*Chapter 18*

# Digital measuring technique and evaluation procedures

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## 18.1 Introduction

The introduction of the digital recording system into the high voltage measuring technique has a great influence on the measuring technique and the evaluation procedures. The formerly used analogue recording instruments were developed for high voltage measurements and in particular for impulse measurements under very noisy conditions or, in other words, for high electromagnetic interferences. One of the best factors against electromagnetic interference was the high signal to noise ratio, reached by a high signal voltage level up to 1500 V for impulse voltage measurements. This high signal level also leads to a high deflection level of about 100 V/cm and requires no amplifier within the analogue oscilloscope.

The use of digital recording devices in high voltage measurement requires, in particular, a number of measures against electromagnetic interferences. The recording device should be inside a Farady cage to prevent the influence of the electric field. The high signal level should be kept by using a so-called input divider inside the shielded cabin to reduce the voltage level from hundreds of volts down to 2 V, which is the normally used input level of a digital instrument. This voltage divider could be used at the same time for remote controlled change of the total impulse voltage divider ratio. Furthermore, the requirements on the digital recorder concerning resolution in amplitude and time should be equivalent to or better than those of the analogue oscilloscope.

The digital recording devices offer a number of advantages compared to analogue systems. Owing to the recording technique the problem of an exact triggering of the analogue oscilloscope no longer exists, because the digital recorder continuously records the data and stops at a given and preselected time. Therefore the history before the event takes place can also be recorded. The recorded data are available in digital form, and zooming and compression are easily possible. This means that a change of timescale can be made by evaluation of the data and does not require another measurement as it was necessary with analogue recording devices assuming that the recorded data allows this procedure. The data can be evaluated automatically with a computer or with a built-in processor. The data can be directly used for documentation, for a figure in a test report, for example. It is also possible to compare two measurements with different amplitudes by scaling the amplitudes. The use of mathematical procedures like Fourier transformations, filtering, neural networks, genetic algorithms, fuzzy logic, etc. allow further evaluation of the recorded data for better evaluation of the test results and for diagnostics.

## 18.2 Requirements on the recording device

It is obvious that the performance of a digital recording device should be at least equivalent to the performance of an analogue recording system. The measurement of DC and AC voltage is simple and the requirements are very easy to fulfil, and therefore only the requirements for impulse measurements are described in the following sections.

It should be taken into account that the recording technique of a digital recorder is different from the analogue oscilloscope and that no information is available between two samples, for example. This means that high frequency oscillations may not be recorded by a digital recording device, but at least indicated by an analogue oscilloscope, because the signal is continuously recorded and the brightness of the beam changes depending on the deflection velocity. The requirements on the digital recording device are given in IEC Publ. 61083 [1] and will be described in detail according to the revision of the IEC Publ. 61083.

The requirements for digital recorders are different for use in approved measuring systems from that in reference measuring systems. Furthermore the requirements are expressed as an overall uncertainty and individual requirements. A digital recorder used in an approved measuring system shall have an overall uncertainty of less than 2% in the peak voltage or current measurement of full and standard-chopped lightning impulses, switching impulses and rectangular impulses. The overall uncertainty for the peak voltage of front-chopped lightning impulses should be less than 3%. All time parameters (front time, time to chopping, time to peak, time to half-value, etc.) shall be measured with an overall uncertainty of less than 4%. The uncertainty budget should be evaluated according to Annex H of IEC Publ. 60060 [3]. These overall uncertainties are usually reached if the individual requirements are fulfilled, but in some cases the individual requirements may be exceeded without exceeding the overall uncertainties. Therefore the most important individual requirements are described.

The amplitude resolution is given by the rated resolution $r$, the nominal minimum increment of the input voltage which can be detected in the output voltage. The rated resolution is expressed by the reciprocal of two to the power of the rated number of bits $N$ of the digital/analogue convertor (digital recorder), namely

$$r = 2^{-N} \tag{18.1}$$

For approved measuring systems a rated resolution of $2^{-8}$ (0.4% of the full scale deflection) or better is required for tests where only the impulse parameters are to be evaluated. For tests which involve signal processing a rated resolution of $2^{-9}$ (0.2% of the full scale deflection) or better is required. The full scale deflection is the minimum input voltage which produces the nominal maximum output voltage in the specified range.

The time resolution is expressed by the number of samples taken per unit. The sampling time is the time interval between two subsequent samples and the reciprocal of the sampling rate. The sampling rate shall not be less than $30/T_x$, where $T_x$ is the time interval to be measured. For a standard lightning impulse 1.2/50 the measured time $T_x$ is $0.6T_1$, the time interval between 30% and 90% of the peak value of the measured lightning impulse. With the lower tolerance of the front time $T_1 = 0.84$ µs the measured time $T_x$ ~500 ns, which leads to

$$\text{sampling rate} > \frac{30}{500^{-9}\text{s}} = 60 \times 10^6 \frac{1}{s} \tag{18.2}$$

For measurement of oscillations in the front the sampling rate should be in accordance with the maximum frequency reproduced by the measuring system.

The scale factor described the factor by which the output is multiplied to get the measured value of the input quantity. Digital recorders may have different amplitude scale factors for different input voltages, e.g. the static scale factor $F_s$ for DC voltage and the impulse scale factor $F_i$ for impulse voltages representing the shape of the relevant impulse. The timescale factor is defined as the factor by which the recorded time interval is multiplied to get the measured value of the time interval.

The rise-time of the digital recorder shall be ≤3% of the measured time interval $T_x$. For lightning impulse measurement this value shall be <15 ns to record the superimposed oscillations.

The interference shall be <1% of the amplitude of the expected deflection, the internal noise should not be less than 0.4% of the full scale deflection for waveform parameter measurements and less than 0.1% of the full scale deflection for measurements involving signal processing.

The record length shall be sufficiently long to allow the evaluation of the required parameter.

