A NEW GENERATOR FOR TESTING OF SPD`S USING MULTIPLE LIGHTNING CURRENT IMPULSES FOR COMBINED TESTS WITH FOLLOW CURRENTS

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ABSTRACT.

The Standards /1/ require a test of varistors and spark gaps for lightning protection of low power distributions and low voltage switchboards. During the combined impulse and power frequency test of metallic oxide varistors, no follow current occurs because of the favourable characteristic of the varistor. During testing of spark gap arresters a follow current may flow. However, does the standard test cover all events during a real lightning strike?

1 INTRODUCTION.

Multiple lightning currents (MLC) are known from the lightning current measurements from BERGER /2/. Surge Protection Devices (SPD´s) as well as other equipment for protection against lightning impulse current and Lightning Electromagnetic Impulse (LEMP) shall be tested against MLC. When considering SPD´s in Power lines, the follow current has to be taken into account. Therefore a new generator was build to generate all required wave shapes which can be combined with follow currents up to 4,5 kA. Also the requirements for testing lightning protection system equipment e.g. down conductors, clamps can be tested according to the latest standards. The design and use of the Generator will be shown in this paper.

2 REQUIREMENTS FOR TESTING OF SURGE PROTECTION DEVICES.

In the case of the product design, it is advantageous to simulate the actual stress during a lightning strike to a large extent realistically. The examination is in particular required for simulation of lightning with multiple flash discharges. Berger /2/ has shown that the first stroke in a strike is followed by multiple subsequent strokes. Subsequent strokes follow at a temporal distance of some 10ms up to some 100 ms. The following effects result from it: During a direct lightning strike into a building, the potential of the foundation ground electrode increases suddenly to some 100 kV. The Protective Earth is also grounded at the foundation ground electrode. If spark gap arresters are installed in the low voltage installation, these respond in the case of multiple flash discharges repeatedly and must carry off and extinguish the follow current. Therefore, the development of a spark gap arrester also must consider this case. The basic functions of a spark gap arrester can be divided into 4 steps. The spark gap must trigger below 4 or 6kV so that isolation is not overstressed. After triggering current will flow through the spark gap. Depending on the properties of the arrester and the phase angle, short circuit current may occur. The spark gap can interrupt the short circuit current due to its extinguishing property. These four effects must be simulated in the lab. However, additional examination is required because of nature of multiple lightning currents in a flash.

3 DESIGN OF A MULTIPLE LIGHTNING IM PULSE GENERATOR COMBINED WITH FOLLOW CURRENT GENERATION.

The Generator was designed for testing of surge arresters as well as for lightning protection components. Table 1 shows the essential system requirements. The values shown in Table 1 indicate the upper limits given in IEC 1024-1. Table 2 show the detailed performance data of the realised Generator.

Table 1: Basic system requirements for test of (SPD´s) and lightning protection system components.

According to IEC 1024-1 the 10/350µs impulse shall provide the additional two following parameters for testing of lightning protection system components as

	Wave form	**Peak value**	**Principle**
Surge current	10/350 µs	200 kA	RLC-Circuit and Crow Bar
Surge current	8/20 µs	200 kA	RLC-Circuit
Follow current	50 Hz	Up to 25 kA (prospective value)	Transformer

follows:

- **Charge of the impulse current Q** which is defined as the time integral of the absolute current impulse for the entire impulse duration: For the best protection level a Charge of Q = 100 C is requested.
- **Specific energy of an impulse current W/R** (also called action integral) of an impulse current is the energy dissipated by the impulse in a unit resistance. It is the time integral of the square of the current impulse for the duration of the impulse. For the best protection level a specific energy of W/R = 10000 kJ/Ω is requested.

Both values determine the costs and are the main design criteria for the development of a surge generator. The values in Table 1 have to be taken into consideration too.

3.1 The Surge Generator.

Further practical requirements refer to the operation of a laboratory. These requirements have been introduced in the detailed design to realise rapid operation of tests and documentation of the results.

- rapid charging time <1 min
- rapid conversion onto other modes <5 min
- rapid connection and alternation of equipment under test <10 min
- recording, evaluation and representation of measuring data with PERSONAL COMPUTER <1 min.

