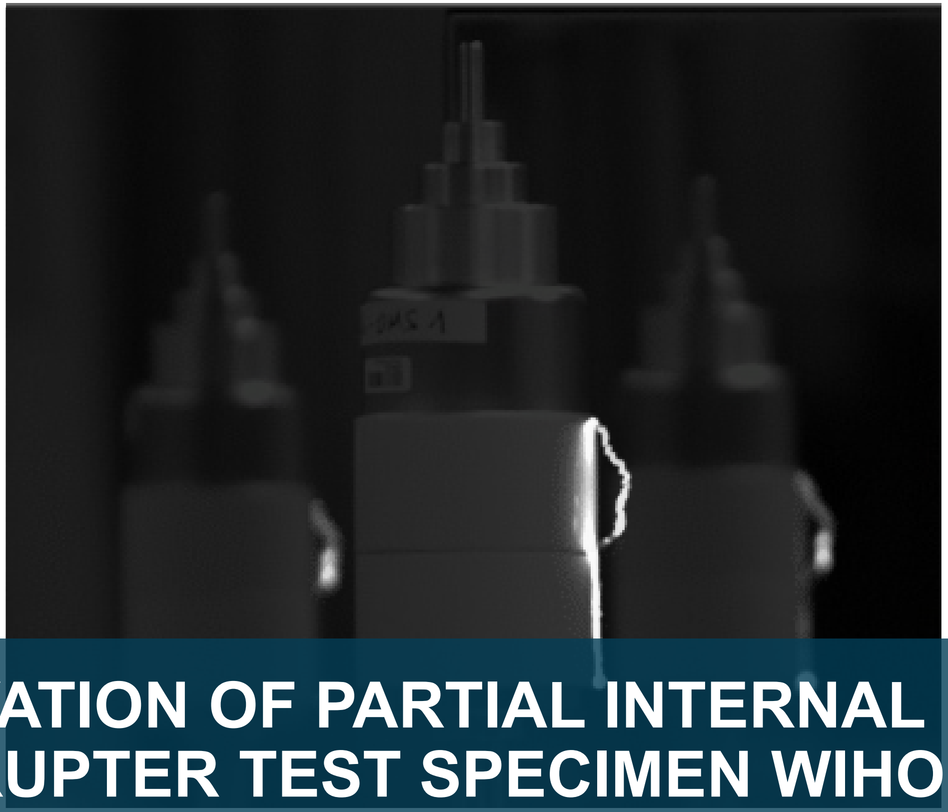
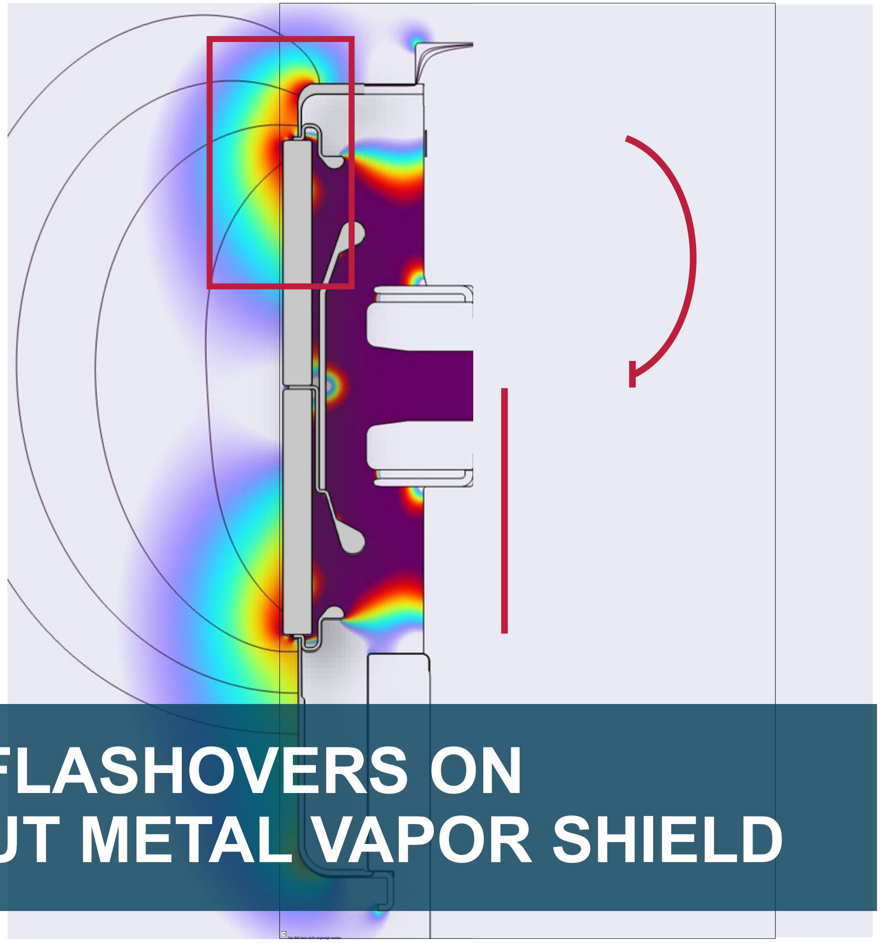




OBSERVATION OF PARTIAL INTERNAL FLASHOVERS ON VACUUM INTERRUPTER TEST SPECIMEN WIHOUT METAL VAPOR SHIELD

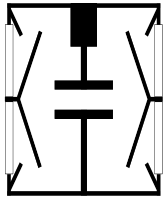
Kai Schulze, Karen Flügel, Dietmar Gentsch, Michael Kurrat | ITG Vacuum Workshop | 28.08.2026

Motivation

The improvement of dielectric on vacuum interrupters requires better understanding of the flashover process

[VDE]

- Regulation of the use of fluorinated greenhouse gases and prohibition of SF_6 by European Union (EU) [2]
- Replacement of SF_6 as an external insulating and switching gas in medium and high voltage is necessary



