Lightning current simulation in the laboratory
- parameters, procedures and test equipment -

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The typical wave shapes and threat parameters of natural lightning discharges are the result of international lightning measurements. They were statistically analysed and defined in different standards. The laboratory simulation of such lightning events is necessary for the dimensioning of protective systems consisting of lightning protection measures and methods for the over-voltage protection. Laboratory techniques of the pulse power application are to differ generally in impulse voltage and impulse current simulations, whereas the lightning stroke is to consider as a current-intensive charge equalisation. Therefore, the standards of the protection against lightning define concrete pulse currents which are to classify in different protection level according to the typical parameters of impact (efficiency of protection). Table 1 describes partial currents of direct lightning strikes with associated parameters. Also other wave-shapes (1/200 µs) are under discussion for the standardisation of the future.

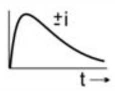
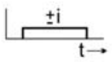
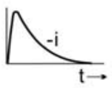
partial currents of lightning discharges	protection level IV - I	typical wave shape
first stroke T_1 / T_2 = 10/350 µs peak current / kA specific energy / $\frac{MJ}{\Omega}$	 100 ... 200 2,5 ... 10	
long duration stroke T_d = 0,5 s current / A charge / As	 200 ... 400 100 ... 200	
subsequent stroke T_1 / T_2 = 0,25/100 µs peak Current / kA mean steepness / $\frac{kA}{\mu s}$	 25 ... 50 100 ... 200	

Table 1: Typical parameters of lightning discharge currents

Among the direct impact of lightning currents also indirect effects can observed during direct or nearby occurred lightning discharges. So called ‘surges’ were generated in secondary loops and metallic structures because of the mainly inductive coupling close to lightning current carrying conductors. The simulation of this influence is to perform by surge currents with the typical wave-shape of T_1 / T_2 = 8 /20 µs with peak values of some kA up to some 10 kA. For conductor loops with high resistances (open loops) a surge voltage test T_1 / T_2 = 1.2/50 µs is to require. Figure 1 compares typical lightning current wave-shapes (laboratory simulation) with normalised peak values of 10 kA.

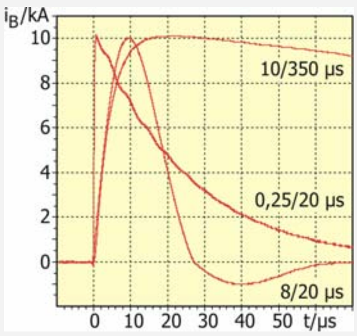


Figure 1: Typical lightning current wave-shapes

The wide range of pulse parameters of the lightning test pulses (some kA up to 200 kA, some kA/µs up to 200 kA/µs, some J/Ω up to 10 MJ/Ω) demands different principles and techniques of the impulse generation. The necessity of impressed test currents gives a special feature for the lightning current simulation in the laboratory. The Ilmenau University of Technology has developed in the past years different impulse generators for the lightning current simulation which are serviced and operated together with the test lab of the CE-LAB GmbH.