The generator is shown in Fig.1. The circuit diagram is shown in Fig.6. The generator is divided into two Groups. Generator 1 contains the crowbar circuit, refer to chapter 3.1.1. Generator 2 contains the same equipment without the crowbar circuit. Both generators can be connected and operated simultaneously. Each capacitor can be connected using air driven remote controlled high voltage disconnector switches on top of the generator. A quick change of testing configurations can be made easily. The computer controlled charging units for each stage are high power chargers. They can charge one generator group with a capacity of 25 µF within 36 s up to 100 kV at a chosen polarity. It is further possible to operate generator 1 with positive and generator 2 with negative polarity and also with different wave forms. Therefore a fast sequence during testing can be provided, e.g. 1 surge per min during combined testing of arresters. Great care has been taken in the evaluation of the overall design. First priority was given to the place of the equipment under test (EUT). The EUT can be placed above the shunt in normal work bench position, refer to Fig.1. The noise during firing of spark gaps can be extreme. The gaps are encapsulated with fibre glass reinforced epoxy resin cylinders and operated with normal air pressure. The control room is separated using special glass. Therefore noise is reduced to an acceptable level and earmuffs are not compolsary. Next to the surge Generator there is an existing surge generator which is an industrial Haefely type. A total of three impulses can be generated.

3.1.1 The crowbar circuit for 10/350 µs surges.

The requirements in IEC 1024-1 cannot be economically realised using a conventional RLC circuit. The crowbar circuit is a solution when testing of lightning protection system components is considered /3/. The principle is shown in Fig. 3. The conventional RLC circuit is simply extended using the crow bar spark gap. The only difficulty in the application of the crowbar gap is the fact that at the desired trigger time the voltage is zero. Therefore an external Marx generator for oscillating lightning impulse voltage /4/ is installed for triggering, refer to Fig.5. The Crowbar spark gap is a three electrode gap which is triggered at the centre electrode. As shown in Fig.6 the trigger impulse is applied to the centre electrode using a step up gap (Refer to Fig.4) in order to generate a step impulse of 140 kV peak with some ns rise time. Then the upper gap triggers at first followed by the lower gap in less than 20 ns. Great care must be taken in the design of the coil which has to withstand the dynamic magnetic forces during current flow as well as 100 kV impulse voltage.

3.1.2 Generation of 10/350 µs surges for testing of metal oxide surge arresters.

The crowbar principle can be applied for EUT with low resistance and low residual voltage only, otherwise the wave shape is strongly influenced and the test parameters cannot be reached. For metal oxide varistors a special RLC circuit is realised. However the current is limited to 10 kA but a clean wave shape without distortion can be generated for testing of low voltage metal oxide surge arresters.

3.1.3 Triggering of spark gaps.

As shown in Fig.6 there are 4 spark gaps and one spark gap inside the Marx generator for 140 kV. The crow bar circuit has to be started by triggering of the main spark gap. When the current reaches its peak value, the crowbar spark gap has to be triggered. This requires the triggering of the Marx Generator and the step up gap to the right time. To avoid accelerated aging of the capacitors, the triggering of the crowbar gap must be performed at 100% reliability with low jitter. A high performance trigger system is therefore required /5/. The complete system is shown in Fig.7 and consists of the basic digital multi channel timing unit, the electrodes of the high voltage spark gaps and the high voltage trigger impulse amplifier inside the electrodes of the spark gaps. For triggering a spark plug is inserted in the surface of the electrode of a high voltage spark gap. A high voltage trigger impulse is than given to the spark plug for triggering of the high voltage spark gap. A high voltage impulse of some kV to ignite the spark plug in the electrodes is generated using a miniaturised battery driven high voltage impulse amplifier as shown in Fig. 7c. The timing unit is triggerable on the zero crossing of the power frequency voltage in order to synchronise the surge current to a given phase angle. The individual channels of the timing unit can be set up with an time resolution of 100 ns. All channels can be operated parallel or sequential. This allows to cover all practical requirements in a laboratory. The digital pulses are then transferred into light impulses using Laser Diodes and transferred to the high voltage electrodes using fibre optic links.

3.1.4 Measuring technique and data processing.

The measurement of the current and the voltage during a test is performed using a shunt and a voltage divider. The follow current is also measured with a shunt. The current is measured using a coaxial 200 kA shunt with a rise time of 175 ns. During the current flow a high magnetic field is generated in the vicinity of the EUT. A voltage divider therefore will be influenced by this magnetic field. Great care must be taken to measure the actual voltage e.g. across a surge arrester for low voltage applications. The residual voltage of the arrester, which has to be measured, can be in the same range as the induced voltage in the loop of the connection of the divider. Furthermore the magnetic field can induce a noise voltage in the divider itself. To solve this problem a differential divider is used. One divider is connected directly to the EUT. A second divider of same design is connected to a variable loop. With a differential amplifier the signal can be processed in such a way that the magnetic induction is compensated. Furthermore the dividers itself and all cables to the recording equipment have to be well screened. The data acquisition uses a commercial digital recorder. The software is our own development. An example is shown in Fig.8c.

