SYSTEMATIC POWER QUALITY MONITORING IN MUNICIPAL POWER GRID

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ABSTRACT

The municipal sub-transmission / distribution power system of Duisburg (Germany) was equipped with a system for consistent and continuous power quality measurement in order to attain a better survey of incidents and to advance satisfaction of customers. Treating large amounts of data generated by 60 power quality recorders installed is a challenging task solved by proper data mining and visualization.

INTRODUCTION

Power quality (PQ) is a key factor for solid energy delivery, and it also contributes to the reputation of a power company. On the other hand, nowadays capable and affordable power quality recorders are available, which allow for systematic and continuous power quality monitoring.
For these reasons the municipal power system operator of Duisburg (Germany), counseled by the power systems institute of the local university, decided to implement a system for consistent power quality surveillance and reporting in the grid, based on ca. 60 PQ recorders firmly installed in the grid. Even if this provides a good insight into system incidents and events, it is a challenging task to reasonably deal with the large amount of data collected by the numerous recorders. Inconspicuous data have to be maintained in the local storages of the recorders for a limited period of time and can then be overwritten, while critical information – such as violation of limits – has to be selectively filtered out and to be immediately announced and properly stored on a central server. Specific analysis software allows for individual treating of data and e.g. visualization, sending alert messages, or generation of printed formal disturbance reports. Furthermore, a graphical system is also under development which would indicate such events on an interactive display, showing the system topology and therein the relevant substation(s) where critical values were identified, thus allowing for rapid and user-friendly tracking of disturbances. It is expected that the investment for the systematic power quality monitoring will certainly pay off by increased customer satisfaction.

INSTALLATION OF PQ RECORDERS

The power system under regard comprises a 110 kV sub-transmission grid, feeding the 10 kV (and still few 25 kV) distribution systems, as well as the sub-posed low voltage.

Substation wiring

Approximately 60 class A power quality recorders [1] are being installed at most of high and medium voltage busbars, as well in those two substations connecting the municipal 110 kV grid with the external 220 kV interconnected system: 7 on 110 kV level, 8 on 25 kV and 45 on 10 kV.
The PQ recorders in use (type PQI-DA manufactured by a-eberle [2]) have 3-phase / neutral voltage and 3-phase current inputs, respectively; the voltage measurements are taken from the particular busbar via existing PTs, the current measurements from the CTs placed at the relevant transformer feeder bays. For the individual localization of any disturbance source identified in the grid, a mobile PQ recorder is also available, which can be positioned as needed. All PQ recorders are parameterized to permanently observe several power quality criteria such as harmonics, asymmetries, voltage sags et cetera.

Data connection and storage

The devices are linked via TCP/IP connection to a central server located in the utility headquarters, which can poll the actual and the stored data on demand. Sequence and synchronization of data transmission from the recorders is controlled by the server-based special data management software "PQ-manager", provided by the manufacturer of PQ recorders [2]. Furthermore, in case of limit exceed or other trigger events, the information is automatically transmitted to the server in order to effectuate immediate situation awareness.
All data are stored in a MySQL database on the central server in form of 9 individual tables per PQ recorder. Four out of these tables are dedicated to the cyclically retrieved data such as 3-seconds, 10-minutes, 2-hrs values and daily statistics, the other 5 tables contain incident-related information – spontaneously transmitted –, such as oscillograms, plots of RMS values, harmonics, ripple control signal recorder and event counter.
In order to limit the data storage volume, the most comprehensive set of continuous 3-seconds data are automatically released for overwriting after 4 weeks; critical events are copied to a durable separate storage for individual treatment, thus also clearing the data archive.

Parameterization

The parameterization of PQ recorders is performed remotely from the central server by use of specific software of the manufacturer [2]. A central topic is the prudent setting of threshold and trigger values of the recorders for particular disturbance occurrences such as flicker, asymmetries, harmonics, voltage sags etcetera, thus allowing for a clear distinction between an early hint on limit approach and occurred limit violation. The following principles have been finally applied:

- setting of PQ limits strictly according to EN 50160 [4];
- where useful (e.g., for harmonics), notification if 75% of EN 50160 admissible values are exceeded (50% on 110 kV level, respectively);
- surveillance of ripple control signal levels (1350 Hz).

