

Performance and Calibration of High-End Impulse Analysing Systems

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Abstract

High-End Digital Impulse Analysing Systems are becoming more and more accurate and surpass the relevant standard. Various performance data such as amplitude resolution and sampling rate are carefully checked for their influence on final accuracy or improvements in connection with sophisticated signal processing.

As important as technical performance are frequent calibrations, which are also influenced by the quality standard ISO 9000. However frequent calibrations are a very expensive procedure. To minimise cost and work, a unique channel insert system has been developed. This channel insert system allows for an easy calibration procedure and a continuous device availability at 60% of the cost of conventional continuously operational systems.

Introduction

Requirements for digital recorders in high-voltage testing are given by the standards, but what is the actual advantage of higher resolution (number of bits) or faster sampling (Mega samples per second) for the user? If just a visual judgement and comparison of impulses on a piece of paper is performed the difference between average and high-end digital recorders can hardly be recognised. However, transformations from time to frequency domain, mostly performed by FFT (Fast Fourier Transformation) and used in Transfer and Coherence analysis, are more sensitive to the recorder's performance data [1]. Actual amplitudes of the excitation impulse are very small at high frequencies which requires a good amplitude resolution for an accurate measurement.

Apart from initial performance data, quality control, which for measuring systems generally involves traceability to National Standards, is becoming more and more important [2,3]. The new quality standard, ISO 9000, as well influences such a development. However, not all users are in favour of frequent traceable calibrations as incurred costs and work are not desirable.

The common calibration procedure for a HV Impulse Analysing System has one big disadvantage: while calibrating a measuring system at the manufacturer works a second, redundant system is required - or testing has to be interrupted, which

generally is not possible. An additional handicap are custom formalities, which often delay transports by weeks. To minimise cost and work of calibrations a new, unique channel insert system has been developed.

Frequency Spectra in HV Testing

Most common impulses in high voltage laboratories are switching impulses (SI), full, chopped and front chopped lightning impulses (LI, CW and FCW). The relatively slow Switching Impulse (250 / 2500 μ s) contains mainly a spectral density at frequencies below 100 kHz whereas the front chopped lightning impulse (chopped in the front at <1 μ s) shows a significant spectral density at frequencies up to several MHz. In general the statement is true that the smaller the time parameters the larger the spectral density at higher frequencies. Chopped impulses contain, due to high dU/dt , which occurs during the chopping process, the largest spectral density at high frequencies. As an example the frequency spectra of a SI, LI and FCW impulse are shown in Figure 1.

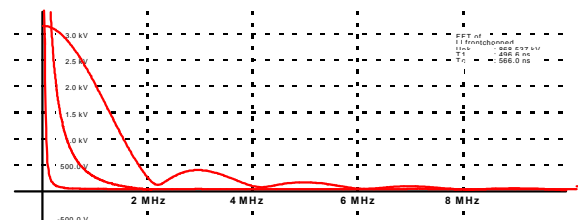


Figure 1

From bottom left to top right: spectral density of SI, LI and FCW. The later one showing largest spectral density at high frequencies.

Performance Data of Digital Recorders

Amplitude resolution describes the smallest increment a digital recorder can resolve. For an 8 bit recorder this corresponds to 1/256 or 0.40%. Every additional bit improves the amplitude resolution by a factor of 2. Therefore 10 bits correspond to 0.10% and 12 bit to 0.02%. This improvement is shown in Figure 2 and 3.

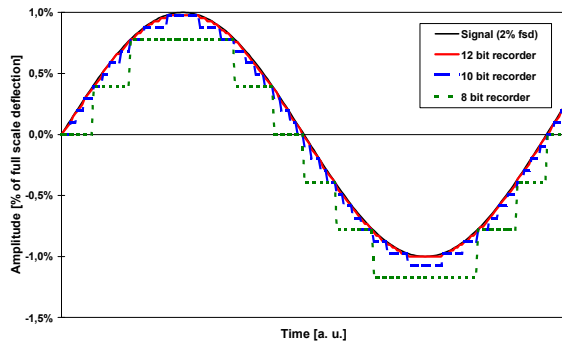


Figure 2

Comparison between 8, 10 and 12 bit amplitude resolution. A 2 % modulation is approached with 5 steps (8 bit), 20 steps (10 bit) and 80 steps (12 bit). The latter one can hardly be distinguished from the original.

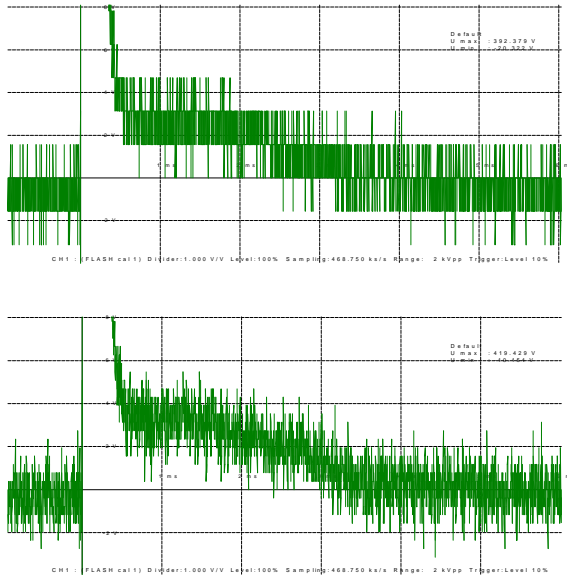


Figure 3

Enlargement of real recordings performed with 10 bit (top) and a 12 bit (bottom) digitisers. The 10 bit digitiser clearly shows the steps of individual bits.