3.2 The follow current.

The equipment for the generation of follow current is shown in Fig.2. The current is generated using a medium voltage transformer 10kV/250 V. The standard /1/ requires for each current class a defined cosφ. Using resistors and coils the requirements can be fulfilled. In the present state prospective follow currents up to 4,5 kA peak can be generated in line with the standards. The required combination of resistors and coils can be remote controlled from the control room. Some protection must be provided for the follow current equipment against the effects of impulse current from the surge Generator.

4. TEST OF A GAP ARRESTER WITH DOUBLE STRESS OF SURGE CURRENT AND FOLLOW CURRENT.

A combined test e.g. of spark gap arresters with an 8/20 µs surge and follow current is a standard test in a laboratory. The surge Generator will be synchronized to the power frequency voltage. At the required phase angle the trigger system starts the surge. The follow current can flow until the voltage zero is reached. According to the standard the phase angle has to be changed and the whole sine wave has to be tested in intervals of 30 degrees.
A speciality of this Generator is the ability to generate two pulses at different phase angles. Such a case is a realistic simulation as it can happen during a multiple lightning strike in a building with external lightning protection system. The earth potential will rise fast up to some 100 kV depending on grounding resistance. The earth potential rise will then cause a flash over to the power lines of the energy supply system. If a spark gap is employed in the supply system, it can conduct the current and will extinguish the follow current. However in the case of multiple lightning currents the spark gap can be triggered again. Fig.9 shows a laboratory simulation of such a case using a gap arrester. At first, at an angle of 60 degrees the 8/20µs surge current is triggered, followed by a second 8/20µs surge with an angle of 90 degrees. Due to the properties of the arrester the current crosses zero before the natural zero of the power frequency voltage. This test example demonstrates the flexibility of the generator.

5 REFERENCE .

/1/ : E DIN 0675 Teil6 (A1,A2)
/2/ : K.Berger: Novel Observations on Lightning Discharges: Results of Research on Mount San Salvatore. Journ. Franklin Inst.,283 (1967), S. 478-525.
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Table 2 Performance data of the generators at BET

Impulse current	Peak value	Charge	Action Integral	Note
	kA	C	MJ/Ohm	
Main Wave Shape				
10/350µs Crow Bar	200	100	10	Lightning protection equipment
10/350µs	10	5	0,025	Testing of Varistors
8/20µs	200	5	0,67	
8/20 µs	100	2,5	0,168	Haefely Generator
4/10µs	108	1	0,1	Haefely Generator
Rectangular wave 1 ms	0,075	0,075	0,005	Haefely Generator
2ms	0,2	0,4	0,08	Haefely Generator
Combined Tests				
+/- 10/350µs Crow Bar;	100	100	7	
+/- 8/20µs;	100	2,5	0,168	2 Pulses +/-
+/- 4/10µs;	108	1	0,1	
Rectangular wave;	0,075; 0,2	0,075; 0,4	0,05; 0,08	
Follow current 50 Hz	4,5	1)	1)	1) depending on current flow
Follow Current				
250 V, 50 Hz Standard Test	1,5---4,5			cosφ according to Standard