DATA HANDLING

The intended exploitation of the retrieved power quality data is bifold:

- providing awareness of actual or developing incidents by immediate data access after spontaneous notification and
- systematic screening of archived data on the server in order to observe and assess the general system performance in terms of power quality criteria.

Achieving awareness of PQ related events

Both immediate access of each particular PQ recorder as well as individual queries for certain signals or events stored in the data archive can be performed by use of the specific software WinPQ which is provided by the manufacturer of PQ recorders [3]. In this tool the superior on line remote access to the particular recorders is organized via "tiles" displayed on the screen, showing general status information of all recorders and allowing to retrieve any detail information on sub-posed information layers by subsequent mouse-clicks. This system is well developed and quite easy to handle; rather, there is only a rudimentary geographical display available. Therefore, an individual design was developed as an overlay. This display shows the complete geographic municipal area with the approximate positions of all installed PQ recorders entered as geometric symbols, see Figure 1. This interface allows for

- easy and fast awareness of occurred incidents by color of geometric symbols:
  red – critical event/limit violation,
  yellow – warning, e.g. 75% of allowance exceeded,
  green – no incident;
  after acknowledgment of receipt of the incident in the first two cases the color falls back to green;
- fast identification of incident(s) location by position of symbol on screen (map);
- clear distinction between voltage levels by symbols:
  square – 110 kV,
  circle – 25 kV,
  triangle – 10 kV.

If the cursor is moved above one of the symbols, the appertaining busbar name is indicated, see Figure 1; mouse-click then opens the "information tile" of the relevant recorder and therewith the entry into the full

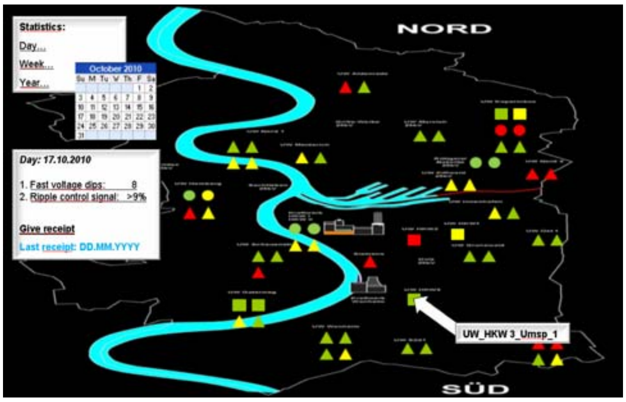

Figure 1 Superior visualization layer.

WinPQ functionality for all on-line as well as recorded data. Thus, the design of the superior layer ideally complements the original WinPQ software.

Furthermore, for those periods of time where the superior display is not in use (e.g., during night hours with no responsible personnel available), in case of an incoming incident an email is automatically sent to relevant persons to make them aware of the event so that they can care for it as soon as possible.

Another useful functionality is provided by the PQ recorder specific software „PQRvReport" [3]: according to chosen pre-selection, PQ reports are autonomously generated, which can arbitrarily contain tables or graphics showing PQ events and/or limit violations within a given period of time. Generation of these reports can either be triggered by occurred events, by time control or manually; they are directly edited in either html, ndr, pdf or rtf data format, or just printed. These reports give a brief survey of the PQ situation on a certain busbar or, collectively, of the entire grid, and thus constitute a weighty instrument to induce evidence and clarification in any potential disputes with customers.

