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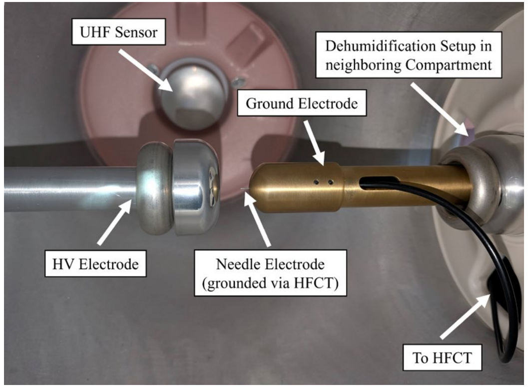

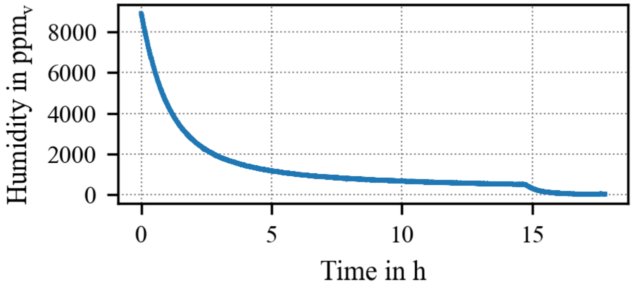

Impact of Humidity on the External Dielectric Strength of Vacuum Interrupters in Synthetic Air Insulation Systems

Niclas Dölzer, Dietmar Gentsch, Michael Beltle, Stefan Tenbohlen

10th IVEW and 16th IVeSC 2026

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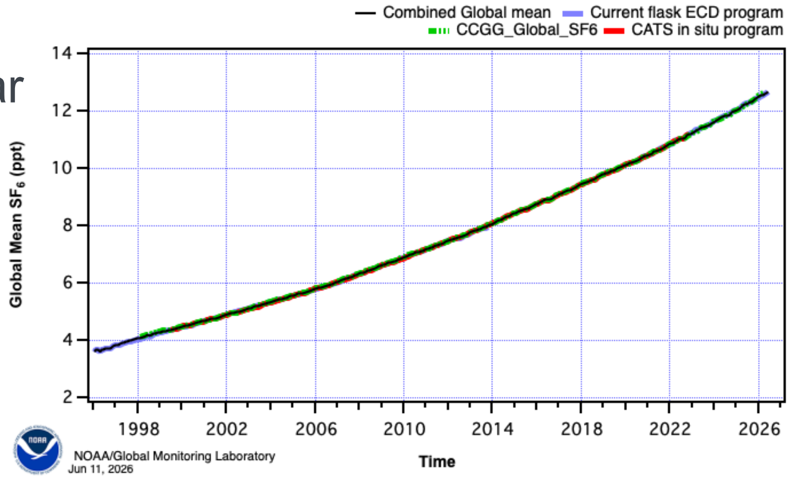
Introduction

Motivation for Non-SF_6 Gas Insulated Switchgear

- Gas Insulated Switchgear (**GIS**) is very **compact** and **low in maintanance**
- SF_6 has been used in GIS for decades due to its highly favourable properties
- With a GWP_{100} of 24.300 it is the **most potent greenhouse gas** known



Source: https://gml.noaa.gov/hats/combined/SF6.html

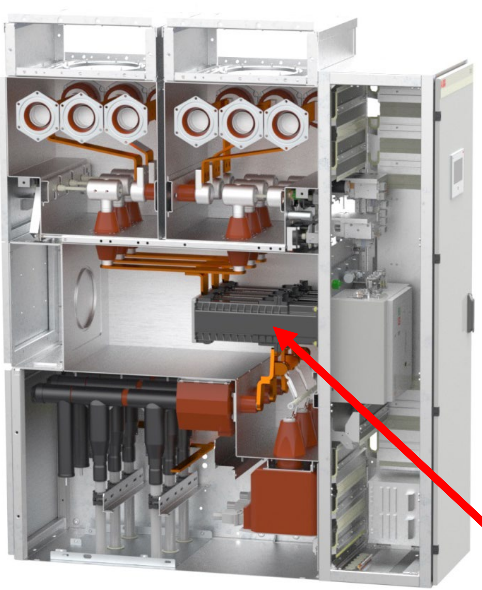
- **Rising demand for electricity** worldwide (EVs, A/C and heat pumps, data centers, hydrogen production)

