3. IMPULSE VOLTAGES: LIGHTNING IMPULSE

SAFETY MEASURES: Interlocks are provided to prevent high voltage to be switched on while the gates/ doors are open. Despite these measures it is necessary to connect the safety earth stick to the HV parts before touching. (There could be some charge left on the capacitors). Special safety rules for the High Voltage laboratory must be read, understood, signed and always followed to every detail!

3.1 Objectives

The student must gain the following knowledge and comprehension in the following topics:

- General description of the lightning test procedure and become familiar with the experimental setup.
- Conduct first lightning test without DUT (Device Under Test) and describe the procedure.
- Measure the volt-time characteristics for sphere-sphere gaps and rod-rod gaps.
- Examine the effect of a surge arrester.

3.2 General Description

There are two types of overvoltage pulses which power systems should withstand – lightning and switching. In the field, these transients can take different wave shapes. Lightning overvoltage typically occur due to lightning strokes hitting the phase wires of overhead lines or outdoor bus bars. Amplitudes are very high (i.e., 1000 kV), therefore the insulation may breakdown and the voltage is chopped, however it is also possible that the insulation may not breakdown and withstand the overvoltage. In case that the insulation does not breakdown a full lightning impulse voltage shape can be observed. In case that the there is a breakdown of the insulation; the voltage can be chopped on the front or on the tail.

Lightning impulses have very fast voltage rise, the standard lightning impulse is described as 1.2/50 μs wave. On the other hand, switching impulses have slower voltage rise, typically 250/2500 μs. Switching impulses are not the scope of this laboratory session; therefore no further details are given.

3.3 Laboratory tasks

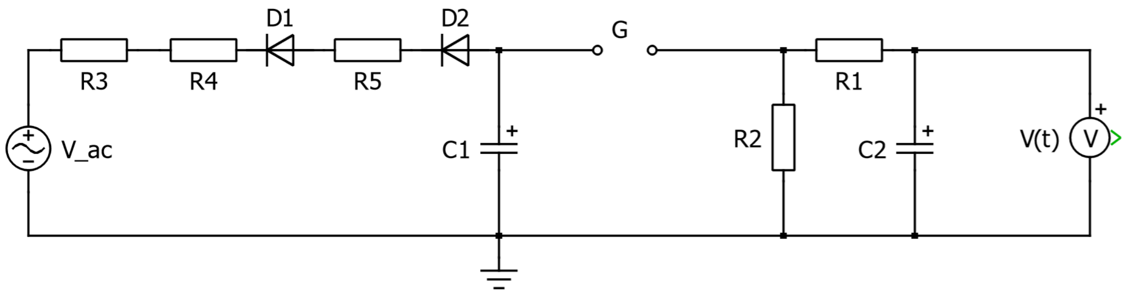
3.3.1 Experimental circuit

In order to generate a wave with $T_1/T_2 = 1.2/50\mu s$, a single-stage generator circuit is used. The student must carry out the following tasks:

- Draw as **detailed as possible** the schematic of the setup, equipment, etc., and explain the charging and discharging processes.
- Calculate the values of R_1 and R_2, as the values of C_1 and C_2 are known. Calculate the efficiency η.
- Compare the measured η, chosen values of R_1 and R_2 in the circuit with the calculated values, comment on it.
- Which type of single-stage impulse generator circuit is implemented?
- How is the impulse generator adjusted to obtain a higher impulse?
- Identify from the setup the type of lightning impulse: positive or negative? Why?

Remember to take a picture of the setup and include it in the mini-project.

Please draw a schematic of the setup with all the equipment that has been used:



3.3.2 Lightning test

Once the student becomes familiar with the setup and understands the principle of the lightning impulse, the next step is to conduct the first lightning impulse without any device under test.

The procedure will be explained during the laboratory session so the student is expected to take notes

The efficiency is calculated following the procedure described in the slides:

$$C_1 := 10000\ pF \qquad C_2 := 1200\ pF \qquad \alpha_1 := \frac{1}{68.2\ \mu s} \qquad \alpha_2 := \frac{1}{0.405\ \mu s}$$

$$R_1 := \frac{1}{2\ C_2} \cdot \left(\left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} \right) - \sqrt{\left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} \right)^2 - \frac{4 \cdot (C_1 + C_2)}{\alpha_1 \cdot \alpha_2 \cdot C_2}} \right) = 3.325\ k\Omega$$

$$R_2 := \frac{1}{2 \cdot (C_1 + C_2)} \cdot \left(\left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} \right) + \sqrt{\left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} \right)^2 - \frac{4 \cdot (C_1 + C_2)}{\alpha_1 \cdot \alpha_2 \cdot C_1}} \right) = 6.085\ k\Omega$$

$$\eta := \frac{1}{1 + \frac{C_2}{C_1}} = 0.893$$

Questions:

3.3.1

-Explain the charging and discharging processes.