Selective mining of archived data

In order to recognize trends of power quality and, in particular, to identify emerging problems in the grid as early as possible, it is expedient to systematically scan the archived data with respect to various criteria. As mentioned above, the data are stored on the server in a MySQL database; rather, the MySQL server does not provide a convenient user interface allowing to easily retrieve relevant information, in particular from and across more than one of the database tables. A typical example of such kind of aggregated query could be, for instance:

"When did long term flickers above 75% of allowed value (warning limit, see above) within the complete recorded period of time occur on busbar qb1uw02ka04 ?"

→ *"SELECT `TIME`, `PLT12`, `PLT23`, `PLT31` FROM `pqswdu`.`qb1uw02ka04_i3_c2h_00918` AS `qb1uw02ka04_i3_c2h_00918` WHERE (`PLT12` > 0.75 OR `PLT23` > 0.75 OR `PLT31` > 0.75)".*

Utility staff dealing with power quality issues is usually not familiar with SQL expressions which even must be logically combined for such kind of queries; this fact necessitates to apply a more convenient way of query formulation.
For this reason the "OpenOffice.org Base" database environment is applied which allows for retrieving arbitrary relevant information by few mouse clicks on a displayed survey table, Figure 2. The results obtained are easily convertible into other data formats such as xls, Table 1.

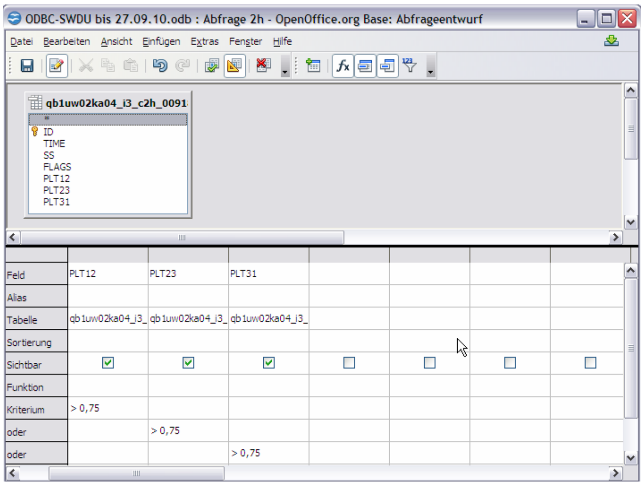

Figure 2 OpenOffice surface based data archive query.

Table 1 Example result of query in Excel format.

BUSBAR	DATE	PLT12	PLT23	PLT31
qb1uw02ka04	05.08.2010 07:59	0.77	0.81	0.80
	16.08.2010 11:43	0.94	1.02	0.96
	21.08.2010 09:12	1.12	1.06	1.03
	30.08.2010 17:38	0.86	0.85	0.91

EXAMPLARY SURVEY OF FIRST RESULTS

In the following, some example results of measurements are presented which were taken during the set up and test phase of systematic PQ monitoring. The data set origins from an arbitrary reference period (Sept 01 – Sept 30, 2010), and it is based on 21 PQ recorders actually installed at that time in the Duisburg municipal system (out of 60 to be installed in total, see above). 73 PQ events were detected within the reference month, each determined by a start and a stop mark. Figure 3 shows the occurrence of marks of particular event types over time within the reference month as displayed by the WinPQ software [3] for *one* selected busbar. It is obvious that all of the 3 scheduled interruptions – with clearly distinguishable start and stop marks each – also induce the identification of voltage dips / deep dips.
It is of particular interest, to what degree the events attain or exceed the given limits (see sub-section "Parameterization" above).

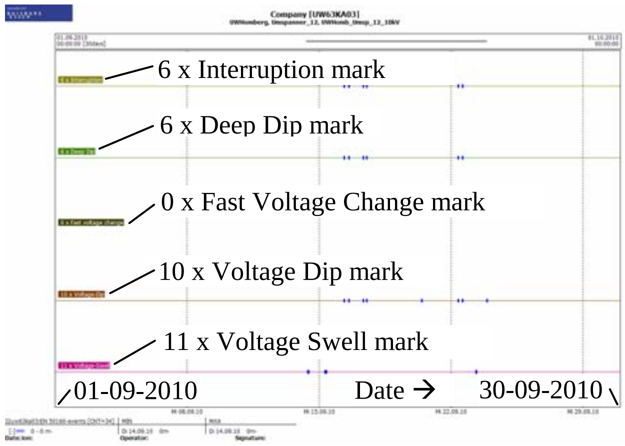

Figure 3 Indication marks of PQ events over time at one busbar (labeled original print).