  → **The necessary ramp-up should not use SF_6-equipment**

Phase-out of SF_6 is beginning in many countries either enforced by regulation or on a on a voluntary basis

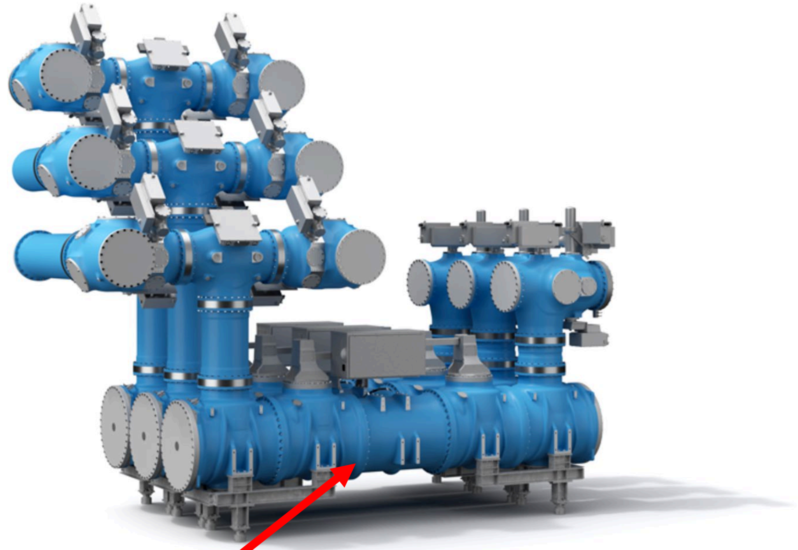
Introduction
Non-SF_6 Alternative: Vacuum Interrupters + Synthetic Air

Medium Voltage GIS (up to 52 kV)



Source: https://www.abb.com

High Voltage GIS (above 52 kV)



Source: https://www.siemens-energy.com/

Vacuum Interrupters **externally insulated**

by pressurized synthetic air (80% N_2 + 20% O_2)

Introduction

Motivation for Partial Discharge measurements in GIS

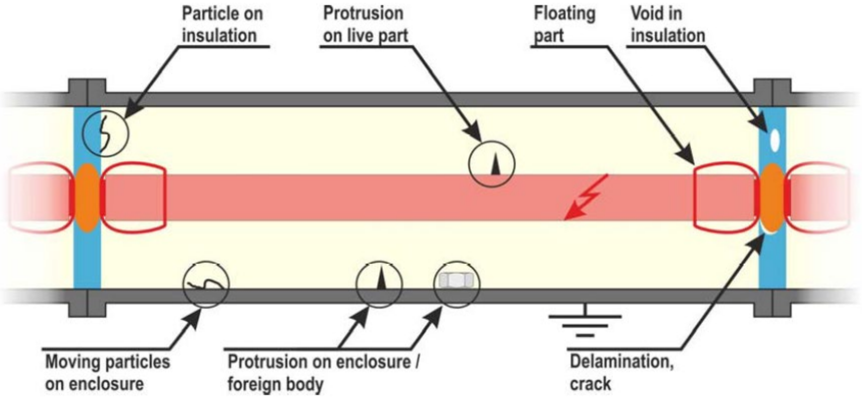
- Defects / Imperfections in GIS can be introduced during production or manufacturing

  → **Insulation failure** and consequently system failure is possible if these go undetected

- **Partial discharge (PD) measurements** have proven to reliably detect common defects in SF_6-equipment

- **Factory** and **Site Acceptance Tests** (FAT & SAT) are carried out to ensure safe operation

→ Are defects in Non-SF_6 GIS detectable using established PD diagnostics?



