

A METHOD FOR ANALYSIS OF COHERENCES BETWEEN POWER QUALITY AND NETWORK CHARACTERISTICS IN MEDIUM DISTRIBUTION NETWORKS

Etienne Gasch

TU Dresden – Germany

etienne.gasch@tu-dresden.de

Jan Meyer

TU Dresden – Germany

jan.meyer@tu-dresden.de

Peter Schegner

TU Dresden – Germany

peter.schegner@tu-dresden.de

Lutz Schulze

eon-avacon AG – Germany

lutz.schulze@eon-avacon.com

ABSTRACT

Electrical power quality in distribution networks mainly depends on type and behaviour of the connected consumers. The interaction of all consumers is stochastic. Furthermore the characteristic of the network as well as environmental conditions (e.g. temperature, clouds) have an influence on power quality.

A new statistical approach will estimate the value of a power quality parameter (e.g. harmonics or unbalance) from parameters of consumers and network structure as well as environmental conditions. Therefore in a first step it is necessary to find out, which parameters influence a specific power quality parameter at all. Most important for the application of the method is the easy provision of the input parameter data. In either case it should be as less as possible parameters, which are easily obtained by the utility.

The paper presents a method based on cluster analyses that quantifies the dependencies of a power quality parameter from the parameters of consumer and network structure and environmental conditions. Finally the paper shortly describes the software realization and gives a first practical result of the application of the method.

THEORY

Parameter specification

Analysing coherences or correlations between the characteristic of network and consumers and power quality requires to find out, which characteristic a specific power quality parameter depends on.

Therefore a set of parameters has to be defined, that describes network, consumer and environmental conditions [2]. In the further text this parameters are referred to as NCE-parameters. Selected parameters are:

- Network structure: (radial, meshed, ...)
- Network size: length of lines
- Consumer type: industry, households
- Supply area: urban, rural

Each parameter is expressed by an equivalent number for further processing.

On the other hand parameters for describing power quality have to be defined. According to EN 50160 voltage quality parameters can be slow voltage variations, long-term flicker, voltage harmonics, etc.

For each of the parameters a value, which quantifies the specific parameter, is required. Derived from descriptive statistics this can be 95%-quantile (according to EN 50160), maximum or variance of a special time interval, like one week (according to EN 50160). These values (e.g. the 95%-quantile of 5th voltage harmonic) are referred to as PQ-parameters in the further text.

In further steps PQ-parameters can also result from advanced statistical methods, like mixture distribution fitting or time series analysis.

It can be useful to consider additional parameters of current or power, like current RMS-value, active power or power factor.

Cluster analysis

The cluster analysis is used to find correlations between different NCE- or PQ-parameters. Clusters are created by finding similar values for all focused parameters.

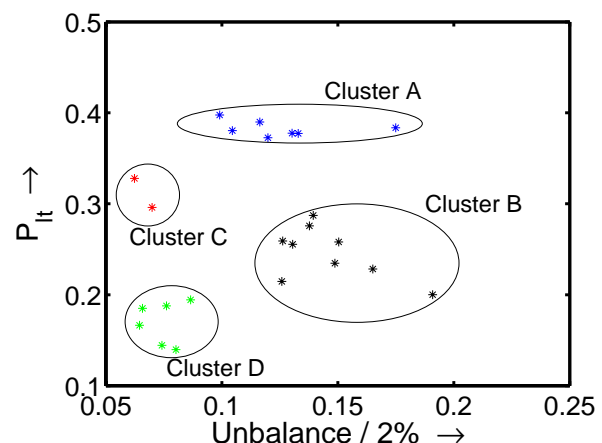


Fig. 1: Scatter plot of 2 PQ-parameters at 24 measurement points

For example, the clusters in Fig. 1 were created from two PQ-parameters (95%-quantiles for two weeks) measured at different points in a network. Each measurement point is represented by one star. Measurement points within one cluster (e.g. cluster D) show nearly similar values for the considered PQ-parameters.

In principle the cluster analysis calculates the difference between two objects [1]. Objects being close enough are connected two one cluster. Further objects can connect to this cluster if they have also a small distance to the first cluster elements. Otherwise those objects form their separate cluster. The graphical presentation like Fig. 1 (scatter plot) is only possible for two parameters. For more than 2 parameters it's hard to recognize the clusters by a scatter plot.

Therefore it is more convenient to use dendrograms (Fig. 2) **Fehler! Verweisquelle konnte nicht gefunden werden.**, which still can visualize the clusters in a comprehensible way.

