Chapter 15

Basic measuring techniques

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15.1 Introduction

The measurements of voltage and current in high voltage tests are difficult because the amplitudes are high and they cannot be measured directly with conventional measuring and recording systems. Furthermore, not only the peak value but also the shape of the signal, particularly for impulse voltage and current, should be measured and evaluated, and this requires an adequate recording system using either an oscilloscope or a digital recorder.

15.2 Measuring system

A high voltage or high current measuring system consists generally of a converting device, a transmission device and a recording device. An optimised measuring system has components which fulfil the required performance and are similar in their characteristics. The measuring system is as good as the weakest part of the system, and therefore it is not necessary to require an exceptional performance from any one of the components.

The converting device should reduce the amplitude of the signal to be measured to a value which is suitable for the transmission and recording device. The output signal of the converting device should be an exact replica of the input signal concerning the wave shape and the time parameters. This requirement is very strong in many cases and therefore the measurement error should be estimated and evaluated carefully.

In the measuring systems the converting device is usually the critical component due to its physical size and transfer behaviour. A simple and typical test to check the transfer behaviour is the measurement of the unit step response. Assuming the input voltage or current is an ideal unit step, the output signal is deformed by the converting device. Figure 15.1 shows a simplified output signal of a voltage divider [1].

The output signal can be described by the initial distortion time T_0, the partial response time T_α, the response time T, the settling time t_s and the overshoot β, whereby the time parameters represent a time-voltage area. The initial distortion time T_0 is the area between the true zero point 0 and the virtual zero point 0_1, which is deduced from the first part of the curve. The partial response time T_α is the area between the y-axis and the measured curve up to the first crossing point with the unit level. The response time T is the value of the sum of all areas, whereby the areas below the unit level are counted with a positive sign and the areas above with a negative sign. The response time T is given by the following equations:

$$T = T_\alpha - T_\beta + T_\gamma - T_\delta + \ldots \tag{15.1}$$

$$T = \int_0^\infty (1 - g(t))\, dt \tag{15.2}$$

with $g(t)$ as a function of the measured signal.

The settling time t_s is a definition of the time from which up to infinity the measured curve will not deviate from the unit level by more than 2% of the settling time. The mathematical interpretation is given in the following equation:

$$t_s = \int_{t_s}^\infty |(1 - g(t))\, dt| < 0.02\, t_s \tag{15.3}$$

Figure 15.2 shows clearly the requirement on the settling time.

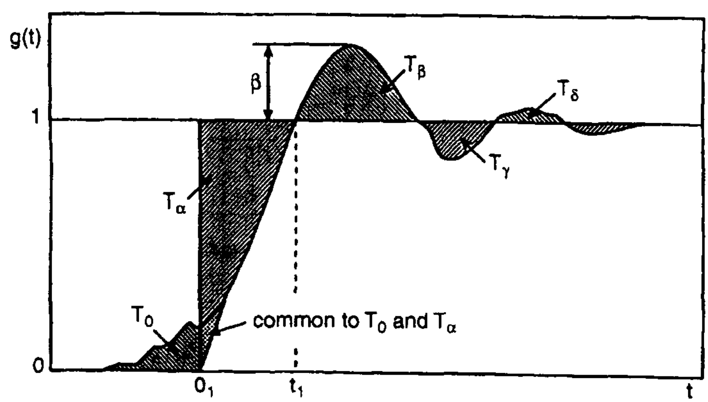

Figure 15.1 Output signal of a voltage divider with a unit step voltage input

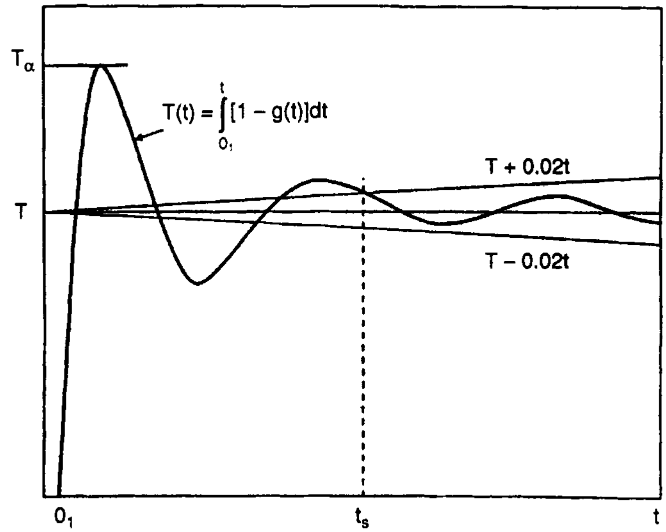

Figure 15.2 Settling time t_s as function of time

The overshoot β is the difference between the peak value of the area T_β and the unit level, related to the unit level and expressed in percentage. The partial response time T_α and the overshoot β are linked and therefore the overshoot as a function of the related partial response time T_α is shown in Figure 15.3, with T_α as time to be measured.

The ratio of the converting device can be determined by different methods like unit comparison measurements, step measurement, etc. Depending on the time or frequency range it is possible that two different ratio levels L exist for the converting device according to Figure 15.4. In the range of µs the ratio level is given by the value L_1 and in the range of ms by the value L_2. It is more convenient if the converting device has only one ratio level for all time or frequency ranges, but it is not necessary.

These parameters describe the transfer behaviour of the converting device and the values define the performance of the equipment. According to IEC Publ. 60060 [2] the following values are required for an approved measuring system. The scale factor shall be linear between the minimum and maximum value of the rated voltage determined by the extreme and three equidistant values within an average value of ± 1%. The scale factor shall be constant before and after the measuring period at full load conditions with a tolerance of ± 1%. Furthermore the scale factor shall not change by more than ± 1% between two consecutive checks. The influence of the temperature and the proximity shall be within ± 1%.