Source: https://fkh.ch/wp-content/uploads/2014/07/2013_Neuhold_Abnahme-Diagnosepruefungen-GIS_ETG-FKH-Fachtagung.pdf

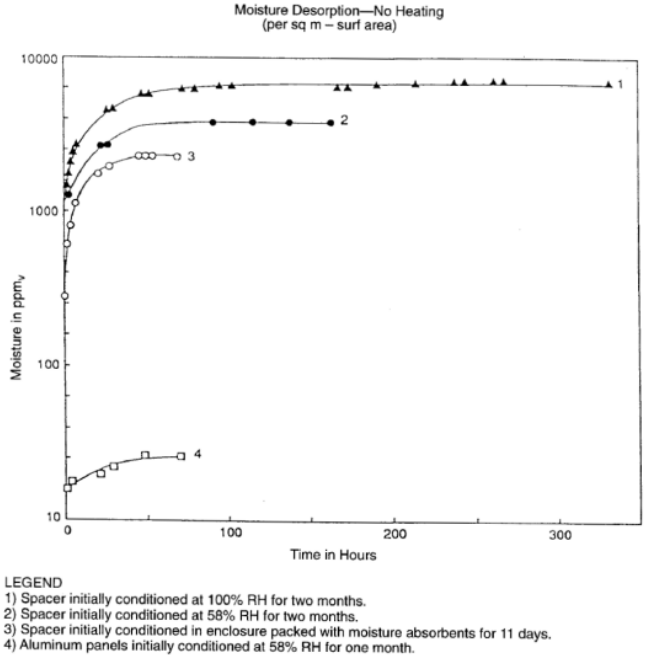
Introduction
Possible impact of humidity contained inside GIS

- **Humidity can enter GIS** either during manufacturing or driven by partial pressure differences
- Condensation on surfaces results in strong reduction of dielectric strength

  → Avoidable by using dessicants

- In gases containing O_2 humidity also results in **formation of $O_2(H_2O)_n^-$ Clusters**
  - Possible impact on electron avalanche formation (and therefore dielectric strength of synthetic air)

  → **Measurement campaign determining PDIV and BDV of synthetic air at variied humidity content**



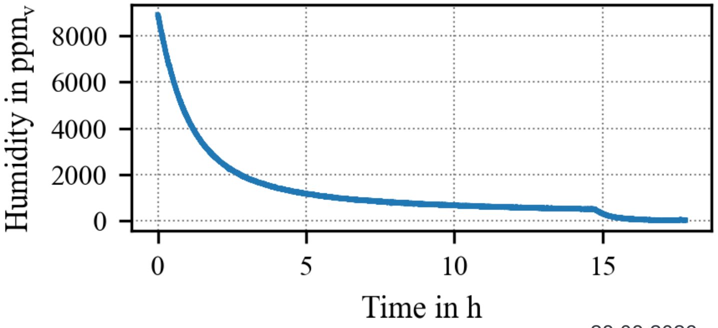
Source: IEEE Guide for Moisture Measurement and Control in SF6 Gas-Insulated Equipment

Laboratory Setup for PD and Breakdown measurements
HV GIS ELK-14 Compartments connected to ELK-3 550 GIS