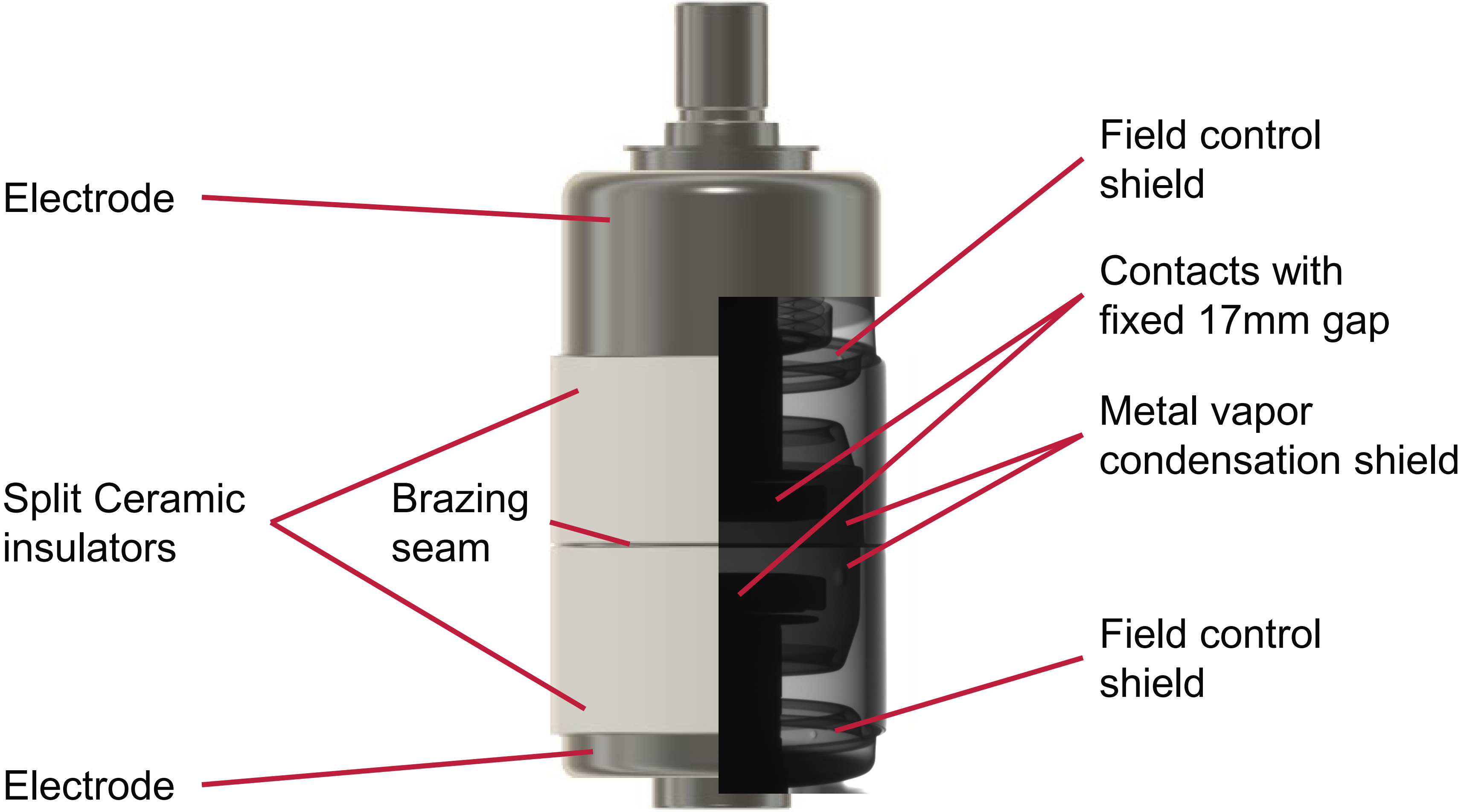
- Vacuum interrupter (VI) as environmental friendly alternative (already widely used in medium voltage)
- Switching and dielectric behavior needs to be improved for high voltage application

- Requirements for the manufacturing process and the internal dielectric influence external dielectric behavior
- Changing inner structure to determine influence on flashover patterns

1 The vacuum interrupter

The vacuum interrupter

Important aspects of the vacuum interrupter as insulation system



The vacuum interrupter

VI design without metal vapor condensation shield

Objective

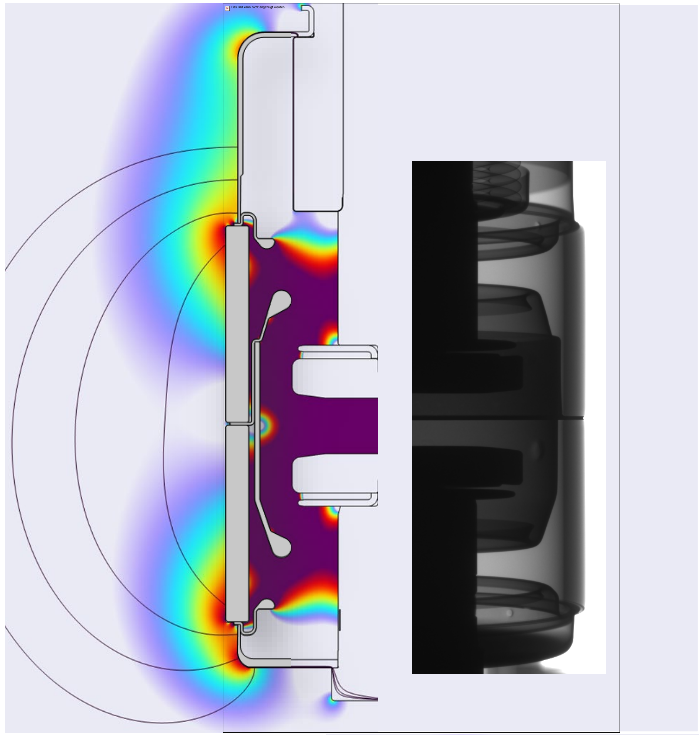
- Understanding the influence of the metal vapor shield on flashovers

Implementation

- VI ABB VG6 in ambient air
- Two DUT with different metal vapor shield configurations
  - Full shield (REF)
  - Without metal vapor condensation shield (OMS)