The nonlinearity of amplitude and time base are given as integral and differential nonlinearity. The static integral nonlinearity of the amplitude shall be within ±0.5% of the full scale deflection, and the differential nonlinearity within $\pm 0.8w_0$ for static and dynamic tests, with $w_0$ as average code bin width (see Figure 18.2). The integral nonlinearity of the time base shall be not more than 0.5% of the measured time $T_x$. Figure 18.1 shows the integral nonlinearity and Figure 18.2 the differential nonlinearity and the code bin width $w(k)$.

The use of a 3-bit digital recorder in Figure 18.2 is only for clarification of the definitions. The differential nonlinearity $d(k)$ can be calculated by the following equation:

$$d(k) = \frac{w(k) - w_0}{w_0} \tag{18.3}$$

The operating range should be not less than $4/N$ of the full scale deflection, where $N$ is the number of bits: this means for an 8-bit digital recorder a peak amplitude not less than 50% of the full scale deflection. For tests which require comparison of records the operating range of not less than $6/N$ is recommended.

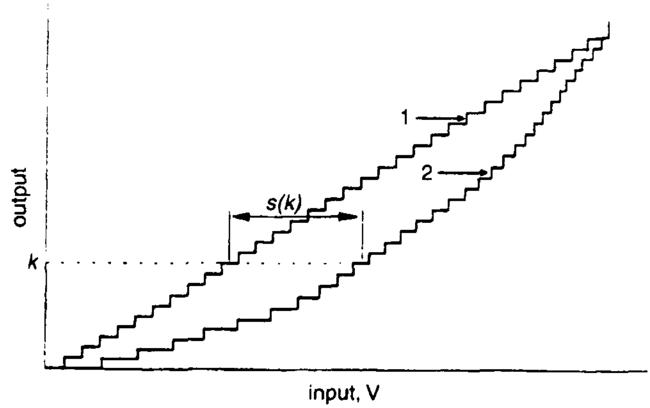


*Figure 18.1 Integral nonlinearity*
*1 Ideal 6-bit digital recorder*
*2 Nonlinear 6-bit digital recorder*

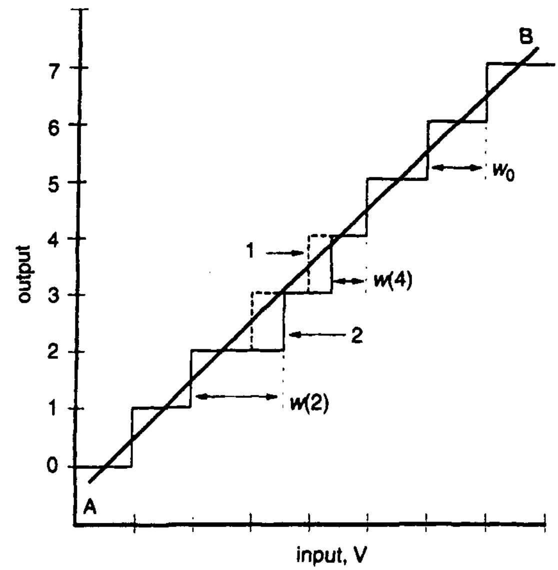


*Figure 18.2* *Differential nonlinearity and code bin width w(k) under DC conditions*
*1 Ideal 3-bit digital recorder*
*2 Large differential nonlinearities at codes 2, 3 and 4*
*$w_0$ = average code bin width, AB = line between midpoints of code bins of an ideal digital recorder*

For digital recorders used in reference measuring systems for the calibration of approved measuring systems the requirements are more stringent. The overall uncertainty for the peak voltage or current measurement of full and standard-chopped lightning impulses, switching impulses and rectangular impulses shall be not more than 0.7%. The overall uncertainty for the peak voltage of front-chopped lightning impulses should be not more than 2%. All time parameters (front time, time to chopping, time to peak, time to half-value, etc.) shall be measured with an overall uncertainty of not more than 3%. The individual requirements are also adapted to the higher performance of the digital recorder.

To establish the impulse scale factor and to check the time parameter determination of an approved digital recorder a pulse calibration by a reference pulse generator is recommended, even if a step calibration is also mentioned in the relevant IEC Publication [2]. The use of a calibrator for checking a measuring device is not new, because already in the IEC Publication for analogue oscilloscopes a calibrator was required [4]. The calibration should be done with impulses of the same shape to be measured, and therefore a number of impulses are listed in Table 18.1.

*Table 18.1 Requirements for reference pulse generators*

| Impulse type | Parameter being measured | Value | Uncertainty,[1] % | Short-time stability,[2] % |
|---|---|---|---|---|
| Full and standard chopped lightning impulse | Front time | 0.8–0.9 μs | ≤ 2 | ≤ 0.5 |
| | Time to half-value | 55–65 μs | ≤ 2 | ≤ 0.2 |
| | Peak voltage | within operating range | ≤ 0.7 | ≤ 0.2 |
| Front chopped lightning impulse | Time to chopping | 0.45–0.55 μs | ≤ 2 | ≤ 1 |
| | Peak voltage | within operating range | ≤ 1 | ≤ 0.2 |
| Switching impulse | Time to peak | 15–300 μs | ≤ 2 | ≤ 0.2 |
| | Time to half-value | 2600–4200 μs | ≤ 2 | ≤ 0.2 |
| | Peak voltage | within operating range | ≤ 0.7 | ≤ 0.2 |
| Rectangular impulse | Duration | 0.5–3.5 ms | ≤ 2 | ≤ 0.5 |
| | Peak value | within operating range | ≤ 2 | ≤ 1 |

[1] The uncertainty is determined in accordance with Annex H of IEC Publication 60060-2 [5] by a traceable calibration where the mean of a sequence of at least 10 pulses is evaluated

[2] The short-time stability is the standard deviation of a sequence of at least 10 pulses

## 18.3 Requirements on the evaluation software

The replacement of the analogue oscilloscopes by digital recording devices is only worthwhile when the digital recorded data are used for an automatic evaluation by a computer. Therefore a standard for the evaluation software was developed and in IEC Publ. 61083 Part 2 the requirements on the software used for the determination of the impulse parameters are described in detail [6]. The raw data are the original record of sampled and quantised information normally corrected by the offset and multiplied by a constant factor (divider ratio) to get the output directly in kV, for example. All other data are called processed data. A test data generator (TDG) is available as a computer program which generates reference test waveforms with the specified parameters of the digital recorder to be used, for example sampling time, full scale deflection, off-set, record length, polarity, trigger delay and noise. The output of the TDG has to be evaluated and the value of the parameters shall be within the given limits.