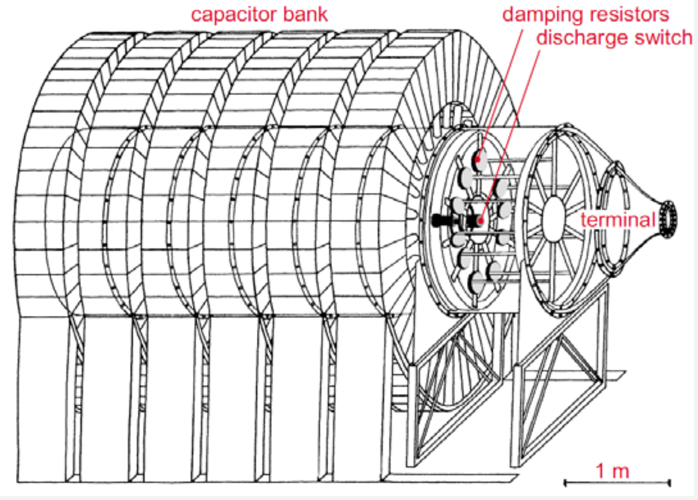


Figure 2: Schematic view of the high-current pulse generator

Because of the most double exponential wave-form, the generation of the lightning current test pulses is to realise according to the principle of the capacitor discharge in a damped oscillating circuit (R-L-C). The major pulse generator of the TU Ilmenau (Fig.1) haves a sum capacitance of 10 mF and operates with a maximum charging voltage of 10 kV (stored energy of 500 kJ). The very high values of current steepness and amplitude are only to obtain by a very low inductive generator design. The coaxial arrangement of the capacitor bank around a circular wave duct (Z_W = 2 Ω) permits a self-inductance of about 200 nH.

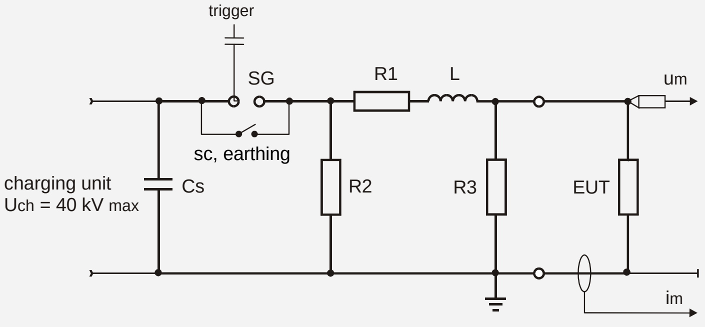


Figure 3: Principle circuit of a pulse generator for 8/20 µs wave-shapes

Figure 3 shows a test circuit for the generation of 8/20 µs impulse currents with peak values up to 100 kA.

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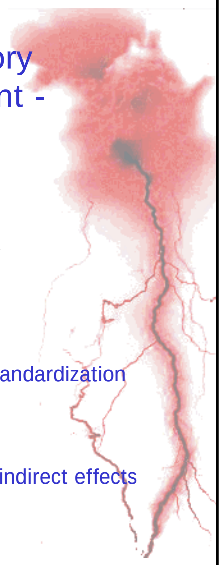

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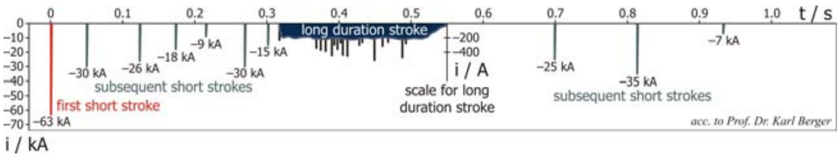
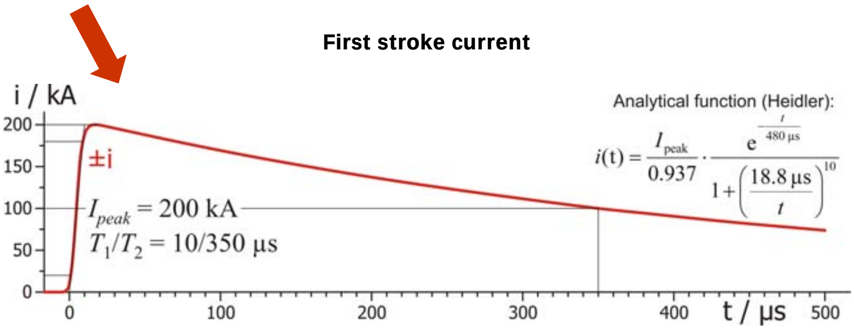
1. Parameters of lightning discharges – natural process and standardization
2. Lightning current tests, test procedures and typical effects
3. Generation of test currents for the simulation of direct and indirect effects
4. Short presentation of some investigations and testing tasks