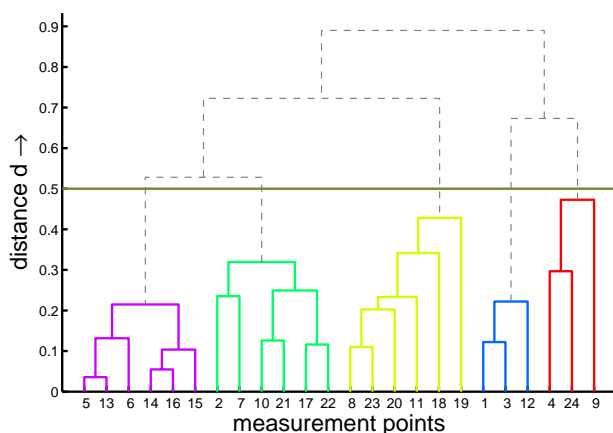


Fig. 2: Dendrogram of 4 PQ-parameters at 24 measurement points

In Fig. 2 the final clusters are drawn coloured. The method starts with two objects (e.g. measurement points 1 and 3) and connects them to one cluster (clustering). Other objects are connected as well. Measurement point 12 has a distance of more than $d = 0.2$ to measurement points 1 and 3. But it has even more to other measurement points. So it is connected to measurement points 1 and 3. The distances in the dendrogram are calculated for 4 PQ-parameters (4 dimensions). The clustering can be applied until only one cluster is left, which contains all objects. For useful results, it is necessary to define a maximum distance, where the clustering is stopped. All connections (dashed lines) above the maximum distance (e.g. $d = 0.5$ in Fig. 2; dotted line) are cut. The resulting number of clusters depends on the maximum distance.

The same procedure can be applied to NCE-parameters, which leads to another set of clusters. If clustering of the measurement points results in nearly identical cluster sets for NCE- and PQ-parameters, it is highly probable, that other measurement points with comparable NCE-parameters have similar PQ-values. This allows a prediction of Power Quality depending on NCE-parameters only.

Because every combination of PQ-parameters and every combination of NCE-parameters results in new cluster sets,

a huge amount of these sets can occur. To analyse and compare this cluster sets a new and automatic method for evaluation is necessary.

Binary distance method

The binary distance method is based on the idea that the distance between two objects can be represented by 2 states (binary), either "small" distance or "large" distance. The limit (critical value) between "small" and "large" has to be found empirically (e.g. circle in Fig. 3). A small critical value would mean that most measurement points create it's own cluster. A large value means that only one cluster for all objects is created.

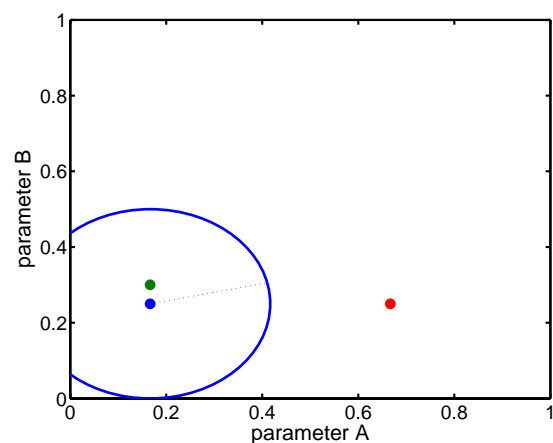


Fig. 3: Idea of binary distance method

Based on the real distances of each object to another a binary distance vector can be calculated. The calculation of the real distances is equal to the cluster analysis. The binary distance vector has to be calculated for a selected set of PQ-parameters and NCE-parameters. In the next step these binary vectors are compared by element wise XNOR-operation. The mean value of this difference vector represents a newly introduced similarity factor.

Finally the similarity factor is calculated for each combination of PQ- and NCE-parameters. All factors are stored in a similarity matrix, which can be presented in a graphical way.

IMPLEMENTATION

For the application of the new method described above, a huge amount of measurement data is necessary. These data has to be stored and analysed automatically. Therefore the power quality analysis system IMEDA was developed. Due to the necessary fast and random access to the data IMEDA uses a Client-Server-Database.

The client component and the server component can be installed on a single computer, or distributed on multiple computers, which can be connected over LAN or WAN (Internet) (cf. Fig. 4). There are two different client applications. One application writes new measurement data

into the database (writing tool). The other application reads the data and performs analysis (analysis tool). The client applications can also be installed on a single computer or on multiple computers. The client applications only need an logical ODBC connection. The writing tool can import measurement data from different PQ-measurement devices.

