A DEVICE FOR CORRECT MEASUREMENT OF THE RESIDUAL VOLTAGE OF LOW VOLTAGE SURGE ARRESTERS AND SPARK GAPS DURING THE APPLICATION OF HIGH RATE OF RISE CURRENT IMPULSES

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Abstract

A new differential voltage divider is presented which is designed to measure correctly the residual voltage in the hostile environment of high rate of rise impulse currents. A numerical simulation analyses the problem. A solution is presented. The design and some applications of measurements on gapped surge arresters as well as on metal oxide surge arresters are shown. Further work is necessesary to standardise a procedure for such measurements.

Introduction

Surge protection devices (SDP's) as metal oxide surge arresters, gas filled spark gaps and lightning impulse current spark gaps are applied in a wide range of applications. The major parameter for the insulation coordination of e.g. low voltage distribution systems or low voltage installations in buildings is the residual voltage of the SPD. The residual voltage can be measured in a laboratory when a surge current, e. g. 8/20 µs is injected into the SPD. The correct measurement of the residual voltage in a laboratory is influenced by the effect of the magnetic field during the flow of the surge current. Due to the high rate of rise of the surge current a disturbance voltage is induced in the measuring loop. In this contribution a device for correct measurement will be shown which compensates the disturbance voltage using a differential voltage divider.

1 Modelling of a surge generator and the measuring circuit

Fig 1 shows the principal arrangement for the measurement of the residual voltage of an SPD. Fig. 2 shows the equivalent circuit. The surge generator e.g. for 8/20 µs impulses generates the surge current. A surge arrester is connected to the generator using a wire and creates an unavoidable loop. This loop (Loop1 in Fig.1) is represented by the shaded area. Since the residual voltage can be easily some 10 kV for medium voltage surge arresters, normally a voltage divider is used for voltage measurement. Due to the geometry of the voltage divider an unavoidable connecting loop (Loop 2 in Fig.1) has to be taken into consideration. The magnetic field with high rate of rise penetrates Loop 1 as well as Loop 2. In Loop 2 an induced voltage **u(t)** will occur and adds to the actual voltage at the terminals of the arrester $\mathbf{u_A(t)}$. Therefore the divider measures $\mathbf{u_M(t)}$ which is the sum of both.

$$u(t) = L_{Loop2} \frac{d\ i(t)}{d\ t} \tag{1}$$

$$u_M(t) = L_{Loop2} \frac{d\ i(t)}{d\ t} + u_A(t) \tag{2}$$

The measured voltage is now depending on the derivative of the current. Using a computer programme the equivalent circuit in Fig.2 can be analysed including the complete characteristic of a commercial available surge arrester Type SIOV B40K385. The result is shown in Fig.3. The inductance of the measuring Loop 2 is 150nH. There is a remarkable difference between the actual voltage at the arrester and the voltage measured at the terminals of the divider. Note that the transient behaviour of the divider is not taken into consideration in the numeric simulation. When the switch (Fig.2) is closed there is a high frequency current oscillation (compare Fig.3) caused by the stray capacitance C2 of the inductance of the surge generator and the capacitance of the arrester. The capacitance of the arrester is build in the model which is provided by the manufacturer. Therefore an high frequency voltage oscillation occurs in the first few ns of the residual voltage. The simulation can be compared with a real measurement as shown in Fig.6,7.

One can easily conclude that the difference between the measured and the real voltage of an SPD increases with decreasing residual voltage. When measuring the residual voltage e.g. of a spark gap with a voltage drop of a few 10 Volts the conventional measurement as shown in Fig.1,2 is not meaningful.It is questionable what the residual voltage of an surge arrester really is. Should a laboratory provide a correct measurement? Or should a laboratory measure the residual voltage using a defined Loop 2? The Standards do not give a clear procedure. The intention of this work was the development of a measuring device for correct measurement of the residual voltage of any SPD.