The measuring uncertainty for the peak value measurement shall be within ± 3% for DC, alternating voltage at power frequency, and full

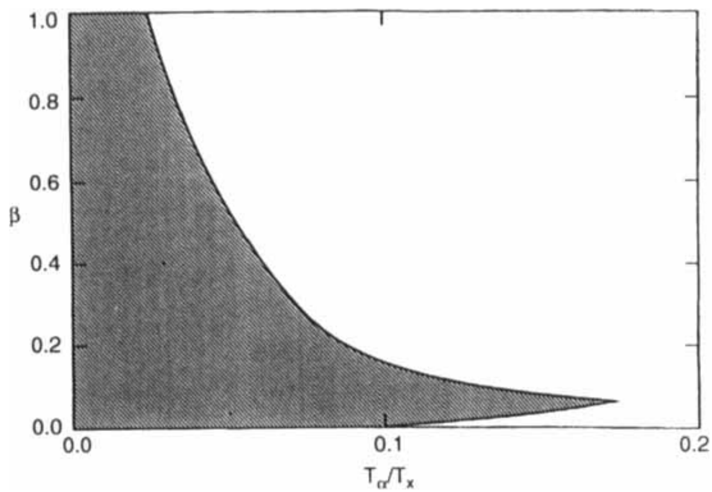

Figure 15.3 Overshoot β as function of the related partial response time T_α

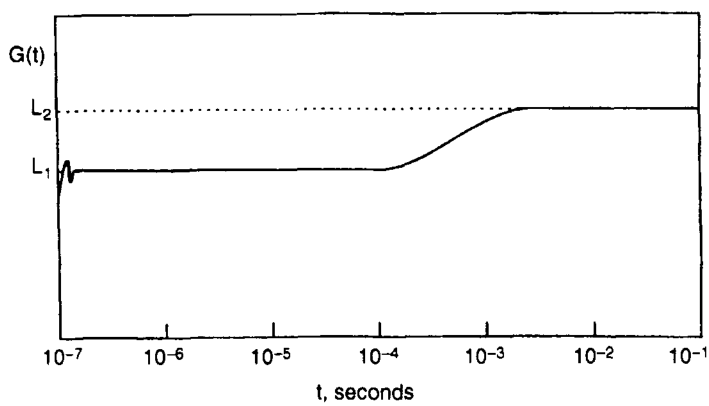

Figure 15.4 Ratio level L of a converting device for different time ranges

lightning and switching impulse voltages. For chopped lightning impulses the uncertainty for the peak value depends on the chopping time and it shall be within ± 3% for impulses chopped in the tail and ± 5% for impulses chopped at the front.

The measuring uncertainty for the time parameter shall be within ± 10% for lightning and switching impulses.

The same requirements are valid for impulse current approved measuring systems.

For a reference measuring system the uncertainty for the peak value measurements shall be within ± 1% for DC, alternating voltage at power frequency, and full and tail chopped lightning and switching impulse voltages. For front chopped lightning impulses the uncertainty for the peak value shall be within ± 3%. The uncertainty for the time parameter shall be within ± 5% for all impulses.

The same requirements are valid for an impulse current reference measuring system.

The requirements on the transformation ratio of a converting device are stability, independence of the frequency, linearity and very small uncertainty. An estimation of the total uncertainty is necessary and examples are given in IEC Publ. 60060 [3].

The transmission system is generally a coaxial cable, which does not influence the amplitude but in particular cases does influence the transfer behaviour of the system.

The recording device very often has an additional converting device on its input in order to reduce the amplitude again, but this converting device is small and normally has a sufficiently good transfer behaviour. The transformation characteristic is normally not critical but it should be checked and included in the evaluation of the whole system.

Depending on the parameter to be measured the recording device can be a simple peak voltmeter, an oscilloscope or a digital recording system. Because a digital system is characterised by its sampling rate, the bandwidth or sampling frequency can be used to evaluate the performance of the recording device. Figure 15.5 shows the amplitude spectrum of different components of a high voltage or current measuring system [4] as a function of the frequency.

It can clearly be seen that the shunt and the voltage divider have the worst transfer behaviour. Therefore these elements determine the transfer behaviour of the complete system. The oscilloscope as well as the digitisers can be neglected concerning its contribution to the transfer behaviour of the complete measuring system.

An important problem for all measuring systems, particularly at high voltage or high current, is the sensitivity to electromagnetic interferences. Some measures to prevent or suppress these disturbances are described here:

1. The most critical tests are impulse tests, where the impulse generation is at the same time a radiation source of an electromagnetic wave. This wave penetrates the whole system – the convertor, the transmission and the recording device – and not all components can be shielded. Therefore it is necessary to reduce the amplitude of the radiation and to increase the signal level to get a very high signal to noise ratio.
2. The voltages and currents flowing within the measuring cable are another source of electromagnetic interferences, because they can be induced by capacitive or inductive coupling or by loops of the

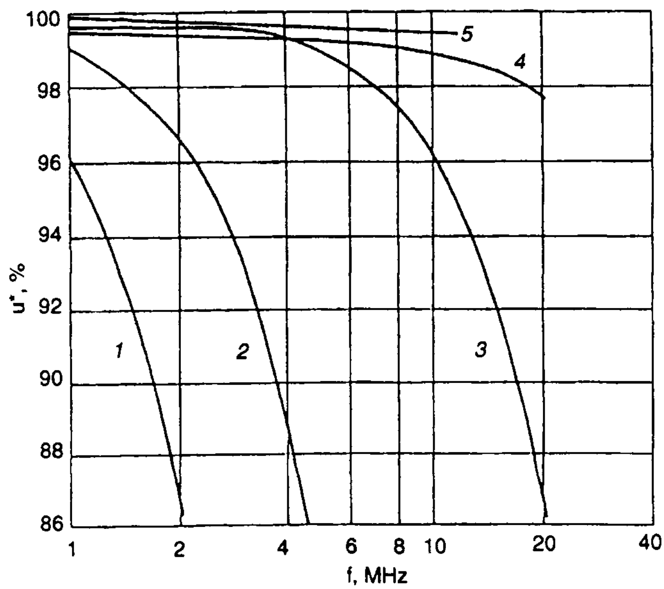

Figure 15.5 *Amplitude spectrum of measuring circuit components*
u = output voltage per unit, 1 = shunt, 2 = voltage divider, 3 = analogue oscilloscope, 4 = 8-bit digital recorder, 5 = 10-bit digital recorder*

measuring cable. The measures against these effects are a proper shielding or, in special cases, a double shielding of the measuring and control cables and the prevention of loops by a star connection of all measuring and control cables. Figure 15.6 shows an example of a bad cable connection and Figure 15.7 an example of a good cable connection for a simple impulse generator circuit.