Therefore, another additionally elaborated table of sorted PQ events (not shown here for space reasons), in generated from data archive contents. This table simultaneously shows the number of particular PQ limit deviations (except implications of scheduled interruptions) on *all* actually observed busbars, indicated in the headline together with their maximal monthly allowance according to EN 50160; numbers exceeding the limits would be marked in red. This sorted table significantly eases the identification of most relevant and critical event occurrences.
According to this sorted table, within the test period (Sept. 2010) there were no critical events at all; rather, uncritical voltage deviations – usually evoked by switching – occurred on most busbars.
Closer investigation of these voltage deviation events (except scheduled interruptions), using the WinPQ tool [3], proves that all deviations, independent of their individual duration, are within, or very close to, the admissible limits given by EN 50160, and, by far, within the ITIC limits curve [5] which was entered as another example of reference, Figure 4.

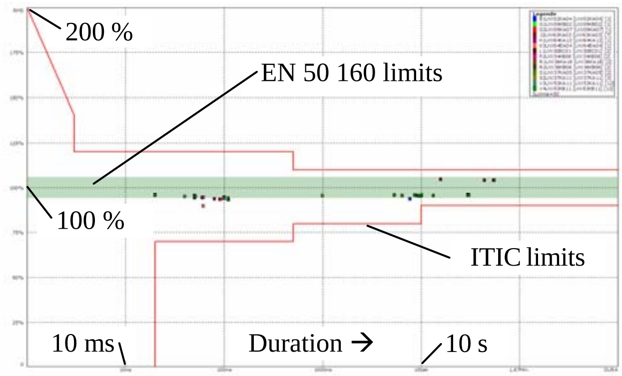

Figure 4 Occurrence of various kind of voltage deviations at all observed busbars (labeled original print).

Of cause, it is also of interest *when* these voltage deviations occurred, which is shown in Figure 5; there is no very significant accumulation within the period of observation.

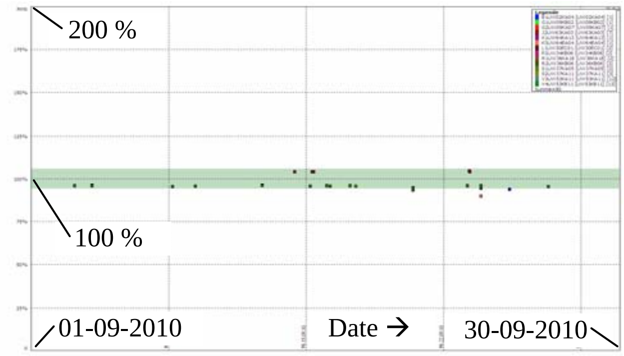

Figure 5 Temporal occurrence of various kind of voltage deviations (labeled original print).

An even more closer look at the daily appearance times of voltage deviations proves that these preferentially occur during the morning hours – those times when typically switching of industrial plants or start-up of larger drives happen, Figure 6. This clearly confirms the assumption of the origin of fast voltage deviations already made above.

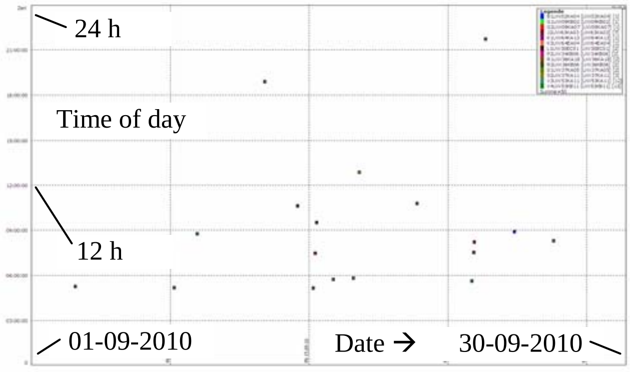

Figure 6 Occurrence of various kind of voltage deviations depending on time of day (labeled original print).