REF

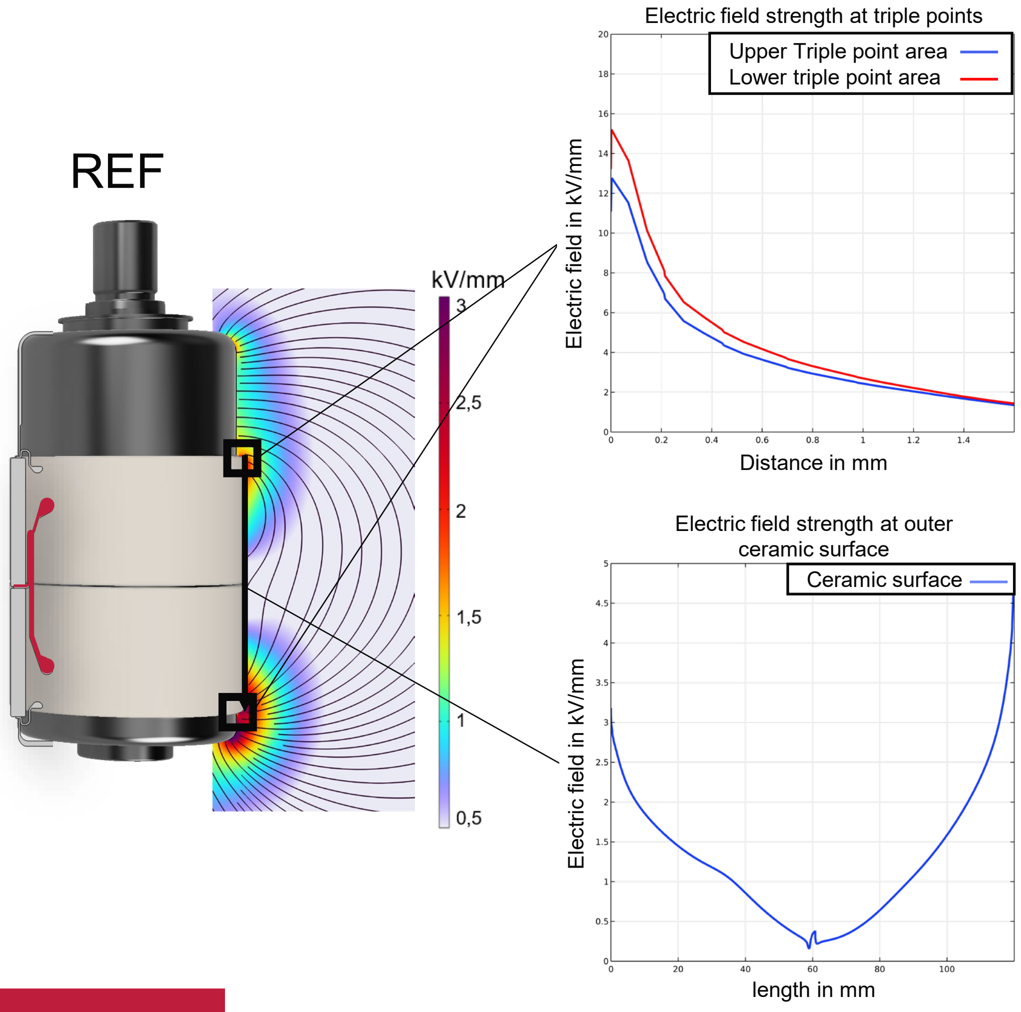
OMS

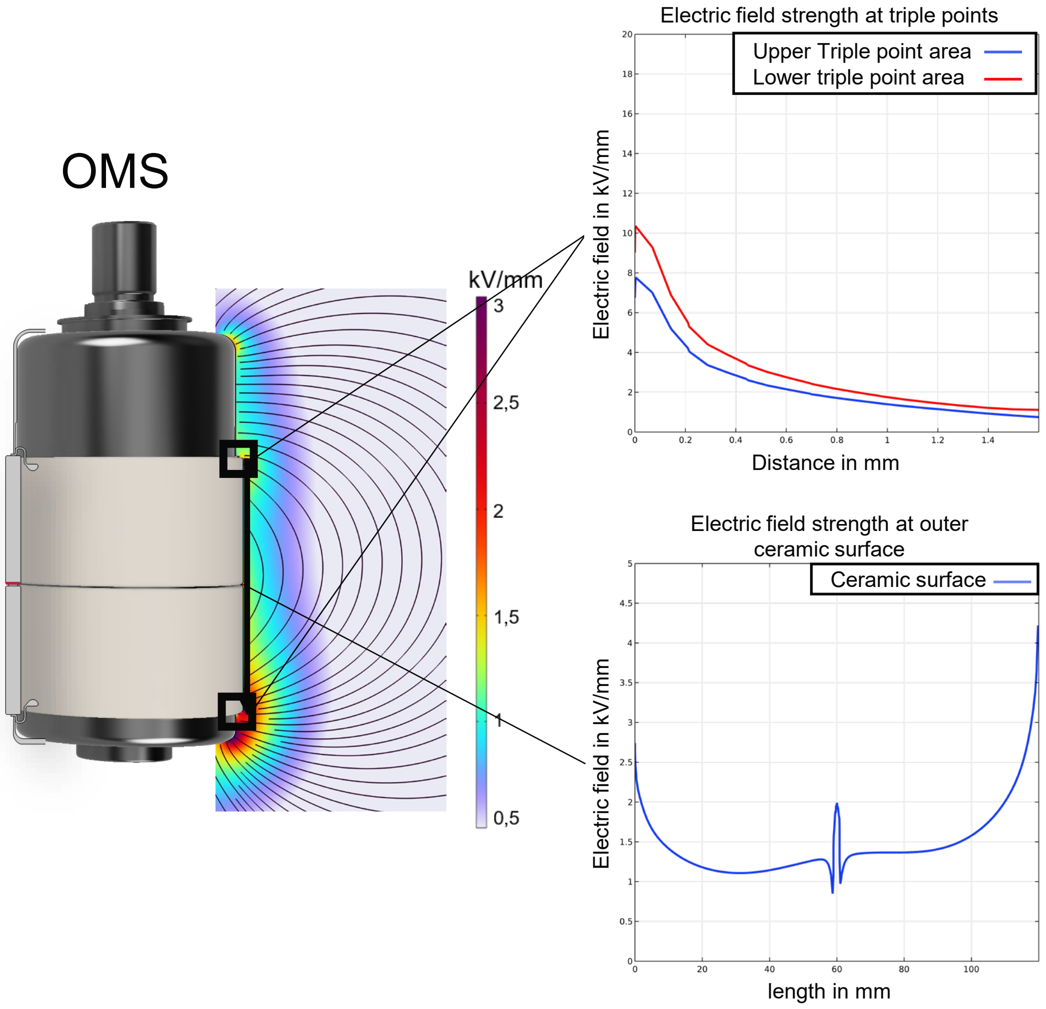


2 Electric field simulation

Electric field simulation

Influence of metal vapor shield on external electric field at 130 kV potential difference

