On-site Impulse Tests and corresponding State of the Art Measurement and Analysis Techniques for Power Transformers

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HIGH VOLTAGE TEST

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Abstract

Compelled by the high quality requirements of HV Power Transformers and increase of average age, on-site tests are becoming more and more important. Impulse on-site testing is a tool for checking the quality of new and already installed equipment. For large Power Transformers a transportation of the entire transformer is, due to the heavy weight, not possible. In this case assembling has to be performed on site and, as a logical consequence, also the testing.

Digital recorders used for on-site testing should, of course, be equipped with state of the art analysis tools such as Transfer and Coherence function. Such sophisticated analysis tools, which take advantage of the transformation to the frequency domain, should have excellent amplitude resolution. The fact that on-site tests are generally performed with full wave impulses, having little spectral density at high frequencies, means that amplitude resolution is the most important factor.

In this article only impulse test systems and analysis are discussed. For information on AC OWTS or other on-site test systems the reader is referred to the literature [1, 2].

Introduction:

There are two main reasons which imply on-site tests of HV Power Transformers;

1. HV equipment becomes more and more powerful. That means the equipment will have larger dimensions. Sometimes the equipment is assembled in the factory for tests, disassembled for transportation and assembled again on site. The quality of the on-site assembling has to be checked with tests on site.

2. A large part of the installed equipment in the HV-networks was put into operation 25 ... 35 years ago. Users of HV equipment (utilities, power plants etc.) must decide whether these equipment can still remain in service with an acceptable low risk of failure. Disassembling, transportation, tests in a lab, transportation back and reassembling are one of the alternatives. A much easier way would be to test equipment already installed on site.

Impulse tests involve strong electromagnetic peak forces and produce mechanical and electrical peak stresses. No other test produces similar stresses on the test object, neither can results of other measuring and diagnostic methods (AC: PD, tan δ, RVM...) replace information gained from impulse tests. Field experience with smaller transformers has shown that these transients have certainly the most strenuous impact on transformers' insulation and cause perhaps approx. 50 % of all pre-mature failures! [3]. International standards have included impulse tests for a long time. On-site tests should also include this important test.

On-Site Impulse Generators

Specialized equipment for on-site tests has to withstand off-road transportation, pass under road-bridges, be equipped with its own power source and withstand frequent assembling & disassembling.

Two different types of impulse test systems (Type A and B) which fulfill all requirements for on-site operation are described:

On-site Impulse Voltage Test System Type A

Figure 1 shows an on-site test systems which can be transported in a horizontal position. The system is erected automatically by a hydraulic tilting mechanism. No additional assembling is necessary. Only connections to control and charging unit, test object and measuring system have to be performed. The total erection procedure takes only 2 - 3 minutes. Systems of type A have been operating successfully for more than 4 years.

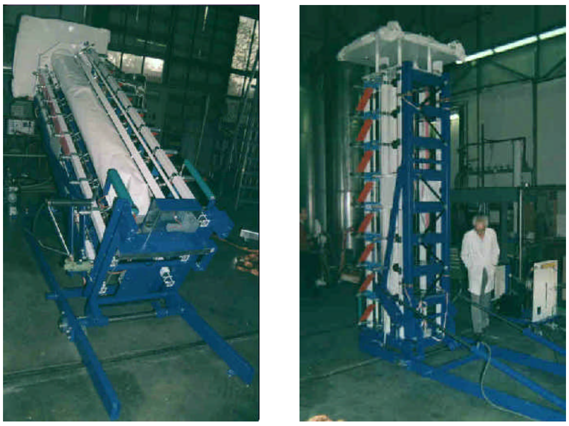

Figure 1

Mobile on-site impulse voltage test system for charging voltages of 800 kV (up to 1000 kV available). The automatic hydraulic erection allows a very fast assembling and disassembling. Suitable for testing large Power Transformers (up to the 220 kV class).

Technical Details System A:

Maximum charging voltage (≤ 1000 m)	800	kV
Energy at max. charging voltage	40	kJ
Max. output voltage LI	765	kV
Max. capacitance of test object	5.2	nF
- with overshoot compensation [3]	18	nF
Max. output voltage SI	650	kV
Max. capacitance of test object	2.3	nF
Max. output voltage OLI	1400....1150	kV
Max. capacitance of test object	2 ... 20	nF
Max. output voltage OSI	1350....1000	kV
Max. capacitance of test object	2 ... 20	nF
Total weight of system	< 1000	kg

On-Site Impulse Voltage Test System Type B

The on-site test system type B is designed for much higher output voltages than type A. The test system is stored on a low bed trailer, Figure 2.

