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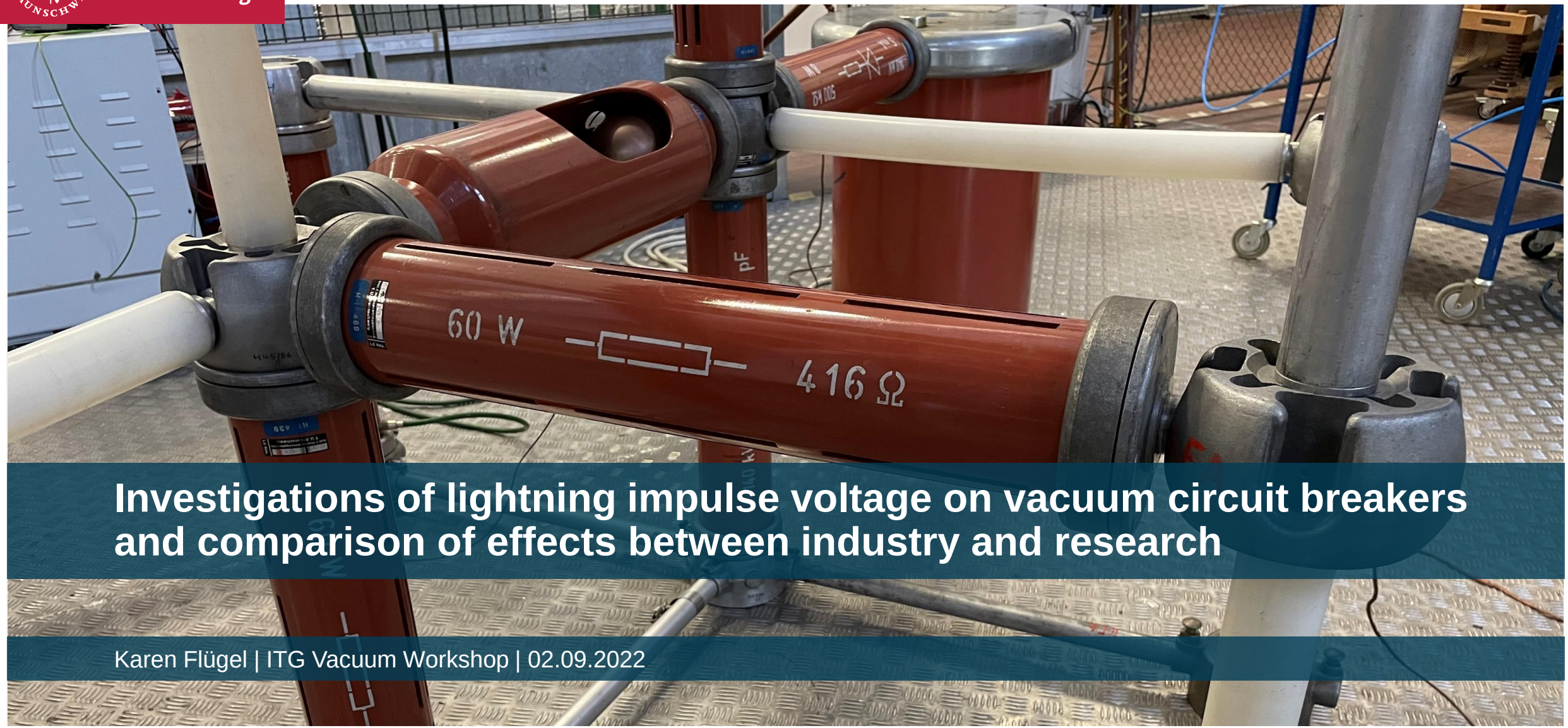



# Investigations of lightning impulse voltage on vacuum circuit breakers and comparison of effects between industry and research

Karen Flügel | ITG Vacuum Workshop | 02.09.2022

# Agenda

1. Motivation
2. Test methods of electrical strength
3. Test setup
4. Results
5. Conclusion

# Agenda

# Motivation

**Vacuum is a climate-neutral option to replace $SF_6$ as an insulating and switching gas.**

- Sulfur Hexaflouride ($SF_6$) is widely used as an insulating and switching gas in high-voltage circuit breakers.
- $SF_6$ is the strongest known greenhouse gas with a GWP of 23,900.