1. Parameters of lightning discharges – natural process

Negative multiple lightning downward flash

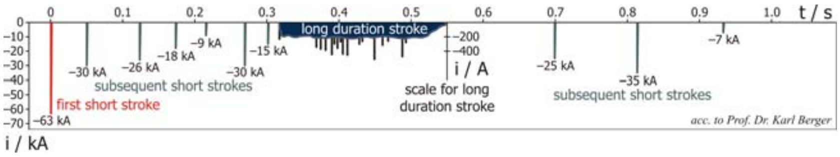


First stroke current

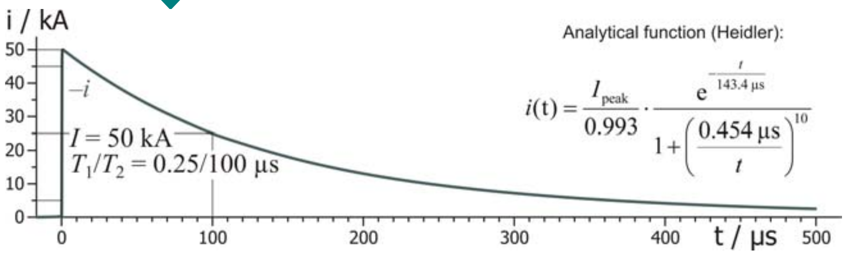


1. Parameters of lightning discharges – natural process

Negative multiple lightning downward flash



Subsequent stroke current



Analytical function (Heidler):

$$i(t) = \frac{I_{peak}}{0.993} \cdot \frac{e^{-\frac{t}{143.4\ \mu s}}}{1 + \left(\frac{0.454\ \mu s}{t}\right)^{10}}$$

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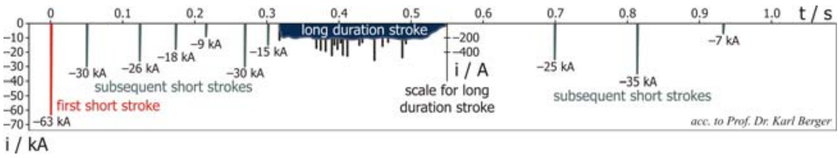
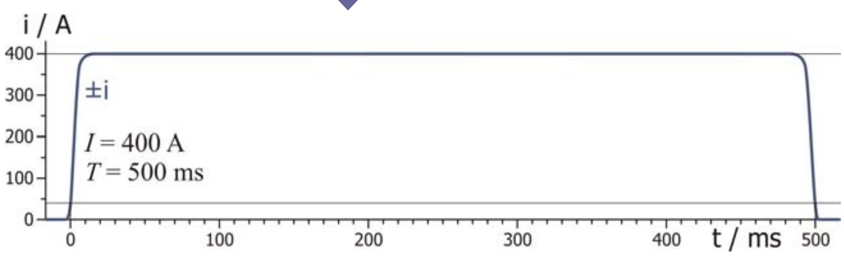
1. Parameters of lightning discharges – natural process

Negative multiple lightning downward flash

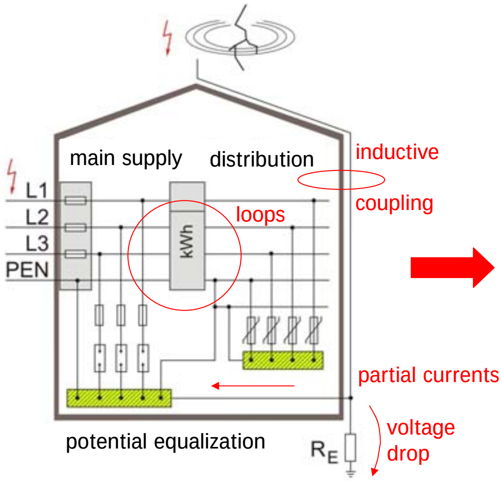


Rectangular impulse current

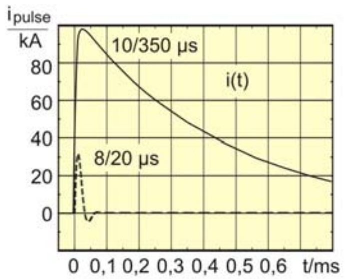


1. Parameters of lightning discharges – natural process

Direct lightning impulse currents

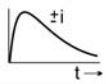
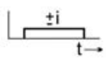
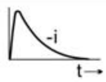