The existing impulses of the TDG are divided into groups of waveforms to check the software only for the relevant type of waveform. The software passes the test if for all impulses within the relevant group all parameters to be evaluated are within the given limits. The waveforms are grouped as follows:

- lightning impulse voltage (LI)
- chopped lightning impulse voltage (LIC)
- lightning impulse voltage with oscillation in the front (LIFO)
- chopped lightning impulse voltage with oscillation in the front (LICFO)
- lightning impulse voltage with long duration overshoot (LILO)
- lightning impulse voltage with short duration overshoot (LISO)
- lightning impulse voltage with low frequency oscillations (LISL)
- lightning impulse voltage with high frequency oscillations (LIFA)
- switching impulse voltage (SI)
- impulse current (CI).

The waveforms can be further divided into analytical impulses with and without noise and in measured impulses as shown in Table 18.2 together with the waveform number within the software of the TDG.

The evaluation shall be done according to IEC Publ. 60060–1 [7] except for the time to peak for switching impulse voltages. An approximation for the time to peak, based on the evaluation procedure for the front time of lightning impulse voltages, gives a better reproducibility of the results. Depending on the time to half-value the time to peak is given by the equation

$$T_p = \mathrm{K}\, T_x \qquad (18.4)$$

with $K = 2.42 - 3.08 \times 10^{-3}\, T_x + 1.51 \times 10^{-4}\, T_2$ and $T_x$ the measured time

*Table 18.2 Reference waveforms of the TDG*

| Waveform group | Analytical | | Measured |
|---|---|---|---|
| | Smooth | Noisy | |
| LI | 1 | 6 | – |
| LIC | 2 | 7 | – |
| LIFO | – | – | 11 |
| LICFO | – | – | 12 |
| LILO | – | – | 13 |
| LISO | – | – | 14 |
| LISL | 3 | 8 | – |
| LIFA | 4 | 9 | – |
| SI | 5 | 10 | – |
| CI | – | – | 15 |

Numbers indicate the TDG reference test waveform between 30% and 90%. The overall uncertainty for this procedure is 1.5%.

The uncertainty of the parameter evaluation of the reference test waveforms is given in Table 18.3 and is approximately 1% for the peak value and 4% for the time parameter.

The reference test waveforms do not cover all possible waveforms of impulse tests. In particular impulse tests on transformers or metal oxide arresters generate waveforms which are different from the reference test waveforms, but also for this type of waveform a check of the evaluation procedure should be available. An international working group of IEC and CIGRE is dealing with this problem, and maybe in future a Part 3 of IEC Publ. 61083 will be produced with reference test waveforms for transformers and other apparatus.

## 18.4 Application of digital recording systems

### *18.4.1 DC and AC voltage measurements*

The measurement of DC and AC voltage with a digital recording device is very simple and should not be explained in detail here. Some advantages of a digital recording system are the monitoring of overvoltage superimposed on the DC or AC voltage or the evaluation of harmonics by Fourier analysis. The resolution in time and amplitude depends on the

*Table 18.3 Specified limits of the reference waveforms*

| Waveform group (number)[1] | Peak value $U_p$ or $I_p$ MV or kA | $T_1$ or $T_p$ | $T_2$ or $T_c$ | Amplitude, oscillation or overshoot, kHz, $\mu$s or % $U_p$ |
|---|---|---|---|---|
| LI (1, 6) | 1.04 ⇔ 1.06 | 0.81 ⇔ 0.87 | 57.5 ⇔ 62.5 | – |
| LIC (2, 7) | 0.86 ⇔ 0.88 | 0.49 ⇔ 0.53 | 0.55 ⇔ 0.59 | – |
| LIFO (11) | 0.94 ⇔ 0.96 | 1.07 ⇔ 1.19 | 82 ⇔ 91 | – |
| LICFO (12) | 0.84 ⇔ 0.87 | 0.48 ⇔ 0.54 | 0.51 ⇔ 0.56 | – |
| LILO (13) | −1.08 ⇔ −1.06 | 3.4 ⇔ 3.76 | 56 ⇔ 62 | $\tau > 1$ $\mu$s; $\beta > 5\%$[2] |
| LISO (14) | −0.97 ⇔ −0.95 | 1.85 ⇔ 2.05 | 43 ⇔ 47 | $\tau > 1$ $\mu$s; $\beta > 5\%$[2] |
| LISL (3, 8) | 1.04 ⇔ 1.06 | 1.6 ⇔ 1.7 | 45 ⇔ 49 | $f < 500$ kHz; $A \leq 5\%$ |
| LIFA (4, 9) | 0.96 ⇔ 0.99 | 1.0 ⇔ 1.1 | 48 ⇔ 52 | $f < 500$ kHz; $A > 5\%$[2] |
| SI (5, 10) | 0.94 ⇔ 0.96 | 240 ⇔ 260 | 2400 ⇔ 2600 | – |
| CI (5) | −10.1 ⇔ −9.9 | 8.3 ⇔ 9.2 | 20 ⇔ 22 | – |

[1] Numbers indicate the TDG reference test waveform

[2] Amplitudes of oscillations or overshoot are above the required limit of ± 5%; these impulses are therefore not standard impulses

signal to be recorded and normally requires no high performance of the digital recorder. The advantage of a digital recording system is the possibility to trigger the device depending on the event to be recorded. A transient overvoltage superimposed on an AC voltage can be recorded by triggering the digital recording device depending on the frequency or the amplitude, and the record includes the event as well as the history before the event.