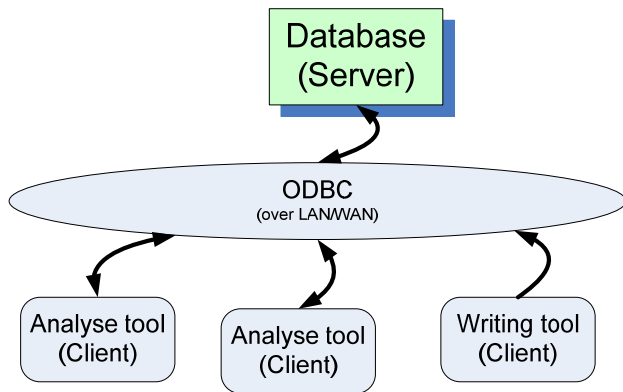


Fig. 4: Concept of a client server database

The structure of the database guarantees a fast access to all information which is necessary. It is independent from the native file format of PQ-measurement devices. This allows direct access from third party programs via the standardized ODBC-connection (e.g. MS Excel, Labview, MATLAB). The modular structure of the IMEDA-system enables an easy extension of the analysis tools.

APPLICATION

The example considers 16 measurement points (A-P), which are randomly distributed in the medium voltage networks of a regional utility.

Step 1: Defining parameter combinations

In this example 6 different NCE-parameters are considered.

- network structure (ns)
- consumer structure(cs)
- network size (nz)
- cabling ratio (cr)
- denseness of consumers (dc)
- supply area (sa)

Environmental parameters are excluded. Each NCE-parameter is expressed by a number between 1 and 3. E.g. network size: 1 $\hat{=}$ small; 2 $\hat{=}$ medium ; 3 $\hat{=}$ large. This results in 63 different NCE-parameter combinations.

Each of these combinations has to be compared with 15 combinations of the following 4 PQ-parameters:

- Long term Flicker P_{lt}
- voltage unbalance U^2/U^1
- 5th voltage harmonic $U^{(5)}$
- slow voltage variation U_{rms}

For each PQ-parameter the 95-%-quantile for 1 week is considered. Table 1 and Table 2 show the possible parameter combination.

Table 1: Possible NCE-parameter combinations

NCE-parameter	ns	cs	nz	cr	dc	sa
NCE ₁	X					
NCE ₂		X				
NCE ₃	X	X				
NCE ₄			X			
...						
NCE ₆₃	X	X	X	X	X	X

Table 2: Possible PQ-parameter combinations

PQ-parameter	U_{rms}	$U^{(5)}$	P_{lt}	U^2/U^1
PQ ₁	X			
PQ ₂		X		
...				
PQ ₇	X	X	X	
...				
PQ ₁₅	X	X	X	X

There are 945 possible cluster sets which had to be compared. In the following explanation only the combinations NCE₄ and PQ₇ is illustrated

Step 2: Calculation of distance vectors

To calculate one distance for the three parameters selected by combination PQ₇, their values have to be normalized, e.g. to the limits given by EN 50160. Table 3 shows the normalized values for selected measurement points.

Table 3: Normalized 95-%-quantiles (q) for comb. PQ₇

m.p. ¹⁾	U_{rms}	$U^{(5)}$	P_{lt}
A	0,14	0,70	0,29
B	0,28	0,31	0,57
C	0,18	0,63	0,29
...

¹⁾ measurement point

The distance $d_{PQ, nm}$ for N PQ-parameters between measurement points m and n is given by

$$d_{PQ, mn} = \sum_{i=1}^N |q_{a,i} - q_{b,i}| \tag{1}$$

The distance between measurement points A and B is

$$d_{PQ, AB} = |d_{U_{rms}}| + |d_{U^{(5)}}| + |d_{P_{lt}}| \tag{2}$$

$$= |0,14 - 0,28| + |0,7 - 0,31| + |0,29 - 0,57| = 0,81$$

All 120 distances (16 measurement points) are stored in the distance vector.

$$\vec{D}_{PQ} = |d_{PQ, AB} \quad d_{PQ, AC} \quad \dots \quad d_{PQ, AP} \quad \dots \quad d_{PQ, QP}| \tag{3}$$

The distance vector for the NCE-parameters is calculated the same way. Because of the unique representation of all NCE-parameters by numbers in the range 1-3 a normalization is not necessary. Selected values for the single parameter selected by combination NCE₄ are given in Table 4.