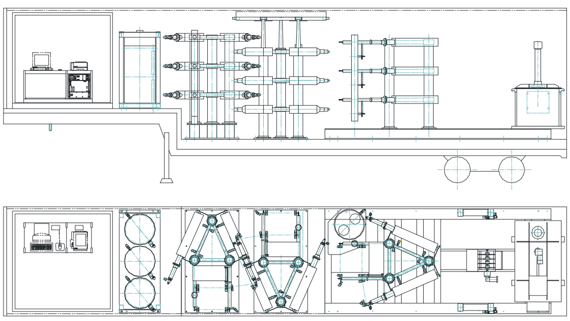

Figure 2

Mobile on-site impulse voltage test system for charging voltages of 1800 kV (up to 2400 kV available). Modular design allows for an easy storage in a low bed trailer. For assembling and disassembling a crane is required. Such systems are suitable for testing Power Transformers of the highest voltage class.

Control and measuring equipment are fitted into a „control container“ which is also mounted on the low bed trailer. This control container is removable and can be placed according the on-site conditions. Additional elements like divider, top electrodes and inductances (for OLI, OSI generation) are stored in a standard container.

For the erection on site a crane is necessary. In general the size of the on-site test equipment is not limited. A system with 1800 kV total charging voltage will be in operation at the end of 1999.

Technical Details:

Maximum charging voltage (1000 m).	1800	kV
Energy at max. charging voltage	90	kJ
Max. output voltage LI	1720	kV
Max. capacitance of test object	3.6	nF
- with overshoot compensation [3]	13	nF
Max. output voltage SI	1200	kV
Max. capacitance of test object	15	nF
Max. output voltage OLI	2200	kV
Max. capacitance of test object	2 ... 20	nF
Max. output voltage OSI	1500	kV
Max. capacitance of test object	2 ... 20	nF
Total weight of system	< 15.000	kg

On-Site Measurements and Advanced Digital Techniques

Impulse testing of transformers often involves the comparison of a reduced with a full wave impulse (e.g. 50 and 100% B.I.L.). If the system is linear, which is generally the case for healthy systems, both recordings are similar in shape. The easiest way to perform a comparison is by normalising both impulses and calculating the difference, see Figure 3.

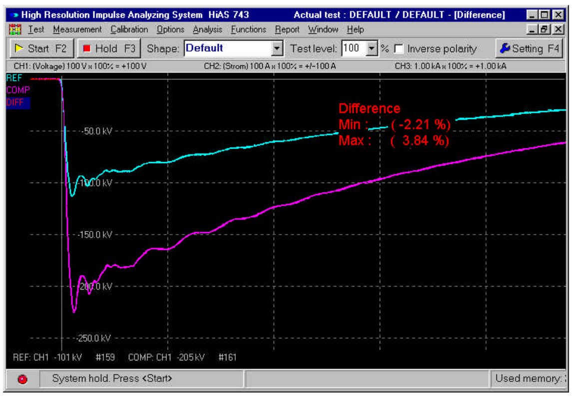

Figure 3

Comparison of L.I. 50% with 100% showing both impulses and the maximum deviations numerically.

However this method is very sensitive to the exact shape of the generated impulse. To avoid this sensitivity new analysis tools which take advantage of a transformation from time to frequency domain have evolved. Frequency spectra of high voltage impulses and critical issues of the digitising process (analogue to digital conversion), with respect to frequency domain analysis, will be discussed.

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 / 2500µs) contains mainly a spectral density at frequencies below 100 kHz whereas the front chopped lightning impulse (chopped in the front at <1µs) shows a significant spectral density at frequencies up to several MHz. In general it is true that the smaller the time parameter the larger the spectral density at higher frequencies. Chopped impulses have, a high *dU/dt*, which occurs during the chopping process, with largest spectral density at high frequencies. As an example the frequency spectra of a SI, LI and FCW impulse are shown in Figure 3.