Coupling of indirect effects



Lightning surge current:
T1/T2 = 8/20 µs

1. Parameters of lightning discharges – standardization

partial currents of lightning discharges	protection level IV - I	typical wave shape
first stroke T_1 / T_2 = 10/350 µs peak current / kA specific energy / $\frac{MJ}{\Omega}$	100 ... 200 2,5 ... 10	
long duration stroke T_d = 0,5 s current / A charge / As	200 ... 400 100 ... 200	
subsequent stroke T_1 / T_2 = 0,25/100 µs peak Current / kA mean steepness / $\frac{kA}{\mu s}$	25 ... 50 100 ... 200	

Lightning current parameters acc. to EN / IEC 62305

- Mainly the current peak values and the integral parameters (W/R, Q, steepness) are defined in the standard. Current wave shapes are only recommended!
- The parameters are graduated in three steps acc. to the lightning protection level respectively the claim of protection.
- The surge current 8/20 µs is specified in different international standards like EN/IEC 62305 “Protection against lightning” or EN/IEC 61643 “Surge protective devices”.

2. Lightning current tests, test procedures and typical effects

Effect of lightning discharges: impulse voltage or current impulses?

- After the first development of the discharge, the lightning stroke is to consider as a very current-intensive charge equalization.

- Therefore, lightning impulse investigations in the laboratory are to differ in 2 objects:

  a) impulse **voltage** experiments → lightning impact, electric strength..
  b) **current** impulse experiments → current carrying capability, current behavior..

- Because of technical and physical limits, the simultaneous simulation of all lightning parameters and effects in the laboratory is not possible!

Typical lightning current effects are:

a) thermal effects, heating
b) electrodynamic effects, forces
c) sparking and origin of fire
d) melting and destruction of materials
e) critical voltage drops and disturbance currents
...

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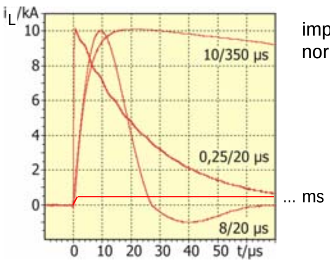
2. Lightning current tests, test procedures and typical effects

The different test currents are to distinguish by there typical threat parameters (W/R, Q, di/dt). The wide range of pulse parameters of the lightning test impulses demands different equipment for the pulse generation. Therefore, the lightning current tests are to realize acc. to the concrete task of the investigation.



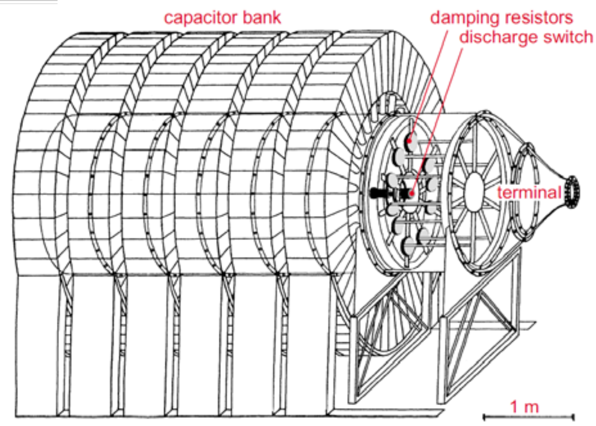
impulse currents normalized on 10 kA

effects	pulse parameters	lightning test currents

a) thermal effects, heating → highest pulse energy, highest peak values → first stroke current
b) electrodynamic effects, forces → highest peak values, current-time-area → first stroke current
c) sparking, origin of fire → highest peak values, dwell time → first stroke, long duration current
d) melting and destruction of materials → highest charge, dwell time → long duration current
e) voltage drops and disturbance currents → highest steepness → subsequent stroke current