Table 4: NCE-parameter combination (NCE₄)

Network	A	B	C	D	...
Network size	3	1	3	2	...

Step 3: Calculation of difference vector

Before comparing both vectors, they have to be normalized on their highest value. Exemplary the first values of these vectors are given by

$$\begin{aligned} \vec{d}_{PQ} &= |0,96 \quad 0,14 \quad 0,68 \quad 0,91 \quad 0,52 \quad \dots| \quad (4) \\ \vec{d}_{NCE} &= |1 \quad 0 \quad 0,5 \quad 0,5 \quad 0,5 \quad \dots| \end{aligned}$$

The binary vector is calculated to separate measurement points with small and large distances. Due to the normalization the critical value d_c for this separation has to be set manually in the range between 0 and 1. The critical values can be different for NCE-parameter and PQ-parameters. The binary distance for vector elements i is calculated by:

$$d_{b,i} = \begin{cases} 0 & d_i < d_c \\ 1 & d_i \geq d_c \end{cases} \quad (5)$$

Choosing a critical value of $d_c = 0.5$ for both distance vectors (cf. eq. (4)), the resulting binary vectors are:

$$\begin{aligned} \vec{d}_{b,PQ} &= |1 \quad 0 \quad 1 \quad 1 \quad 1 \quad \dots| \quad (6) \\ \vec{d}_{b,NCE} &= |1 \quad 0 \quad 1 \quad 1 \quad 1 \quad \dots| \end{aligned}$$

Finally the difference vector is calculated by an XNOR operation, which is equivalent to the difference:

$$\Delta \vec{d}_b = \left| \vec{d}_{b,PQ} - \vec{d}_{b,NCE} \right| - 1 \quad (7)$$

The calculation for the example distance vectors (cf. eq. (6)) gives

$$\Delta \vec{d}_b = |1 \quad 1 \quad 1 \quad 1 \quad 1 \quad \dots| \quad (8)$$

Step 4: Calculation of similarity matrix

The similarity factor for each combination of cluster sets is calculated by

$$s = \text{mean}(\Delta \vec{d}_b) \quad (9)$$

This represents the percentage of elements $\Delta d_{b,i} = 1$ in the difference vector.

The similarity factor of the example combination NCE₄ / PQ₇ gives $s = 56.7\%$. That means that the focused parameter combinations do not match very well for these

networks.

The similarity matrix contains all 945 calculated similarity factors. The color-coded graphical presentation of the similarity matrix is shown in Fig. 5. The element of the example combination NCE₄ / PQ₇ is highlighted.

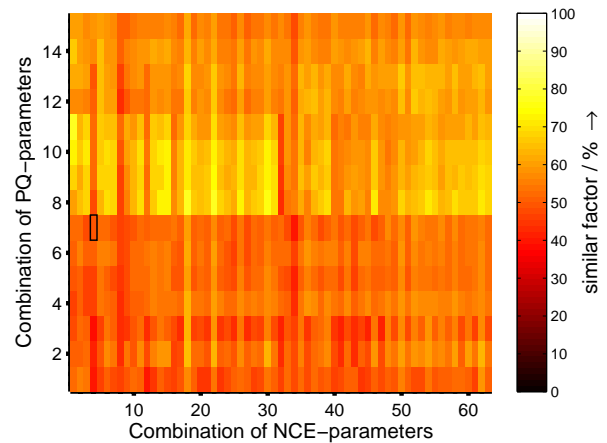


Fig. 5: Similar matrix from real measurement data

A light matrix element shows that the NCE-parameters have a strong correlation with the PQ-parameters of the selected combination.

CONCLUSIONS

The method presented by the paper is able to detect coherences between characteristics of network structure, consumer structure and environmental conditions on one hand and power quality on the other hand. The method is a first step in the development of a power quality prediction system.

More measurement data together with more detailed information about network and consumers as well as environmental conditions will help to optimize the method. Actually the in-depth analysis of suitable NCE-parameters and PQ-parameters is still going on. The verification of the method is based on the best-fitting NCE- / PQ-parameter combinations. PQ measurements for measurement points with similar NCE-parameters are compared to the PQ-parameters.

In future the method can be used to include power quality aspects in planning and optimizing PQ-performance of existing networks.

REFERENCES

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- [2] F. Otto; W. Rupf; J. Meyer; G. Winkler, 1999, "Determining the network harmonic impedance mainly for planning purposes in low voltage systems", CIRED Nizza.