The capacitor C1 is charging until the breakdown voltage. If the breakdown voltage is reach, the gap will closed and current will flow trough to C2,R1 and R2. So C1 is discharging and C2 is charging at this time. The gap will open, if the voltage dropped under the breakdown voltage value.

-Which type of single-stage impulse generator circuit is implemented?

We use the type b.

-How is the impulse generator adjusted to obtain a higher impulse?

The gap length have to larger to obtain a higher impulse

-Identify from the setup the type of lightning impulse: positive or negative? Why?

It is a negative impulse because the diode are revearse biased

3.3.2

Explain the lighting test

AC voltage rectified by the two diodes to charge C1 with a DC voltage. The test is carried out first before without the test object to see the impulse voltage waveform that is generated in C2 and, therefore, efficiency of the system. The SW assumes the efficiency is 1 so the test need to be carried out without the test object to calculate the real efficiency. The test's procedure consists in using a software to apply a peak DC impulse voltage to C1. The distance of the sphere gap is changed automatically based on the charging voltage of C1. A negative lightning impulse voltage is applied to C1 to see the breakdown voltage between the sphere's gap. This value is noted down together with the time it takes to reach the breakdown point.

and include them in the mini-project. Figure 1 represents a typical negative lightning impulse without breakdown.

Hint: pay attention to the input voltage applied and how the sphere gap spacing adjusts when conducting the lighting test, write down the peak voltage obtained as well as T_1 and T_2.

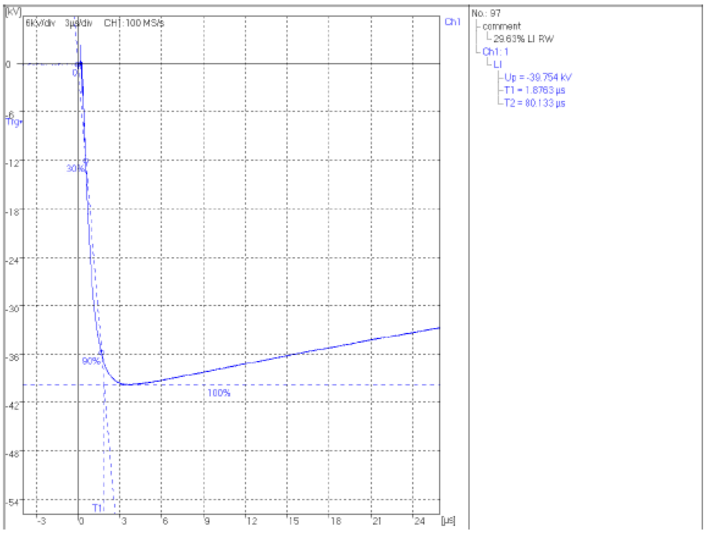


Figure 1. 40 kV negative lightning impulse without breakdown: T_1 = 1.876 µs & T_2 = 80.133 µs

3.3.3 Volt-time characteristics for sphere-sphere gaps and rod-rod gaps

When an impulse voltage of sufficiently high value is applied to a gap, breakdown will result on each voltage application. The time required (time lag) for the spark development will depend upon the rate of voltage and the field geometry. Therefore, for each gap geometry, it is possible to construct a volt-time characteristic by applying a number of impulses of increasing amplitude and noting the time required (time lag) for spark. The volt-time characteristic is an important practical property of any insulating device or structure. It provides the basis for establishing the impulse strength of the insulation as well as for the design of the protection level against over voltages. A schematic plot of such a characteristic is shown in Figure. 2.