There are some cases where a cable loop cannot be avoided. A typical example is the residual voltage measurement of a metal oxide arrester. In this case the high magnetic field induces in the loop – consisting of the test object, the divider connection, the voltage divider and the earth potential – a voltage which is superimposed on the residual voltage. Figure 15.8 shows the schematic diagram [5].

The earth connection of the divider cannot be changed for some reasons, and therefore a compensation of the magnetic field H by a suitable connection of the voltage divider is necessary, because the magnetic field induces a reasonable voltage in the residual voltage measuring loop. A simple check is the replacement of the surge arrester by a metallic tube with the same geometry and the application of an current impulse. In this case the measured residual voltage across the metallic

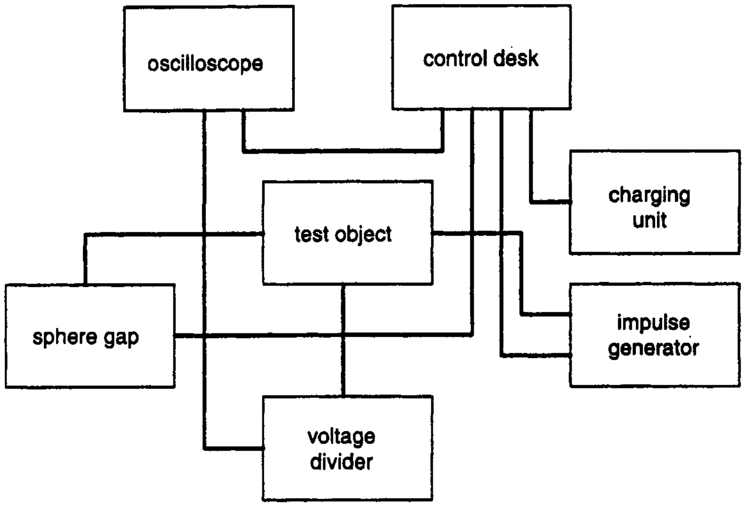

Figure 15.6 Bad cable connection of an impulse voltage set-up

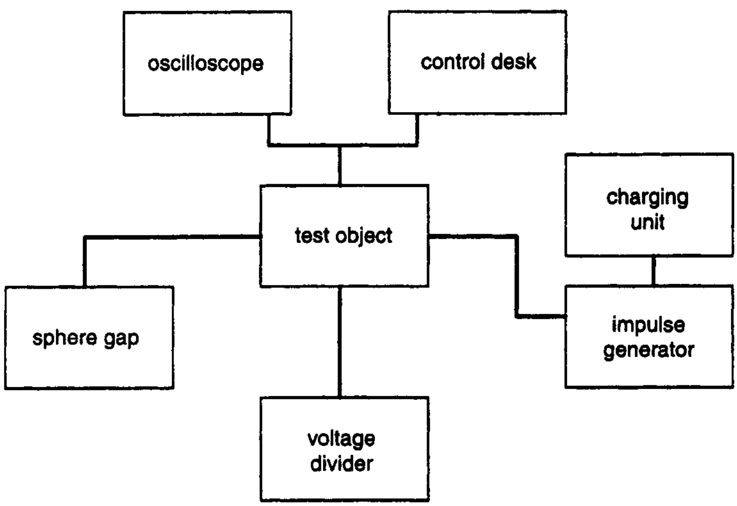

Figure 15.7 Good cable connection of an impulse voltage set-up

tube should be zero; if not, the measuring circuit is not sufficiently compensated against the induced voltage.

The measuring system should be designed according to the requirements of the measuring uncertainty concerning the transformation behaviour or amplitude measurement and the transfer behaviour or time parameter measurement.

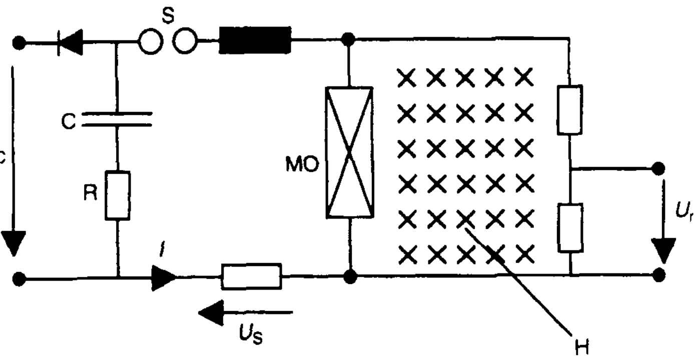

Figure 15.8 *Schematic diagram of a metal oxide residual voltage measuring circuit*
U_c = charging voltage of capacitor C, C = charging capacitor, R = damping resistor, S = spark gap, MO = metal oxide surge arrester, U_r = residual voltage across the surge arrester, U_s = voltage across the shunt, representing the current I, I = current through the surge arrester, H = magnetic field in the residual voltage measuring loop

15.3 Amplitude measurements

The amplitude of a supplied voltage or current is the main parameter of the high voltage or high current stress of the object to be tested, and therefore it should be measured and checked very carefully. Furthermore the amplitude will be changed very fast and adapted to the different test objects according to the requirements.

15.3.1 Direct voltage

The amplitude of a direct voltage can be measured with a high ohmic resistor. The current through the resistor is proportional to the voltage if it is assumed that the resistance of the measuring instrument is negligible. Figure 15.9 shows the equivalent circuit diagram.