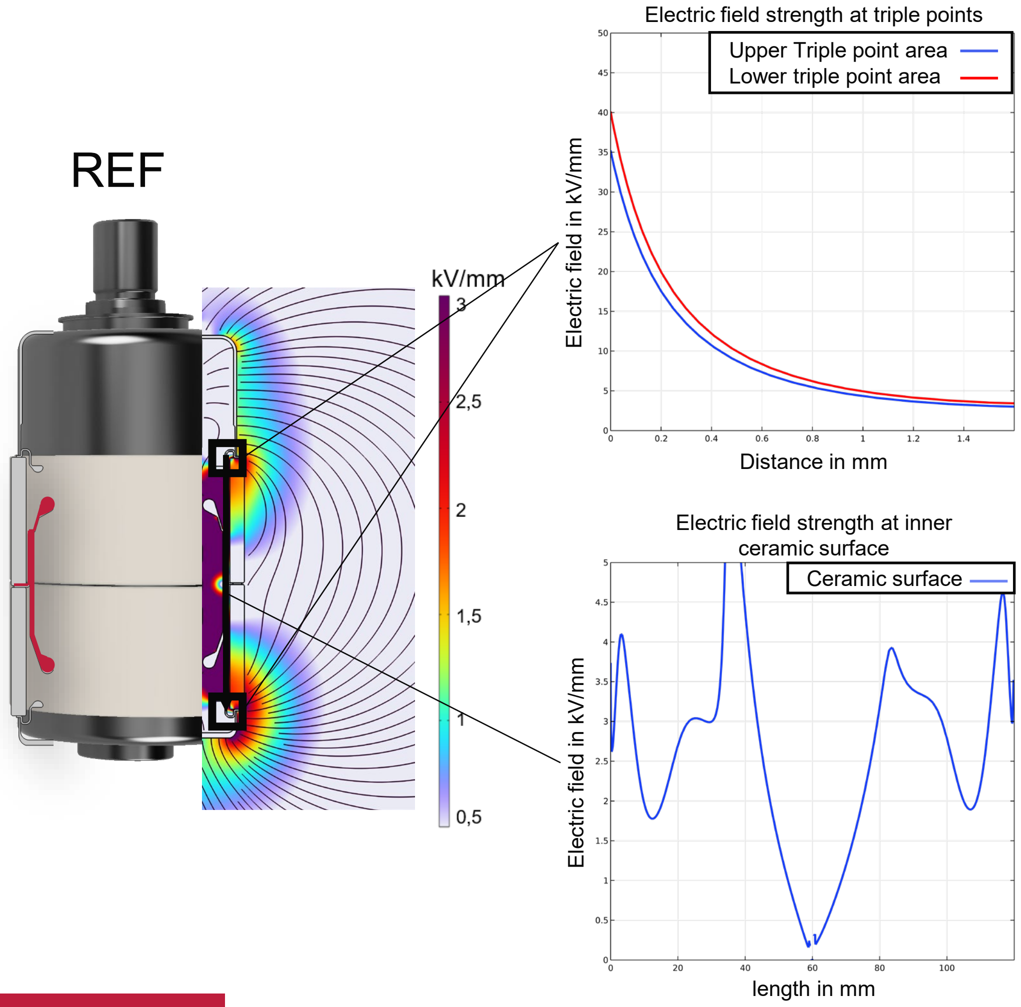




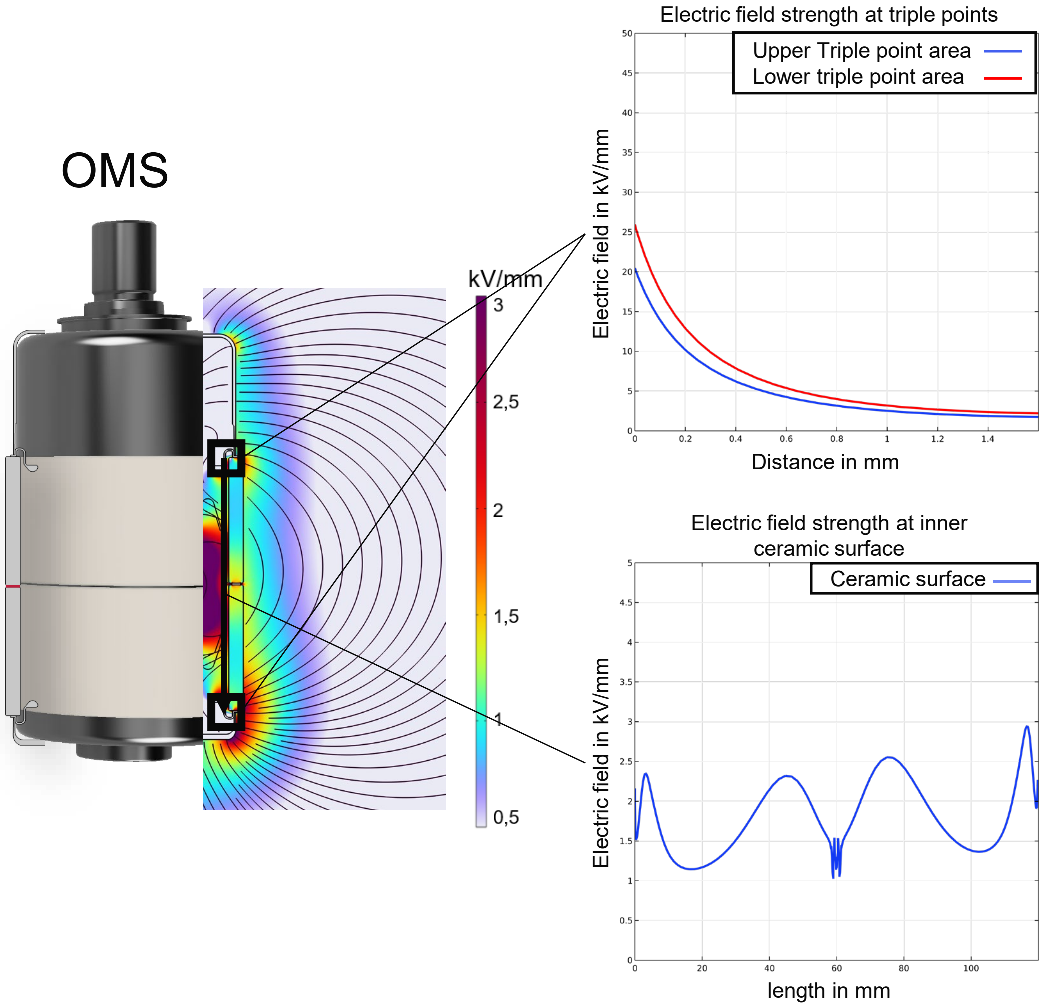
Electric field simulation

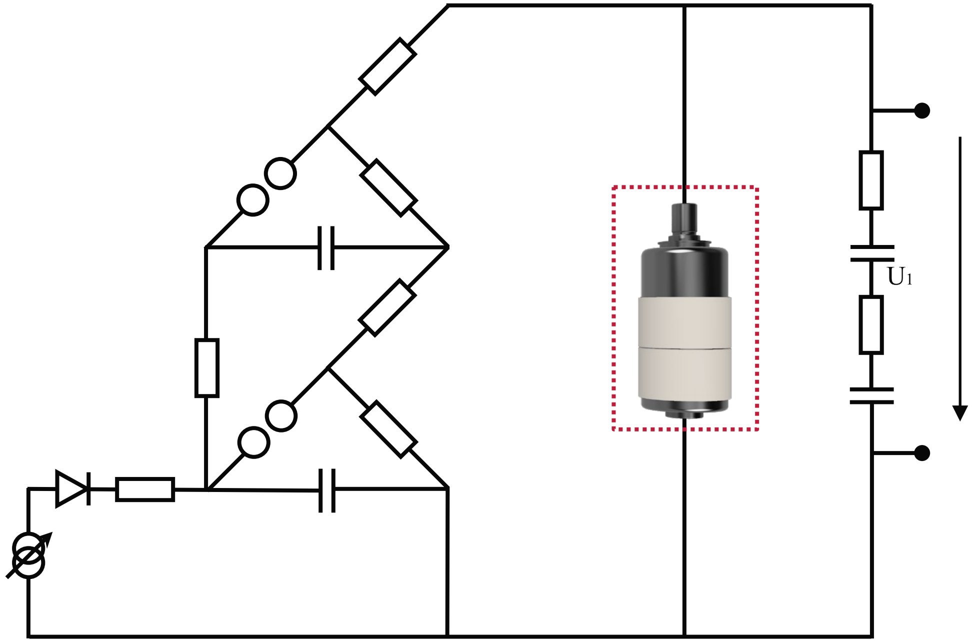
Influence of metal vapor shield on internal electric field at 130 kV potential difference

REF



OMS



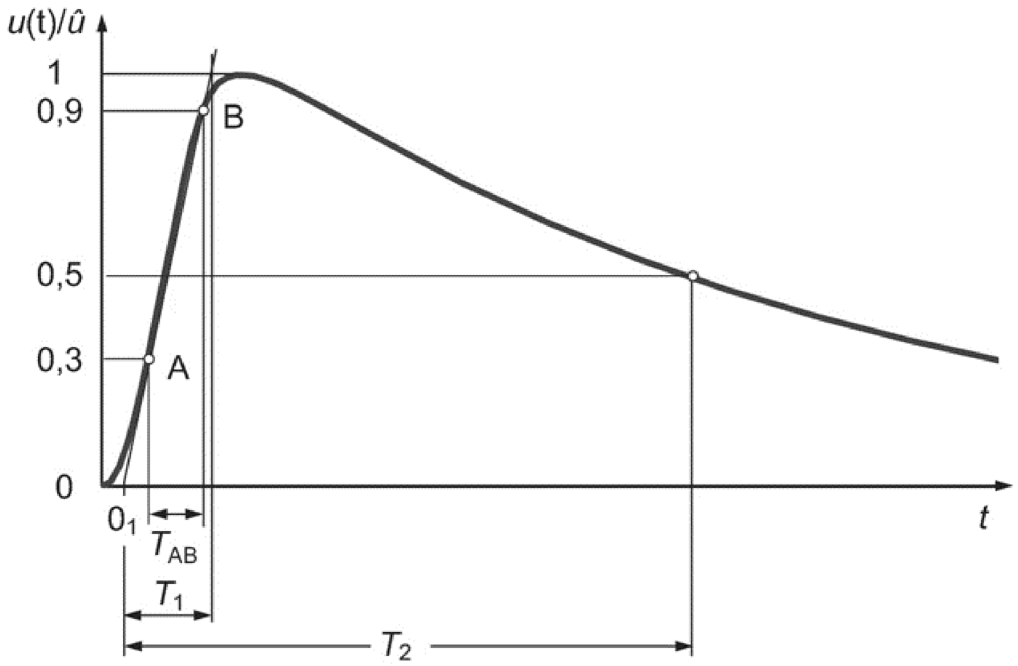


3 Test setup

Test setup

Testing environment and methodology for testing with Lightning impulse voltage

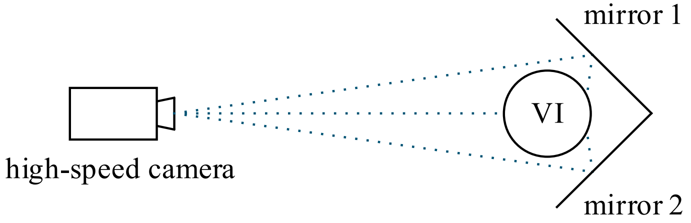
- 1.2/50 lightning impulse voltage (LIV) stress