Regarding the occurrence of harmonics, there were also no critical events (limit violations) during the reference test period; rather, the warning limit at 75% of allowance – see above – was exceeded by the 5th harmonic at three busbars, Figure 7.

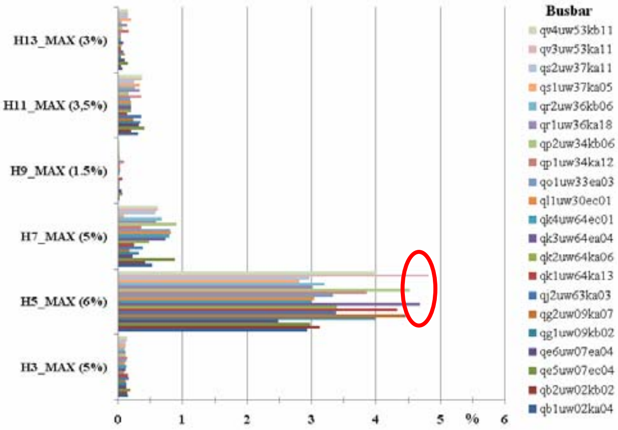

Figure 7 Voltage harmonics occurred at busbars (in %).

Obviously, this display (Figure 7) gives a useful survey of harmonics on the particular busbars; an even better general assessment is facilitated by indication of maximal harmonics occurred on *all* busbars, immediately related to their individual admitted limits (set to 100 % each), as shown with the Kiviat diagram in Figure 8.

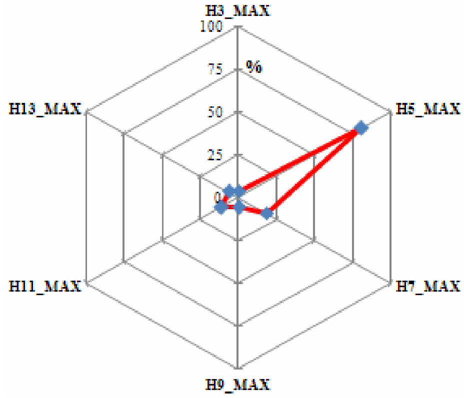

Figure 8 Kiviat diagram of voltage harmonics related to their individual admitted limits (full span of diagram each).

Rather, besides pure indication of harmonics incidence in Figures 7 and 8 it is of additional interest at what *times* certain levels occurred. This is easily possible by a specific database query as described in the relevant section above. Querying "At what times and where did the 5th harmonic exceed 75 % of admitted limit ?" leads to following reply:

busbar	time	H5_MAX (6%)
qk3uw64ea04	13.09.2010 22:09	4.67805
qp2uw34kb06	20.09.2010 19:39	4.52228
qv3uw53ka11	04.09.2010 20:59	4.80518

which immediately relates to the peaks marked in Figure 7.

CONCLUSION

Continuous and systematic monitoring of power quality in a municipal utility is achieved by comprehensive installation of PQ recorders and proper treatment of collected data. It is expected that the effort will certainly pay off by increased customer satisfaction. Some exemplary analysis aspects applied to a data set taken during the test and implementation period already prove the enhancement of insight into, and transparency of, the power system under regard as a further benefit.

REFERENCES

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[2]NN: Operating Manual for PQI-DA, A-Eberle GmbH & Co. KG, Nuremberg, Germany, 2009

[3]NN: WinPQ Program description, A-Eberle GmbH & Co. KG Nuremberg, Germany, 2010

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[5] Information Technology Industry Council (ITIC): http://www.itic.org/clientuploads/Oct2000Curve.pdf