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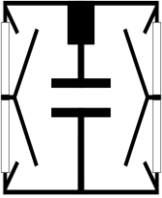


Additive Manufactured Field Control Ring for Improving External Dielectric of Vacuum Interrupter

Karen Flügel, Dietmar Gentsch, Michael Kurrat | ITG Vacuum Workshop | 30.08.2024

Motivation

The complete climate-neutral solution of vacuum circuit breakers requires an improved external dielectric



- vacuum is a climate-neutral and non toxic option for circuit breaker
- external insulation of vacuum interrupter (VI) typically involves materials such as silicone, epoxy resin, and Sulfur Hexafluoride (SF_6)
- replacement of SF_6 as an insulating and switching gas in medium and high voltage is necessary
- regulation of the use of fluorinated greenhouse gases and prohibition of SF_6 in medium voltage systems by 2030 by European Union (EU)
- emphasizing the importance of external electric strength of vacuum interrupters
- VI as insulation system consists of three different potentials insulated with ceramics
- requirements for the manufacturing process and the internal dielectric determine the external design
- discharges starts at triple points as a connection of three different materials



**How does a field control ring improve
the external dielectric of a vacuum interrupter?**

External Field Control Ring

VI with field control ring is tested with LIV to examine the control effect of triple points

Objective

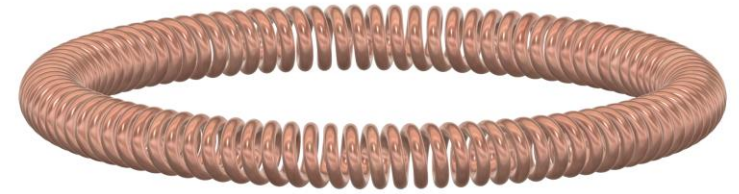
- reducing electric field at triple points of brazed seams of a VI

Implementation

- field control ring at high potential triple point
- ring shape copper coil with 10 mm diameter
- winding wire with 1.4 mm diameter

Test Setting

- VI ABB VG6 with field control ring in ambient air
→ only flashover expected
- positive 1.2/50 μ s lightning impulse voltage (LIV)
- determination of statistical withstand voltage using extended up-and-down method