### *18.4.2 Impulse voltage or current measurements*

The measurement of impulse voltage or current is the most important application for digital recording systems in the field of high voltage testing. The record of the impulse and the later evaluation of the impulse parameter can easily be done with the support of the digital recording system. The recording device which is in operation during the impulse generation is placed in a shielded cabin to prevent the influence of the electromagnetic field, generated by the discharge of the impulse capacitors. The recorded data can be shown with different time and amplitude scales to demonstrate details of the shape without any additional measurements. In Figure 18.3 a lightning impulse voltage is shown recorded with an 8-bit digital recorder at a sampling rate of $40 \times 10^6$ samples/s and with a record length of 4096 samples, equivalent to ~100 µs.

The same measurement is shown in Figure 18.4 but with another timescale to show the front of the measured impulse in detail.

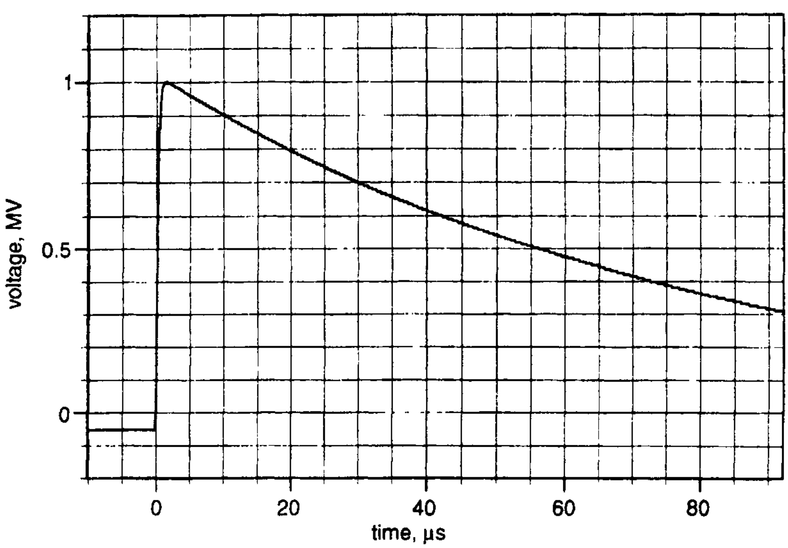


*Figure 18.3 Standard lightning impulse*

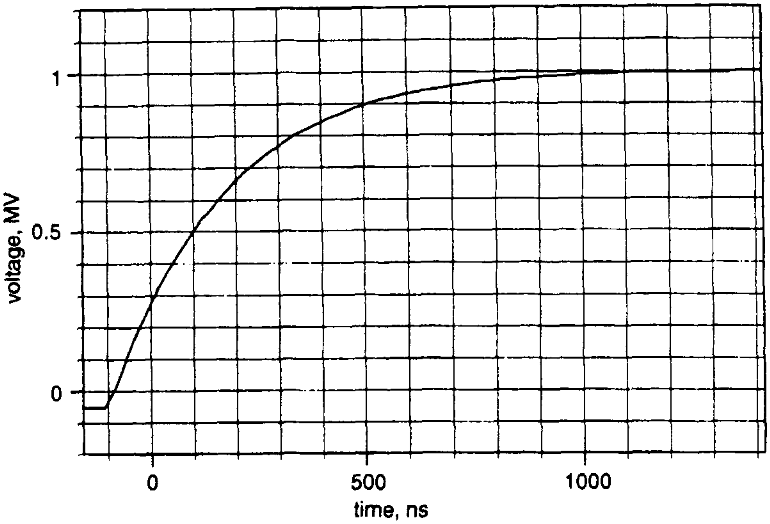


*Figure 18.4 Zoomed front part of the standard lightning impulse of Figure 18.3*

The limits are reached if the zooming goes above the limits of the recording parameters, which means for the impulse shown in Figure 18.4 a time resolution below 25 ns, which is the time between two consecutive samples.

The digital recorded data also allows a comparison between two impulses. The adaptation of the amplitude can be done by a simple multiplication of the amplitude values with a constant factor. The adaptation of the time can be done by shifting the complete data set in steps of the sampling time interval or even in parts of the sampling time interval. Figure 18.5 shows a comparison between two voltage impulses at 62.5% and 100% together with the current measured at the neutral point of the transformer. The difference between the two measurements of voltage and current is so small that only an enlargement of the difference between the two signals by a factor of 8 shows some small deviations at the triggering time.

Besides the comparison of two measurements a two channel digital recording system can be used for the calculation of the transfer function, which represents the ratio of the output signal to the input signal as function of the frequency, whereby the current is the output signal and the voltage the input signal. Figure 18.6 shows the transfer function of a transformer with a standard lightning impulse as the input signal.

### *18.4.3 Partial discharge measurements*

A digital recording system can also be used for partial discharge measurements. The monitoring of all pulses allows the determination of the

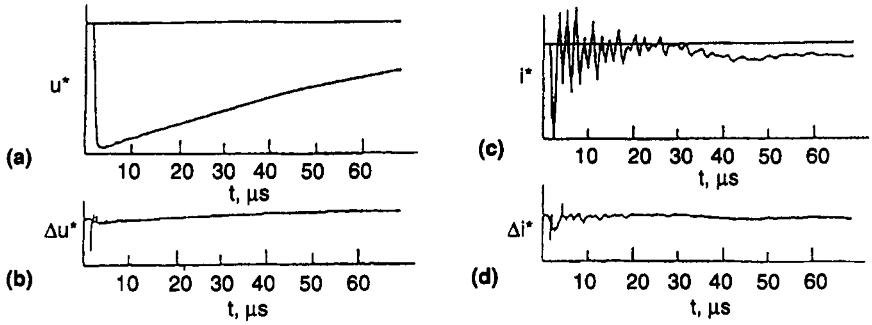


*Figure 18.5* *Comparison between two impulse voltage and current measurements*
*u*– measured voltages,*
*i*– measured currents,*
*Δu*– voltage difference between two impulses (zoom factor 8)*
*Δi*– current difference between two impulses (zoom factor 8)*