2 Development of a differential voltage divider.

Table 1 summarises the values of several arresters when tested in a laboratory. It is a wide range of

	Gapped Surge Arrester	Low Voltage Metal Oxide Surge Aarrester	Medium High Voltage Metal Oxide Surge Aarrester
Wave Shape	8/20µs 10/350µs	8/20µs 10/350µs	4/10µs 1/5µs
Peak Current	100 kA	100kA Not standardised	100kA 20kA
Residual Voltage	Some 10 V up to some kV	Some 100 V up to some kV	Some 10 kV

The requirements for a differential voltage divider can be derived from the results of the simulation. The induced voltage has to be compensated. Furthermore the magnetic coupling into the divider itself has to be reduced by magnetic screening of the divider. A well screened measuring cable with low transfer impedance has to be used.
The principle design is shown in Fig.4. The equivalent circuit is shown in Fig.5. The differential divider measures the voltage at the terminal of the arrester in the conventional way. To compensate the induced voltage, a second identical divider with a shorted compensation loop is placed next to the first divider. Both signals of the dividers are send to the differential amplifier. The induced voltage in the compensation loop is adjustable using an instrument amplifier.

The principle of measurement is as follows:

1. The arrester under test will be replaced by a short circuit of the same geometry of the arrester, preferably a metal disc. The voltages will be measured at the same surge current as the arrester will be tested. The voltage has to be compensated to zero.
2. The arrester has to be connected at the same position as the short circuit in Step 1. The residual voltage can be measured correctly.

3 Application during residual voltage measurements on arresters.

Fig. 6 shows the measurement of the residual voltage across a gapped surge arrester. There is a remarkable difference between the conventional measurement in Fig. 6a and the measurement using the differential divider in Fig. 6d.
Fig. 7 shows the measured residual voltage across a metal oxide surge arrester SIOV-B40K385 as used in the numerical simulation, compare Fig.3.
Table 2 Results of measurements

	Maximum of the residual Voltage	Current Peak
Conventional measurement	1,425 kV	18,8 kA
Compensated measurement	1,118 kV	18.8 kA
Relative failure	$F = \frac{1{,}425 - 1{,}118}{1{,}118} * 100 \quad \% = 26 \quad \%$	
Calculated using Siemens Data from CD	1,64 kV	18,8 kA

Fig 7a shows the conventional measurement. Fig 7b shows the compensated measurement. In Fig.7d the arrester is bridged using a short to demonstrate the effectiveness of the compensation. In Fig. 7c the arrester is also bridged using a short to demonstrate the value of the induced voltage without compensation, which is app. 500 Volts. The charging voltage was maintained on a constant level in all experiments, Fig. 7a—c. Therefore the current is increased to app. 20 kA in case of a short.

4 Conclusion

From the results of measurements it can be concluded that the conventional measurement of the residual voltage of surge arresters can vary from laboratory to laboratory due to non standardised measuring procedure. The relative failure can be several 10%. This may lead to controversery discussions e.g. during type or acceptance tests. The proposed measuring technique and procedure avoids such failures. Using this approach the accuracy of the insulation coordination in low voltage installations can be performed with higher precision.

Bibliography
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Adress of Author: Prof. Dr.-Ing. Jan Meppelink. BET Blitzschutz &EMV Technologiezentrum GmbH.