Laboratory Setup for PD and Breakdown measurements

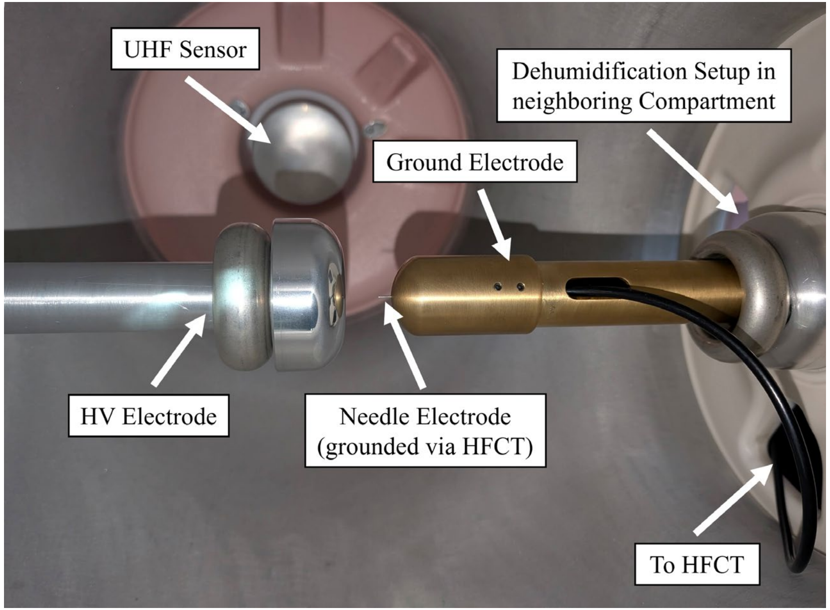
Setup for controlling humidity inside test cell

- Humidity is introduced into the compartment and successively removed by use of dessicant
  → **Humidity level can be controlled**
- Fan ensures homogeneous conditions
- Heating of compartment to 25 °C
  during experiments



Laboratory Setup for PD and Breakdown measurements
Electrode configurations I

PD measurements



Breakdown experiments

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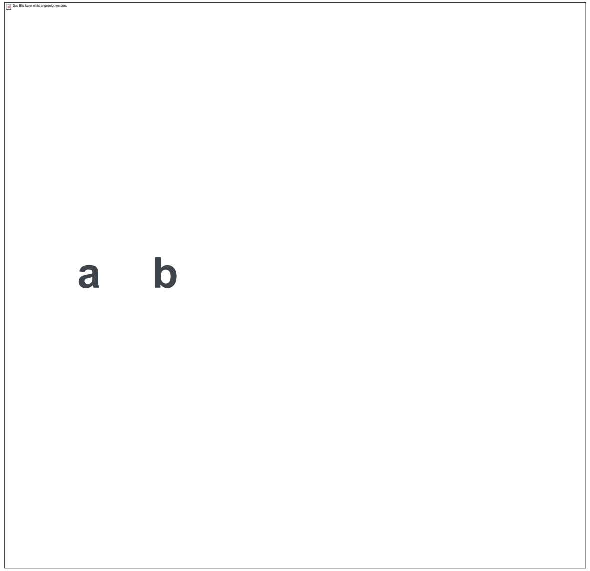
Laboratory Setup for PD and Breakdown measurements
Electrode configurations II

Two different electrode configurations used

1. **15 mm gap** distance *(a)* and **7.5 mm protrusion** length *(b)*
   → *worst case* conditions
2. **70 mm gap** distance *(a)* and **3 mm protrusion** length *(b)*
   → *realistic dimensions* in GIS