The surge protective device SPD in parallel to the measuring instrument is very important, because in case of disconnection of the measuring cable or flashover of the high voltage resistor the full voltage will be applied to the measuring instrument and/or to the operator.

The high voltage resistor *R* consists normally of many elements which are connected in series. The whole chain can be fixed on an insulating tube to get a reasonable mechanical strength and a certain distance between high potential and ground. To prevent a large measuring error, the minimum required current through the high voltage resistor is 0.5 mA according to the IEC Publ. 60060 [2]. A resistance of the insulating

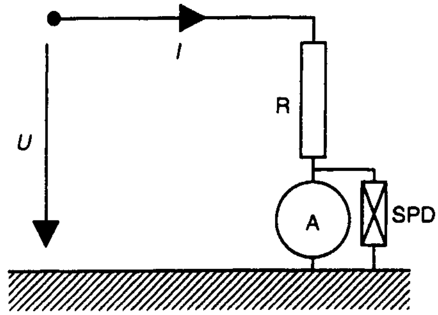

Figure 15.9 *DC measuring system*
U = DC voltage, I = DC current, R = high voltage resistor, SPD = surge protective device

material of $10^{12}\ \Omega$ leads to a current of 1 μA at a DC voltage of 1000 kV, which is only 0.2% of the total current.

Under normal conditions the voltage and temperature coefficients do not play an important role. For very small measuring uncertainties the temperature coefficient has to be taken into account because it has a greater influence than the voltage coefficient. Figure 15.10 shows an example of the relative resistance change as a function of the temperature for preselected sets of resistors [6].

The relative change of the total resistance is less than 0.05% in the temperature range between – 15 °C and + 50 °C, but such a small deviation can only be reached if the resistor elements are carefully selected, according to its temperature coefficient, and combined in such a way that the temperature coefficient for one stack of resistors fulfils the requirement. Each resistor element may have a larger coefficient than that allowed for the complete chain.

Another possibility to compensate the influence of the voltage and temperature coefficient is the use of a voltage divider, where the elements in the high voltage and low voltage arm are stressed under the same conditions. This type of voltage measuring device is commonly used in the high voltage measuring technique. The simplified equivalent circuit diagram is shown in Figure 15.11.

It should be noted that the measuring instrument needs a very high input impedance to prevent any influence on the transformation ratio.

The direct voltage normally has a certain ripple content. Depending on the measuring instrument the reading is the mean arithmetic value (moving-coil instrument) or the RMS values (static voltmeter). This means that the instantaneous value of the high voltage can be much higher than the measured mean arithmetic value as shown in Figure 15.12 depending on the instrument to be used.

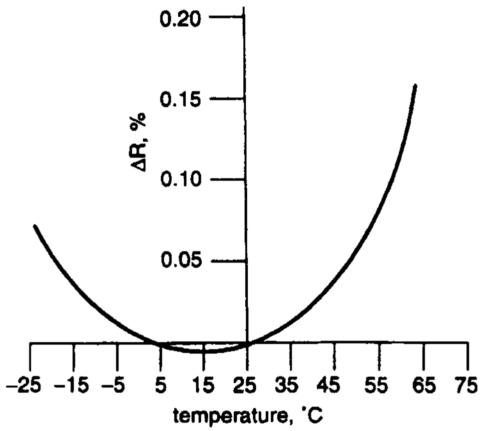

Figure 15.10 *Relative resistance change as function of the temperature*

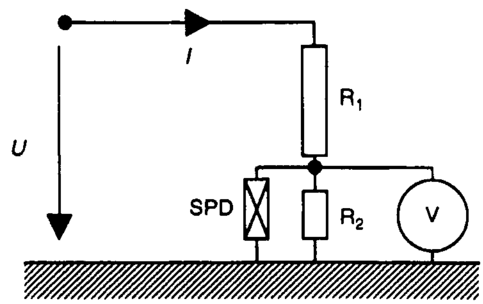

Figure 15.11 *DC voltage divider*
U = DC voltage, I = DC current, R_l = high voltage arm resistor, R_2 = low voltage arm resistor, SPD = surge protective device

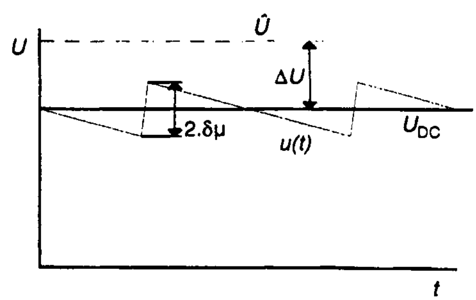

Figure 15.12 *DC voltage*
$\hat{U}$ = peak value of the AC supply voltage, U_{DC} = arithmetic mean value of the voltage $u(t)$, ΔU = difference between peak voltage and DC voltage, $2.\delta\mu$ = difference between highest and lowest value of $u(t)$

An important point is the voltage distribution in the case of fast transient voltages. The voltage distribution of a resistive divider, shown in Figure 15.11, is linear as long as the frequency is near zero, which means DC or very low frequency AC. As soon as the stray capacitances influence the voltage distribution, which is the case for voltage contents of higher frequencies, the linear voltage distribution is no longer valid.

In high voltage tests flashover cannot be prevented, and therefore the voltage divider should at least be protected against nonlinear voltage distribution. The measuring uncertainty may be much higher for fast transient voltages. Figure 15.13 shows the equivalent circuit diagram with stray capacitance and distributed resistor elements.

The ratio of the stray capacitances strongly influences the voltage distribution. Starting from a linear ideal voltage distribution for large parallel or low earth stray capacitances the voltage distribution becomes more and more nonlinear if the parallel stray capacitance decreases or the earth stray capacitance increases. This phenomenon should be taken into account by the design of the pure resistive voltage dividers.

15.3.2 Alternating voltage

A resistor or resistive divider can also be used for alternating voltage measurements if the loss power is not too high, but an additional error comes from the phase shift due to the influence of the capacitance and inductance. Therefore a capacitor instead of a resistor will normally be used for alternating voltage measurements. Figure15.14 shows the circuit diagram.