  - Positive and negative polarity
  - Both vertical orientations of the VI
- Determination of statistical withstand voltage using up-and-down method
  - Till 50 discharges reached



Test setup

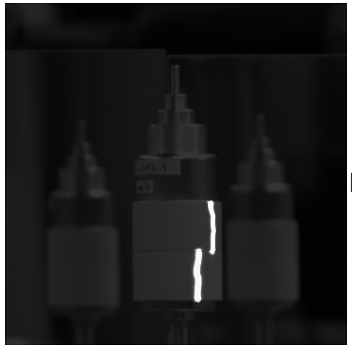
Analyses of external flashover pattern with high speed camera footage

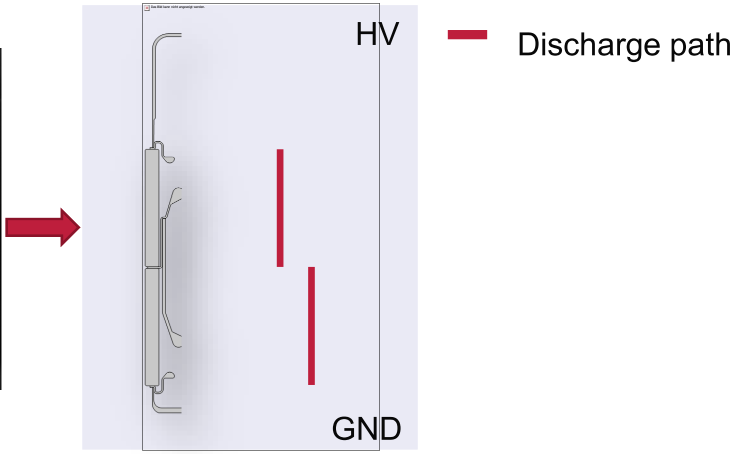
- Analyses of flashover pattern using speed camera recordings
  – 36.000 fps
  – Mirror setup for full view of external VI insulation