Ref

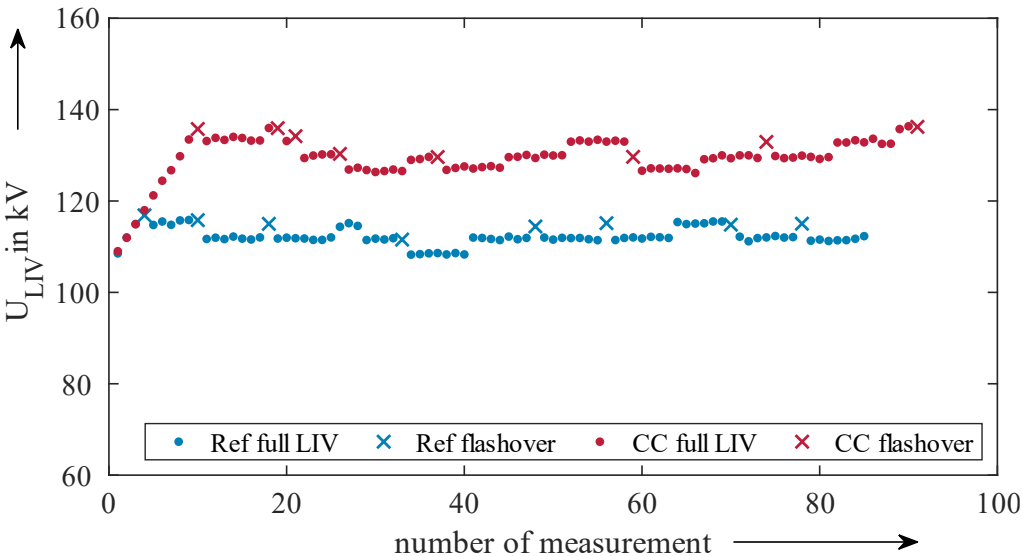


CC

Voltage Results of External Field Control Ring

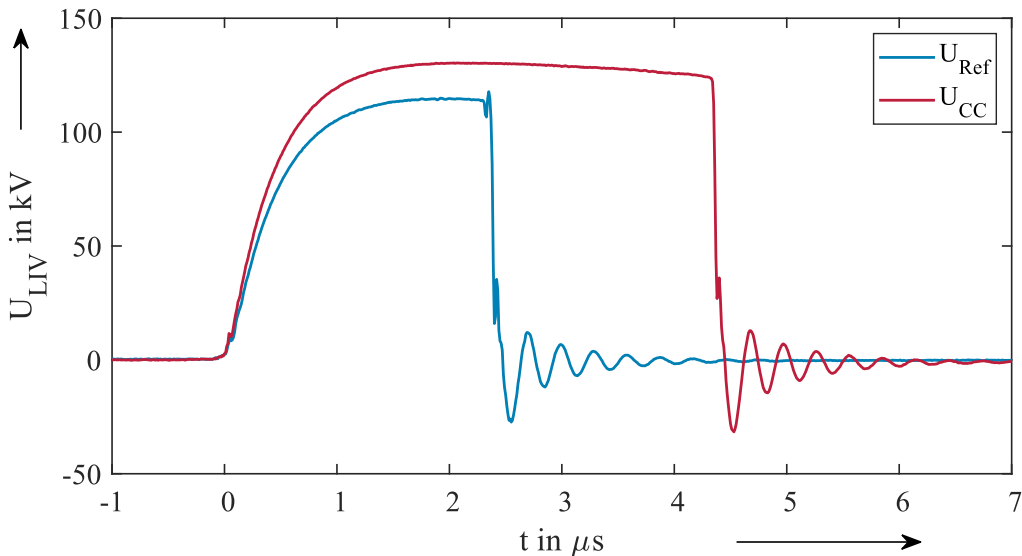
The field control ring increases the withstand voltage and changes the voltage curves

Statistical Withstand Voltage



| | Ref | CC |
|-----------------|----------|----------|
| U_{BD10} | 113.4 kV | 130.8 kV |
| rel. difference | 0 % | +15 % |

Voltage Characteristic of Flashover



- flashovers occur from 2 μs to 5.5 μs after LIV peak
- **Ref** with oscillation before voltage collapse
→ typical for surface flashover
- **CC** without characteristic oscillation
→ indicate change in flashover process

Effect of External Field Control Ring

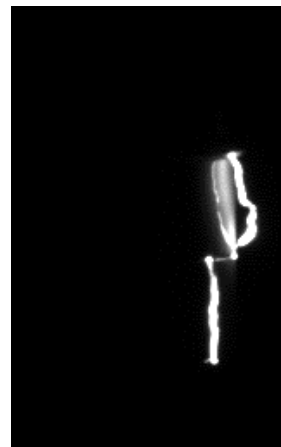
A change in flashover mechanisms by field control ring can be confirmed with high speed camera data

Ref



- split of flashover path with offset at brazed seam
- flashover follows ceramic surface
→ surface streamer

CC



- flashover starts as streamer in gas
- continues following ceramic surface
→ streamer changed into surface streamer



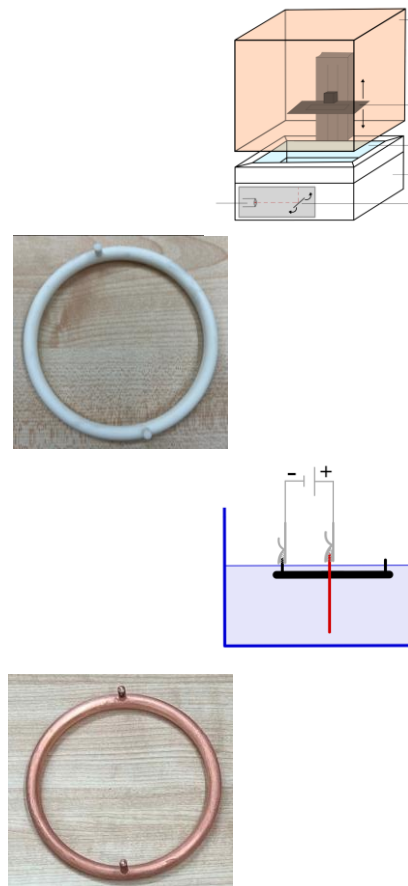
Is it possible to manufacture field control rings additively?

Additive Manufactured Field Control Ring

Conductive field control rings can be produced with additive manufacturing and electroplating

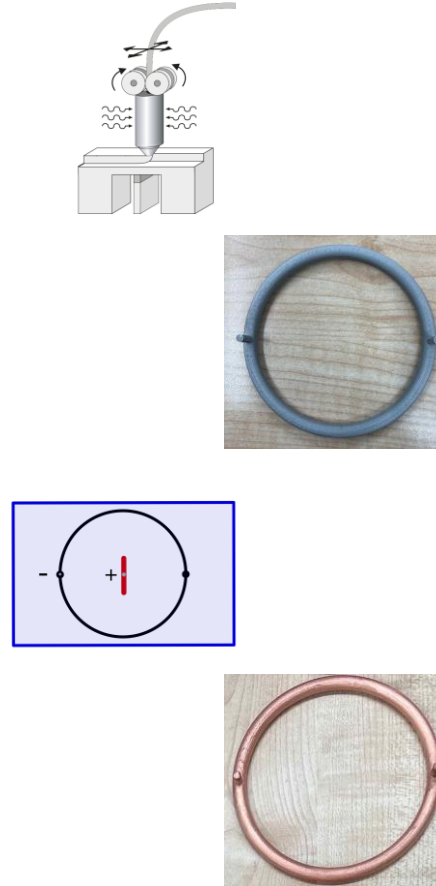
Stereolithography / SLA

- polymerisation with UV-laser
- photosensitive synthetic resin
- selectively curing, layer by layer
→ insulator
- electroplating the surface with copper
→ conductive field control ring