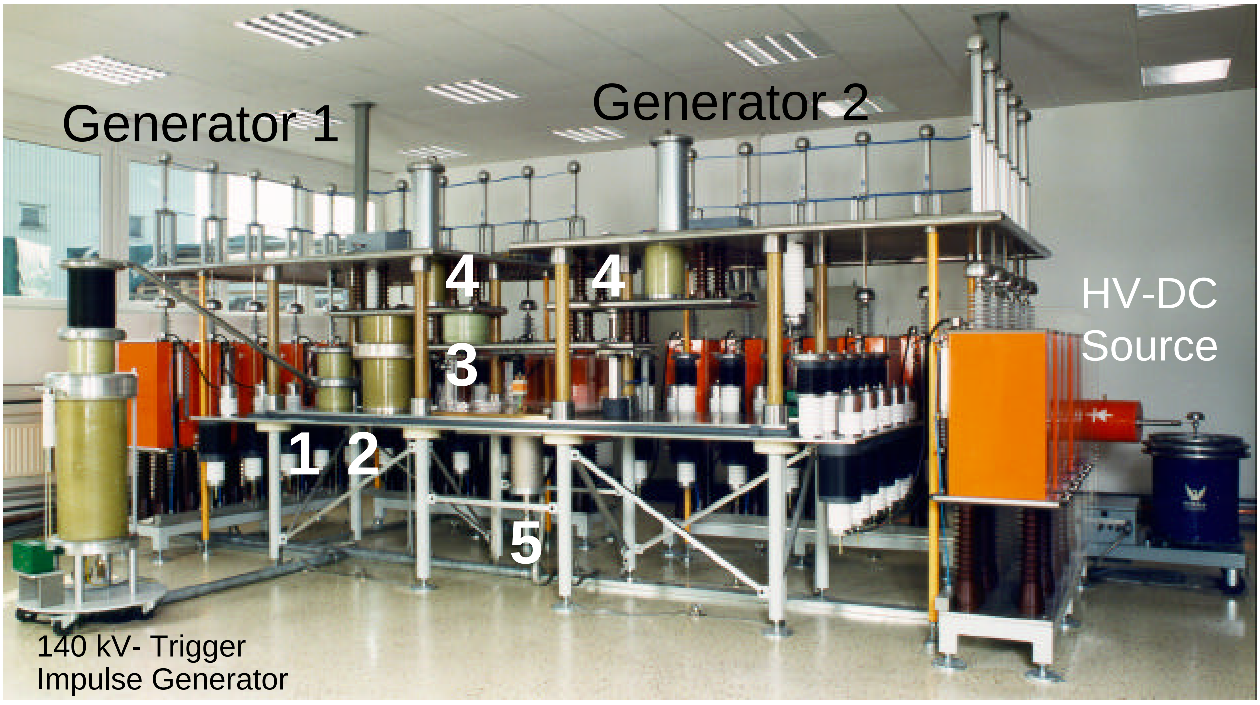


Fig. 1 : View of the Generator. Generator 1 contains the crowbar circuit. Generator 2 contains the stages for conventional impulses. Total Capacitance: 2 x 25 µF, 100kV. Stored Energy: 250kWs. **1**: Step up gap. **2**:Crowbar spark gap. **3**:Coil. **4**: Main spark gap. **5**: Shunt.

Fig. 2: Installation for the generation of follow currents with power frequency 50 Hz.
Left: 10kV/250V Transformer.
Right: Cabinet containing several switching devices and the additional coils and resistors for the shaping of the follow currents according to the standards.

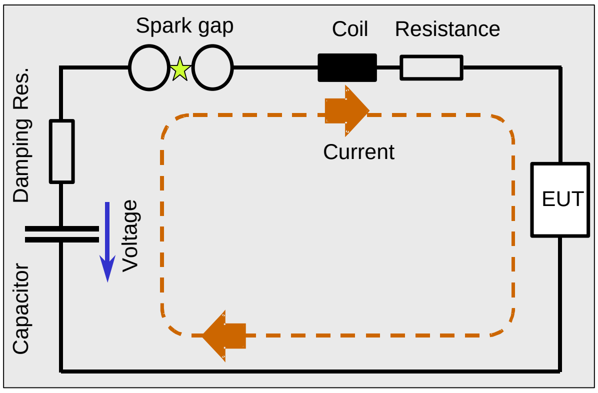


Fig.3a : Circuit for generation of an oscillatory surge current. Resistance is given by the total ohmic losses in the circuit.

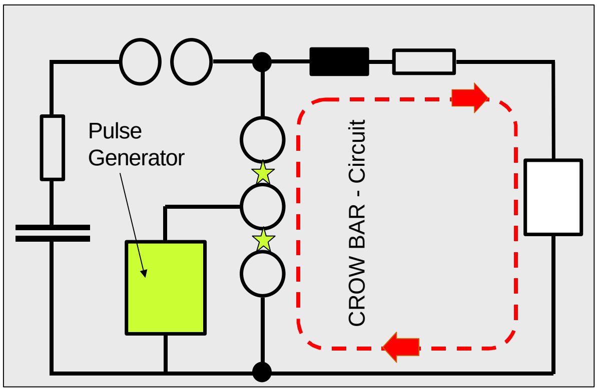


Fig.3b: Modification of Fig 3a using a Crowbar Spark gap and a pulse generator for triggering of the Crowbar spark gap.