[10]

- In 2018, approximately 667 tons of $SF_6$ were used in electrical power engineering in Germany.
- The European Commission's goal is to achieve climate neutrality for Europe by 2050.


[9]

→ Vacuum offers itself as a climate-neutral and non-toxic insulating medium!

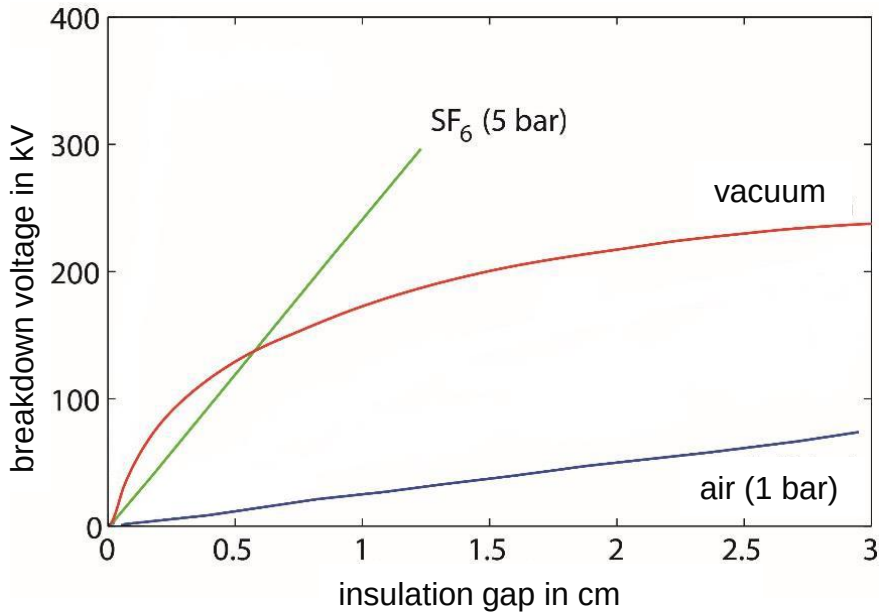
# Motivation

**Comparison of research-oriented measurements and realizations of industry can provide new insights.**

- Vacuum has already been established as an insulating and switching gas in medium voltage applications for decades.
- Vacuum circuit-breakers are characterized by maintenance freedom and a high number of switching cycles.
- Due to the degressive curve of the electrical strength, there is a need for research for use in high-voltage technology.

- Giere [3] has compared publications which experimentally show which lightning impulse voltage is possible at which gap.
- Transfer of possible breakdown voltage out of basic experiments to complex design of switching devices is challenging.

→ Comparison of research-oriented measurements and realizations of industry can provide new insights



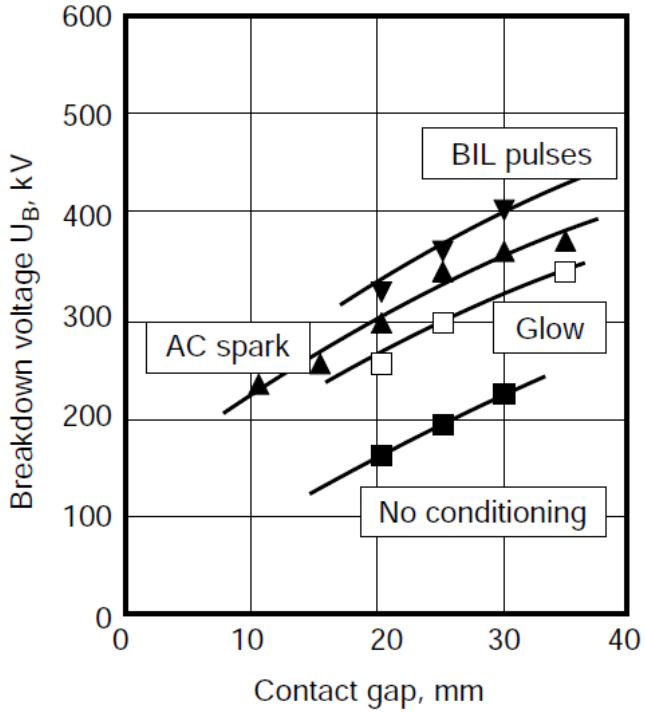

[8]