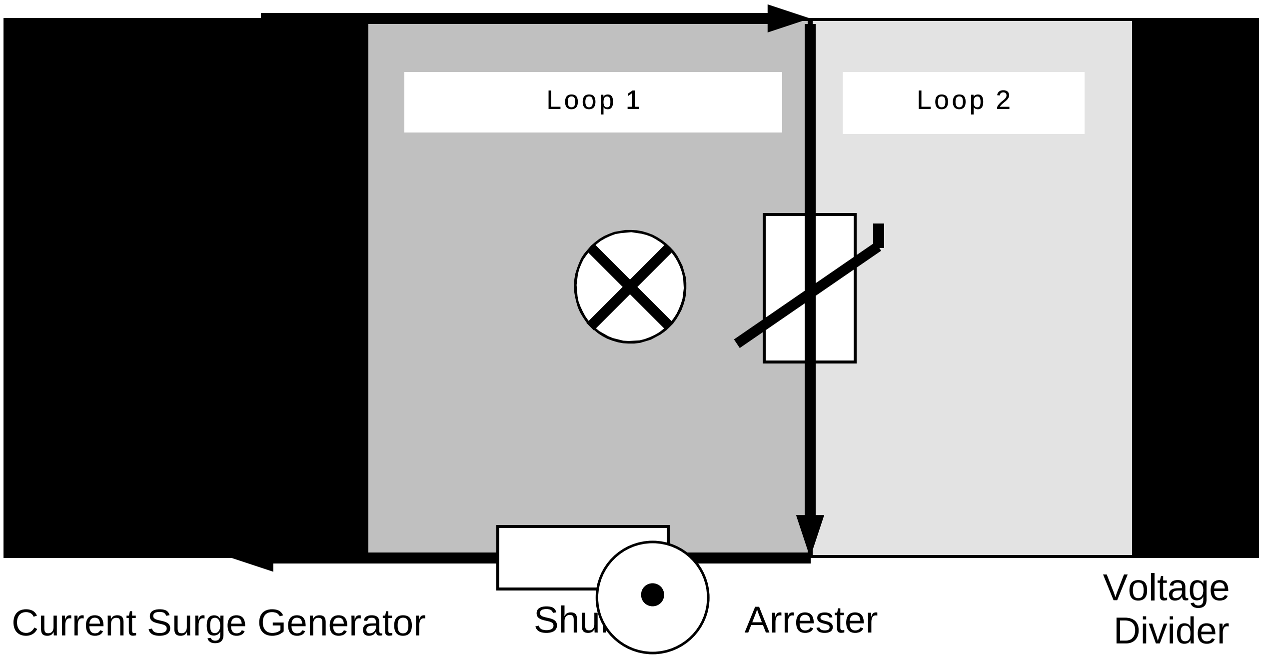


Fig.1 Principal arrangement for the measurement of the residual voltage of an SPD. Loop 1 represents the connection of the surge generator to the surge arrester. Loop 2 represents the connection of a conventional voltage divider to the surge arrester.

