ASSESSING COMPLICATED POWER QUALITY ISSUES OFF-LINE WITH IEC 61000-4-30 COMPLIANT TOOLBOX

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1. Introduction:

The first edition of the international standard IEC 61000-4-30 has been published in February 2003. It describes power quality measurement methods. To find fully compliant equipment to this new standard was not a sinecure. The experts from Laborelec (The Belgian competence centre in energy processes and energy use) with the support of Elia (Belgian Transmission System Operator) have decided to benefit from their knowledge in power quality, data acquisition and data processing to develop a compliant toolbox able to assess complicated power quality issues (for a 50 Hz net): the Digital Wave Recorder (DWR).

2. Principles:

The developed 'power quality' platform is innovating from different points of view and differs largely from the existing measurement and analysis devices. This platform is:
- universal: it is not limited at all to the electricity studies,
- integrated: it allows measurements as well as thorough analyses and simulations,
- evolutionary: able to rapidly comply with the latest progresses in power quality.

The basic philosophy is simple: the device is a desktop computer equipped with a digital acquisition that records waveform signals, just like a digital oscilloscope, but over long periods (up to two months). The phase locked loop (PLL) is not applied: sampling frequency remains constant. As soon as the campaign is finished, all data concerning the electric behaviour of the installation and the grid under study are available in digital mode. The power quality computations and assessments are performed «off-line» by means of a toolbox which has been developed in MATLAB®. In fact, the recorded waveforms can be submitted afterwards to any possible algorithm in order to extract any quantifiable parameter in power quality (or in any other field).

This paper integrates all aspects dealing with conditioning, acquisition and processing of the measurements.

Figure 1: Digital Wave Recorder

3. Objectives and advantages

Liberalization of the electricity market in Europe involves a steadily increasing significance of « power quality », for the network operators as well as for power suppliers, manufacturers and consumers. The network operator guarantees the quality of the electrical supply imposing therefore emission limits to the disturbances generated by the different network users.

The use of new technologies by the customers induces new problems: on one hand, power electronics that raise the level of the generated disturbances and, on the other hand, control electronics that raise susceptibility to disturbances.

Facing this new framework, identification of the disturbance sources, as well as their accurate quantification, becomes increasingly important in order to optimise the investments required for mastering the concerned disturbances.

In addition to the effective need of simplifying the commonly used measurement and analysis methods as to reduce the cost, it was also necessary to provide new and more elaborated techniques for the determination of the emission levels of disturbing installations. A few years ago, complex measurements and analyses, such as the commissioning of arc furnaces in the steel industry, required the simultaneous use of a large amount of miscellaneous devices (developed by universities and/or suppliers) in order to monitor all required parameters.

A basically different approach of the problem has to be found in order to cope with the fast progress. A new measurement, analysis and simulation tool became absolutely necessary. It has to be modular and evolutionary in order to meet Charles Darwin's statement:

'It is not the strongest species that survive, nor the most intelligent, but the ones most responsive to change'.

The result of these reflections is the DWR: a measurement device able to capture the complete waveforms. Thus, except the sampling frequency, no choices have to be taken concerning the configuration of the equipment. As all power quality computations and assessments are performed off-line, all decisions can be taken afterwards. In other words: the first measurement is always the good one!

4. Measurement

4.1 Signal conditioning

Safety of personnel and installations are two major concerns when measurement devices are installed in electrical power systems. In the specific case of transmission networks,

extremely severe safety requirements have to be met, owing to the harmful consequences of the slightest fault. The conditioning of the signal is the interface between the electrical installation on one hand and the measurement device on the other hand. This interface is entitled to guarantee a fully safe coupling of the measurement equipment. It includes three parts:
- The adapted cable works and their connectors,
- The protections of the voltage signals,
- The voltage transformers that make the signals compliant with the input voltage of the acquisition card and guarantee the galvanic separation.

Particular attention was paid to all these elements, based on the advice of the different consulted experts and end-users. The most significant topics that were withheld are quoted hereafter.