Fused Deposition Modeling / FDM

- material extrusion through nozzle
- polylactide (PLA)
- fused deposition, layer by layer
→ insulator
- electroplating the surface with copper
→ conductive field control ring



Breakdown Traces on Electroplated Surface of Field Control Ring

Despite breakdowns destroy the electroplated surface no decondition effect is occurred

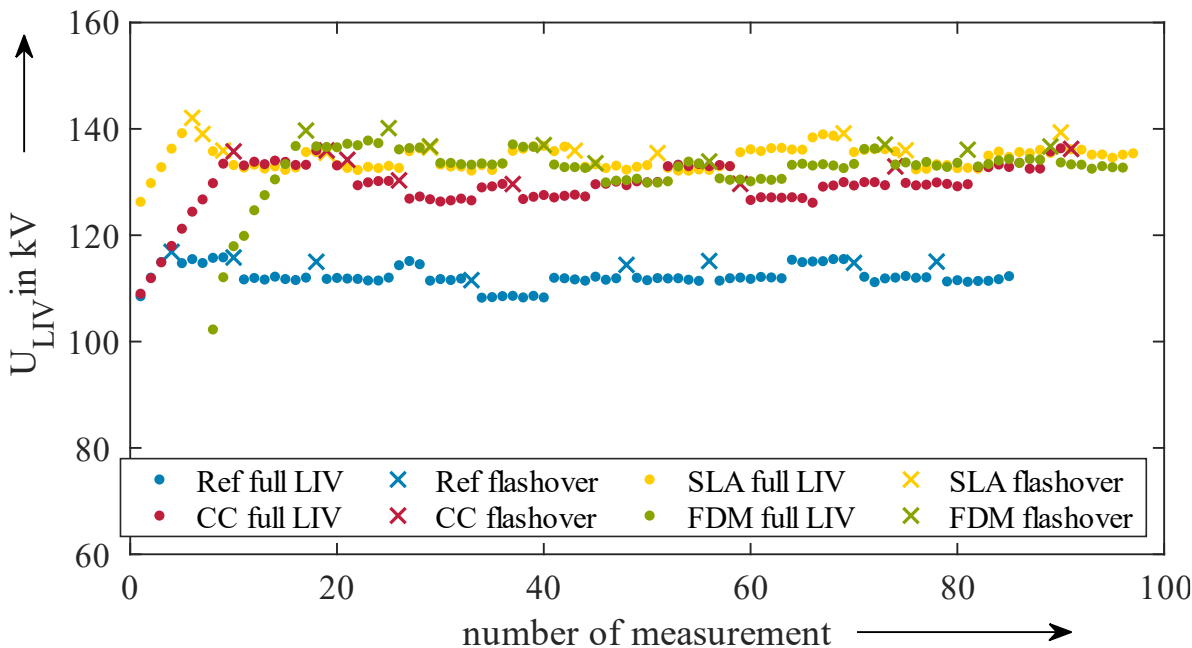
Destroy breakdowns the electroplated surface?

- each field control ring see 20 breakdowns
- clear visible breakdown traces on surface
 - breakdown destroy surface locally
 - no deconditioning



Results of LIV Test

Additive manufactured field control rings are comparable with copper field control rings

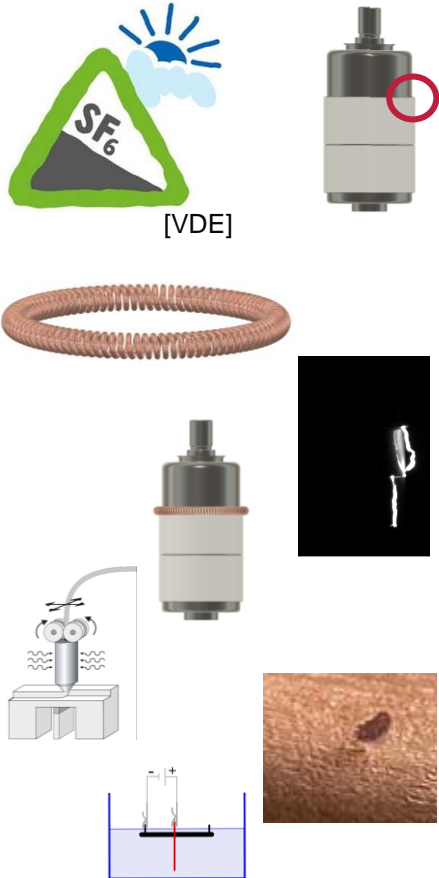


- test sequence without deconditioning
- U_{BD10} of SLA and FDM is the same
- field control rings of CC, SLA and FDM are comparable

| | Ref | CC | SLA | FDM |
|-----------------|----------|----------|----------|----------|
| U_{BD10} | 113.4 kV | 130.8 kV | 135.2 kV | 134.9 kV |
| rel. difference | 0 % | +15 % | +19 % | +19 % |