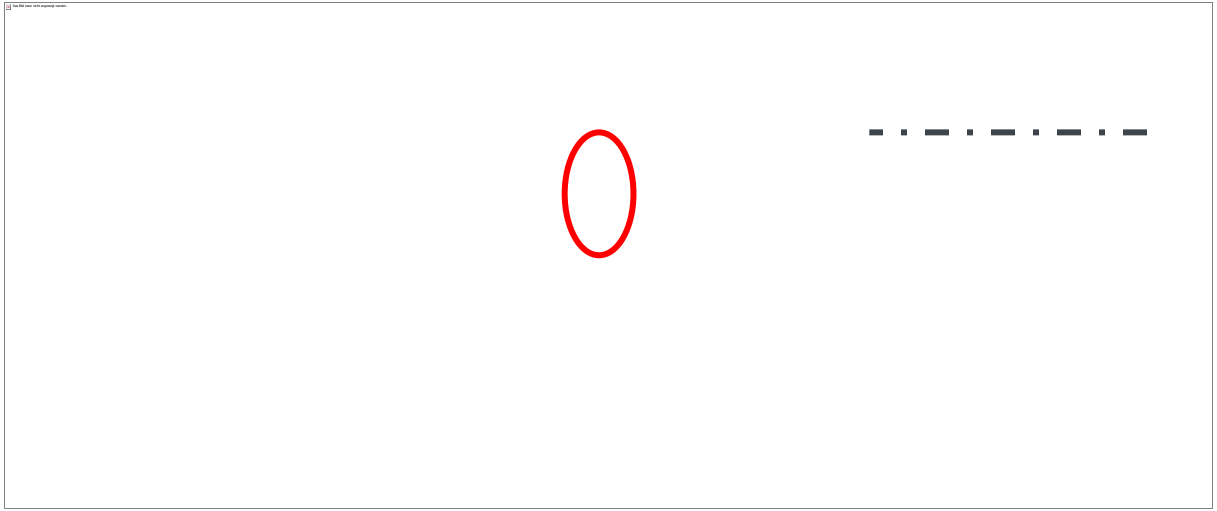
In both cases needle tip radius = 50 µm



Source of technical drawing: CIGRE TB 849

Measurement Results

PDIV using 15 mm gap and 7.5 mm needle protrusion length



- High scatter of PDIV for 0.15 MPa → lack of starting electrons?
- Significantly deviating PDIV at 50 ppm_v humidity at 0.3 MPa
- Mostly stable PDIV at 0.5 MPa without obvious trend

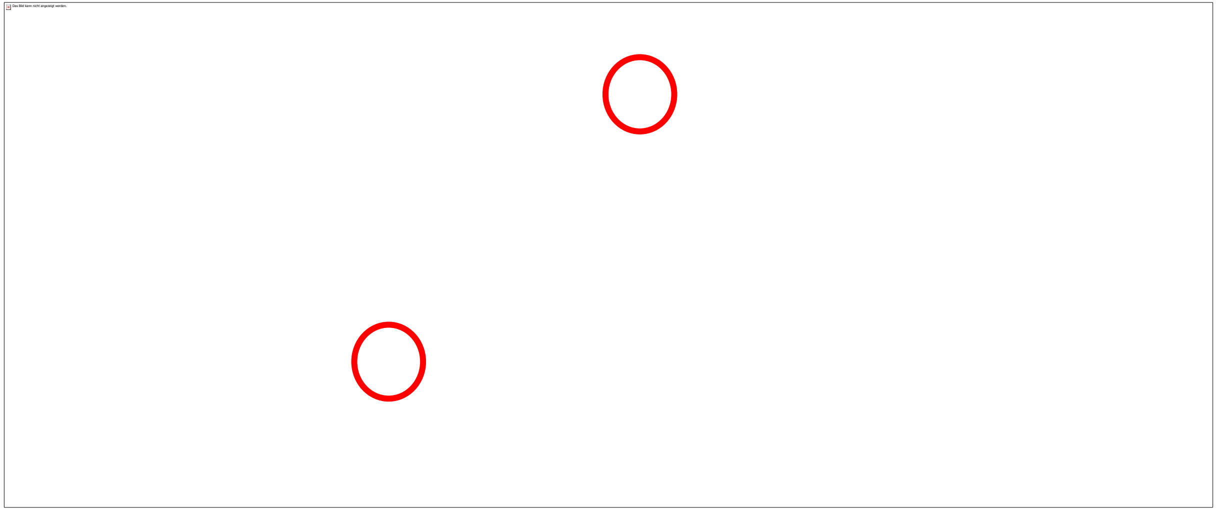
Measurement Results

PDIV and BDV using 15 mm gap and 7.5 mm needle protrusion length

- PDIV determined before each breakdown → needle tip erosion minimized by limiting resistor and automatic switch-off
- No significant influence of humidity on PDIV or BDV
- Margin between PDIV and BDV increases with gas pressure