Measurement accuracy:
- frequency response of the voltage transformers (important for the harmonic measurements),
- synchronous 8-channel sampling and shielding filter auto-adapted to the sampling frequency ranging between 2 and 50 kHz,
- protection against electromagnetic influences (EMC),
- calibration of the complete measurement chain in one time (current clamp, conditioning unit and acquisition card together).

Safety :
- inaccessibility of energized components,
- redundancy and strength of the connections for the current loops (to prevent the opening of the secondary circuit of the current transformer),
- different connectors for the current and voltage loops,
- testing of the entire conditioning system by Laborelec's EMC laboratory and elaboration of the « CE label » record.

Convenience and reliability of the equipment:
- replacement of the conventional voltage transformers by insulated, light and compact instrumentation amplifiers,
- fast and safe mounting ensured by the cables with adapted connectors.
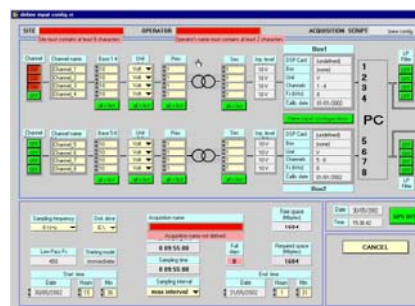
4.2   Signal acquisition

The Digital Wave Recorder relies on an industrial PC equipped with an acquisition card. The build-in GPS system allows highly accurate dating and enables synchronization at less than 0,1 ms. With this option, the system meets the most severe requirements of the latest standards for power quality measurements (IEC 61000-4-30 [1] , IEC 61000-4-7 [2] , IEC 61000-4-15 [3]). The measurement of the electrical signals sampled over several weeks at many kHz results in records as bulky as many tens of Gbytes. During these long measurement periods the system can be monitored and controlled remotely.
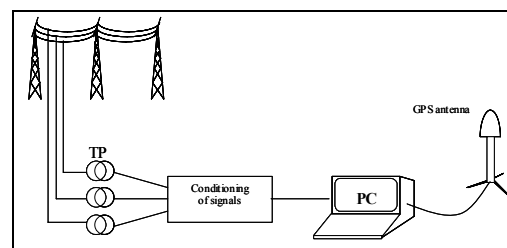
Figure 2: general principle

The measurement and computation uncertainty (which is of course decreasing with sampling frequency) has been calculated for all parameters and is much below the requirements for class A devices according to IEC 61000-4-30 standard. The measurement and assessment device has received an ISO 17025 accreditation by Belac (Belgian Organisation for Accreditation). The purpose is for example to be able to use this platform in possible juridical disputes.

The signal-recording program has been written in LabVIEW®, a programming environment for virtual instrumentation. Particular attention has been paid to the user interface.

Figure 3: Acquisition user interface

The synoptic of the measurement chain is provided to help users with the configuration. The sequence of the phases and the amplitude of the signals can be verified at a simple glance with the graph of waveforms and the vectorial representation.

4.3   Analyses

The most important work starts as soon as the device is picked up. The PC that performed the data acquisition will from now on be used for processing, analysis and simulation purposes.
After a measurement campaign the PQ-toolbox is used to perform all required power quality processing operations and analyses.
The PQ-toolbox is equipped with a graphical interface that ensures the fast and intuitive definition of the required processing operations. The system starts with the standard analyses, which are generally available on most of the other monitoring devices. More advanced analyses and simulations are often necessary. That's where the PQ-toolbox makes the difference by offering almost unlimited processing
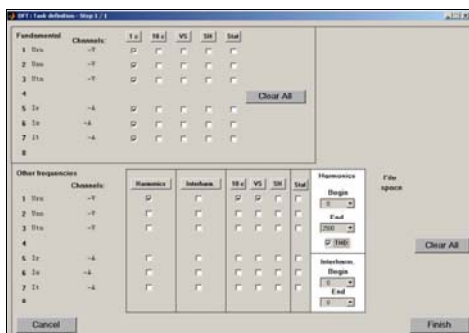
possibilities.