Summary

Additive Manufactured Field Control Ring for Improving External Dielectric of Vacuum Interrupter



- The complete climate-neutral solution of vacuum circuit breakers requires an improved external dielectric

How does a field control ring improve the external dielectric of a vacuum interrupter?

- VI with field control ring is tested with LIV to examine the control effect of triple points
- The field control ring increases the withstand voltage and changes the voltage curves
- A change in flashover mechanisms by field control ring can be confirmed with high speed camera data

Is it possible to manufacture field control rings additively?

- Conductive field control rings can be produced with additive manufacturing and electroplating
- Despite breakdowns destroy the electroplated surface no decondition effect is occurred
- Additive manufactured field control rings are comparable with copper field control rings

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RESEARCH

- Investigation of external dielectric of vacuum interrupter
- Investigation of the electric strength of electrode arrangements in vacuum
- Flashover mechanism of complex insulation systems

PUBLICATIONS (Selection)

- Flügel, K., Jesberger, T., Gentsch, D., Kurrat, M.: **Effect of External Field Control Ring for Vacuum Interrupter using Lightning Impulse Voltage**, IEEE International Conference on High Voltage Engineering and Application (ICHVE), Berlin, Germany, 18. – 24. August 2024
- Flügel, K., Meyer, T., Gentsch, D., Kurrat, M.: **Partial Breakdown Detection in Vacuum Interrupter under Lightning Impulse Voltage**, The 23rd International Symposium on High Voltage Engineering, Glasgow, United Kingdom, 28. August - 1. September 2023
- Flügel, K., Gentsch, D., Kurrat, M.: **Overview of Test Methods for Electric Strength of Vacuum Interrupter using Lightning Impulse Voltage**, 30th International Symposium on Discharge and Electrical Insulation in Vacuum (ISDEIV), Okinawa, Japan, 25. Juni - 30. Mai 2023



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- [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] IPCC: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Cambridge University Press, 2013)
- [3] 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.
- [4] Hauschild, W. Mosch, W.: Statistical techniques for high-voltage engineering, Peregrinus, Stevenage, 1992.
- [5] Flügel, K., Meyer, T., Gentsch, D., Kurrat, M.: Partial Breakdown Detection in Vacuum Interrupter under Lightning Impulse Voltage, The 23rd International Symposium on High Voltage Engineering, Glasgow, United Kingdom, 28. August - 1. September 2023.
- [6] Flügel, K., Jesberger, T., Gentsch, D., Kurrat, M.: Effect of External Field Control Ring for Vacuum Interrupter using Lightning Impulse Voltage, IEEE International Conference on High Voltage Engineering and Application (ICHVE), Berlin, Germany, 18. – 24. August 2024.
- [VDE] <https://www.vde.com/de/fnn/arbeitsgebiete/umwelt-naturschutz/sf6>

Abstract

Worldwide, more than 90 % of the switchgear produced for medium voltage application is based on vacuum switching technology [1]. In vacuum interrupters (VI) vacuum is used as the switching medium and internal insulation, while the external insulation is usually provided by silicone, epoxy resin or sulphur hexafluoride (SF_6). As SF_6 is the greenhouse gas with the highest global warming potential GWP 100 year of 23,500 [2], the EU is progressively prohibiting its use [3]. External electric strength of VI is therefore an important issue.

To improve the electric strength of an insulation system, triple points are usually considered, as the emission of electrons is particularly probable here. To reduce the electric field strength in the triple points of the VI field control rings are used. For this study, the field control rings were additively manufactured from polylactide (PLA) and the surface was electroplated. Additive manufacturing makes it possible to produce prototypes quickly and cost-efficiently. Electroplating then transforms the insulator into a conductive field control element.

As insulation systems are designed with the highest voltage that occurs in the grid, the measurements are carried out with lightning impulse voltage. The extended up-and-down method according to Powell and Ryan is used as test procedure to determine statistical withstand voltage [4]. As a result of the investigations, it can be summarized that additive manufactured and electroplated field control elements function in the same way as conventionally manufactured metallic field control elements. After several breakdowns, small traces of melting can be observed on the rings, but the functionality is still given.