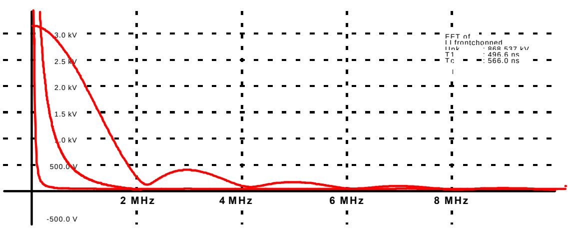

Figure 3

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

On-site tests are generally performed with full wave impulses (SI or LI) which contain very low spectral density at frequencies at and above 1MHz. It is therefore important to take advantage of the best available amplitude resolution if the complete wave shape information has to be captured.

Digital Recorders

Requirements for digital recorders in high-voltage testing are given by the standards. But which quantities are especially important in connection with on-site tests and sophisticated analysis tools? 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 [3, 4]. Actual amplitudes of the excitation impulse are very small at high frequencies which requires a good amplitude resolution for an accurate measurement.

Amplitude resolution describes the smallest increment a digital recorder can resolve without signal processing (resolution enhancement). 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 4.

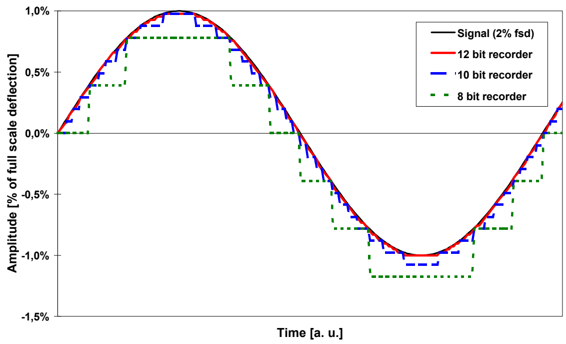

Figure 4

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.

Influence on Transfer / Coherence Analysis

Transfer Functions (TF) are often used to compare, for example, power transformers of the same electrical and mechanical design. A comparison of reduced and full wave recordings can be performed and the results compared with similar transformers or older recordings. 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 [5]. An example for a TF (and CF) of a power transformer is given in Figure 5.

To understand the performance data of digital recorders, which have the best sensitivity for Transfer Functions, the mathematics are described briefly.

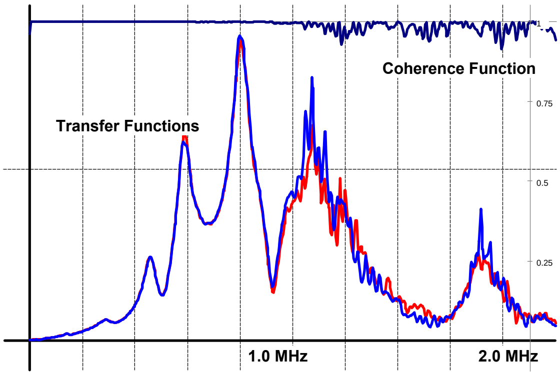

Figure 5

Coherence Function (top) and Transfer Function (bottom). This example shows that this TF is reliable up to approximately 1 MHz. A recording which was performed using a 12 bit system. A similar 10 bit system could reproduce the same reliability for the two peaks at 0.6 and 0.8 MHz.

The transfer function is the calculated by FFT (Fast Fourier Transformation) of the recorded voltage *U(t)* and current *I(t)*. The results are *U(f)* and *I(f)*. The quotient of *I(f)* and *U(f)* is called Transfer Function *TF*

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

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

What is the influence of technical performance data on the calculation of a TF? As we have seen in the paragraph *"Frequency Spectra of High-Voltage Impulses"* amplitude of excitation *U(f)* decreases strongly towards higher frequencies already dropping far below the 1% level at 1MHz. Therefore the error of 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%. If the voltage level U(f) drops to 0.50% the digitising error of a 10 bit recorder (0.10%) would be 20% whereas a 12 bit recorder shows a 4 times smaller uncertainty of 5%.

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 [6]. 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, digitising error becomes the most critical quantity. This is not very surprising as the same basis, namely *U(f)* and *I(f)*, are involved in the TF calculation.

Conclusions

In future more frequent tests and diagnosis will improve the reliability and increase the life cycle of high voltage equipment. On-site impulse testing is one of those methods which can be used for both, new and already installed equipment. Specialised equipment for on-site tests is readily available and experiences have been collected.

Technical performance data of digital recorders for on-site measurements are similar to the requirements for laboratory testing. As on-site tests generally do not involve chopped impulses a good amplitude resolution is advantageous. Especially in connection with sophisticated analysis such as Transfer and Coherence Function the amplitude resolution of the analogue to digital converter is the most important quantity.

References

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