-commands. During import the data amount, especially the harmonics are reduced to approximately 50%.

The analysis software is developed in MATLAB® and consists of two modes: interactive and automated. While the interactive mode allows the user to analyse the data manually and in detail, the automated mode reduces the user input to the selection of sites and intervals for analysis. All necessary calculations are done automatically and finally a detailed report for each site and a summary report combining the results of all sites is generated in PDF format.

SELECTING PARAMETERS FOR EVALUATION

Power quality surveying requires a reproducible measurement method for calculating the actual level of a power quality parameter and a clearly defined limit for comparison with the actual level. All power quality parameters given by DIN EN 50160 can be classified into 3 groups (tab. 1). DIN EN 50160 defines for all parameters of group 1 a measurement method to obtain the actual level. The minimum measurement interval is specified to 1 week. Limits are available for all parameters assigned to group 1. Consequently all parameters of group 1 can be included in a survey, if the measurement interval is equal or larger than the required one week per site.

The indicative values for the parameters of group 2 are usually given by ranges per year (e.g. from 10 to 1000 dips/year). If measurements per site are limited to a couple of weeks only, the significance of analysis results for these parameters is dubiously, particularly because clear limits don't exist anyway.

Because there is no information about limits and measurement methods given, the parameters of group 3 are also not relevant for the surveying purposes covered by the paper. Due to the above parameter classification and the suggested measurement intervals less a month (see cp. Performing Measurements), only the parameters of group 1 are included in the further considerations.

PRE-PROCESSING MEASUREMENT DATA

Fig. 3 shows the time plot of the phase to phase voltage RMS for one week. A weekly voltage time plot may include several short-term events (e.g. sags due to switching operations or transient earth fault conditions) and long-term events (e.g. maintenance interruptions, which will not effect costumers). According to IEC 61000-4-30 [2] such "non-normal"
operating conditions can produce unreliable values and should be flagged to avoid that a single event is counted more than once in different power quality parameters.

The analysis software (module 3 in fig. 2) includes an algorithm, which scans the measurement data of voltage RMS for “non-normal” operating conditions. The data points recognized by the algorithm are flagged automatically. Now the user can decide, which data points should be excluded from the further calculations. The exclusion always affects the data of all power quality parameters and gives better comparability between results of different sites for the considered parameters (group 1, tab. 1).

**CALCULATING PERFORMANCE INDICES**

The definition of the performance indices is derived from [3], where a unified power quality index (UPQI) for continuous disturbances is presented.

In a first step the performance indices covered by this paper should:

- be comparable between parameters, sites and networks
- be proportional to the distance between actual levels and given limits (i.e. the reserve)
- be concise and easy to understand, even in the case of a large number of monitored sites
- clearly show, if limits are exceeded

For a power quality parameter q at a site v, if required for a phase p, a normalised single performance index \( r_{E(v,q,p)} \) is calculated using the actual disturbance level \( m_{(v,q,p)} \) resulting from the measurement data and the limit value \( g_{(q)} \) (e.g. given by DIN EN 50160):

\[
 r_{E(v,q,p)} = 1 - \frac{m_{(v,q,p)}}{g_{(q)}} \quad (1)
\]

The expression \( m_{(v,q,p)}/g_{(q)} \) realises the normalisation. Subtracting the expression from 1 gives the final value for \( r_{E} \) that is proportional to the existing reserve between actual disturbance level and given limit (e.g. \( r_E = 0.72 \) means 72% reserve). In theory a maximum value \( r_{E} = 1 \) is possible in the case of no disturbance level at all (\( m = 0 \)). If the disturbance level complies with the applied standard, which means the disturbance level is smaller than the limit, the single performance index is positive and in the range \( 0 < r_{E} < 1 \). In the case of equality between disturbance level and limit the performance index gives \( r_{E} = 0 \). If the disturbance level exceeds the specified limit, the performance index \( r_{E} \) becomes negative.