# Agenda

# conditioning processes

**A wide range of conditioning processes are used in research and industry.**

- Conditioning improves and stabilizes the electrical strength of a vacuum gaps by changing the electrode surface.
- For vacuum circuit breakers, 3 conditioning methods are most commonly used:
  - AC spark conditioning with limited current
  - LIV pulse conditioning with limited surge energy
  - current conditioning with contact opening under load and closing without load
- Other conditioning processes are used in research:
  - glow discharge with inert gas
  - pulsed electron beam treatment
  - various surface treatments (mechanical polishing, electropolishing)
  - bakeout processes

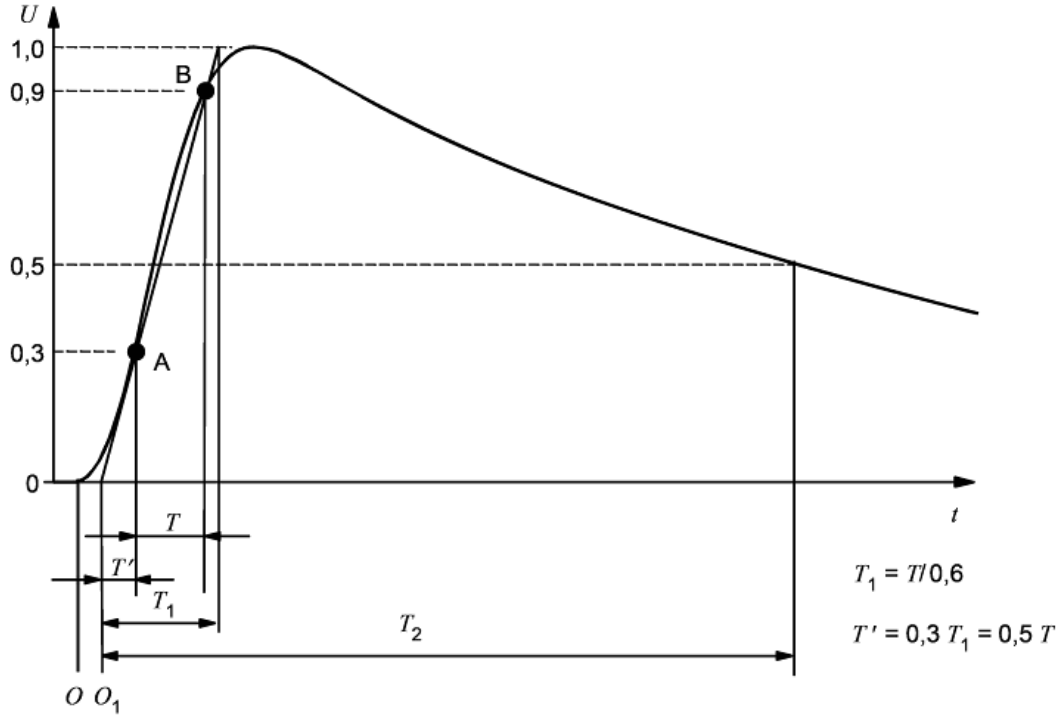



A comparison of different conditioning processes using Cu-Cr contacts [6]

# withstand voltage test for vacuum circuit breakers

**The test procedure for basic impulse level is specified according to the standard.**

- Tests in industry are carried out in accordance with the applicable standard.
- Using the test procedure for self-healing insulation:
  - value BIL according to standard
  - series with 15 pulses
  - maximum 2 breakdowns may occur for passing the test
  - no signs of failure of the non-self-healing insulation