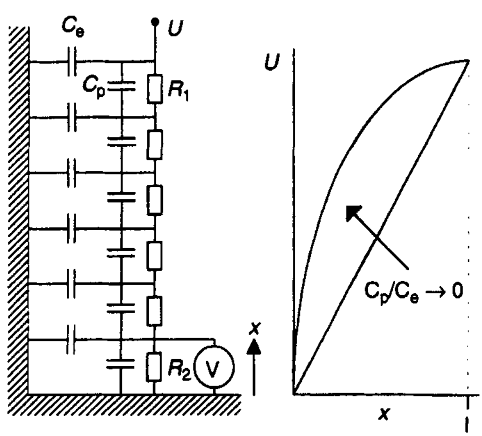

Figure 15.13 *Resistive divider with stray capacitors and voltage distribution*
U = DC voltage, R_1 = high voltage resistor, R_2 = low voltage arm resistor, C_p = parallel stray capacitance, C_e = earth stray capacitance, x = distance from earthed floor

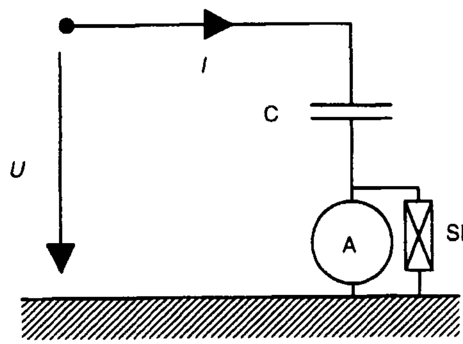

Figure 15.14 *AC measuring system*
U = AC voltage, I = AC current, C = high voltage capacitor, SPD = surge protective device

The high voltage U can be determined by measuring the current I according to the following equation:

$$I = U \omega C \tag{15.4}$$

with ω as the frequency of the measured voltage. Assuming that the measuring instrument indicates the RMS value, then the true RMS value of the voltage is given by the equation

$$U = \sqrt{U_1^2 + U_3^2 + U_5^2 + \ldots} \tag{15.5}$$

but the total current, driven by the harmonics, is higher than the current of the basic frequency, and this increases the uncertainty of the measurement. Therefore a capacitive voltage divider will normally be used for AC measurements, which is also not influenced by the temperature and voltage coefficient of the capacitor. Figure 15.15 shows the simplified equivalent circuit diagram.

The impedance of the measuring system should be as high as possible, similar to the resistive divider, in order not to influence the load and the frequency independent transformation ratio. The divider output voltage is given by the ratio of the capacitors according to the equation

$$U_2 = U \frac{C_1}{C_1 + C_2 + C_i} \tag{15.6}$$

with C_i as capacitance of the measuring instrument.

The dielectric strength of insulating material depends on the peak value of voltage, if the voltage stress is short. Therefore the recommendations normally require the peak value, which can be calculated from the

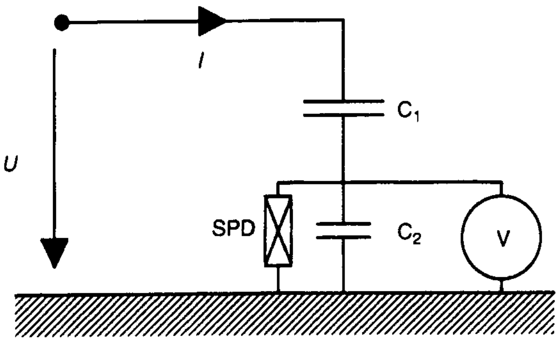

Figure 15.15 *AC voltage divider*
U = AC voltage, I = AC current, C_1 = high voltage arm capacitor, C_2 = low voltage arm capacitor, SPD = surge protective device

RMS by multiplication with the factor √2 if the wave shape is pure sinusoidal. In all other cases the evaluation of the peak value from the RMS measurement is not possible. Figure 15.16 shows therefore a measuring circuit for peak voltage measurement according to Chubb and Fortescue [7].

Assuming a symmetrical shape of the voltage and no harmonic content the current through the measuring instrument is given by the integral of the first half positive period representing the arithmetic mean value peak by the equation

$$i_m = \frac{1}{T}\int_0^{T/2} i(t)dt = \frac{1}{T}\int_0^{T/2} C\frac{du(t)}{du}\,dt = 2fC\,\hat{U} \tag{15.7}$$

From eqn (15.7) the relationship between the measured current and the peak value can be determined by the following equation:

$$\hat{U} = \frac{i_m}{2fC} \tag{15.8}$$

For this measuring circuit the frequency directly influences the measuring uncertainty, and therefore the measurement of the frequency is required in addition.

The peak value of a voltage can also be measured with a capacitive voltage divider according to the circuit diagram shown in Figure 15.17.

The measuring capacitor C_m will be charged up to the peak value of $u_2(t)$ and the measuring instrument shows the peak value of this voltage, which is only a part of the high voltage $u(t)$ given by the divider ratio. The series resistance of the diode D must be small in order to have a negligible voltage drop across the diode. There are three parameters

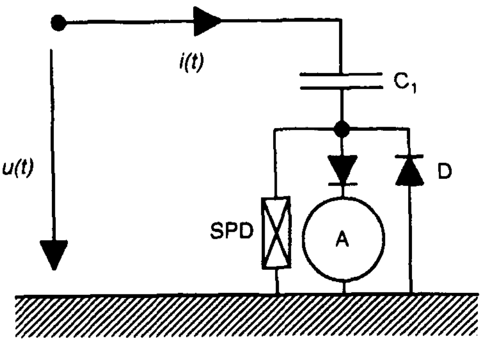

Figure 15.16 *AC peak value measuring circuit*
$u(t)$ = AC voltage, $i(t)$ = AC current, C_1 = high voltage arm capacitor, D = diode, SPD = surge protective device