3. Generation of lightning test currents

High-current pulse generator
- simulation of the first stroke current, direct effects -



Charging voltage: U_{ch} = 10 kV
charging device P = 17 kW

Storage capacitance: C_s = 10 mF
charge Q = 100 As
energy W = 500 kJ

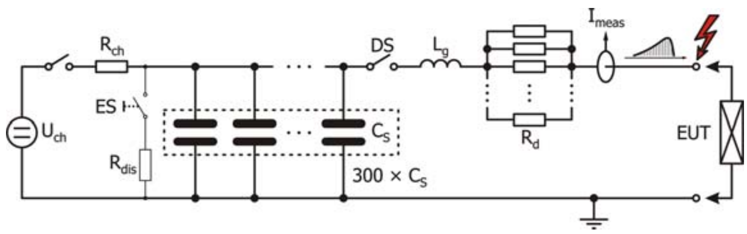
Typical impulse current:
waveform T_1/T_2 10/350 µs
peak value, up to 200 kA
specific energy 10 MJ/Ω

Construction:
extremely low-inductive generator design L_g = 200...300 nH due to a coaxial arranged wave duct

Damping resistance:
high-capacity resistors
R_d = 1 ... 0,05 Ω

3. Generation of lightning test currents

High-current pulse generator
- simulation of the first stroke current, direct effects -



- formerly designed as NEMP-generator, characteristic wave impedance Z_W = 2 Ω, highest current steepness by 2Ω-termination of the wave duct (I_{max} = 5 kA with U_{max} = 10 kV, T_1/T_2 = 100ns/10ms, R_d = Z_w)
- function as aperiodic damped resonant circuit with a very flexible arrangement, R-C-(L) are variable in a wide range
- the dumping switch is pneumatic operated, radial designed and very efficient
- the linking with other test equipment (long duration current generator) is possible

3. Generation of lightning test currents

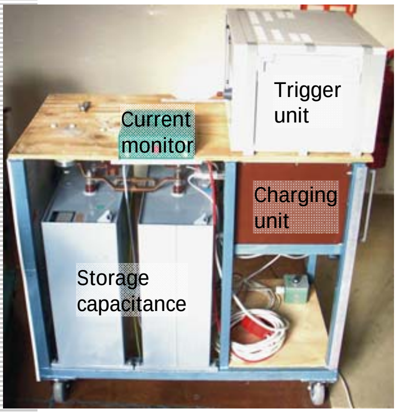
Photographic view of the high-current pulse generator

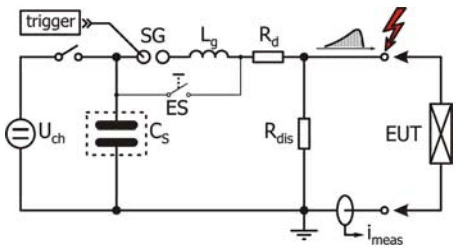
Investigations:
mechanical effects, resistive heating and melting, sparking, effects of electrodynamic forces, thermal damages on the attachment point, inductive coupling

Tests:
arresting / connecting components, surge protective devices, overvoltage arresters, coupling loops, cables, constructive arrangements and materials

3. Generation of lightning test currents

Smaller mobile lightning current generator





Charging voltage: U_{ch} = 10 kV

Storage capacitance: C = 500 µs
energy, charge W = 25 kJ, Q = 5 As

Typical impulse current:
waveform T_1/T_2 = 10/350 µs
peak value I_{peak} = 10 kA
specific energy W/R = 25 kJ/Ω