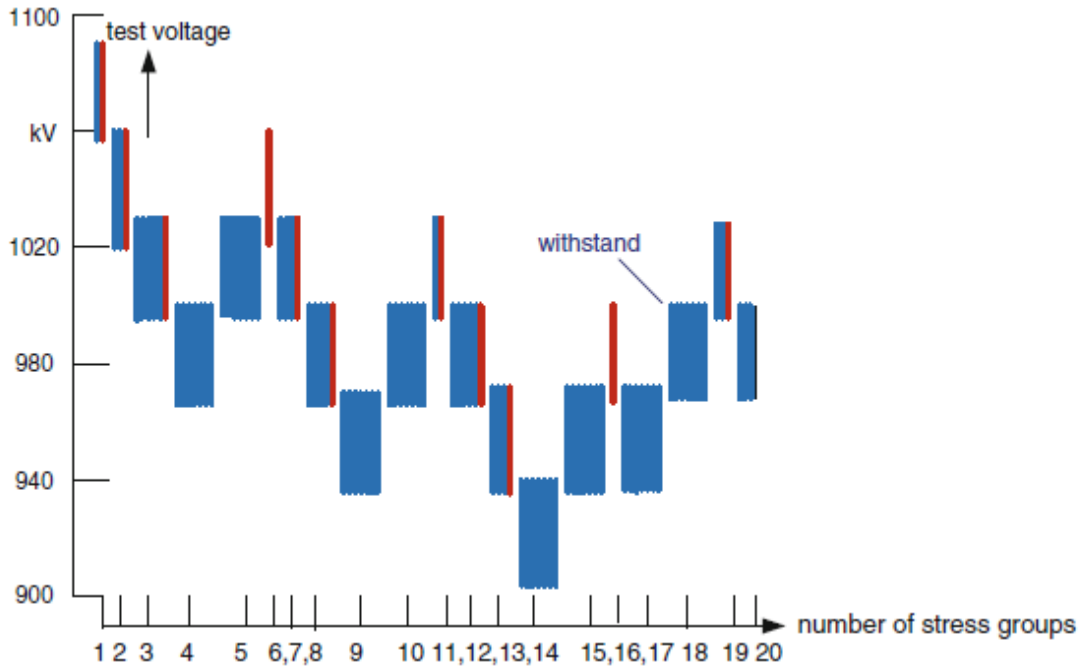

1,2 µs/50 µs- lightning impulse voltage [11]

# extended up-and-down method according to Powell and Ryan

**$U_{BD10}$ can be determined fast and simple with the extended up-and-down method.**

- Target value: 10 %-braekdown voltage $U_{bd10}$
- Using the withstand procedure of extended up-and-down method
  - Initial value: estimate for $U_{bd50} = \hat{U}_K$
  - $\Delta\hat{U}_K \approx \sigma$ standard deviation
  - $m = 7$ stresses per series
  - $n = 16$ series
  - $U_{bd10}$ corresponds to the arithmetic mean value

$$U_{bd10} = \frac{\sum n_i \cdot U_i}{n_i}$$




up-and-down test for the determination of the 10 % quantile [4]