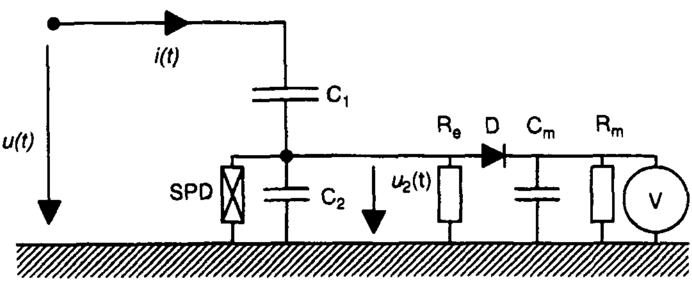

Figure 15.17 *AC peak value measuring circuit with a capacitive divider*
$u(t)$ = AC voltage, $i(t)$ = AC current, C_1 = high voltage arm capacitor, C_2 = low voltage arm capacitor, R_e = earthing resistor, D = diode, R_m = measuring resistor, C_m = measuring capacitor, SPD = surge protective device

which mainly influence the measuring uncertainty of this peak voltage measuring circuit. The resistor R_e influences the transformation ratio, the resistor R_m discharges the measuring capacitance C_m and the capacitor C_m is in parallel with the capacitor C_2 during the charging time, which changes the capacitive transformation ratio. The last two factors are in addition frequency dependent, but all these influences on the measuring uncertainty can be compensated.

Another possibility to measure the peak value is the use of an analogue digital convertor as a recording device. The evaluation of the recorded signal can be done by built-in computer or by a host computer. Furthermore the computer can make more calculations, e.g. fast Fourier transformation, and can evaluate the amplitudes of the relevant harmonics. With a 12-bit resolution of a commercially available digitiser, the measurement uncertainty of the recording device is negligible compared with the other components of the measuring system.

Finally the sphere gap is also a device for peak voltage measurements. A disadvantage is the relatively high number of tests, because in the tables of the IEC Publ. 60052 [8], the mean value of the disruptive breakdown voltage is noted. The measurement uncertainty is ± 3%, but the device is very simple and the gap can be checked with a simple scale.

15.3.3 Impulse voltage

The measurement of impulse voltages requires a system which has a known scale factor and adequate dynamic behaviour because not only the peak value but also the wave shape should be recorded and evaluated.

A resistive divider can be used for impulse measurements, if the resistance is low enough, that the transfer behaviour is not influenced by the stray capacitances. A good estimation of the time constant T of the unit step response of a resistive divider, which characterises the transfer behaviour, is given by the equation

$$T = \frac{R\, C_e}{6} \tag{15.9}$$

where C_e is the stray capacitance and R the resistance of the divider. From eqn (15.9) it can be deduced that the stray capacitance and the resistance should be as small as possible. Due to a low resistance of the measuring system, the wave shape of the impulse may be influenced in such a way, that no switching impulses can be measured with resistive dividers. Therefore resistive-capacitive dividers are often used for the measurement of impulse voltages. Figure 15.18 shows the schematic diagram.

If the time constants in the high voltage arm R_1 C_p and the low voltage arm R_2 C_p are identical, the divider is frequency independent, but the inductance of the high voltage lead and the capacitance of the divider builds up a series resonance circuit, which may cause oscillations.

To prevent these oscillations, in particular for high voltage dividers with large dimensions, a combination of resistors and capacitors in series is a very frequently used solution. The so-called damped capacitive divider is shown in Figure 15.19.

It is clear that the time constant R_1C_1 should be equal to R_2C_2 to make the divider frequency independent. Two types of damped capacitive dividers exist, depending on the value of the damping resistor, the optimum damped and the slightly damped divider. The total resistance R of an optimum damped divider can be estimated by the following equation:

$$R \approx 3 \ldots 4\sqrt{\frac{L}{C_e}} \tag{15.10}$$

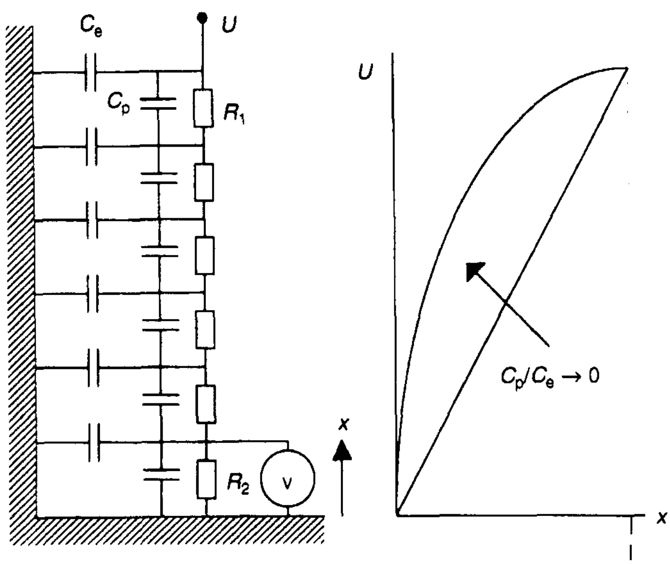

Figure 15.18 *Resistive capacitive voltage divider and voltage distribution*
U = input voltage, R_1 = high voltage resistor, R_2 = low voltage arm resistor, C_p = parallel stray capacitance, C_e = earth stray capacitance, x = distance from earthed floor.

and leads to a resistance of 400 . . . 800 Ω for a divider in the MV range, with L as inductance of the voltage dividers.

The slightly damped divider has a smaller resistance, which does not depend on the stray capacitance but only on the inductance of the measuring circuit. Therefore it is possible to remove the resistor in the secondary part [9]. The resistance for such a divider can be estimated according the equation

$$R \approx 0.2\sqrt{\frac{L}{C_l/n}} \qquad (15.11)$$

and leads to a resistance of 60 . . . 100 Ω for a divider in the MV range, with n as number of the elements C_l in the high voltage arm.