Sampling rate describes how often the analogue signal is measured per second. The faster this is done the higher frequencies can be measured by the digital recorder. For a given sampling rate F_{sample} the maximum frequency which can be recorded is given by the Nyquist theorem:

$$F_{Nyquist} = \frac{F_{sample}}{2}$$

Frequencies larger than the $F_{nyquist}$ are reproduced with strong aliasing components. In Figure 4 an example of aliasing is shown.

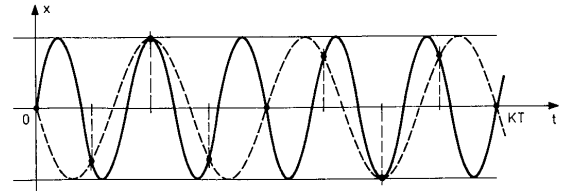


Figure 4

Aliasing effect: A signal of frequency $5/8 f_{sample}$ (solid line) sampled with f_{sample} . Connecting the resulting samples with a line (dashed) shows an aliasing signal of $3/8 f_{sample}$.

Influence on Transfer / Coherence Analysis

Transfer Functions (TF) are often used to compare e.g. power transformers of the same electrical and mechanical design. TF are in first order insensitive to the wave shape of the exciting impulse. Physically TF reflects the electrical characteristics of the winding and reveals its natural oscillations. Each resonant pole on the TF plotted against frequency corresponds to a natural resonance of a winding section [4]. An example for a TF (and CF) of a power transformer is given in Figure 5.

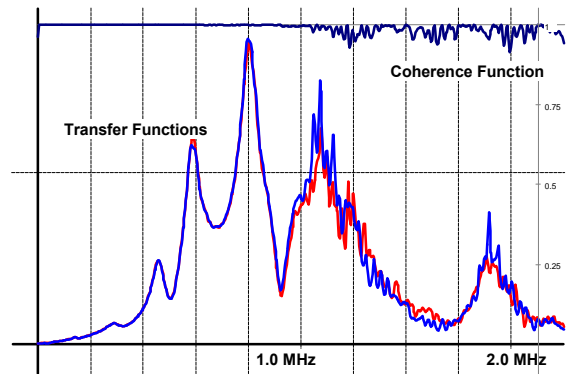


Figure 5

Coherence Function (top) and Transfer Function (bottom). This example shows that this TF is reliable up to approximately 1 MHz.

To understand the performance data of digital recorders most important to obtain best sensitivity for Transfer Functions, the mathematics are described briefly.

To receive the transfer function the frequency spectras of the recorded voltage $U(t)$ and current $I(t)$ signals are calculated by FFT (Fast Fourier Transformation) resulting in $U(f)$ and $I(f)$. The quotient of $I(f)$ and $U(f)$ is called Transfer Function TF

$$TF(f) = \frac{I(f)}{U(f)} = \frac{1}{Z(f)}$$

where $Z(f)$ reflects the impedance spectrum of the transformer under test.

Now what is the influence of technical performance data on the calculation of a TF? As we have seen at paragraph *"Frequency Spectra of High-Voltage Impulses"* amplitude of excitation $U(f)$ decreases strongly towards higher frequencies dropping already at 1MHz far below the 1% level. Therefore the error in the denominator $U(f)$ at small amplitudes is the most important quantity. This is generally the digitising error of the A/D (analogue to digital) converter, e.g. for a 12 bit recorder 1/4096 respectively 0.02%.

The Coherence Function (CF) is an additional tool, which, mainly in connection with the TF, provides an indication of the areas where the ingress of noise made the signal processing unreliable. For further details the reader is referred to literature [5]. Mathematically the CF is derived from all the time domain records used in the TF calculation and therefore has the same requirements from the digital recorder - mainly a good amplitude resolution.

As we have already seen during the calculation of TF, the digitising error becomes the most critical quantity. This is not very surprising as the same basis, namely $U(f)$ and $I(f)$, are involved as with the TF calculation.

Calibration Procedure required by Standards

In many fields manufacturers of calibrated measuring equipment e.g. multi-meters or digital oscilloscopes quote a certain period during which the calibration is guaranteed, e.g. one year.

Following the standard for high-voltage test techniques, IEC 60-2, recommends that the Performance Test is repeated annually and in any case it shall be repeated at least once every five years. The Performance Check shall be made at intervals based on the recorded stability of the Measuring System as shown in the Record of Performance. IEC 1083-1 (1991) on the other hand requires a Performance Check daily before and after measurements.