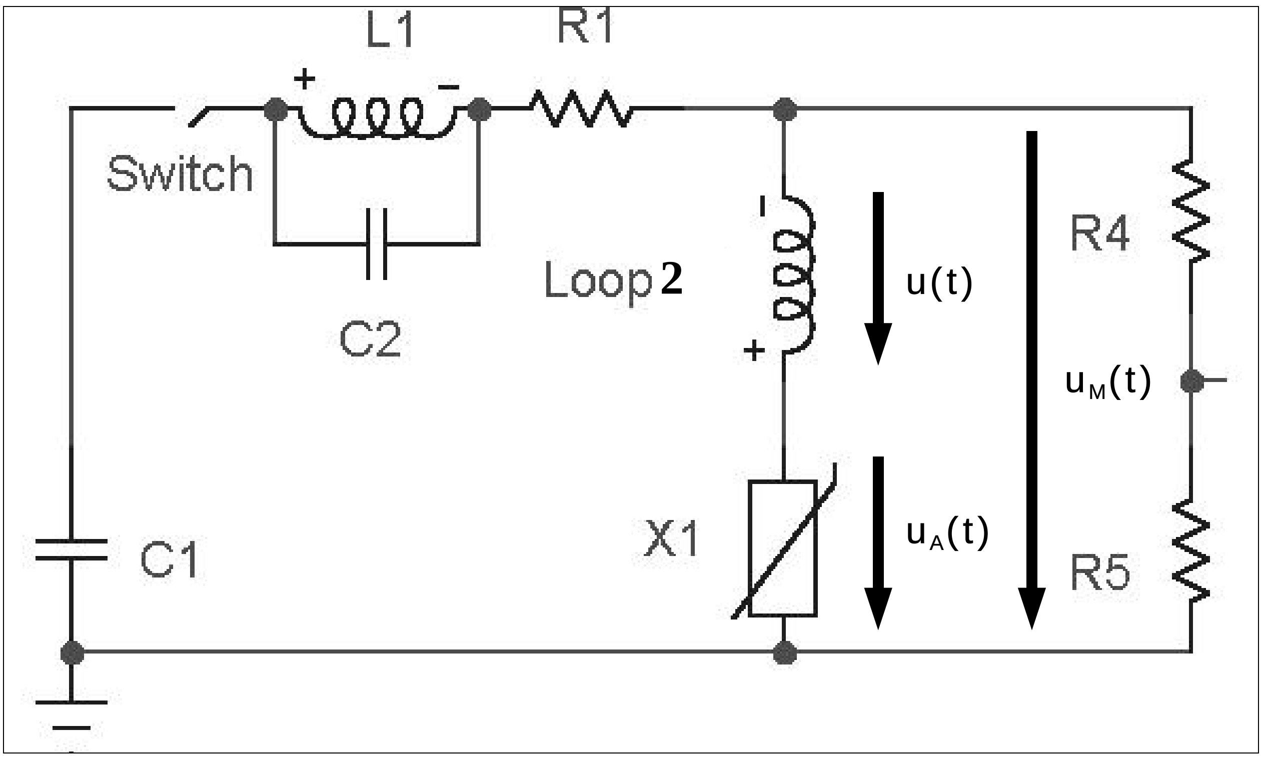


Fig 2 Equivalent circuit of the arrangement in Fig.1.
Values for numeric simulation: C1=2µF Charging Voltage: 66 kV, L1=26,5µH, C2=20pF Stray capacitance of the inductance L1, R1=3,63Ohm, Loop2=150nH repesents the inductance of the measuring circuit Loop2 which is penetrated by the magnetic flux from Loop1, R4=200Ohm, R5=2Ohm. Surge arrester Type SIOV-B40K385.