Total weight appr. 280 kg

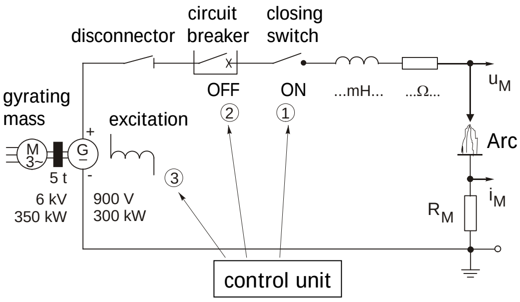
Impulse voltage:
waveform T_1/T_2 = 1/3000 µs
peak value U_{peak} = 10 kV

3. Generation of test currents for the simulation

Simulation of the long duration current – direct effects

Motor-generator set

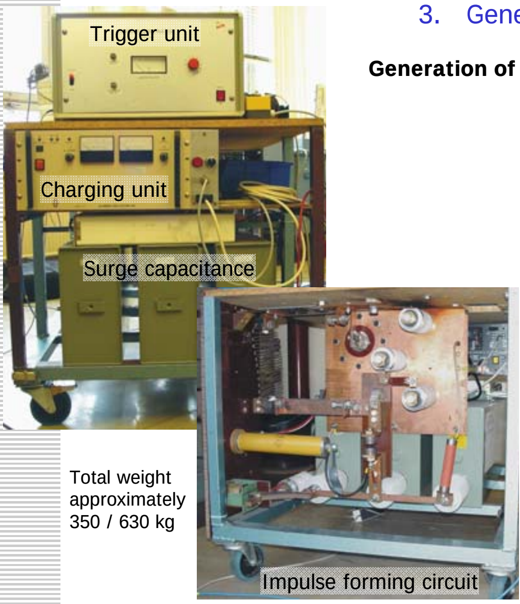
Equivalent circuit



Investigation and tests: melting effects on the lightning attachment point, heating on root points of arcs, origin of flammable temperatures and fire

3. Generation of test currents

Generation of the surge current – indirect effects



Total weight approximately 350 / 630 kg

Charging voltage:	U_{ch} = 40 kV
Configuration:	two stages
Surge capacitance:	C = 19.5 µF / 39 µF
charge	Q = 0.88 As / 1.76 As
energy	W = 16.7 kJ / 33.4 kJ
Typical impulse current:	
waveform	T_1/T_2 = 8/20 µs
peak value	I_{peak} = 50 kA / 100 kA
Impulse voltage:	
waveform	T_1/T_2 = 1.2/50 µs
peak value	U_{peak} = 40 kV
Design:	mobile generator
Function:	combination wave generator

Investigation and tests:

surge protective devices (SPD) and overvoltage arresters

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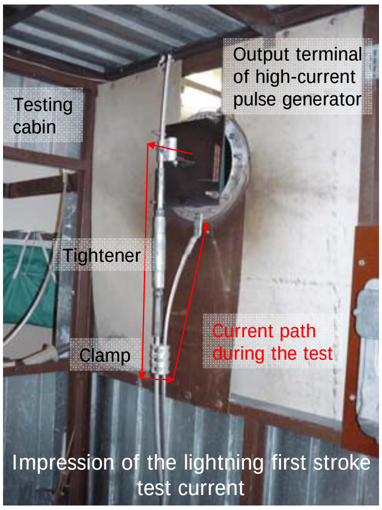
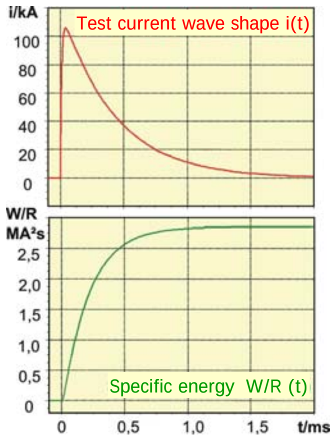
4. Short presentation of some investigations and testing tasks

Example 1: Effects on mounting components of overhead lines



Performance of the test:
Repeated stress with the test level H
(3 times, 100 kA 10/350 µs)