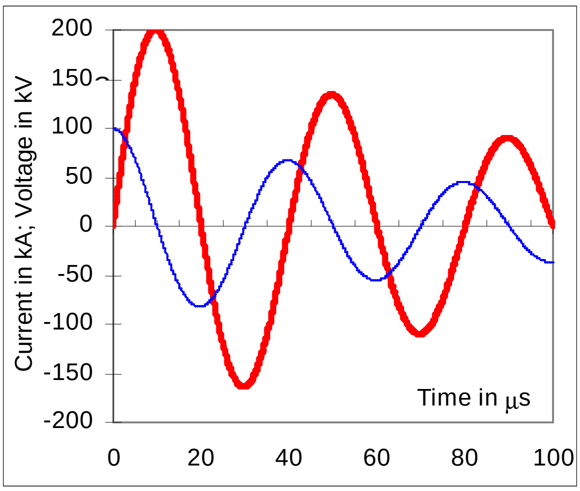


Fig.3c: Current and Voltage across the capacitor in a circuit as shown in Fig.3a.

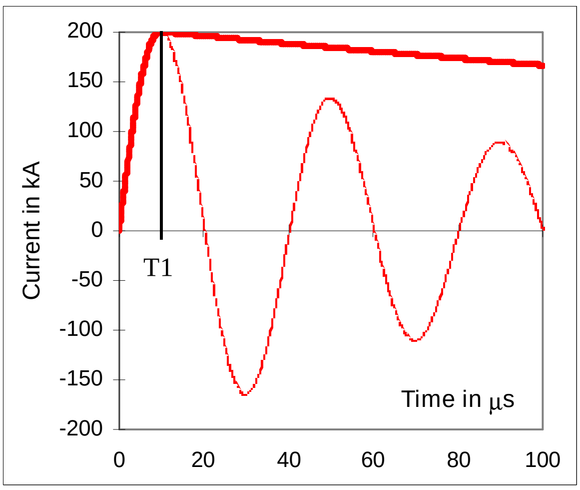
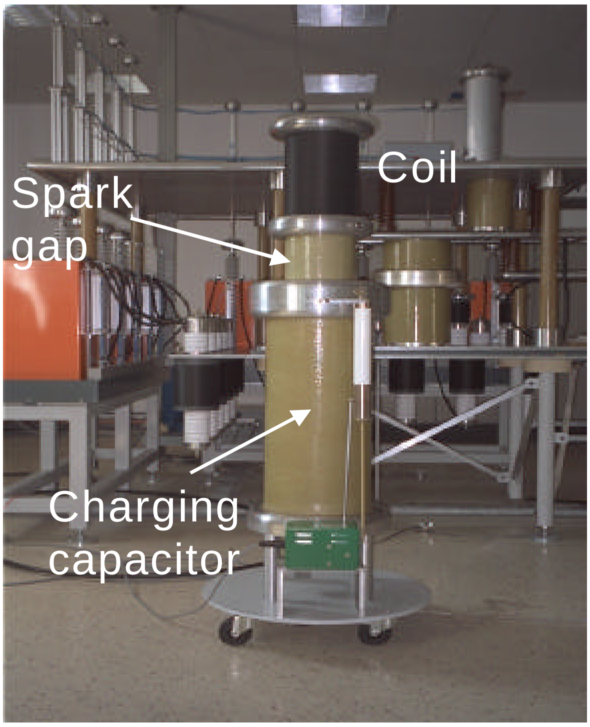


Fig.3d: Current after triggering of the crowbar spark gap at T1.



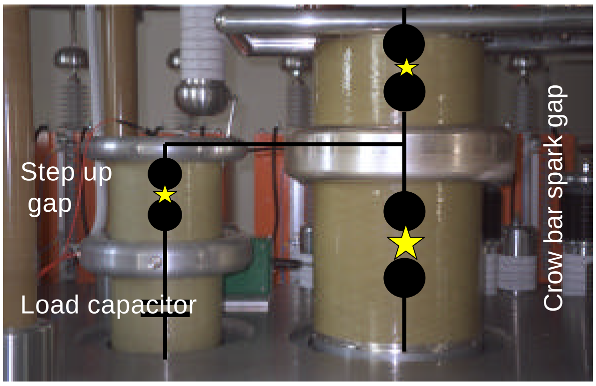


Fig.4 : Detailed view of the crowbar spark gap and the step up gap.

Fig.5 (Left): View of the impulse generator for triggering of the crowbar spark gap.