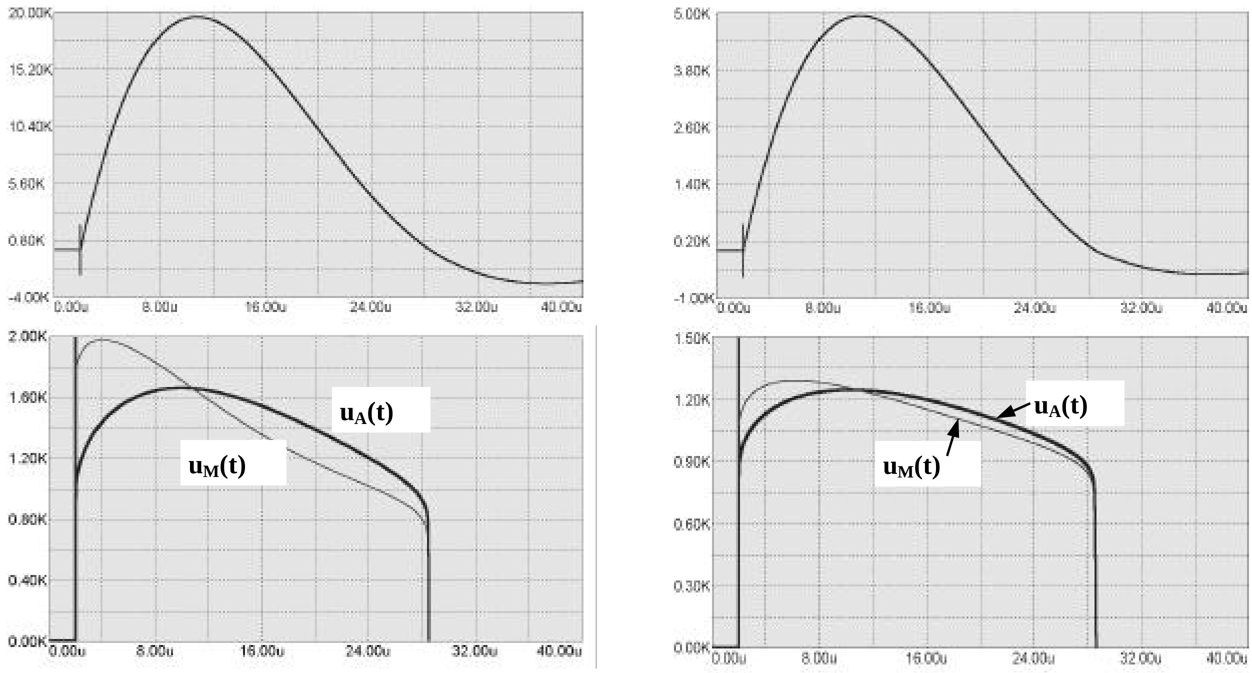


Fig.3 : Result of numerical simulation of the equivalent circuit as shown in Fig.2. (SIOV-B40K385)
Left: Current 8/20 µs , Peak 18.8 kA. Residual Voltage $\mathbf{u_A(t)}$ Peak:1,64 kV.
Right: Current 8/20 µs, Peak app.5 kA. Rsidual Voltage $\mathbf{u_A(t)}$ Peak: 1,25 kV.
Bottom: Voltage at the terminals of the arrester $\mathbf{u_A(t)}$ and the voltage at the terminals of the voltage divider $\mathbf{u_M(t)}$.

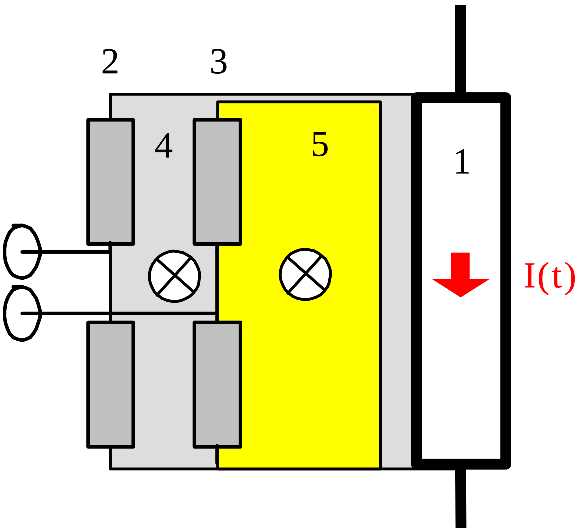


Fig.4 Principle of a differential voltage divider
1: Surge arrester or gapped arrester under test
2: High voltage divider, connected via the indicated area 4 to the surge arrester, measures the voltage at the terminals of the arrester.
3: High voltage divider connected to a loop which consists of the area 5.
Area 4 and 5 are penetraded by the magnetic flux originated from the current in the surge arrester.

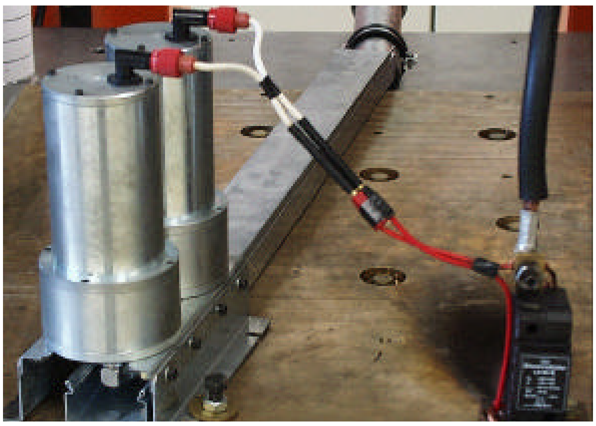


Photo 1 View of the screened high voltage dividers.

