Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

Fachgebiet
Hochspannungstechnik /
Werkstoffe der Elektrotechnik /
Theoretische Elektrotechnik

# Evaluation of the Breakdown Characteristics of Silicone Elastomers under Distorted Voltage Stress

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# Content




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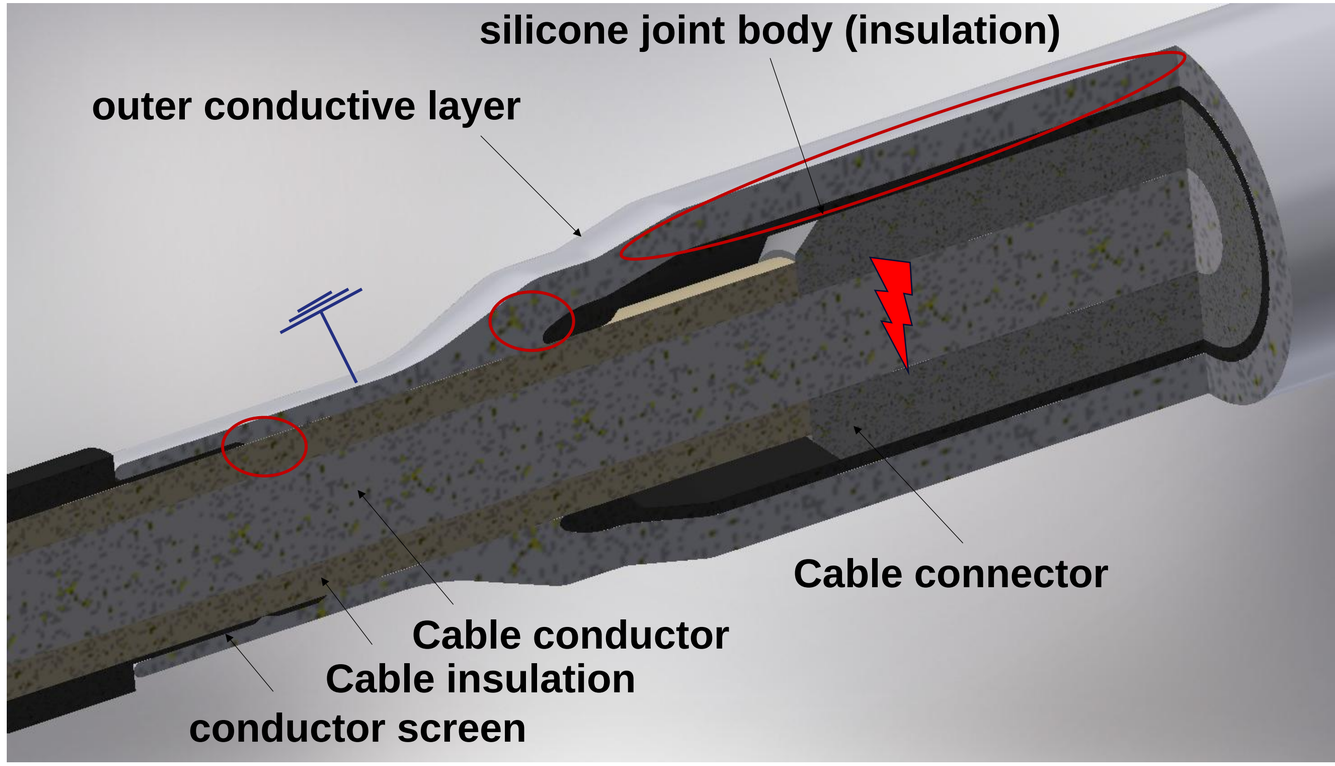
# Introduction

- Electrical insulation materials are widely used in power engineering and electronics e.g. high voltage cable joints
- Areas of high electric field strength stresses the material

➢ Electrical breakdown strength of insulating materials is a key property

➢ Material must withstand over decades without severe degradation and failure (lifetime ≥ 40 years)



# Introduction

- To achieve this, a proper component design (e.g. field strength grading) and material selection is necessary
- There material tests (e.g. IEC 60243) and minima criterions are available
  - Test are dedicated to compare with minima criterions and for quality control
  - Can be done with different arrangement considering several influencing factors and time
  - No direct correlation with real components (e.g. cable joint), as the geometry differs completely

**Breakdown Mechanisms (Time-Dependent)**

- **Short-term: Electric Breakdown** (Release of electrons by an electric field; formation of electron avalanches ; occurs within nanoseconds to microseconds).
- **Mid-term: Thermal Breakdown** (Heat generation exceeds heat dissipation; leads to lower resistance, melting/degradation, seconds to hours/days).
- **Long-term: Aging & Erosion** (Slow degradation due to PD, moisture, heat or chemical deterioration).