# Agenda

# Test setup

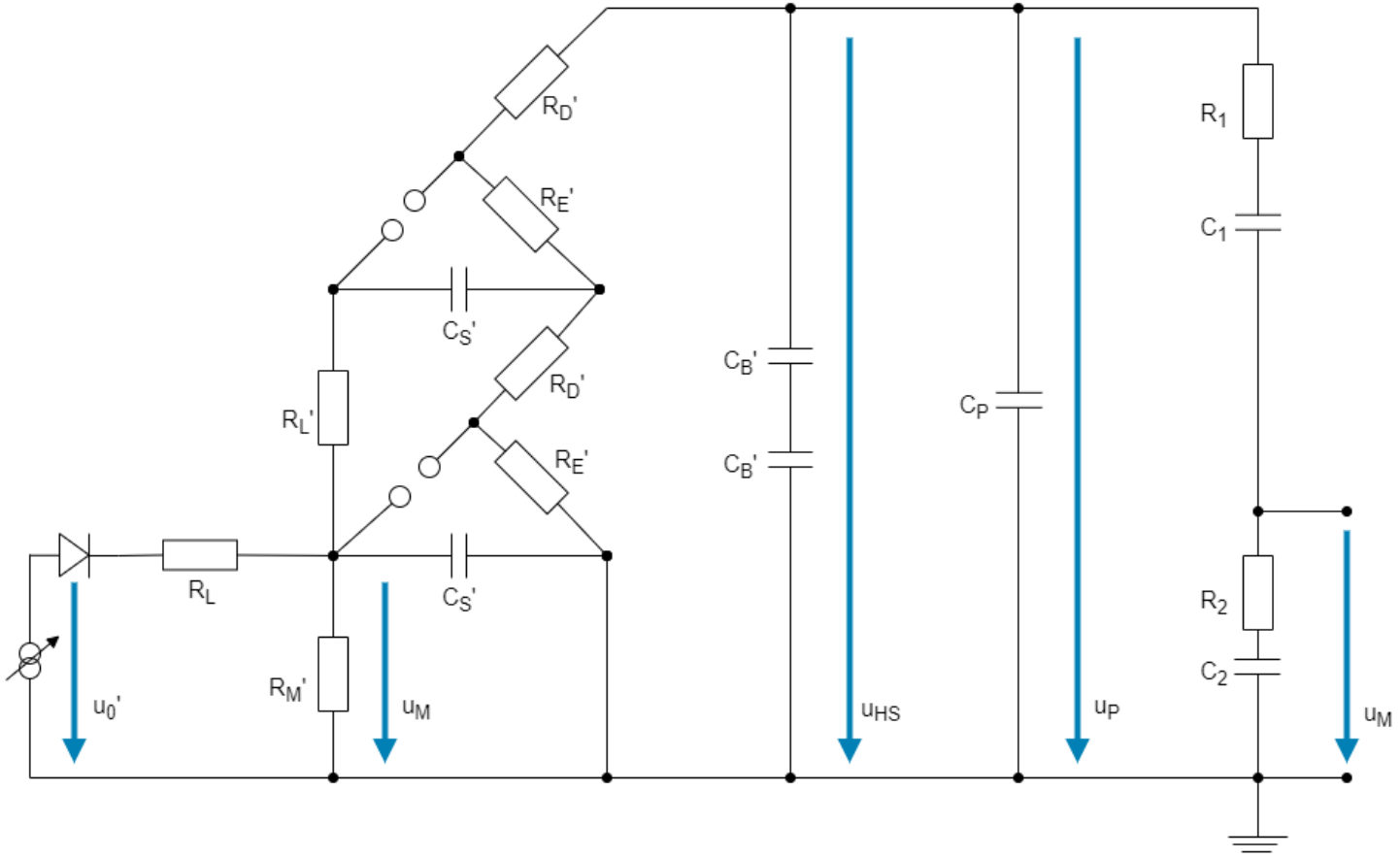
**Components for generating and measuring of lightning impulse voltage are given.**

$$R_E \cdot C_S \gg R_D \cdot C_B$$

$$W = 0{,}5 \cdot n \cdot C_S' \cdot (U_0')^2$$
$$W = 120\ \mathrm{Ws}$$

$$C_S' = 6000\ \mathrm{pF}$$
$$C_B' = 1200\ \mathrm{pF}$$

$$R_E' = 9500\ \Omega$$
$$R_D' = 416\ \Omega$$
$$R_L = 500\ \mathrm{k}\Omega$$
$$R_L' = 50\ \mathrm{k}\Omega$$
$$R_M = 280\ \mathrm{M}\Omega$$