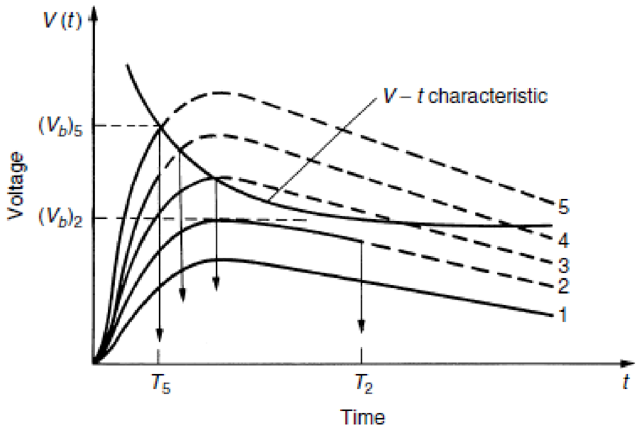


Fig.2 Impulse ‘volt-time’ characteristics

The students need to obtain the ‘volt-time’ characteristics of sphere - sphere gap and rod - rod gap respectively under negative lightning impulse.

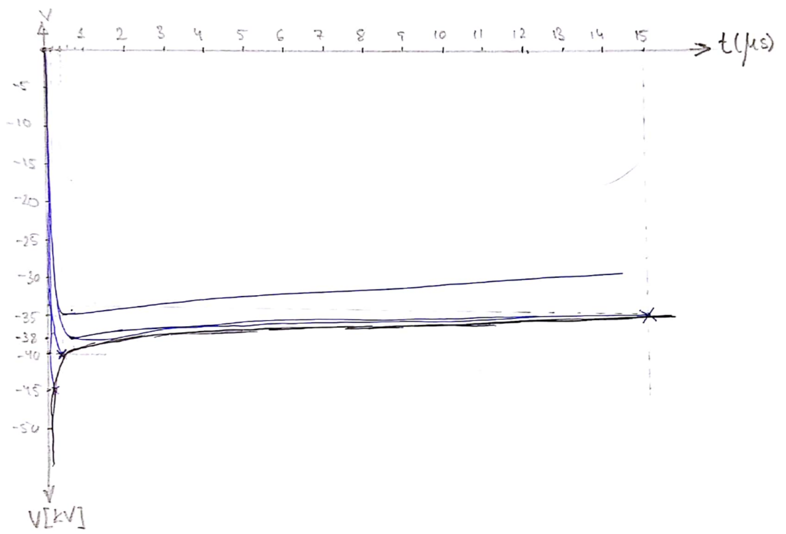
A d=100mm sphere - sphere gap with a gap length s=10mm is adapted. The students need to measure 3 points of the volt-time characteristic of the sphere – sphere gap. For each point, measure the breakdown voltage 5 times and calculate the arithmetic mean value. <u>Remember to convert the measured values to standard atmospheric conditions.</u> Use negative impulse voltage polarity and a charging voltage of app. 35, 45 and 55kV for the 3 points, respectively.

Pre-setting peak voltage [kV]	**Average breakdown voltage [kV]**	**Average breakdown voltage in standard atmospheric conditions [kV]**	**Average time lag**
-35			
-45			
-55			

For the rod-rod gap, a gap length s = 20 mm is adapted. The students need to measure 3 points of the volt-time characteristic of the rod-rod gap. For each point, measure the breakdown voltage 5 times and calculate the arithmetic mean value. <u>Remember to convert the measured values to standard atmospheric conditions.</u> Use negative impulse voltage polarity and a charging voltage of app. 35, 45 and 55kV for the 3 points, respectively.

Pre-setting peak voltage [kV]	**Average breakdown voltage [kV]**	**Average breakdown voltage in standard atmospheric conditions [kV]**	**Average time lag**
-38	-37.55	-37.28	8.699 us
-45	-41.97	-41.67	2.563 us
-55	-43.3	-42.99	1.066 us

Please draw the 'volt-time' characteristics of sphere - sphere gap and rod - rod gap respectively under negative lightning impulse



V-t of sphere-sphere

Remember to **compare and evaluate** the volt-time characteristics of sphere – sphere gap and rod – rod gap. Please include your analysis in the miniproject report.

3.3.4 Effect of a surge arrester

A surge arrester is a typical overvoltage protection device in modern power transmission system. It is parallel connected to the component that needs to be protected. A proper surge arrester breaks down at lower voltage than the withstand voltage of the protected component when a transient happens, thus the component will not be overstressed. The students need to find out the effect of a surge arrester.

The students should conduct a lightning impulse test on the rod-rod gap with a gap length s=30mm and record the breakdown voltage waveform. Then connect the surge arrester over the rod - rod gap and keep the other conditions unchanged. Then conduct the lightning test again and the voltage waveform should also been recorded. The students should **compare** the two waveforms with/without the sure arrester and explain the differences.