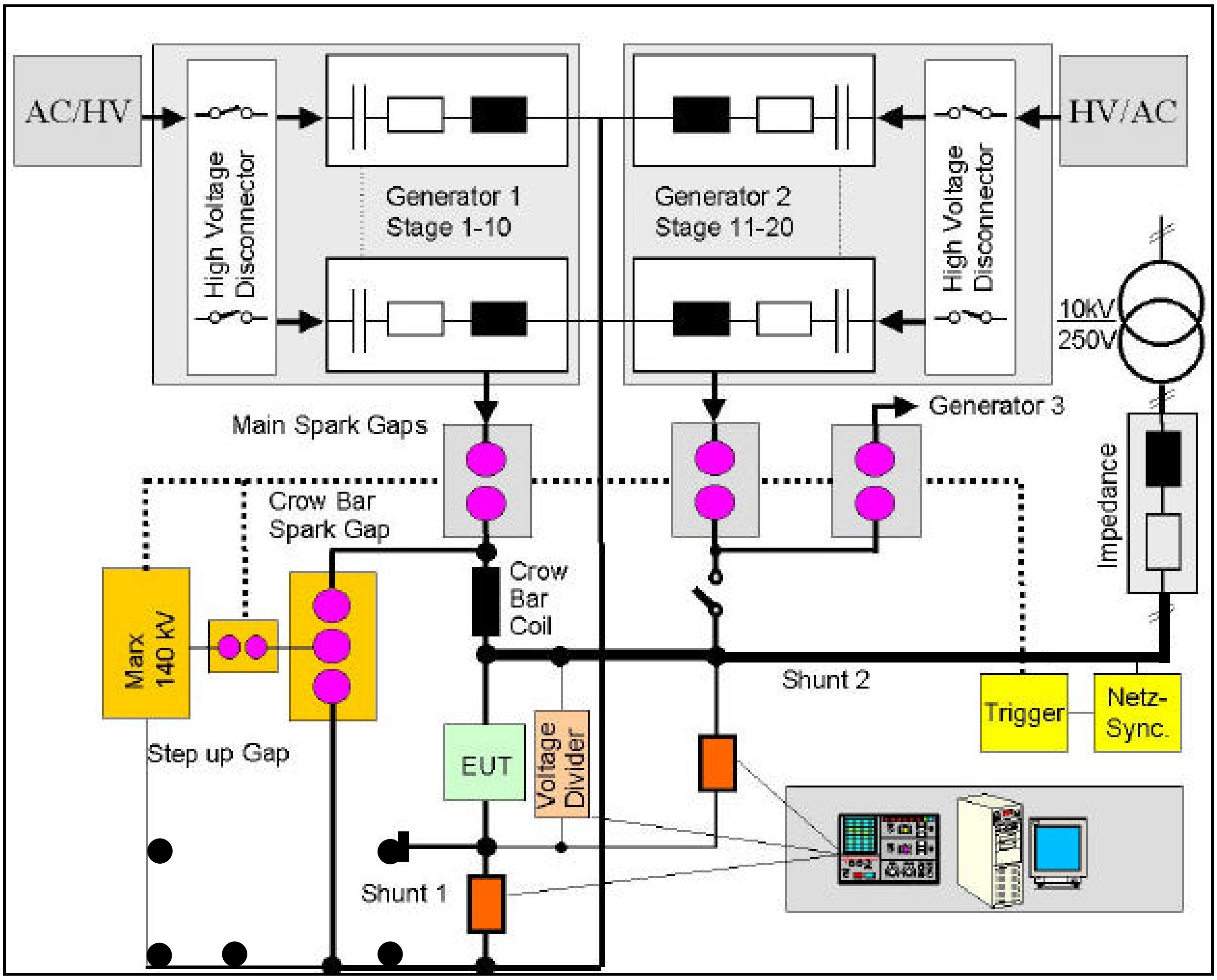
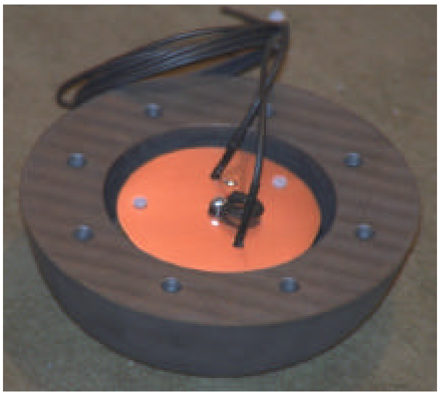


Fig.6 : Complete circuit diagram of the generators at BET.