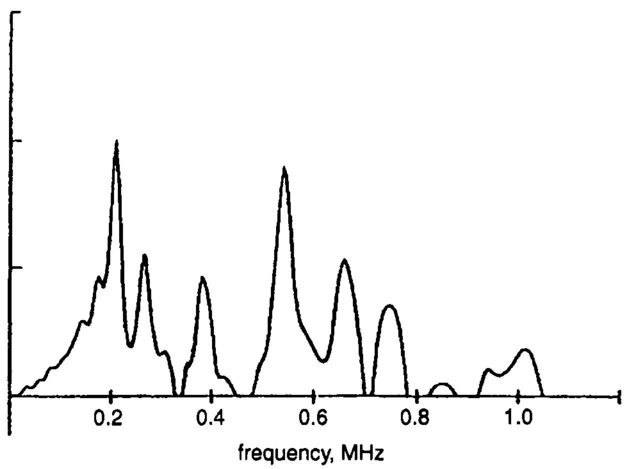


*Figure 18.6* *Transfer function of a transformer*

largest partial discharge impulse within a given time, the determination of the number of pulses per time, the determination of the apparent charge per pulse and the relation between the pulses and the phase of the applied power frequency voltage. A digital partial discharge measuring systems includes normally filtering procedures to exclude noise from the measured signal and to measure only within a small frequency range, if necessary. Figure 18.7 shows a measured signal, where in the upper figure (*a*) the partial discharges cannot be recognised due to the high noise level, and in the lower figure (*b*) after filtering of the sinusoidal noise.

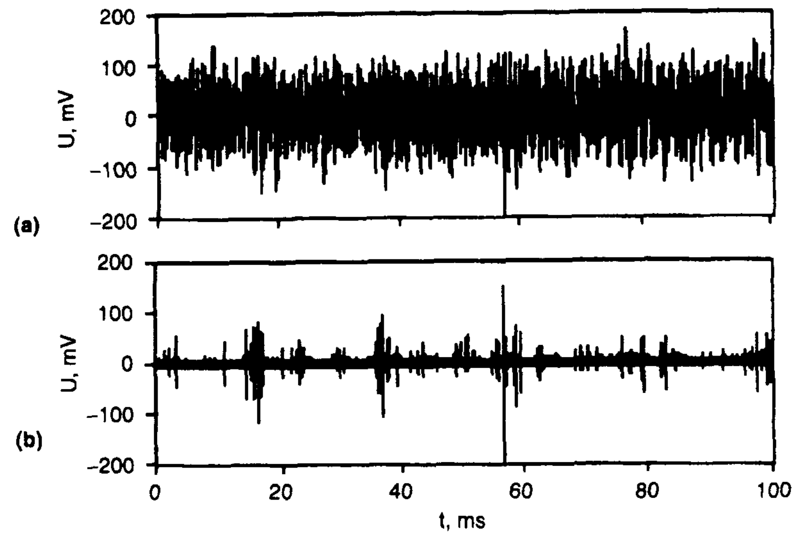


*Figure 18.7 Partial discharge measuring signal without* (**a**) *and with* (**b**) *filtering of sinusoidal noise*

The large impulse at ~60 ms is a calibration pulse of the measuring system.

Figure 18.8 shows in an enlarged timescale in the middle (*b*) and lower figure (*c*) the same signal shown in Figure 18.7*b* after filtering of the noise pulses which appear synchronous with the applied power frequency voltage. These procedures are only possible with digital recorded data due to the digital filtering for sinusoidal noise for Figure 18.7 and due to the comparison of signals recorded at the time phase angle for Figure 18.8, because all signals which appear at the same phase angle are declared as noise signals and are set to zero.

This procedure is based on the assumption that partial discharge signals occur randomly and never at the exactly the same phase angle in two consecutive cycles. The most critical type of noises are the impulses which occur randomly with more or less the same shape as the partial discharge signals. These signals can only be detected and removed by additional measures, e.g. by the detection of the signal travelling direction or by a bridge method. Therefore it is necessary to measure at least at two different places or with two circuits. An example of a measurement of partial discharges on a transformer is shown in Figure 18.9. The upper two signals (*a*, *b*) show the already filtered measuring signal of partial discharges measured via a capacitive coupling device $u_c$ and a so-called Rogowski coil $u_{Rog}$. The output voltage of a Rogowski coil is proportional to the derivative of the current signal and by an integration of this signal the output voltage is proportional to the apparent charge, which is similar to the capacitive

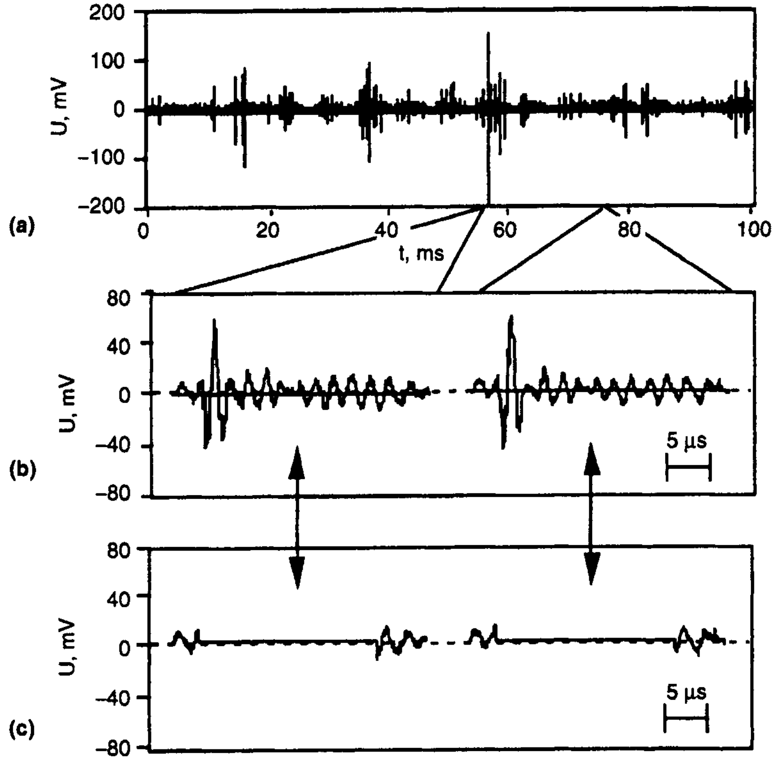


*Figure 18.8* *Partial discharge measuring signal after filtering of sinusoidal noise* **(a, b)** *and with additional filtering of synchronous noise* **(c)**