Breakdown with or without surge arrestor

In the *Figure 1. Lightening impulse without surge arrestor.*, it can be seen the waveform of a lightening impulse without the surge arrestor. The negative voltage reaches a value of -45kV, if the system is not rated for such high absolute electrical potentials, it is possible that it breaks down. For this reason, a surge arrestor can be implemented in the circuit.

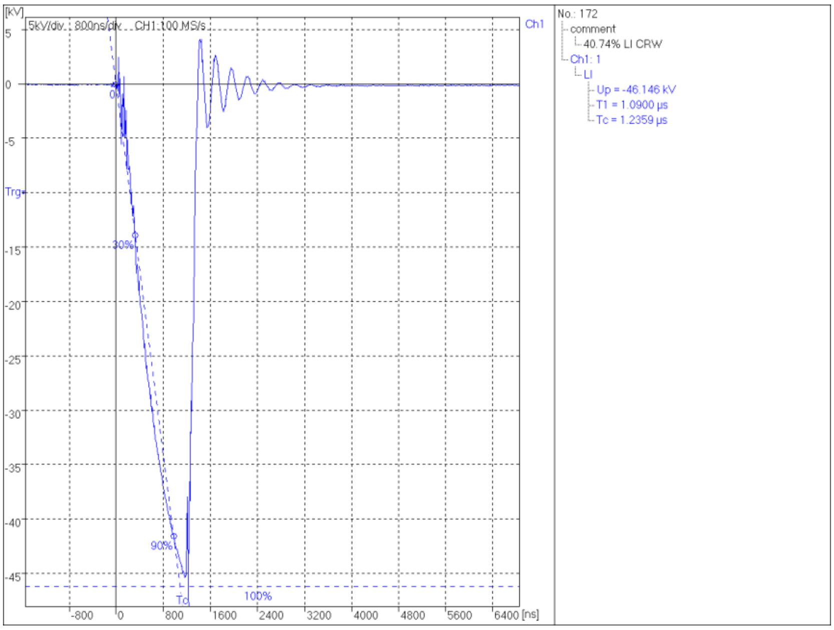


Figure 1. Lightening impulse without surge arrestor.

If the surge arrestor is implemented in the circuit, a different reaction is seen when a lightening strike occurs. In the *Figure 2. Lightening impulse with surge arrestor.*, it is shown how the maximum absolute voltage reached is about 34kV even though the input voltage strike was equal. This means that the surge arrestor has broken down before the actual circuit does, preventing it from having a breakdown.

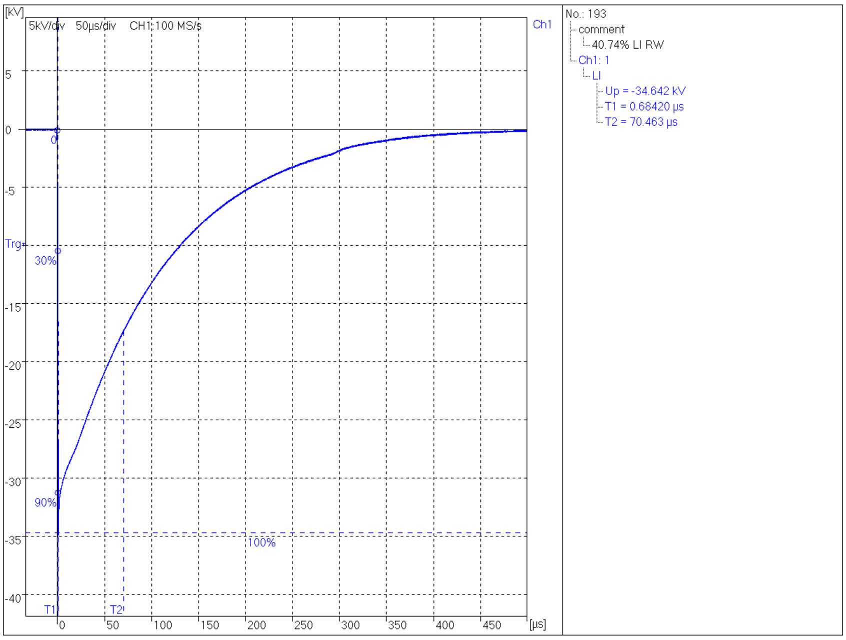


Figure 2. Lightening impulse with surge arrestor.