Photo 2 View of the secondary unit containing the amplifier and adjacent equipment

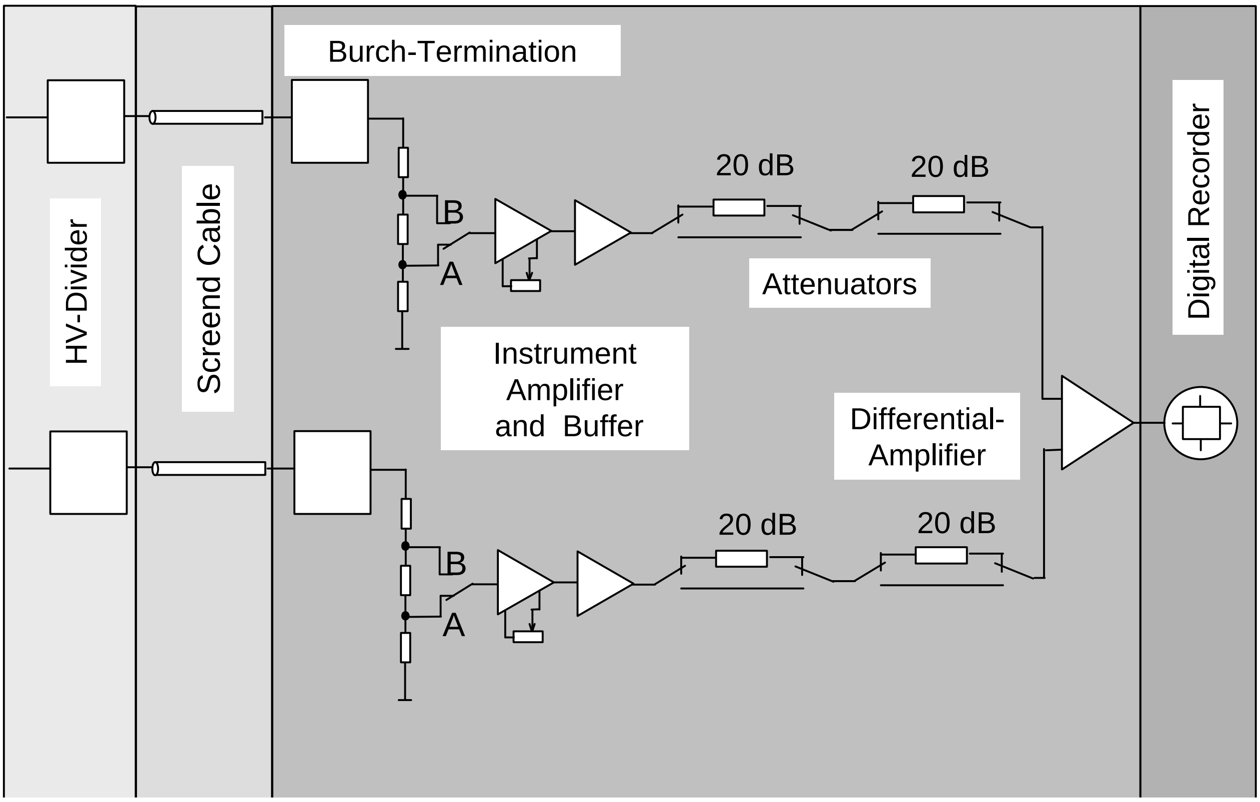
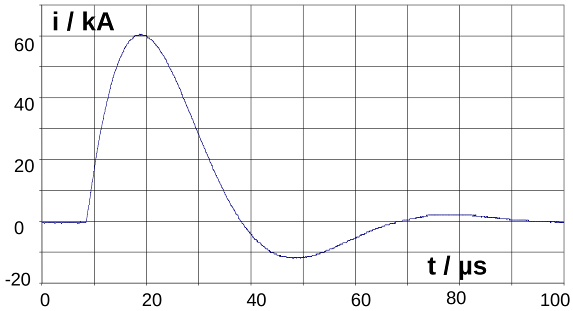
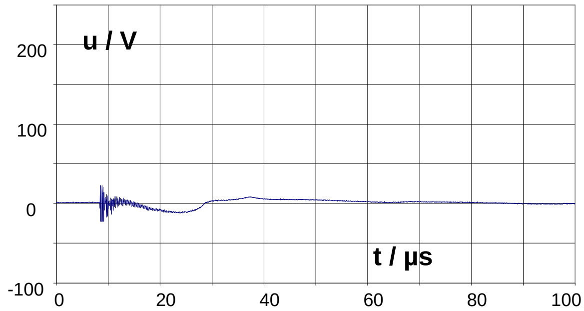