coupling method. Zooming of the two signals allows the detection of the signal direction, because signals generated by partial discharges outside the transformer pass the two measuring units in the same direction, whereas signals generated by partial discharges inside the transformer pass the measuring units in the opposite direction. The first signal in Figure 18.9*c*, *d* has a first positive peak for $u_c$ and at the same time a negative peak for $u_{Rog}$; the second signal has a first negative peak for both signals. Depending on the calibration of the measuring device one signal is a partial discharge outside the transformer and the other inside the transformer. With this method, discrimination between signals coming from outside the transformer and interpreted as noise and signals coming from inside the transformer and interpreted as partial discharges is possible.

The same procedure can be used when two more or less identical objects are available and the partial discharge measurement is done in a balanced circuit arrangement. Figure 18.10 shows such a circuit, given in Reference 8.

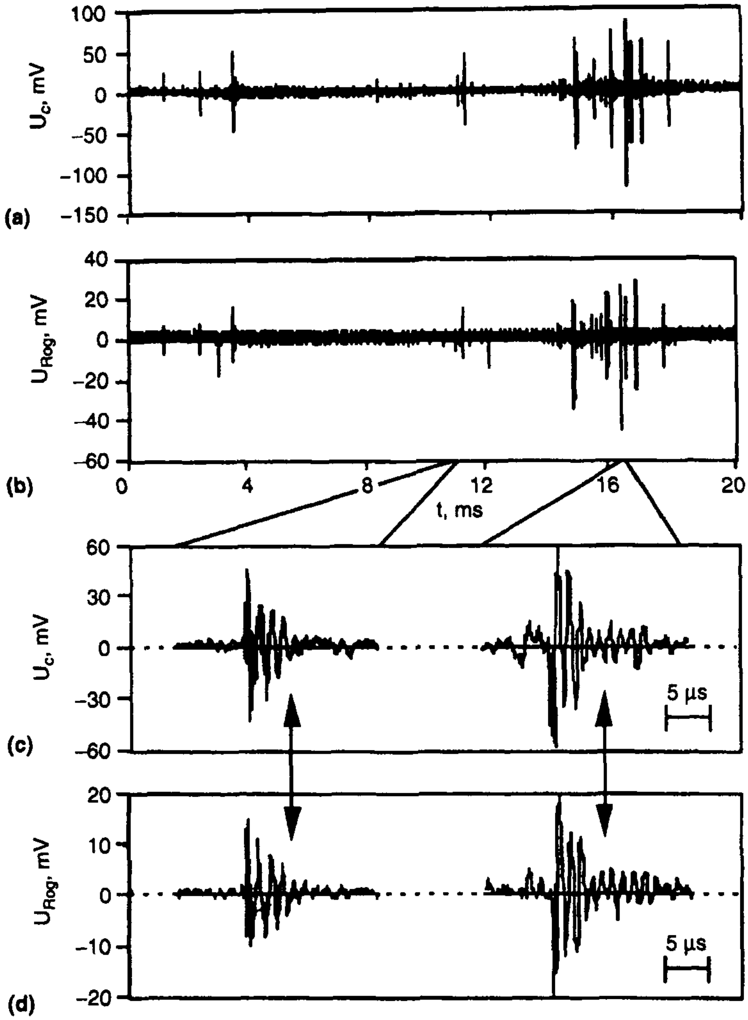


*Figure 18.9 Partial discharge measuring signal after filtering of sinusoidal and synchronous noise* **(a, b)** *and with additional filtering of impulse shaped noise* **(c, d)** *by detection of the signal direction*

## 18.5 Application examples of evaluation procedures

The digital recorded data can be evaluated by using a number of different procedures. In any case the raw data should be maintained and they are the basis for the evaluation of the performance of the digital recorder.

The impulse voltage or current measurements are the most interesting field of application of evaluation procedures in the high voltage test

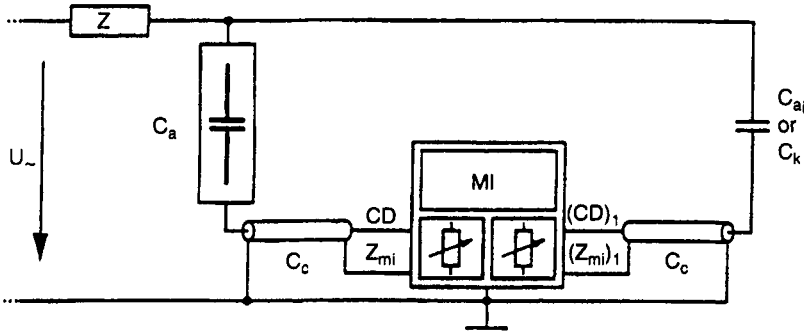


*Figure 18.10* *Balanced circuit arrangement for partial discharge measurements*
$U_{\sim}$ = *high voltage supply*
$Z_{mi}$ = *input impedance of measuring system*
$C_c$ = *connecting cables*
$C_a$ = *test object*
$C_k$ = *coupling capacitor*
*CD = coupling device*
*MI = measuring instrument*
*Z = high voltage filter*

technique. For smooth voltage impulses the evaluation of the front time and the time to half-value is simple, because the relevant values are given by the nearest sample to the relevant reference value. Figure 18.11 shows a simplified example for the evaluation of the 30% value.

The time at which the impulse voltage has reached the 30% value is given by sample no. 3 under the condition that the nearest sample has to be used. An interpolation between samples 2 and 3 gives a time value which is between the time value of samples 2 and 3, depending on the voltage levels of the two samples.

The evaluation is more difficult if the signal crosses the relevant level more than ones due to noise or oscillations. Figure 18.13 shows again a simplified example for a record superimposed by noise.