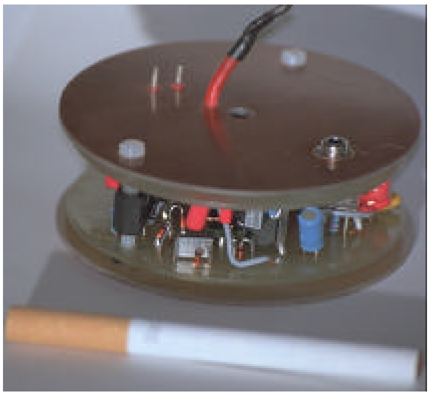


Fig.7 Digital multi channel time control unit. Resolution: 100ns. Optical outputs with laser impulse light.
Left : Electrode of a high voltage spark gap with integrated high voltage impulse amplifier for triggering of a spark plug inside the electrode.
Right: High voltage impulse amplifier. Top left: Connection for battery (1,5V).Top right: Connection of the fibre optic cable.

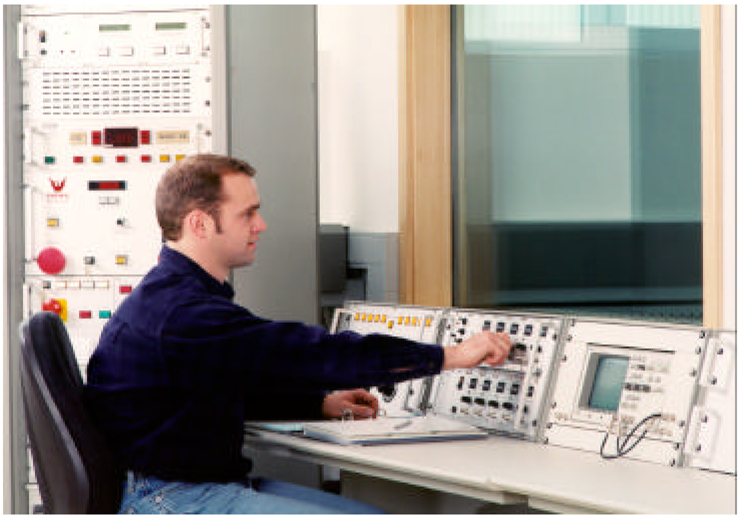


Fig.8a : Partial view to the control room at BET. The control unit for the HV Charging systems is on the left side inside the rack.
The digital timing control unit is visible in the table. Next to it the commercial digital oscilloscope is installed.

Fig.8b: Partial view to the control room at BET. The Personal Computer is underneath of the table. The Keyboard is protected by a metallic housing. A special screening of the PC and the Monitor is not required.