In a next step the single performance indices are consolidated to a site performance index \( r_{V} \). If all appropriate single performance indices are positive, the site performance index is given by

\[
 r_{V(v)} = \min(r_{E(v,q,p)}) \quad (2)
\]

Otherwise the site performance index is calculated by

\[
 r_{V(v)} = \sum_{v=1}^{n} r_{E(v,q,p)} \quad (3)
\]

In equation (3) only the single performance indices \( r_{E(v,q,p)} < 0 \) are taken into account.

The same way only selected single performance indices may be consolidated to grouped performance indices \( r_{G} \).

Finally the site performance indices are consolidated to network performance indices \( r_{N} \) by using the same consolidation method as described above by eq. (2) and (3). Fig. 4 shows the system of performance indices. A further consolidation of different network performance indices to an overall performance index \( r_{C} \) is also possible, but doesn’t necessary for the surveying covered by this paper.

**SURVEYING RESULTS**

The calculation of performance indices is based on the selection of 8 sites per DSO and a measurement interval of 14 days during a 3 month period (August to October 2004). The following power quality parameters were selected for further evaluations: supply voltage variation, flicker, harmonics, unbalance (THD partially). While DSO A operates primarily rural networks, DSO B owns urban networks only. The site of DSO A was selected according to the enhanced sampling method explained in the chapter Selecting measurement sites. DSO B has monitoring devices installed at the MV-busbars in it’s HV/MV-substations. Both DSO used for all measurements the same type of instrument with analogous settings.

Fig. 5 and fig. 6 on next page show the grouped performance indices for each power quality parameter. While supply voltage variation and flicker consolidate the 3 phases only, harmonics consolidate the 3 phases and all harmonics up to 25th order to a single performance index (72 single performance indices). The index represents almost only the 5th harmonics, which is the dominating harmonic in public networks. The unbalance doesn’t need consolidation at all, because there is only one single performance index per site calculable (grouped index = single index).

Compared with DSO B the grouped performance indices of DSO A show wider variation ranges, slightly smaller reserves for harmonics and slightly higher reserves for flicker level.
Unbalance shows always high reserves of about 80% and above for both DSO. The supply voltage variation averages about 50%, but shows a higher variance for DSO A compared with DSO B.

The variations for DSO A are associated with the generally "weaker" networks (with higher impedances) in rural structures compared with urban ones and the more differing consumer structure from site to site. On the other hand the "stronger" networks (with lower impedance) and the more homogeneous consumer structure as well as the limitation of measurement sites to HV/MV substation busbars result in less-varying performance indices for DSO B.

The same conclusions apply to the site performance indices in fig. 7 and fig 8: Nearly unchanging site performance indices with small variance for DSO B; averaged slightly smaller reserves with higher variation for DSO A. The calculation of site performance indices additional includes the power quality parameter THD.

The statistical parameters of site performance indices are shown in tab. 2. None of the analysed power quality parameters at all measurement sites of both DSO exceed the limits given by DIN EN 50160. For DSO A the minimum reserve is 27.0%, for DSO B 43.8%. These minimum values are equivalent to the network performance indices. Calculating the mean value for each grouped performance index and site and a subsequent averaging of these mean values results in averaged network performance levels. These are nearly the same for both DSO, which means no significant differences of the power quality levels between both DSO. The greater variance for DSO A is quantified by the greater min-max range in tab. 2 compared to DSO B.

CONCLUSIONS

The paper describes a method for realising power quality surveys to obtain average power quality levels in public distribution networks. It gives concise, easy to understand performance indices, which directly quantify the existing distances between actual disturbance levels and specified limits (e.g. by DIN EN 50160). A high automation of data management and analysis enables an efficient handling of measurement data without an increasing need of manpower. Including the performance indices in existing control systems or GIS helps to make power quality to an integrated part of network operation and planning.

Suitable weighting factors for external benchmarking purposes (see fig. 4), especially to compensate possible disadvantages of rural networks compared to urban networks, are under development. Furthermore the application of advanced methods for calculating confidence intervals and probabilities of error as well as minimum sample sizes for different conditions are currently under study.

REFERENCES