The interpolation between two samples will not solve the problems. One possibility is the calculation of the mean value between the last sample below and the first sample above the relevant voltage, which are in the example samples 1 and 3. Another method is the averaging of three consecutive samples. This leads to a signal shown in Figure 18.14.

The number of samples used for the averaging depends on the impulse shape and the frequency, which should be at least recorded, because with increasing numbers of samples the damping of the oscillations also increases. That means that the averaging is a kind of filtering.

The evaluation is more complicated if the impulse has oscillations in

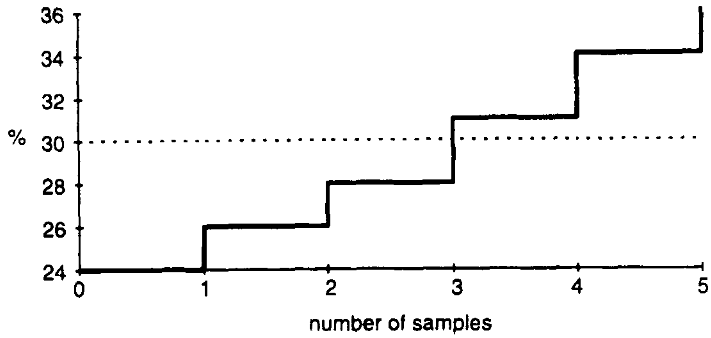


*Figure 18.11 Evaluation of the 30% value using the nearest sample*

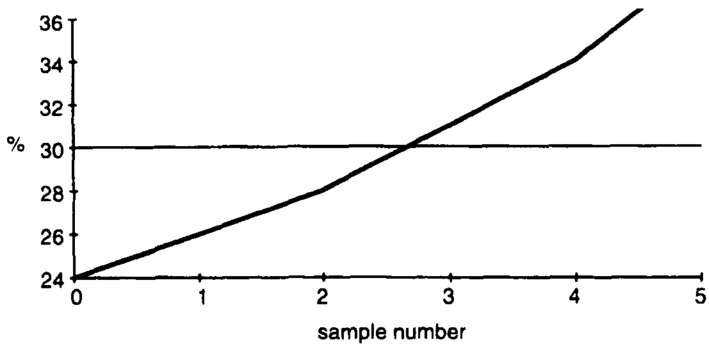


*Figure 18.12 Evaluation of the 30% value using an interpolation*

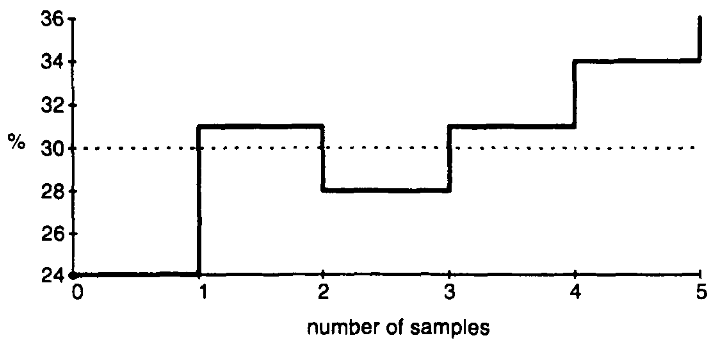


*Figure 18.13 Evaluation of the 30% value using the nearest sample*

the front or near the peak. Figure 18.15 shows the limits of oscillations in the front according to the relevant IEC Publ. 60060 [7]. It can be clearly seen that a mean curve is necessary, but a description by an equation is not given in the Standard.

If oscillations or overshoot exist near the peak, the evaluation of the

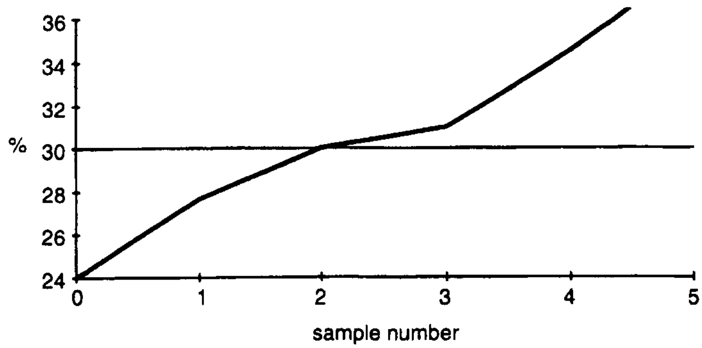


*Figure 18.14 Evaluation of the 30% value using an average method*

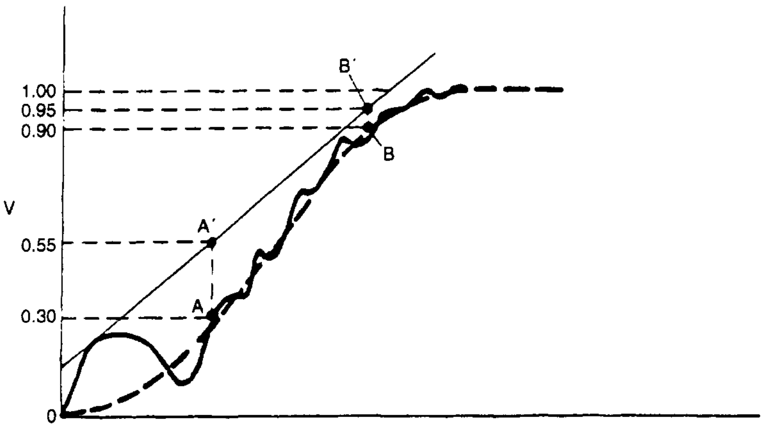


*Figure 18.15 Limits of oscillation in the front of a standard lightning impulse*

peak is also complicated according to the ambiguous definitions in the standard evaluation of the so-called mean curve, and the determination of its peak value is not clearly described in the relevant Standards and therefore a number of proposals exists and the research is still going on [9, 10]. Figure 18.16 shows an example of an overshoot, where the peak of the mean curve determines the test voltage according to the requirements in [7].