For impulse voltage measurements it is necessary that the measuring cable will be matched with its characteristic impedance. With an oscilloscope or a analogue digital convertor as the recording device the input impedance is very high if the cable is directly connected to the deflecting system or the input divider. Therefore the standard transmission system has the characteristic impedance at the beginning of the measuring cable. Figure 15.20 shows the equivalent circuit diagram for the low voltage side of a capacitive divider.

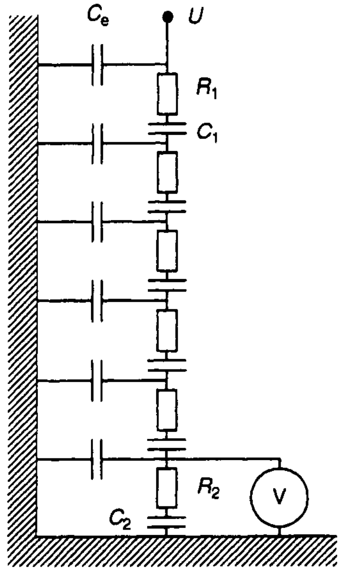

Figure 15.19 *Damped capacitive voltage divider*
U = DC voltage, R_1 = high voltage resistor, R_2 = low voltage arm resistor, C_1 = high voltage capacitor, C_2 = low voltage arm capacitor, C_e = earth stray capacitor

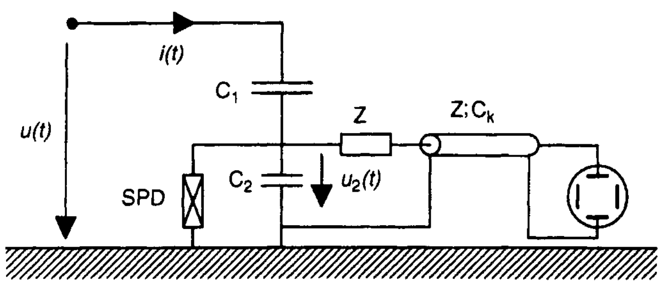

Figure 15.20 *Equivalent circuit of a capacitive divider*
$u(t)$ = impulse voltage, $i(t)$ = impulse current, $u_2(t)$ = impulse voltage across the low voltage capacitance, C_1 = high voltage arm capacitor, C_2 = low voltage arm capacitor, C_k = measuring cable capacitance, Z = characteristic impedance, SPD = surge protective device

The measuring signal $u_2(t)$ will be divided by the factor 2 due to the characteristic impedance Z and the characteristic impedance of the cable, which act as an additional voltage divider. The voltage will then be doubled at the end of the measuring cable, where the recording device is connected, because the cable is open at this side due to the high impedance of the recording device and the incoming wave will therefore be reflected. The wave travelling back has no reflection at the voltage divider side because the cable is matched with the impedance Z. For fast transients the transformation ratio is given by the equation

$$n = \frac{u(t)}{u_2(t)} = \frac{C_1 + C_2}{C_1} \tag{15.12}$$

After twice the travelling time of the signal through the measuring cable the ratio changes to

$$n = \frac{u(t)}{u_2(t)} = \frac{C_1 + C_2 + C_k}{C_1} \tag{15.13}$$

with the cable capacitance C_k.

Depending on the cable length the measuring error can be neglected or should be compensated. Figure 15.21 shows a compensated measuring circuit with a constant ratio for high and low frequencies with the requirement that

$$C_1 + C_2 = C_k + C_3 \tag{15.14}$$

The evaluation or measurement of the peak value can be done by an oscilloscope, a peak voltmeter or a digital recorder. The oscillogram evaluation permits a determination of the mean curve through oscillations, if necessary, according to the relevant recommendations. A peak voltmeter gives only the highest amplitude recorded, but this is in

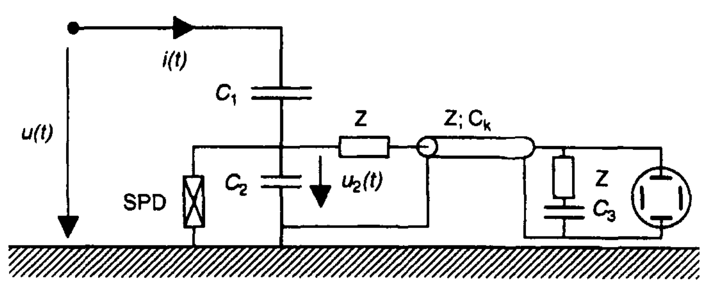

Figure 15.21 *Equivalent circuit of a capacitive divider with compensation*
$u(t)$ = impulse voltage, $i(t)$ = impulse current, $u_2(t)$ = impulse voltage across the low voltage capacitance, C_1 = high voltage arm capacitor, C_2 = low voltage arm capacitor, C_3 = compensation capacitor, C_k = measuring cable capacitance, Z = characteristic impedance, SPD = surge protective device

many cases sufficient, in particular if the wave shape is checked by an oscilloscope. With an analogue digital convertor as recording device the data can be evaluated, stored and treated depending on the need of the test.

15.3.4 Impulse current

The measurement of an impulse current can be done by the measurement of a voltage across a defined resistor, but it is very important that the influence of the high magnetic field is considered. Figure 15.22 shows a simplified measuring arrangement taking into account the voltage drop across a resistor or shunt and the voltage induced by the magnetic field of the current flowing through the shunt.

Figure 15.23 shows the single component of the measured signal.

It can be clearly seen that with increasing current an inductive part of the measured current is superimposed on the resistive part and this should be compensated by the design of the shunt or by other measures. Furthermore the power loss and the mechanical forces have to be taken into account for the proper design of a high impulse current shunt.

Another technique for impulse current measurement is the use of a so-called Rogowski coil. The measuring principle is very simple and based on the induction of a voltage in a winding with changing magnetic field. The voltage is proportional to the change of current and therefore integration is necessary to obtain the current, which can be achieved by an *RC* circuit. The advantage of the Rogowski coil is the potential-free measurement of the current due to its separation from the ground.