Measurement Results

PDIV using 70 mm gap and 3 mm needle protrusion length



- High scatter of PDIV for 0.15 MPa and deviation at 5000 ppm_v
- Significantly deviating PDIV at 100 ppm_v humidity at 0.3 MPa

Measurement Results

Partial Discharge Rise Times and Peak Currents at 0.3 MPa

15 mm gap

70 mm gap

Summary and Discussion

- Generally **minor impact of humidity** on PDIV and BDV
- However, at 0.3 MPa significant deviations were observed for both electrode geometries

  → Cause has yet to be determined (Physical effect? Reproducibility?)
- High Scatter of PDIV at 0.15 MPa for both electrode geometries
  - Possible cause: **Missing starting electrons**

  → Planned experiments using **UV light source** to provide starting electrons
- **Margin between PDIV and BDV increases** significantly with gas pressure (as expected, caused by corona stabilization)

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Thank You!

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REGULATION (EU) 2024/573 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on fluorinated greenhouse gases

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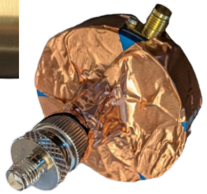
Setup for PD measurements

Overview of available PD measurement techniques

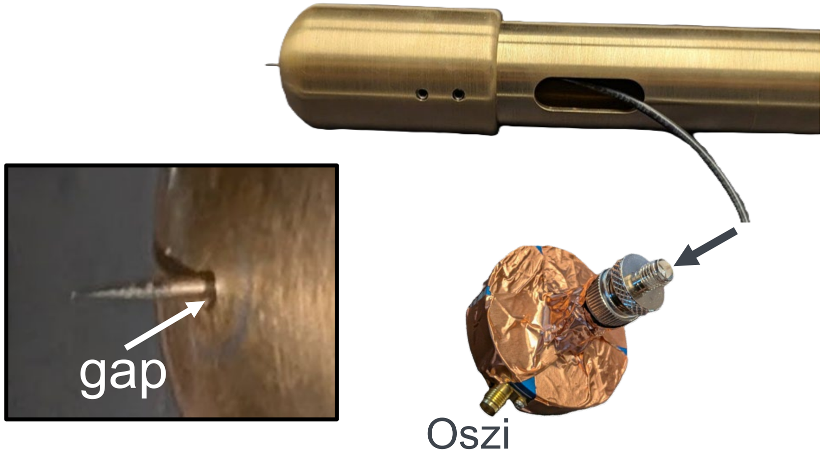
- **Conventional charge-based measurement** according to IEC 60270
  - 1 nF coupling capacitor integrated into HV-GIS
    → low noise floor (≈ 0.5 pC)
- Measurements of radiated signals using **UHF-sensors** (multiple units integrated into GIS setup), well-established in practical application
- **Direct current measurements** on grounded needle (using **coaxial RF probe (HFCT)** to protect measurement equipment)