The proposed peak value of the mean curve is defined by the crossing point of the line representing the exponential shape of the tail and the perpendicular line at the highest recorded sample. This can be one solution for a definition of the mean curve peak value, because the extrapolation of the tail is very simple and this part is generally not disturbed by oscillations, and furthermore the highest recorded sample changes its position very little even under noisy conditions. With a little more mathematical effort other solutions are possible where the oscillations are

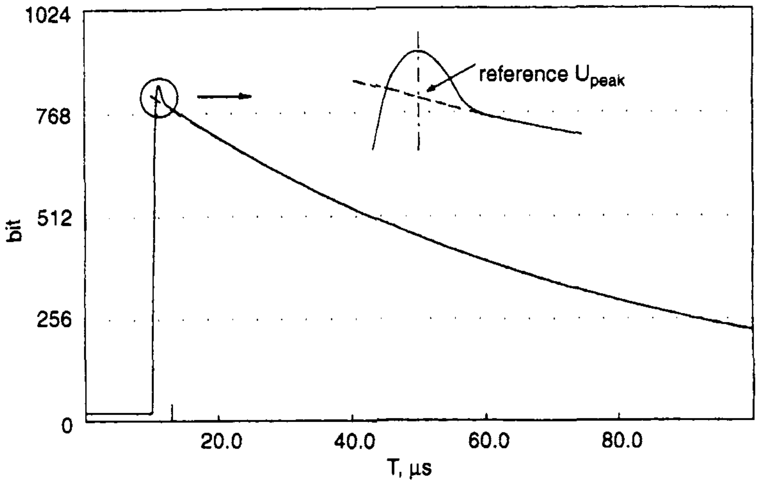


*Figure 18.16 Proposed determination of the peak value of the mean curve*

calculated and subtracted from the original curve to get the main more or less double exponential basic waveshape. This idea also leads to the test equipment used in Reference 9 for the determination of the most important parameters of the lightning impulse voltage.

This kind of evaluation, however, is not used within tests of transformer with lightning impulses. In this case the voltage stress of the insulation is given by the peak value of the applied voltage and by its derivative. In these cases the oscillations are less important concerning the peak value, and the highest recorded value is very often used as the test voltage. Figure 18.17 shows an example of a typical lightning impulse voltage on a power transformer.

The switching impulse voltage evaluation is less critical except the determination of the time to peak. The beginning of the impulse should be determined similar to the virtual beginning of a lightning impulse. The time to peak is determined according to the relevant standard [7] as the time difference between the beginning of the impulse and the highest recorded value. For digital recorded switching impulses a number of samples exist which have the same voltage level, and therefore this definition leads to different time to peak values depending on the evaluation procedure. Figure 18.18 shows a zoom of the peak area for a switching impulse.

It can be seen that the highest value takes place over a time range of some 10 µs and is already outside the tolerance of the time to peak. Therefore the calibration generator described in Reference 6 uses another evaluation procedure for switching impulses similar to the lightning impulses, but with a correction factor depending on the time to half-value given in eqn (18.4).

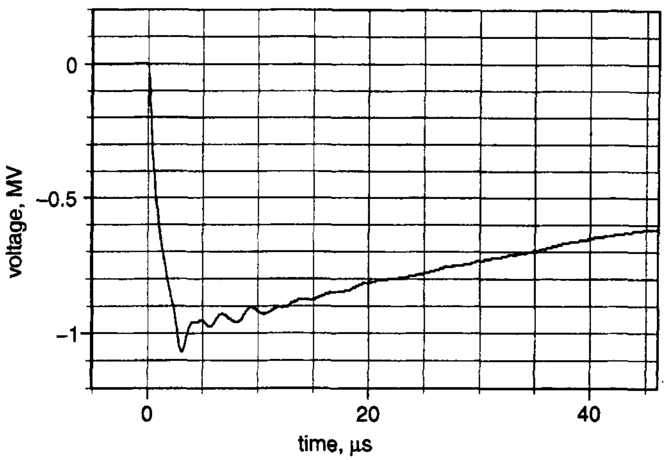


*Figure 18.17 Lightning impulse voltage on a power transformer*

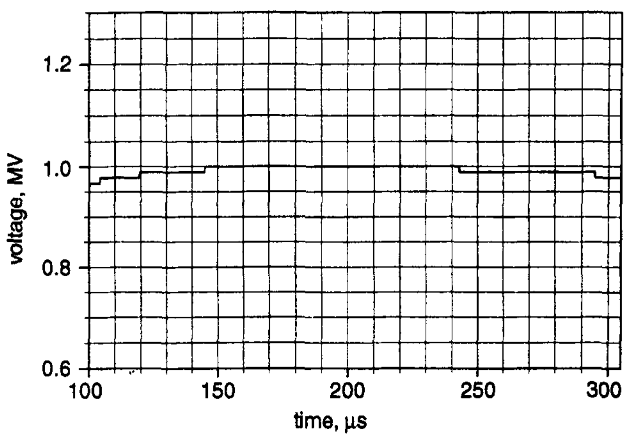


*Figure 18.18 Peak area of a switching impulse*

The evaluation procedures should take into account the performance of the digital recorder and the computer to get a reasonable result in an acceptable time. The weak definitions in the recommendations lead to a number of software solutions for the evaluation of lightning, switching and impulse voltages with all the described problems and differences in the result. Evaluation by an experienced engineer is still necessary for nonstandard impulse shapes, but the improvement of the recommendations and the mathematical evaluation procedures will contribute to the future unambiguous evaluation of all impulse waveshapes.

## 18.6 Summary

- The available digital recorders can be used for the high voltage impulse voltage or current measurements without any problems if the electromagnetic compatibility has been checked.
- The digital recording systems have large advantages in data acquisition and treatment for e.g. impulse or partial discharge measurements.
- The evaluation procedures for smooth impulses are simple, but for impulses with oscillations or overshoot the procedures suffer from the ambiguous definitions in the Standards based on analogue measuring techniques.

## 18.7 References


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