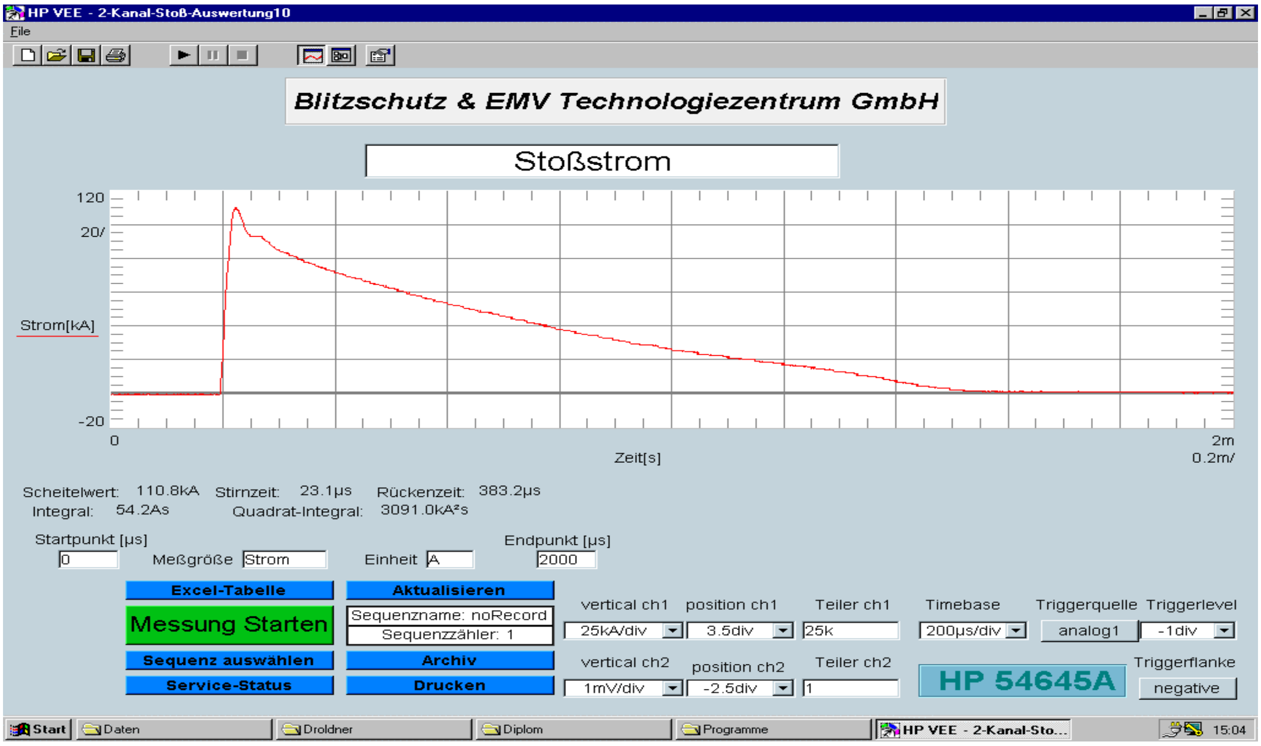


Fig.8c: Example of a measurement of a 10/350µs surge current generated with the crowbar circuit.

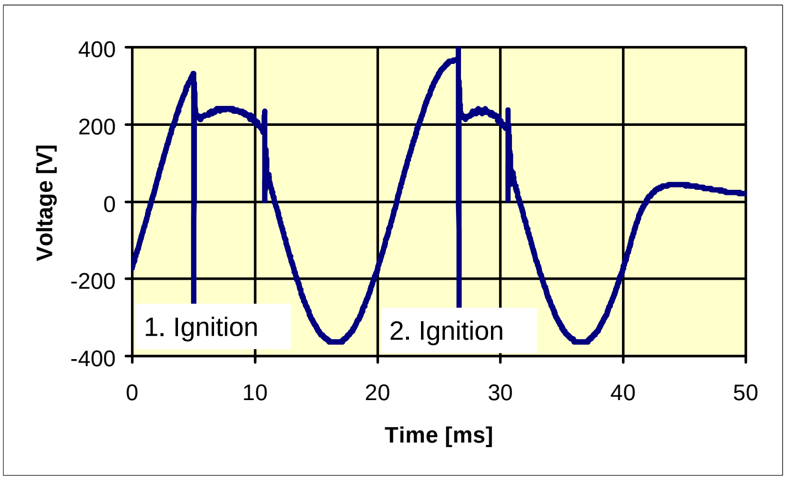


Fig. 9a: Voltage across a gap arrester during a combined test with surge current 8/20 µs, 20 kA. First ignition at 60 degrees, second ignition at 90 degrees.

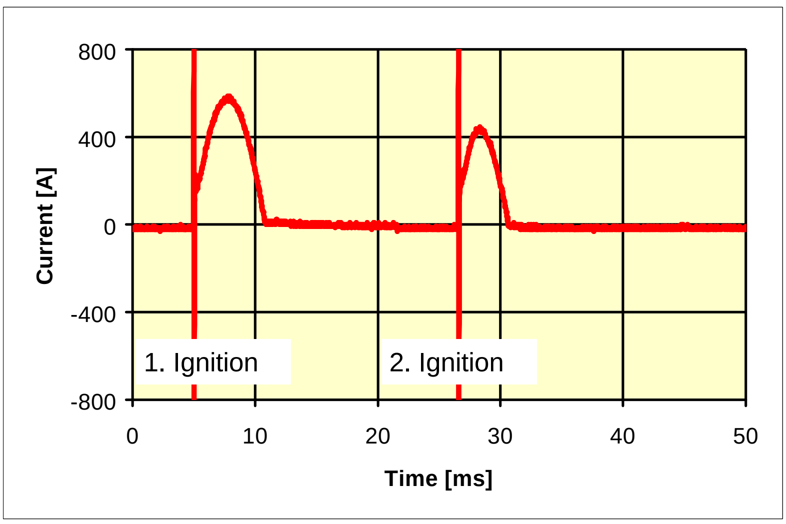


Fig. 9b. Current through a gap arrester during a combined test with surge current 8/20 µs, 20 kA. First ignition at 60 degrees , second ignition at 90 degrees.