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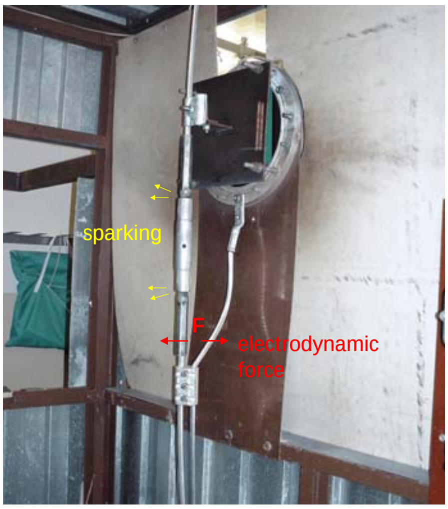
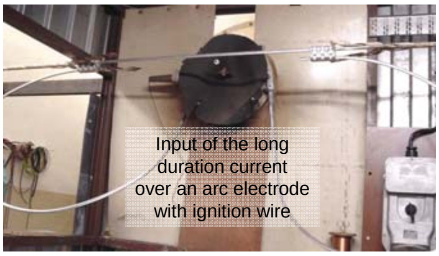


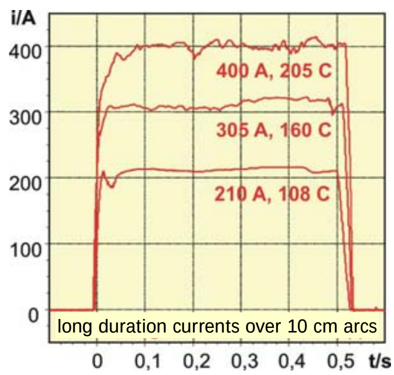
Typical effects of the pulse current stress

4. Short presentation of some investigations and testing tasks

Example 2: Melting effects on earth wires due to long duration current arcs



A high length of the test arc is necessary to reach of real results (l_{min} = 5 cm)!



4. Short presentation of some investigations and testing tasks

Example 2: Melting effects on earth wires due to long duration current arcs

Results in function of the load parameters:

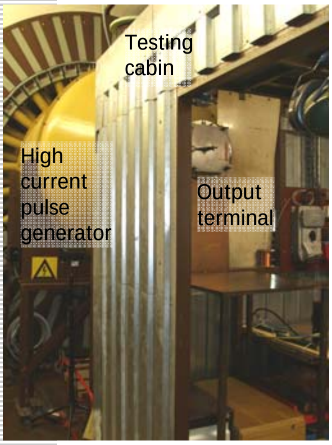
200 A – 0.5 s, 100 C
→ 3 single wires damaged

300 A – 0.5 s, 150 C
→ 4 single wires damaged

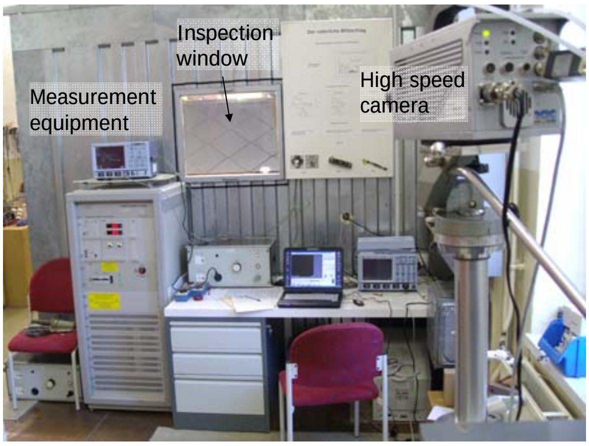
400 A – 0.5 s, 200 C
→ 4 single wires damaged

4. Short presentation of some investigations and testing tasks

Example 3: Lightning pulse current investigations on metal roofs



Lightning current laboratory



Measurement equipment

4. Short presentation of some investigations and testing tasks

Example 3: Lightning pulse current investigations on metal roofs