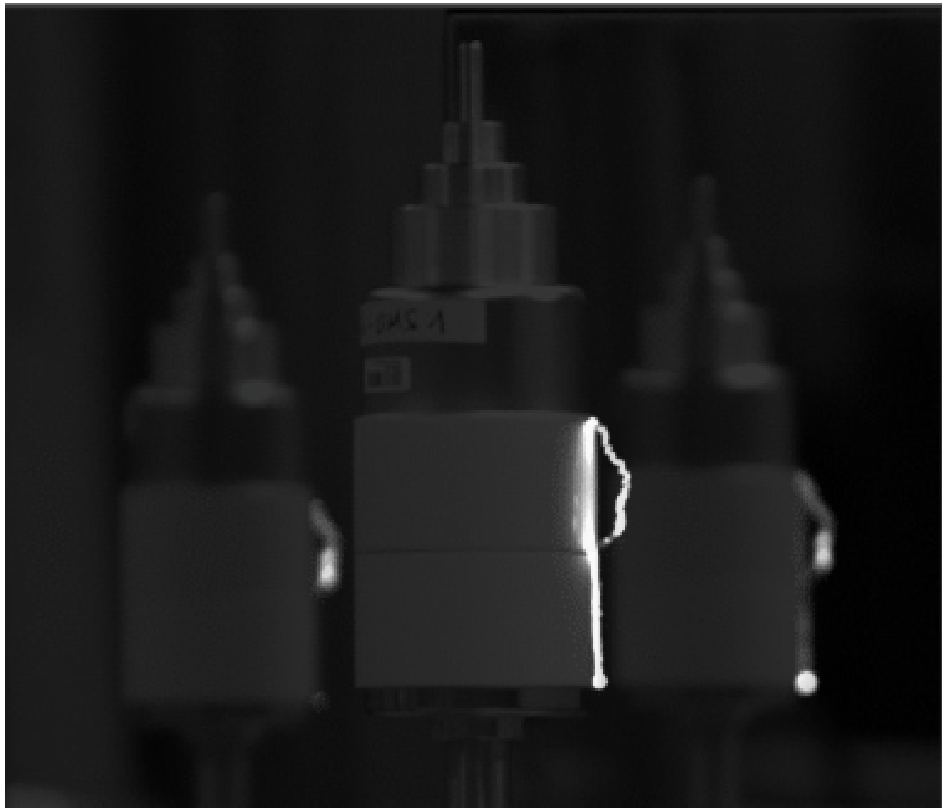


- Example: typical discharge REF VI with negative polarity stress
- Discharge path clearly visible
- Split of flashover path with offset at brazed seam
- Flashover follows ceramic surface

→ Complete external surface flashover






4 Test results

Voltage Results of metal vapor shield variations

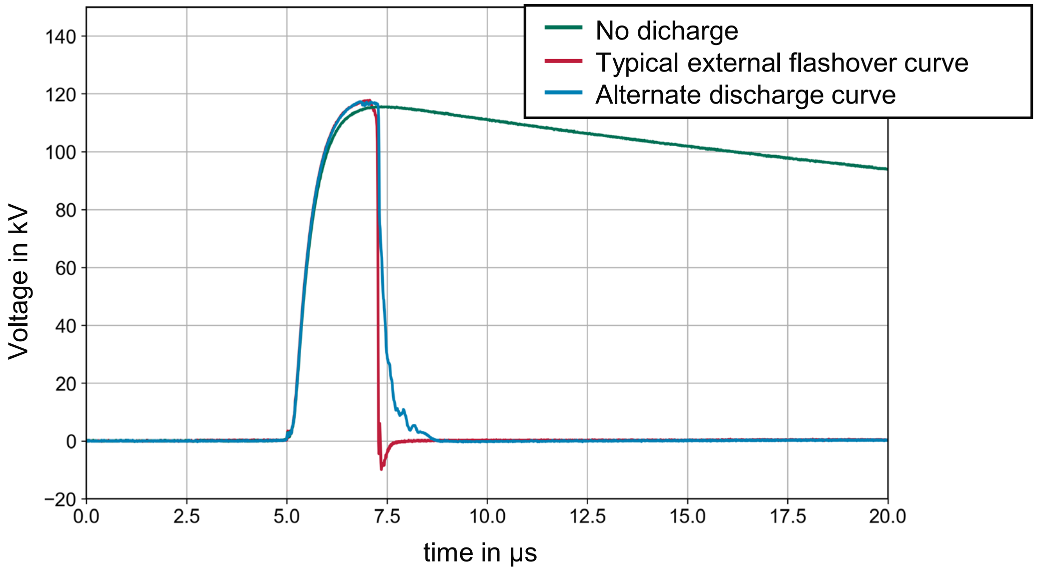
Comparison of withstand voltages and discharge curve characteristics

Statistical Withstand Voltage (U_{D50})

	REF	OMS	Difference
Pos.	113 kV	124 kV	+8.9 %
Neg.	-127 kV	-172 kV	+26.2 %

	REF inv.	OMS inv.	Difference
Pos.	104 kV	126 kV	+17.5 %
Neg.	-124 kV	-122 kV	-1.6 %

Voltage Characteristic of flashover



Voltage Results of metal vapor shield variations

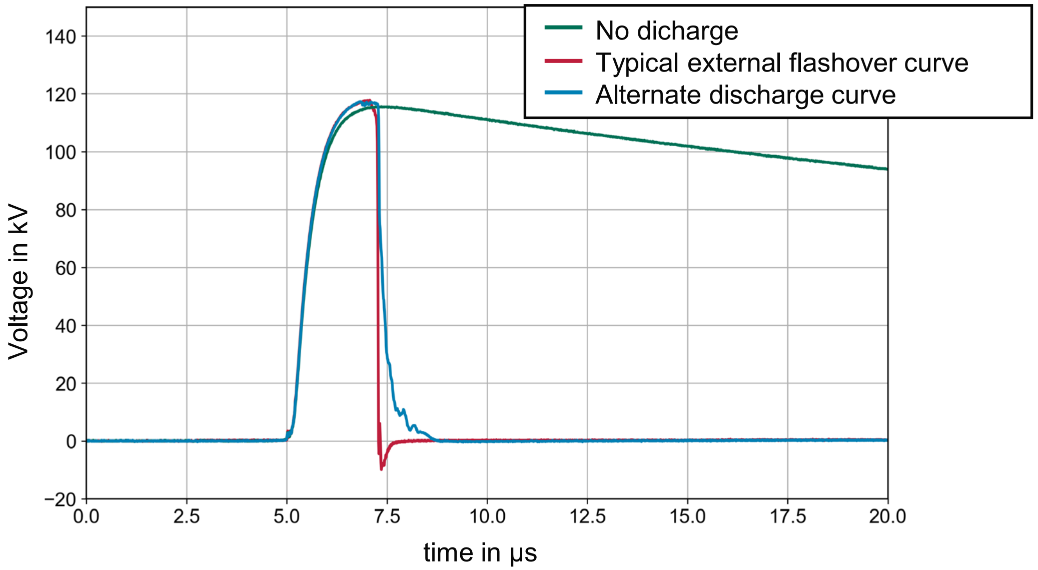
Comparison of withstand voltages and discharge curve characteristics