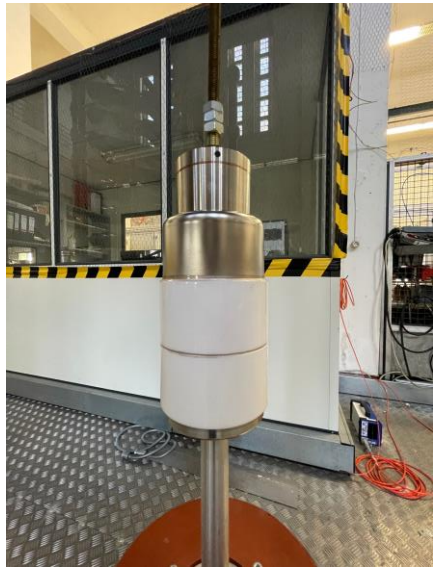


# Test setup

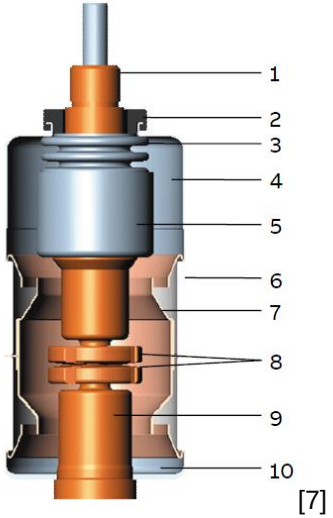
**A vacuum circuit breaker is the device under test and its structure in the test field.**

- vacuum circuit breaker ABB VG6
- rated lightning impulse voltage 95 kV
- contact gap 17 mm

- tested in air without outer insulation
- Isopropanol cleaning
- elevated position for less ground potential influence



| | |
|---|---|
| 1 | Stem / Terminal |
| 2 | Twist protection |
| 3 | Metal bellows |
| 4 | Interrupter lid |
| 5 | Shield |
| 6 | Ceramic insulator |
| 7 | Shield |
| 8 | Contacts |
| 9 | Stem / Terminal |
| 10 | Interrupter lid |




[7]