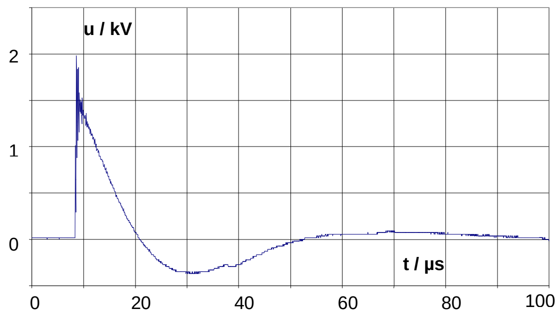
Fig.5 Equivalent circuit of the differential voltage divider.



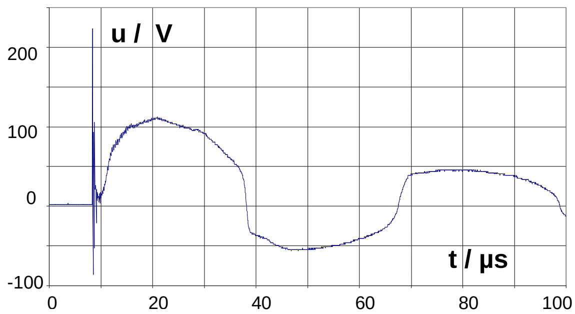
a) Applied surge current



c) The gapped arrester is replaced by a short circuit af nearly same geometry. The differential voltage divider is tuned to get the optimal compensation.



b) Residual voltage without compensation



d) Residual voltage at the terminals of the gapped arrester using the differential voltage divider

Fig.6 Measurement ot the residual voltage across a gapped surge arrester during application of 8/20 µs 60 kA current surge, compare Photo 1.

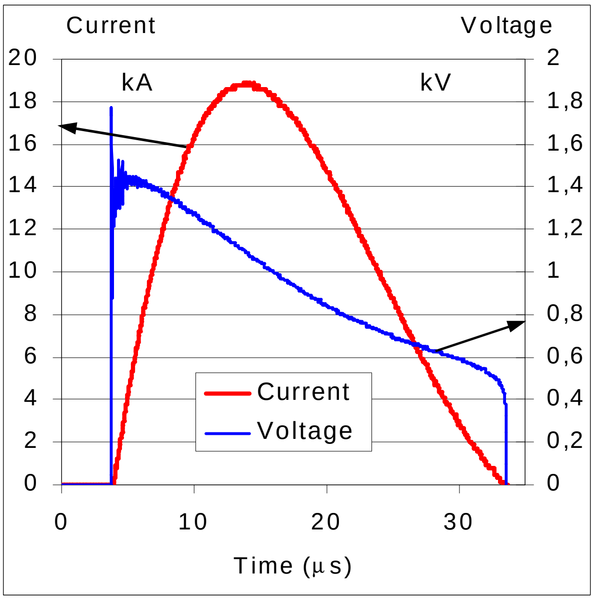


Fig.7a Conventional measurement of the residual voltage of the arrester SIOV-B40K385 with one divider only.
Current peak: 18,8 kA..
Residual voltage: 1,425 kV.