Statistical Withstand Voltage (U_{D50})

	REF	OMS	Difference
Pos.	113 kV	124 kV	+8.9 %
Neg.	-127 kV	-172 kV	+26.2 %

	REF inv.	OMS inv.	Difference
Pos.	104 kV	126 kV	+17.5 %
Neg.	-124 kV	-122 kV	-1.6 %

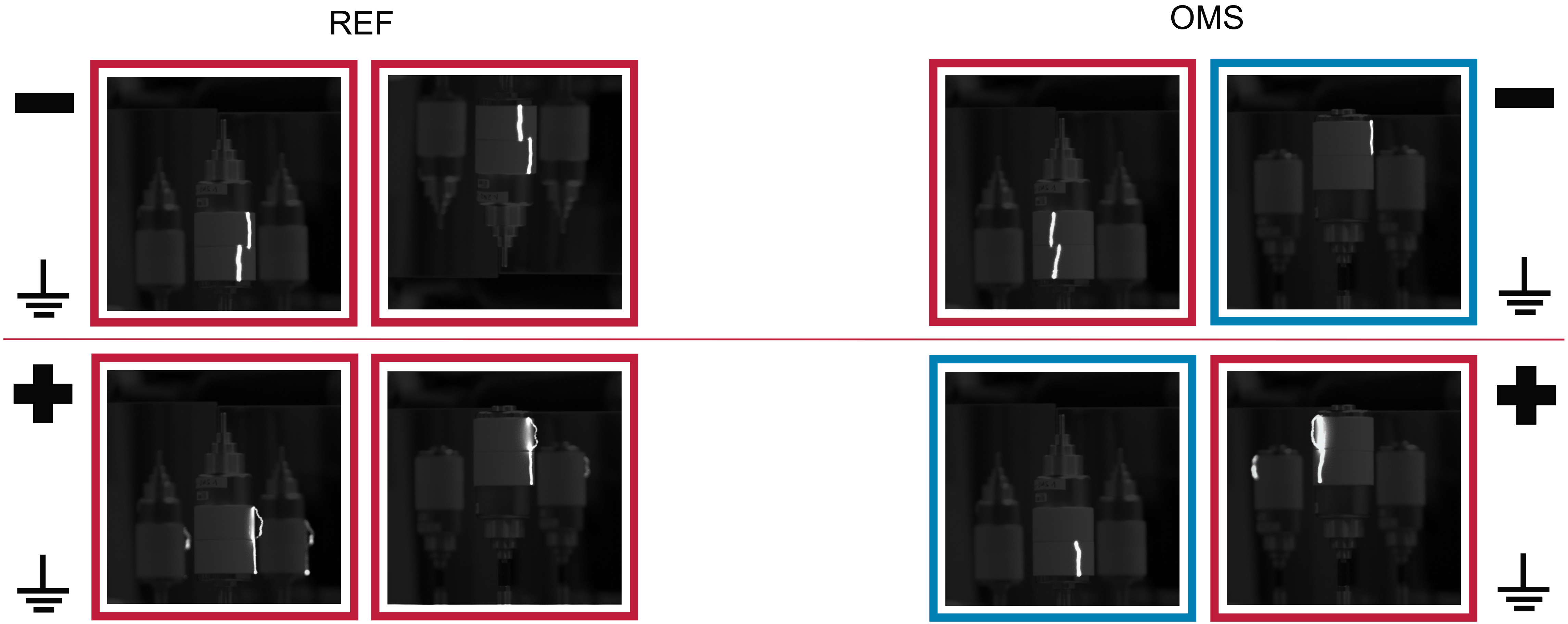
Voltage Characteristic of flashover

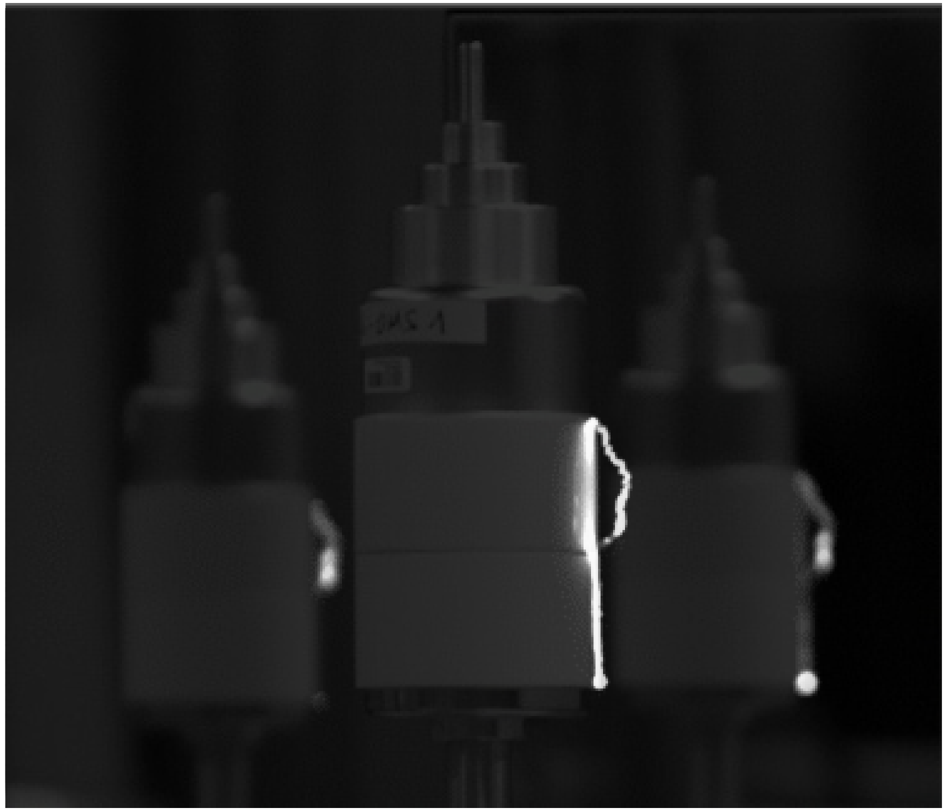


- External flashover: steep flank when breakdown happens → typical external flashover behavior
- Alternate discharge: exponential decrease in flank while breakdown → indicates change in discharge process