# Test setup

**Test setup placed in the high voltage laboratory of elenia consisting of voltage divider, DUT and LIV generator.**

# Agenda

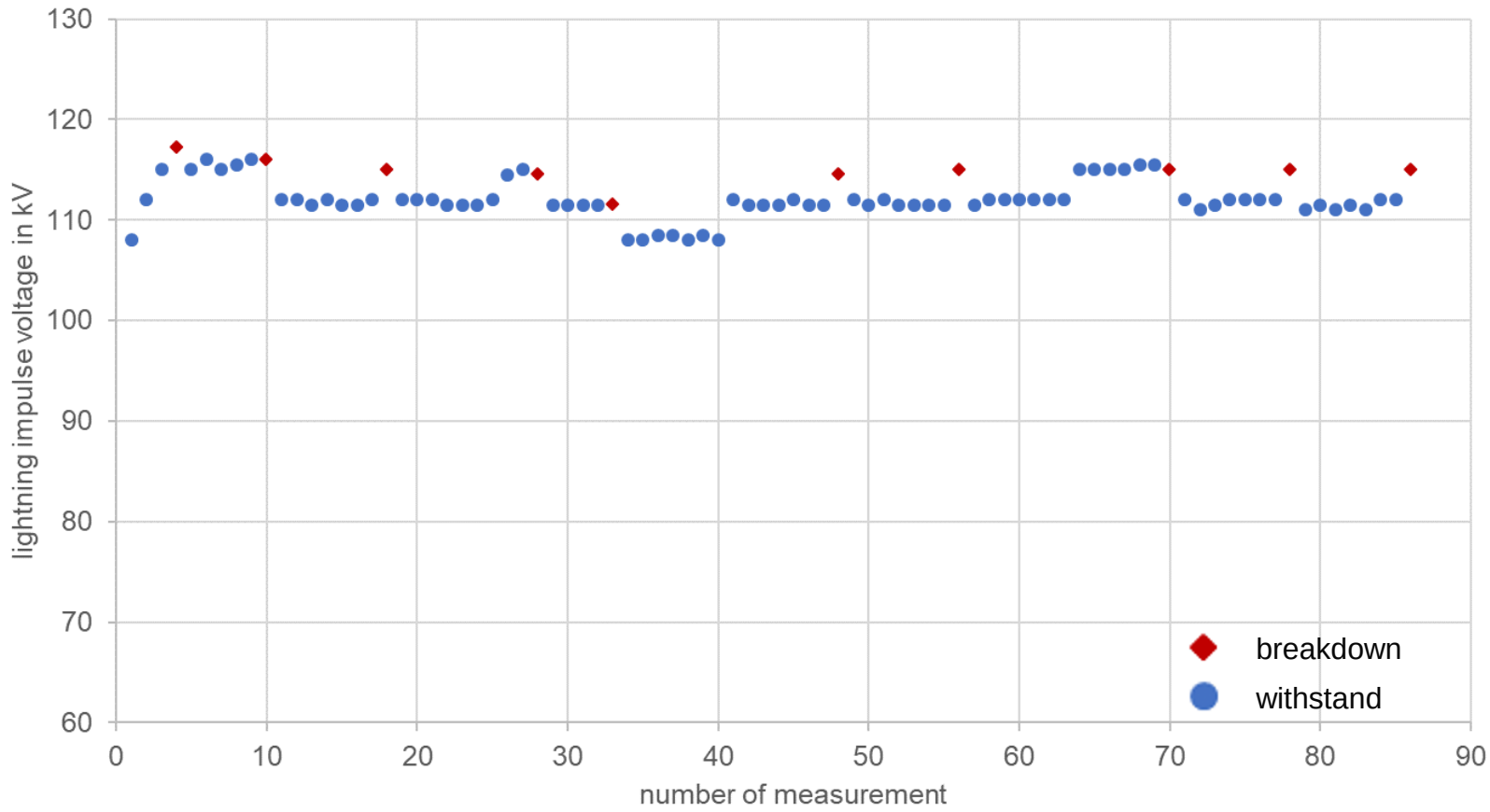
# Results of LIV measurements

**With the extended up-and-down method the 10% breakdown voltage could be determined.**

- Ambient conditions:
  996,7 hPa
  26,9° C
  50 % r.H.