Figure 4: wizard for results request

Any measurement device can be implemented virtually on this platform. It appears possible to easily apply to the recorded signals any complex algorithm described in professional literature or in the international standards. The modular and open structure makes it possible to add additional blocks to the basic environment, which is a must as power quality is a permanently progressing discipline.
Another advantage of the system is the enormous possibilities of graphical representation of the results of analyses and simulations. As shown by experience, a clear graphical visualisation of a problem improves its understanding and highly facilitates its solving.
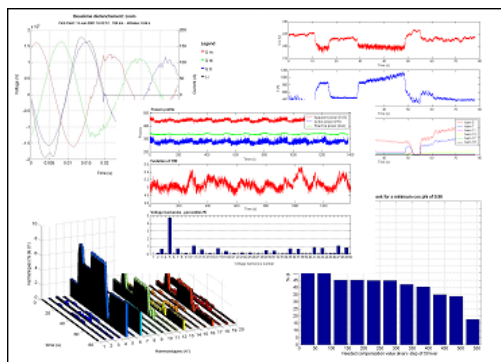

Figure 5: examples of graphical possibilities

When developing the computation functions, special attention has been devoted to compliance with the standards. Laborelec's and Elia's participation to international working groups and commissions allows to follow progresses of the standards very closely and to implement them immediately in the PQ-Toolbox. Laborelec's mathematics department scrutinizes the algorithms where they are perfected in order to ensure an excellent performance under all circumstances (accuracy and computation time).

5. *Signals processing*

5.1   Pre-processing

When a measuring campaign is completed, the data processing can be started. Context information is available and can be modified during computation but the acquisition files containing the samples of the waveforms can never be changed (original version is conserved).
The signal processing is composed of two consecutive phases. The first one, called pre-processing, must be realised on the reference voltage channel. As default, the first voltage channel is chosen as reference but it's always possible to select another one. The purpose is to determine the different time intervals required by the IEC 61000-4-30 standard: 10-cycle, 150-cycle (or very-short), 10-min (or short) and 2-hour intervals. This operation consists in detecting the zero-crossings of fundamental wave (50 Hz) of the reference signal (obtained by filtering this signal without phase-shift).

A general rule is applied: "all what begins in an interval makes part of this interval". At the beginning, at least two periods are required to stabilise the filter. After this pre-amble, the first 10-cycle interval begins at the first positive zero-crossing (from negative to positive values) after a 10-min top from the GPS antenna. The next interval starts just after the preceding one. The first short or very-short interval starts at the first 10-cycle interval after a 10-min top. Short intervals end with the last 10-cycle interval beginning in the 10 minutes.
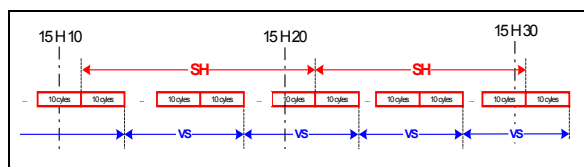

Figure 6: standard intervals

Very-short intervals contain always fifteen 10-cycle intervals. As demonstrated in Figure 6, there is a natural de-synchronisation between very-short and short intervals. The decision was taken to re-synchronise all standard intervals every day at midnight to guarantee the synchronisation between different devices (Figure 7).
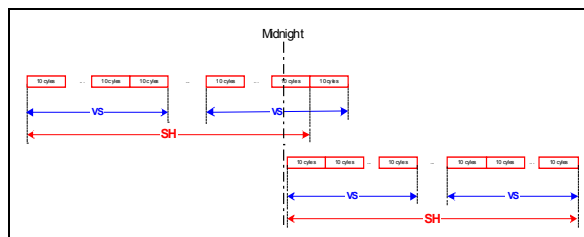

Figure 7: Re-synchronization at midnight

After this operation and in order to optimise computation, a re-sampling algorithm is performed to obtain a constant number of samples per period. This also guarantees the DFT to be performed on an integer number of cycles as required by the standard (to avoid spectral leakage).
It can happen that the reference signal disappears during an

acquisition. In this case, synchronisation with zero-crossings is no more possible between the last accepted one and the comeback of the signal:

Index of samples: M   N

Last accepted   Firt re-accepted
Zero-crossing   Zero-crossing
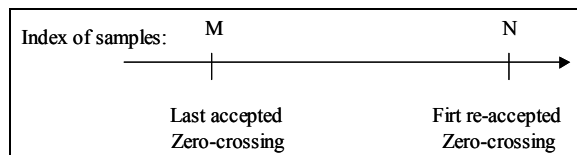
To check the presence of the reference signal, verification is done for each 20 ms-interval regarding the maximum value of the filtered signal. The following condition has to be respected:

$$\max\left(ABS\left(S_i\right)\right) \geq U_{stop}.\sqrt{2}$$

The value for U_{stop} has been chosen equal to 10% of the dynamic of the acquisition card. The computation of the missing zero-crossings is made as hereafter:
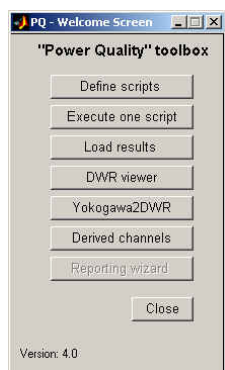
$$P = \max((round((N-M).(\frac{f_n}{f_s}))),1)$$

With: f_n = net frequency
f_s = sampling frequency

$$ZC_k = M + k\frac{N-M}{P}$$

With: k = 1,2,..., P-1
ZC_k = Position of ZC

5.2   Standard processing

A wizard helps to define the different requested computations. This is a real "toolbox" offering to users several possibilities:

scripts describing the requested computations can be defined, saved and executed. Results can be loaded in MATLAB® (with period selection, channels choice…). It's also possible to view and to print acquisition signals (in a way to use the platform as a digital oscilloscope). Acquisition from other systems can be transferred. The possibility to generate supplementary virtual channels is also proposed.

As far as standard analyses are concerned, all the power quality parameters defined in the IEC 61000-4-30 are proposed: power frequency, magnitude of the signal, unbalance, flicker, harmonics and interharmonics. Flagging is realised in case of swells, dips or interruptions and statistics on very-short and short values are

proposed. It is also possible to calculate active and reactive power at fundamental frequency.

The results are saved in special formats easily readable by MATLAB®. All the information needed for reporting (context, units, scales…) can be loaded in the workspace. For parameters requesting huge memory place (1-cycle power, 10-cycle FFT…), the results are separated day by day.

6. *Advanced investigations*

The standard possibilities described above are interesting but this is not what makes the platform so powerful; some additional options are very interesting as well.

Concerning emission of disturbances (evaluation of the contribution of one particular consumer in the total level of disturbance in a point of the network), special investigations are needed. A lot of theories and theses have been written but few have been validated. With the DWR, it's now possible to test the different options on selected and interesting cases and to analyse and compare the results of different methods. As soon as a new procedure is officially accepted, it is immediately integrated into the platform.

A special tool has been developed to be able to apply any function or algorithm directly to the basic signals in a way to generate new "virtual" channels. The possibilities are unlimited: filtering, modification of scale, combination of existing channels (sum, multiplication…), user-defined mathematical expressions…

The DWR platform is not limited to electrical measurements: new developments have already been realised to record simultaneously the electrical profile of an installation and some mechanical characteristics (such as speed of a motor or vibrations of a generator). The only requirement of the system is to have conditioning racks to transform the level of the analogical sensors to the input level of the acquisition cards.