Effects on flashover patterns

Differences in dominant flashover pattern for tested configurations



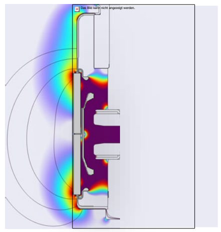


5 Summary

Summary

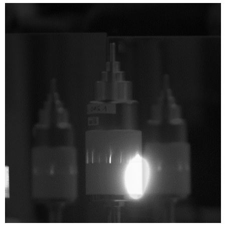
Observed internal flashover on Vacuum Interrupter without metal vapor shield

- The complete climate-neutral solution of vacuum circuit breakers requires an improved dielectric
- Simulation and experimentation based studies without metal vapor condensation shield were conducted



Which dielectric behavior can be expected without metal vapor condensation shield based on simulation?

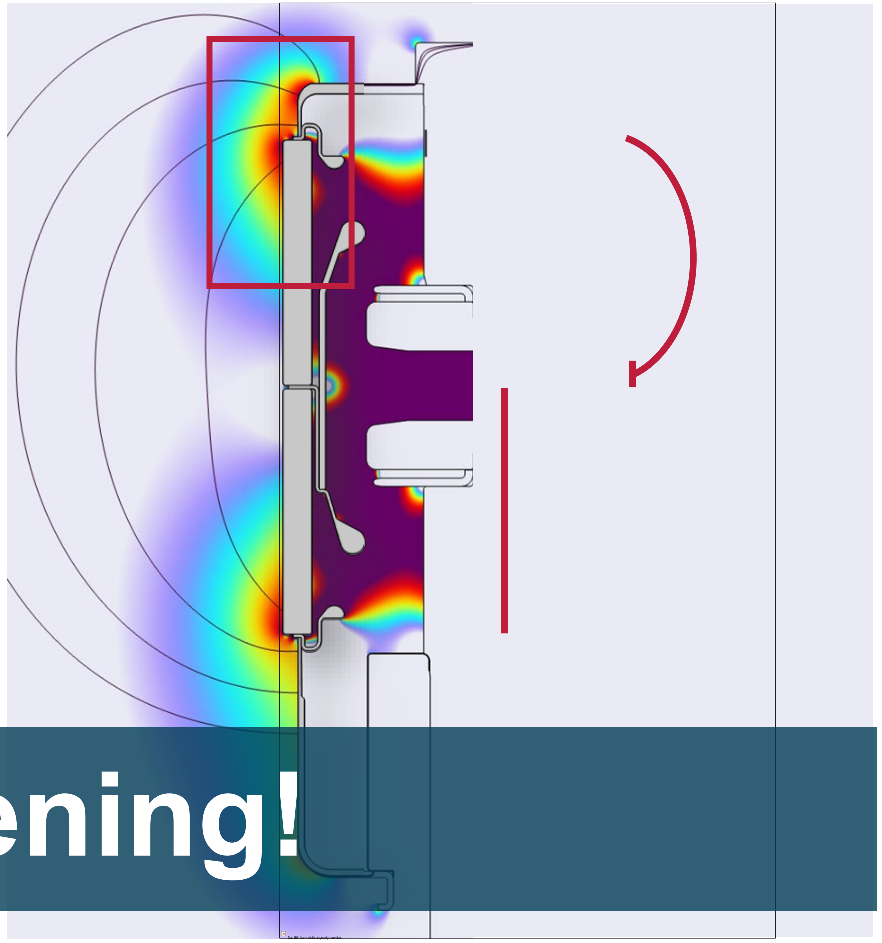
- Higher withstand voltage without metal vapor condensation shield due to lower electric field at critical points
- External flashovers with different propagation paths due to different electric field pattern



How does the metal vapor condensation shield influence the dielectric of a vacuum interrupter?

- A change in flashover mechanisms can be confirmed with high speed camera data, voltage curves and withstand voltage
- It is assumed that partial internal flashovers occur without metal vapor condensation shield

Technische Universität Braunschweig



Thank you for listening!

Kai Schulze, Karen Flügel, Dietmar Gentsch, Michael Kurrat | ITG Vacuum Workshop | 28.08.2026

Abstract

In medium voltage, the vacuum interrupter (VI) has emerged as the predominant switching technology [1]. As SF_6 is subsequently banned in Europe for higher voltages, the emerging gap in technology can be filled by vacuum technology [2]. To efficiently enhance its electric strength and enable an application at higher voltages, among other things a more profound comprehension of the VI as an insulation system is imperative.

The present contribution is an examination of a modified VI devoid of a metal vapor shield with the objective of observing the influence of the shielding on the breakdown process under lightning impulse stress. The results of the performed measurements are documented in the form of voltage data and recordings with a high-speed camera.

A reference measurement of a VI with metal vapor shields reveals the presence of an external flashover path on both halves of the split ceramic insulation structure. In certain experiments involving the modified VI, an external flashover is observable on only one half of the ceramic structure. In addition to the camera footage, it is observed that these breakdowns exhibit a voltage curve that is significantly different from the typical flashovers, where the entire path is externally visible. Therefore, it is hypothesized that the other part of the breakdown propagates inside the VI in vacuum.

While the occurrence of partial internal breakdown is discernible in positive polarity as well as in negative polarity with an inverted VI, the non-observable part is invariably located on the anode side of the VI. Furthermore, it has been observed that subsequent to multiple instances of breakdown, a slight deconditioning effect may be discerned in the series of measurements where partial internal breakdowns are assumed to occur.

The observation of the transition from external to internal breakdown or vice versa leads to the conclusion that it is necessary to observe breakdowns in VIs more closely especially when raising the external flashover voltage to a point where internal breakdowns may occur even on non-modified VIs. The results indicate that a combination of breakdown processes occurs concurrently and is not always limited to the external insulation. A more thorough examination of the mechanisms behind the observed phenomena is necessary to provide a precise description of the breakdown process of VI as an insulation system.

References:

[1] Falkingham, L. T.: The Strengths and Weaknesses of Vacuum Circuit Breaker Technology, 1st International Conference on Electric Power Equipment - Switching Technology, Xi'an, China, 2011.

[2] REGULATION (EU) 2024/573 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014, Official Journal of the European Union 2024/573, 2024.

[VDE] https://www.vde.com/de/fnn/arbeitsgebiete/umwelt-naturschutz/sf6