- $U_{BD10}$ = 112,9 kV

- $\sigma \approx 3{,}5$ kV

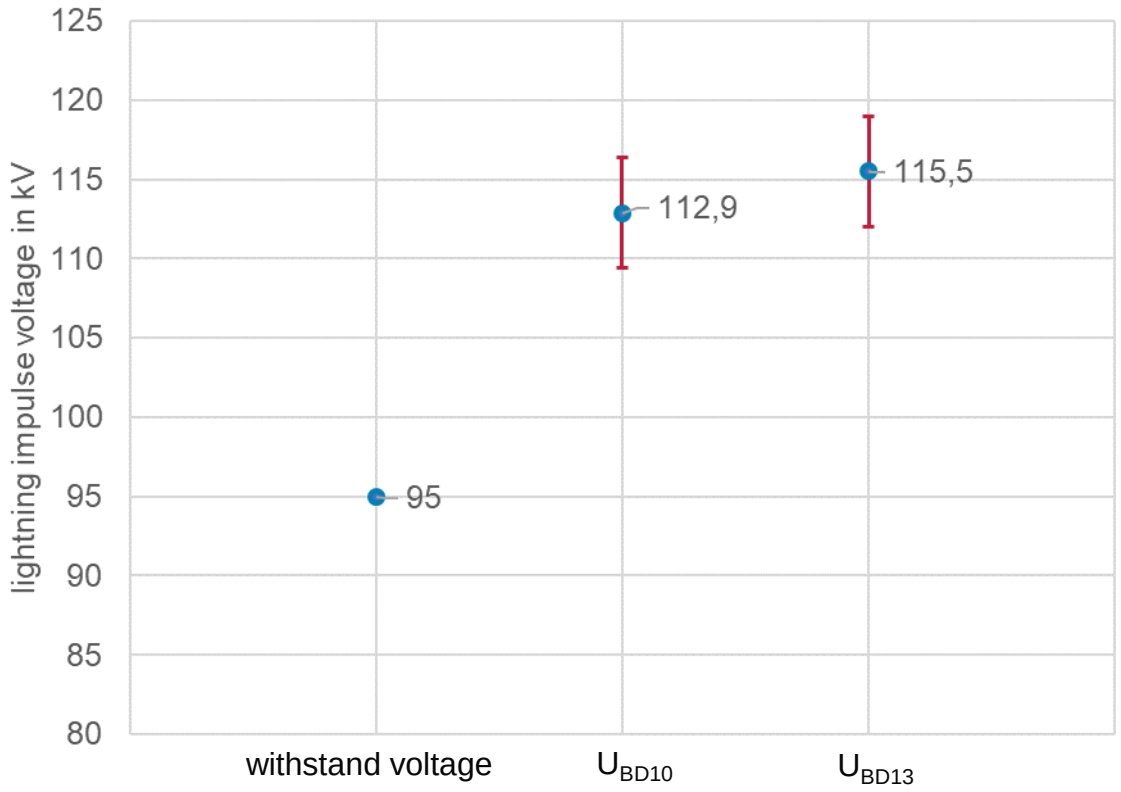


# Comparision with BIL levels of the industry

**As expected, 10% breakdown voltage is higher than the withstand voltage.**

- Differences in the test procedures:
  - different test fields with different measuring devices
  - setup according to standard with 3 phases and housing
  - Environmental conditions

$$U_{Withstand} < U_{BD10} < U_{BD13}$$
$$95\ kV < 112{,}9\ kV < 115{,}5\ kV$$



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# Conclusion

**Measurements on vacuum circuit breakers in research and industry are comparable.**

- Vacuum is a climate-neutral option to replace $SF_6$ as an insulating and switching gas.
- Comparison of research-oriented measurements and realizations of industry can provide new insights.

- A wide range of conditioning processes are used in research and industry.
- The test procedure for basic impulse level is specified according to the standard.
- $U_{BD10}$ can be determined fast and simple with the extended up-and-down method.

- Components for generating and measuring of lightning impulse voltage are given.
- A vacuum circuit breaker is the device under test and its structure in the test field.
- Test setup placed in the high voltage laboratory of elenia consisting of voltage divider, DUT and LIV generator.

- With the extended up-and-down method the 10% breakdown voltage could be determined.
- As expected, 10% breakdown voltage is higher than the withstand voltage.

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# Thank you for your attention

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# Abstract

Avoiding the use of sulfur hexaflouride ($SF_6$) as an insulating and switching gas is important for the goal of reducing greenhouse gas emissions from energy production and distribution. Particularly vacuum insulated switchgears are suitable to replace $SF_6$ switches due to their climate neutrality and non-toxicity. Vacuum circuit breakers (VCB) have been established for decades in medium-voltage systems, and research and development are in progress for high-voltage applications. In addition to modified short-circuit currents and larger gap distances [1], the electric strength of vacuum insulation for high voltage is an important issue. Due to the degressive curve of the electrical strength of the vacuum, multiple interruptions are used for high voltages [2]. As the highest voltage occurring in the grid, the lightning impulse voltage (LIV) is decisive for the investigation of the electric strength. Giere [3] has compared some publications which experimentally show which lightning impulse voltage is possible at which gap. In particular, it is shown that the conversion of electric strength from basic experimental setups to the complex design of a vacuum circuit breaker is challenging. [3]

In this publication, measurements will be made on industrial VCBs by the up-and-down method using the withstand procedure according to Powell and Ryan [4]. A LIV generator is used to generate the LIV and a Zaengl voltage divider is used to measure the applied voltage and breakdown voltage. The measurements on a test field of the research are carried out after LIV conditioning. The experimental results are compared with lightning impulse withstand levels of the industry.

The common researches are dominated by experiments on electrode setups with investigation of the influence of the gap, the area and the electrode surface. Usually the up-and-down method is used to determine the 50 % breakdown voltage [4]. In contrast, industry relies on tests to determine the lightning impulse withstand voltage when investigating complex chambers. In the case of vacuum circuit-breakers with contacts, metal vapor condensation shields and ceramics for use in the power grid, the internal electric strength is just as important as the external electric strength [5]. Here, the focus is on the reliability of the insulation for a long period of time. When comparing the measurements from research and industry, the differences in the possible conditioning processes are also obvious. Here, conditioning processes with high AC voltage, LIV pulse or glow discharge as well as various surface treatments and bakeout processes can be used. [6]

- von der Europäischen Kommission am 30. September 2020 veröffentlichten Bericht "*Assessing the availability of alternatives to fluorinated greenhouse gases in switchgear and related equipment, including medium-voltage secondary switchgear*"