# Influence of Distorted Voltage

- For many arrangements and tests, dielectric loss is one of the key factors influencing breakdown (thermal breakdown)
  - It is dependent on several factors
  - If more heat generated than dissipated, material heats up and breakdown will occur sooner or later

Material dependent

$$P_\delta = 2\pi \boxed{f} \cdot \boxed{U^2} \cdot \boxed{\varepsilon_r'} \cdot \boxed{C_0} \cdot \boxed{tan\delta}$$

**Voltage dependent**

Arrangement/component dependent

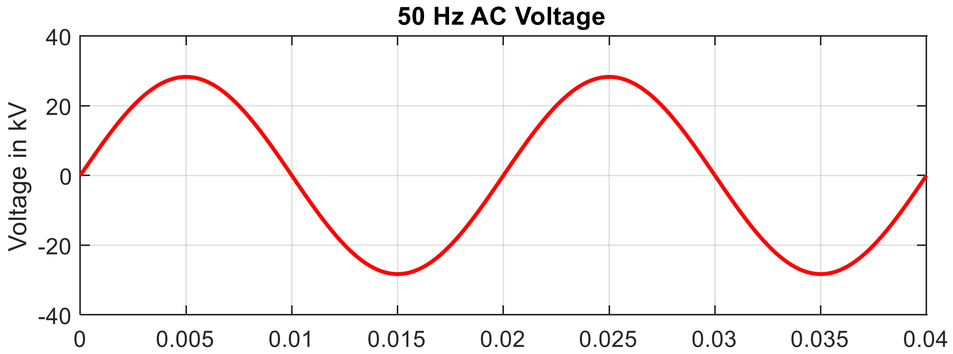
- Losses are highly frequency dependent, i.e. increase linear with f

➢ increased use of power electronics leads to distorted voltages i.e. a 50 Hz AC voltages is superimposed with a high frequency harmonic component

# Introduction

## AC 50 Hz sine

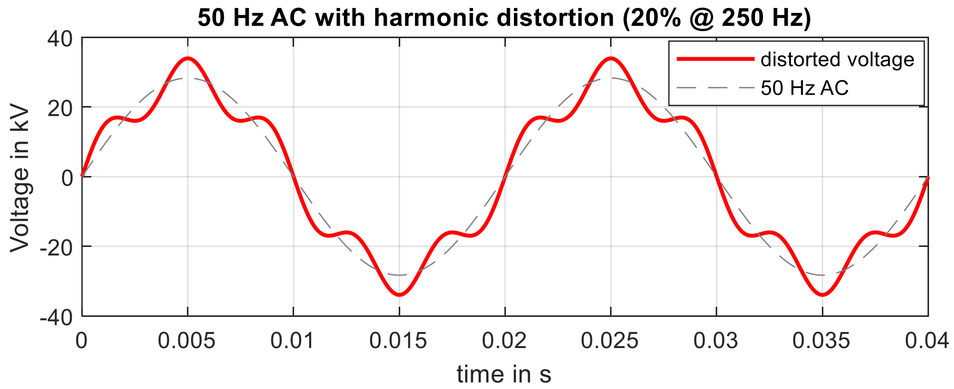
- Still main base for power engineering
- designing the insulation for AC is also challenging, the material behavior is well understood and there is relevant experience
- Dielectric loss only for one frequency




## Distorted Voltage

- Increasingly influences on power grid by power electronics leads to distortion
- Leads to various harmonic with different with different amplitudes and frequencies

➢ Dielectric loss for each harmonic has to be superimposed!