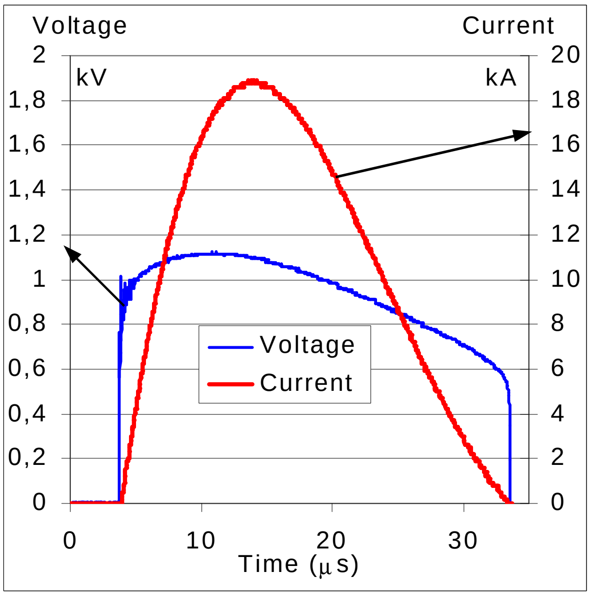


Fig.7b Compensated measurement of the residual voltage of the arrester SIOV-B40K385 with two dividers (differential voltage divider).
Current peak: 18,8 kA..
Residual voltage: 1,118 kV.

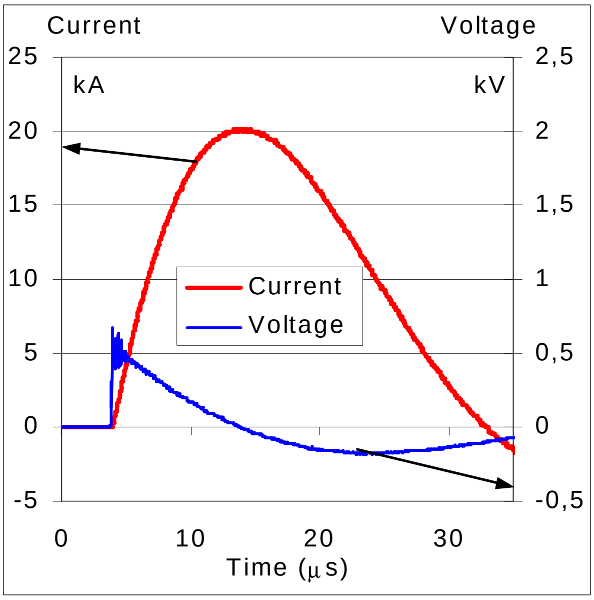


Fig.7c: Conventional measurement of the residual voltage of the arrester SIOV-B40K385 with one divider only when the arrester is bridged using a short.
Current peak: 20 kA, due to same charging voltage as used in Fig. 7a.
Residual voltage: app. 0,5 kV.

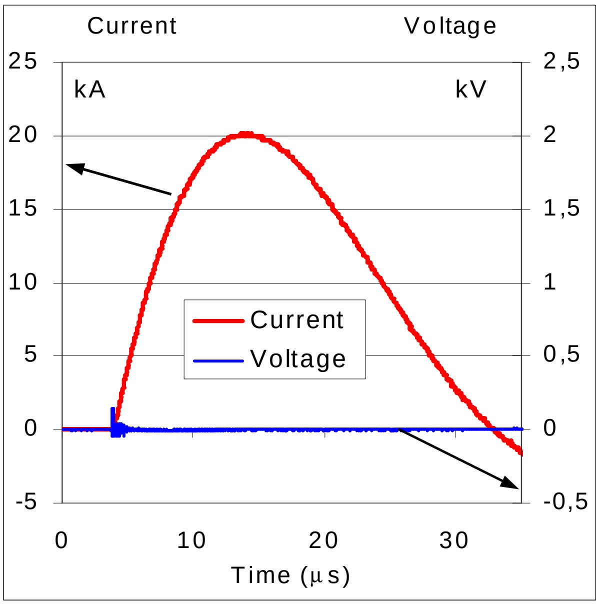


Fig.7d: Compensated measurement of the residual voltage of the arrester SIOV-B40K385 with two dividers (differential divider) when the arrester is bridged using a short.
Current peak: 20 kA, due to same charging voltage as used in Fig. 7b.

Fig.7 Comparison of a measured residual voltage across one surge arrester SIOV-B40K385. Maximum Residual voltage is 1,425 kV uncompensated and 1,118 kV compensated during a 8/20 surge of 18,8 kA Maximum.