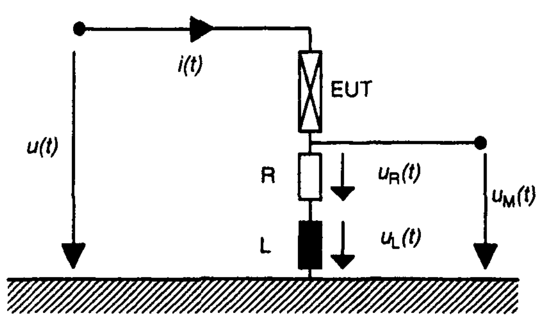

Figure 15.22 Impulse current measurement with a shunt
$u(t)$ = impulse voltage, $i(t)$ = impulse current, R = shunt resistor, L = shunt inductance, $u_M(t)$ = measured impulse voltage representing impulse current, $u_R(t)$ = resistive part of measured impulse current, $u_L(t)$ = inductive part of measured impulse current, EUT = equipment under test

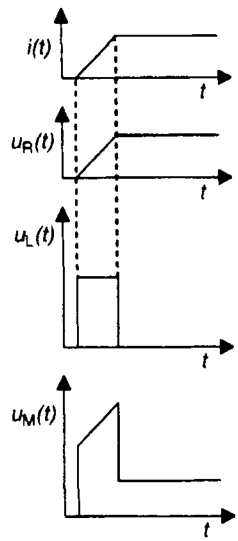

Figure 15.23 *Shape of the measured impulse current and voltages*
$i(t)$ = impulse current, $u_R(t)$ = resistive part of measured impulse current, $u_L(t)$ = inductive part of measured impulse current, $u_M(t)$ = measured impulse voltage representing impulse current

15.4 Time parameters

The measurement of time parameters is mainly limited to impulse measurement. It is necessary to record the shape of the impulse and then to evaluate the required parameter. The evaluation method depends on the recording device. With an oscilloscope as recording device the evaluation can be done only manually using an oscillogram. With an analogue/digital convertor the evaluation can be carried out automatically by a computer. The requirements are defined in the IEC Publ. 61083 [10] for the analogue/digital convertor as well as for the evaluation software. Problems exist for both type of recording device in the evaluation of impulses with oscillations or overshoot near the peak of the impulse. Intensive research work is going on to solve these problems and to find solutions for an automatic evaluation of the impulses even for nonstandard wave shapes [11].

15.5 Measuring purposes

The measurement has two main reasons:

(i) a check on the applied voltage and current to ensure that the

required voltage and current waveform and amplitude have been applied
(ii) a decision on the test results for compliance with a test requirement.

15.5.1 Dielectric tests

A dielectric test consists of applying a voltage up to a certain level and proving that no partial discharges or flashover occur. The measurement during these tests confirms the required waveform and amplitude. In addition the test criterion – flashover or no flashover – will be recorded at the same time, but for that the measuring system is not necessary in any case. For chopped impulse the record of the impulse should show the applied waveshape and the time to chopping, which are determined within certain limits in the relevant recommendations. A switching impulse on a transformer is also determined by the test object itself and the test prehistory. Therefore the measurement should not only detect a flashover but also record the waveshape for the evaluation of the different time parameters.

15.5.2 Linearity tests

Besides pure dielectric tests, linearity tests will also be carried out, in particular on transformers. The reason for such tests is to check the linear behaviour of the test object. The transformer will be stressed first with 50% of the voltage, later with 100%, and the neutral current will be measured. The test will be judged as successful if the comparison between the current and voltage of 50% and 100% levels shows no differences. The result of these measurements can also be the basis for a monitoring or diagnostic procedure. The digital recorded data can be used for further evaluation and improvement of the diagnostic.

15.6 Conclusions

1. The performance of a measuring system is given by the weakest part of the measuring system chain.
2. The transformation ratio as well as the transfer behaviour of the complete measuring system should be sufficient for the requirements on the signal to be measured.
3. All factors concerning the stability, reproducibility and uncertainty of the measuring system should be taken into account by a so-called uncertainty budget.
4. Depending on the signal to be measured the recording device should be selected.

5. Even for measurements at DC or low frequencies the behaviour of the measuring system under transient stress should be considered at least for safety reasons.

15.7 References

1 'Impulse voltage dividers', Bulletin E 142 (E. Haefely & Cie. Ltd., Basel, Switzerland)

2 IEC Publication 60060. 'High voltage testing techniques. Part 2: Measuring systems', 1994

3 IEC Publication 60060. 'High voltage testing techniques. Part 2, Amendment 1: Procedure for estimating uncertainty in high-voltage measurements', 1996

4 MALEWSKI, R. and GOCKENBACH, E.: 'Neue Möglichkeiten der Beurteilung von Stoßspannungsprüfungen an Transformatoren durch Einsatz eines digitalen Meßsystems', *ETZ Arch.* 1989, **11**, pp. 179–185

5 MODRUSAN, M. and GOCKENBACH E.: 'Eine kombinierte Prüfanlage für die Arbeitsprüfung von Metalloxidableitern'. 19th Int. Blitzschutzkonferenz (ICLP), 1988, Paper 6. 10

6 GOCKENBACH E. *et al.*: 'DC voltage divider with high precision for HVDC transmission'. 4th Int. Conf. on AC and DC power transmission, London, 1985, IEE Conf. Publ. 255, pp. 223–228

7 SCHWAB A.: 'Hochspannungsmeßtechnik', Chap. 3.4.1, (Springer Verlag, Berlin, 1981)

8 IEC Publication 60052. 'Recommendations for voltage measurements by means of sphere gaps (one sphere earthed)', 1960

9 FESER, K.: 'Heutiger Stand der Messung hoher Stoβspannungen'. PTB Seminar 1982, Physikalisch-technische Bundesanstalt, Braunschweig

10 IEC Publication 61083. 'Digital recorder for measurements in high-voltage impulse tests. Part 1: Requirements for digital recorders', 1991

11 BENDA-BERLIJN, S. *et al.*: 'Today's problem with the evaluation methods of lightning impulse parameters described in IEC 60060–1'. 11th Int. symposium on *High voltage engineering*, London, 1999