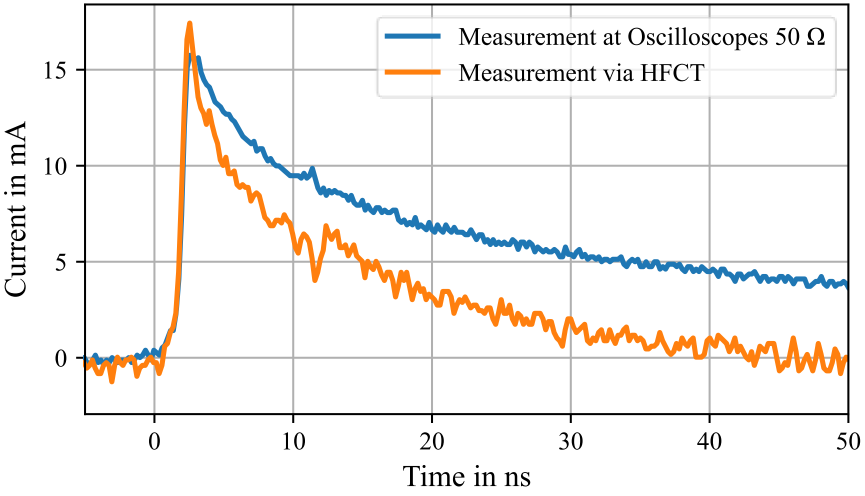


Setup für TE-Messungen
HFCT-Strommessung

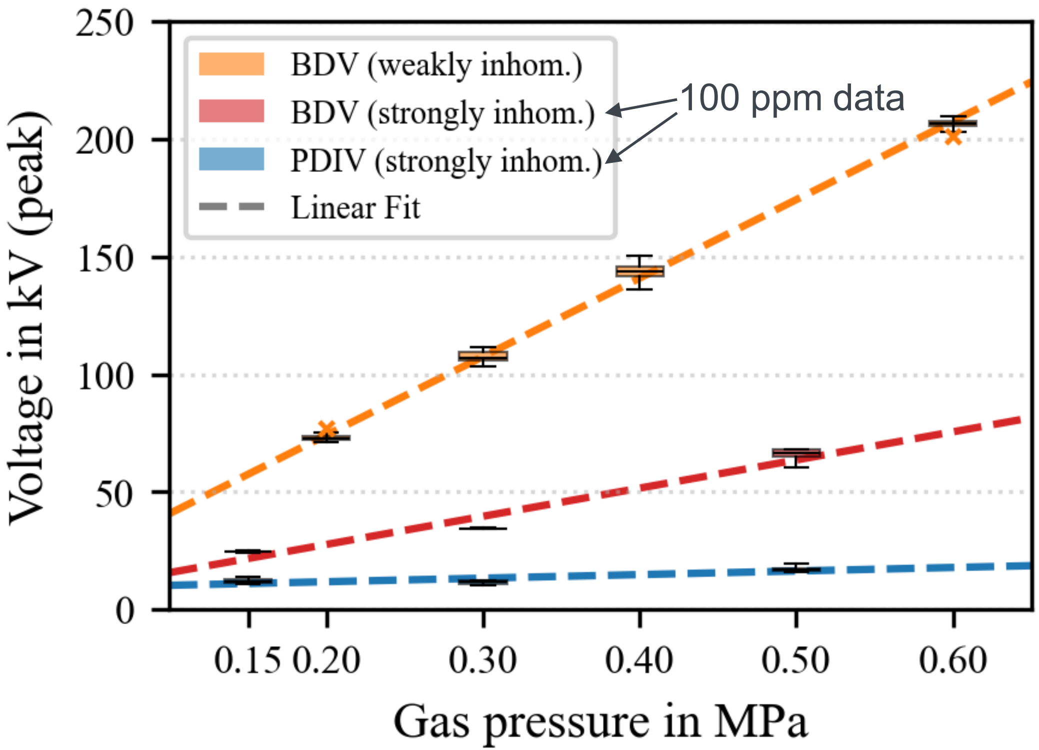
- Measurement of PD discharge currents using **HFCT** for **protecting the oscilloscope** in case of breakdown
- Current **rise time** and **peak value** are **well represented**, the impulses decay is being altered by the HFCT

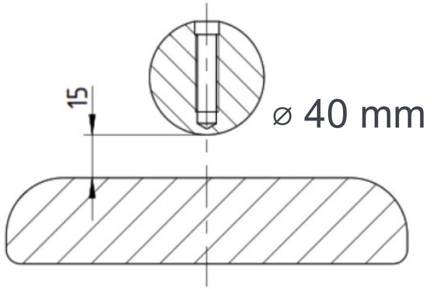
  → **True charge** of current impulses **cannot be determined** correctly by this method





Measurement campaign on varied humidity in synth. air
Results using 15 mm electrode gap (weakly and strongly inhomogeneous)





Electrode arrangement for weakly inhomogeneous el. field
(from Cigré TB 849 Round Robin)

Measurement campaign on varied humidity in synth. air
Reproducibility of PDIV and BDV