However the mentioned standards are in practise adopted differently by users - mainly because calibration procedures are cost and work intensive. With increasing accuracy of High-End Impulse Analysing Systems, calibration on a regular basis should be equally important to the user as technical performance data. What is the advantage of a highly precise measurement device if it is not calibrated?

Most users would like to perform calibrations frequently but the involved cost and time should be reduced. Therefore a new system which allows for an easier calibration procedure has been developed.

Device Architecture for easy Calibration

Many users of digital recorders do not possess a calibrator to perform the above tests. If no calibrator is available locally, the measuring device must be

return the manufacturer or a laboratory capable of performing the described tests. However many test labs use their measuring equipment continuously, and interruption of testing is not possible. To reach a continuous availability for a measuring device either a second redundant system or a device with a new structure is required.

To address this problem a new so called **Channel Insert System** has been developed. The system is based on individual measuring channels which include for each channel all accuracy sensitive elements in **fully closed** aluminium casings (see Figure 6). Inserting / exchanging a channel is performed in less than 30 seconds and absolutely no work other than putting the Channel in the relevant slot is required.



Figure 6
Individual Channel Inserts, small compact and easy to send back for calibration.



It has been proven with a series of comparisons that accuracy of a system which strictly follows the Channel Insert design philosophy is only dependant on the accuracy of the Channel Inserts. Measuring an impulse is entirely performed by the Channel Inserts which pass a completely digitised impulse measurement via bus system to the CPU.

Caution:

If individual channels are not covered by a complete casing, mechanical work, sensitive cable connections or other adjustments have to be performed, it is most likely that the reliability of an exchange will suffer. E.g. if individual measuring cards (no complete casing) and/or mechanical work is required, an exchange by non-experienced users can influence the accuracy or damage such a channel. We therefore strongly recommend that non of the above work will be accepted if a channel calibration, as described later, is performed.

A schematic block diagram of a system featuring Channel Inserts is shown on the next page in Figure 7.

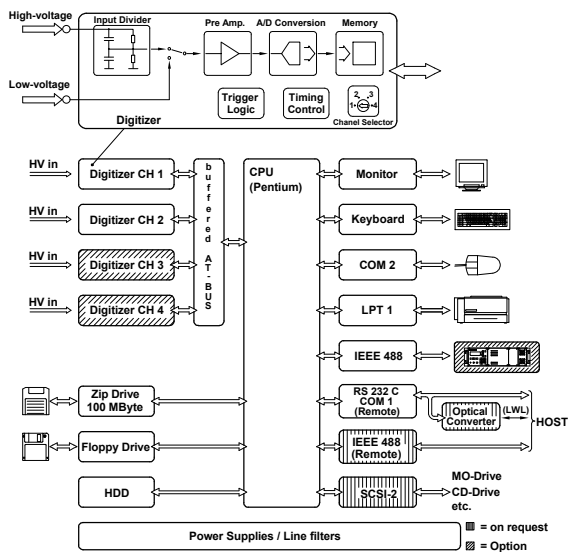


Figure 7

System Architecture of new digital recorders featuring the Channel Insert System. All accuracy sensitive elements are built into individual Channel Inserts. Important: the system is operational with any number of Channel Inserts.

Additional software is only responsible for analysis, display, saving and reporting of the measured impulse. The software can be checked separately for its conformity with the so called software validation IEC 61083-2. A software validation passes the same kind of measurement data to CPU for evaluation as the Channel Inserts do for real measurements. Therefore calibrating Channel Inserts and performing software validation ensures overall system performance.

Proposed Calibration Procedure

With such a **Channel Insert System** a so called "circular calibration" is proposed which will be explained using a system with 3 channels.

- A new 3 channel system is installed
- Channel 1 is sent back for calibration
- Channel 2 is sent back for calibration
- Channel 3 is sent back for calibration
- Channel 1 is sent back for calibration

The calibration interval could e.g. be scheduled once every year as foreseen in the new draft of IEC 61083-1 (1998). Additional comparison should be performed by parallel measurements using the recently calibrated channel (reference) and one of previously calibrated channels (channel under test). The channels have to agree in time and amplitude parameters within the limits required by the standard IEC 61083.

Using the Channel Insert System with the above described "circular calibration procedure" has the

advantage of a fully operational system at the cost of one additional channel. This is approximately 60% of the cost compared to a fully operational conventional system which involves a second redundant device.

Conclusions

Technical performance data of digital recorders for measurements in high-voltage impulse tests have been continuously improved during the past few years. Especially in connection with sophisticated analysis such as Transfer and Coherence Function the amplitude resolution of the analogue to digital converter seems to be the most important quantity.

To ensure initial accuracy and technical performance data on a long term, frequent calibrations of digital recorders are required. The aim to hierarchically trace uncertainties from the user to national standards as well as the influence of the quality standard ISO 9000 are pointing in this direction. The Channel Insert System described in this paper will allow for a simple calibration procedure and a continuous device availability at a very economical price.

References

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