6.1   Case 1:

The purpose was to study the influence of changes of configuration of an electrical transmission network on the generator of a power plant. Some people in the plant were afraid of an increase of the torsion constraints in the machine due to the proximity of large fluctuating loads in the foreseen configuration of the network. Four equipments have been use simultaneously: two of them were connected in two separate points of the transmission network; the two others were directly installed in the power plant (one to measure voltages and currents at the output of the generator and one equipped with two optical sensors to measure the speed).
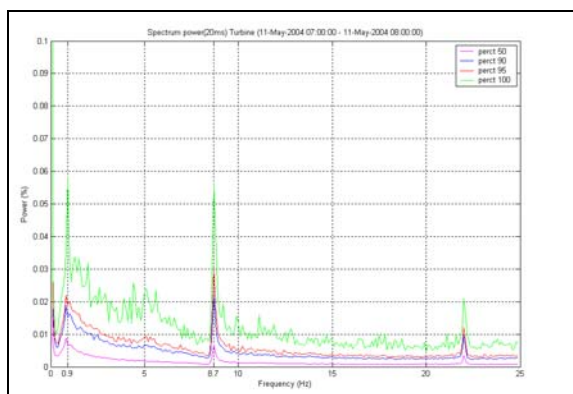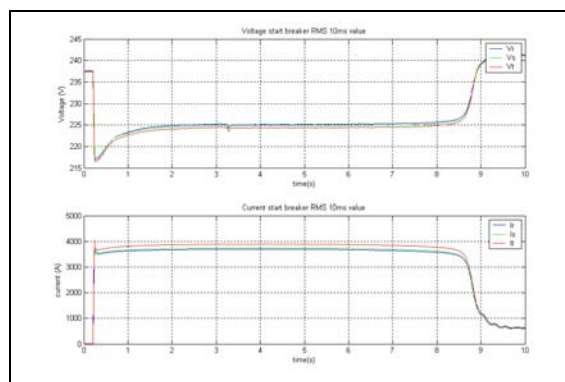
Figure 8: spectrum of the power (20ms) of the turbine
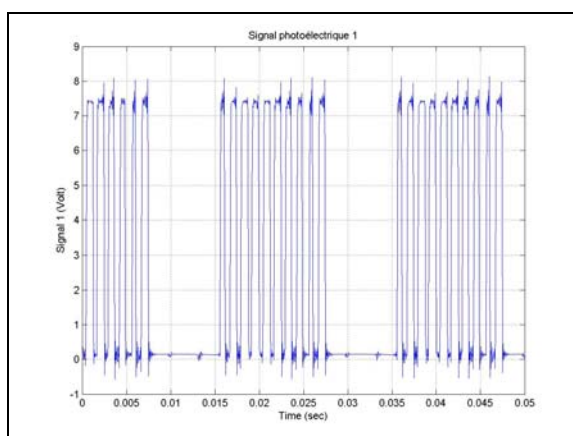

Figure 11: Current & voltage during start of the motor

7. *Conclusions*

The implementation of the IEC 61000-4-30 standard is a very hard goal to achieve. You have to be aware not only of the requirements of the standard but also of its spirit. Different time intervals (based either on a certain number of cycles of the reference waveform or on absolute time) generate problems of synchronization. We're still far from having reached the limits of our platform. Many more developments are already foreseen: increasing the number of channels per device, acceleration of computation time, packaging of non-electrical measurements...

Figure 9: basic photoelectric signal (from which the speed of the machine is derived)

8. *References*

[1] IEC 61000-4-30: Electromagnetic Compatibility (EMC) Part 4-30: Testing and measurement techniques – power quality measurement methods (2003-02)

[2] IEC 61000-4-7: Electromagnetic Compatibility (EMC) Part 4-7: General guide on harmonics and interharmonics measurements and instrumentation, for Power supply systems and equipment connected thereto (2002-08)

[3] IEC 61000-4-15: Electromagnetic Compatibility (EMC) Part 4: Testing and measurement techniques – Section 15: Flickermeter – Functional and design specifications (2003-02)

6.2   **Case 2:**

The customer wanted to have a signature of big crusher to be able to dimension the protection of the motor. The voltages, currents and the speed of the motor have been recorded at the same time for some specific working conditions.
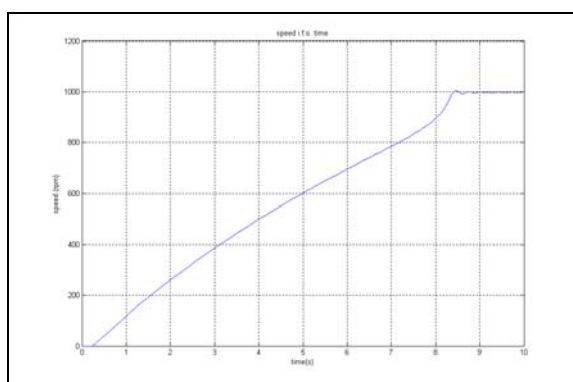

Figure 10: Speed of the motor