➢ **Influence on the material behaviour /breakdown strength under distorted voltage still in evaluation**

➢ **influence already been proven for materials with a high loss factor or functionally filled materials**

# Test Arrangement and Procedure

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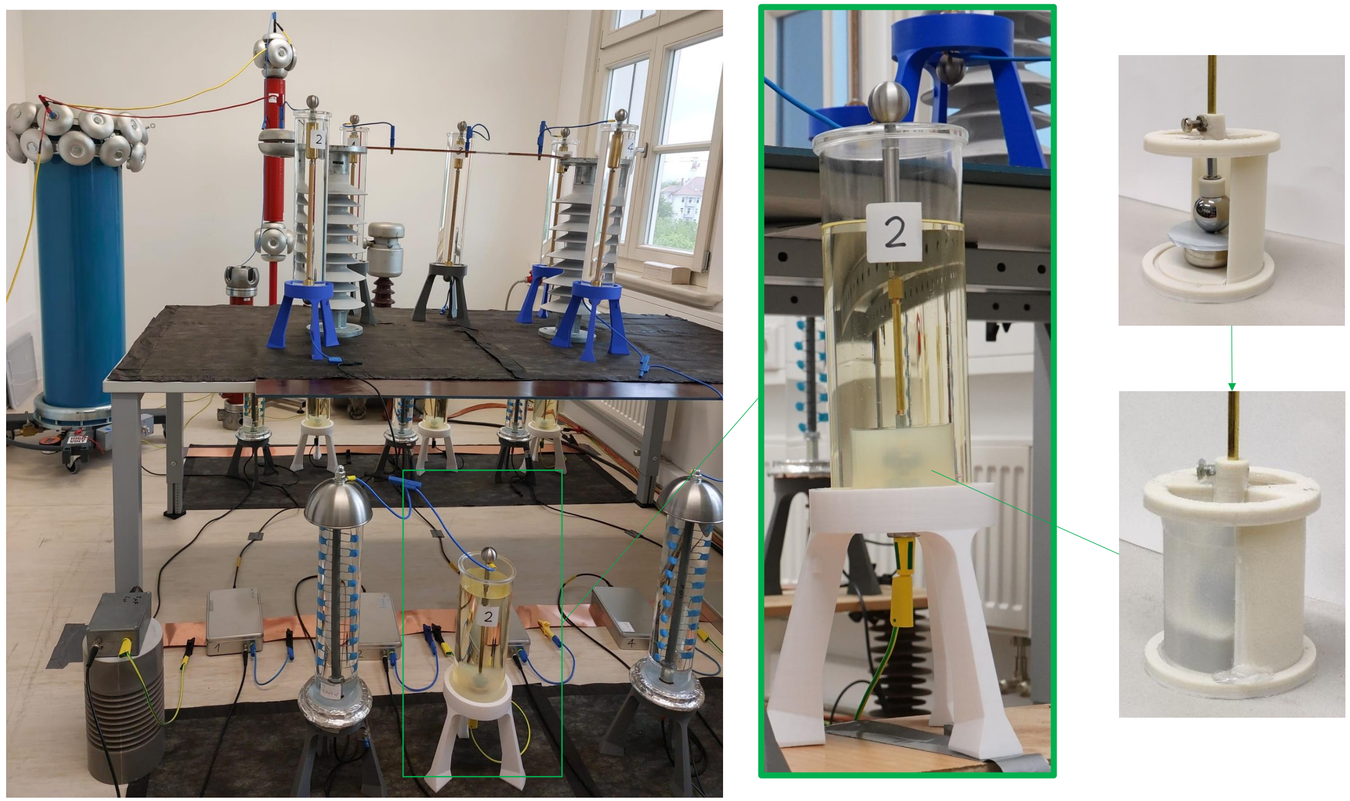
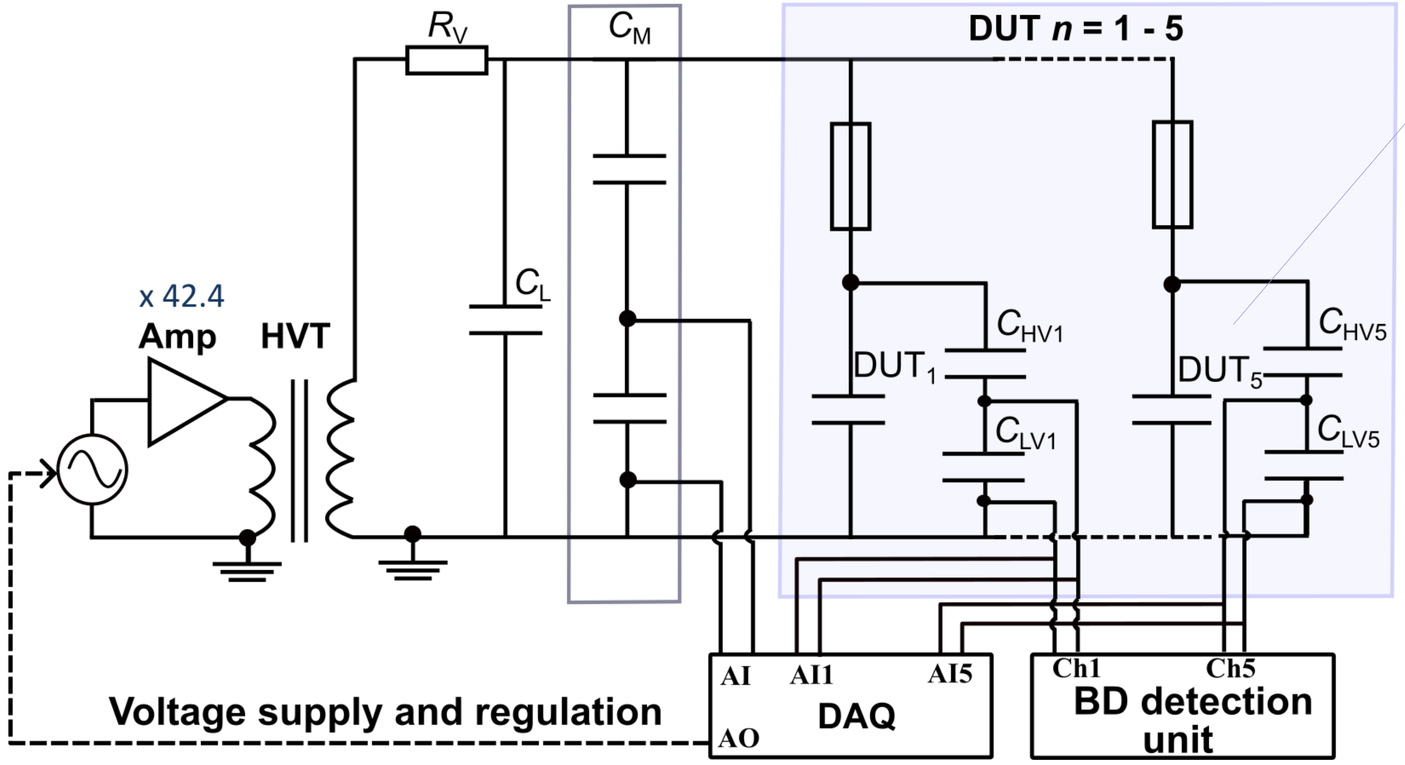
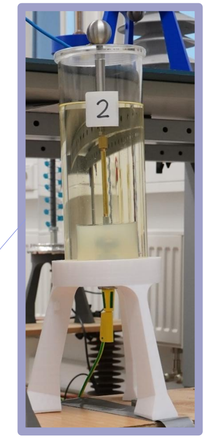
- Measurement of breakdown strength in acc. to IEC 60243-1 / IEC 61251
- Test rig for parallel testing 5 specimen
- Silicone elastomer test specimen without functional filler (ø 40mm x 0.5 mm)  for all tests (low loss factor)
- Electrode arrangement “plate- sphere electrode” acc. to IEC 60243-1
- Test specimens molded in silicone and immersed in insulating oil to prevent partial discharges
- Test are done with continuous voltage ramp up and voltage step test (and constant voltage test)



# Electrical Test Circuit

- Voltage signal generated at low voltage (DAQ), is amplified (AMP) and stepped up by a high-voltage transformer (HVT)
- High Voltage is measured and used for regulation (especially necessary for distorted voltage)
- Breakdown detection and separate HV fuse for each DUT
- Test procedure is fully automated



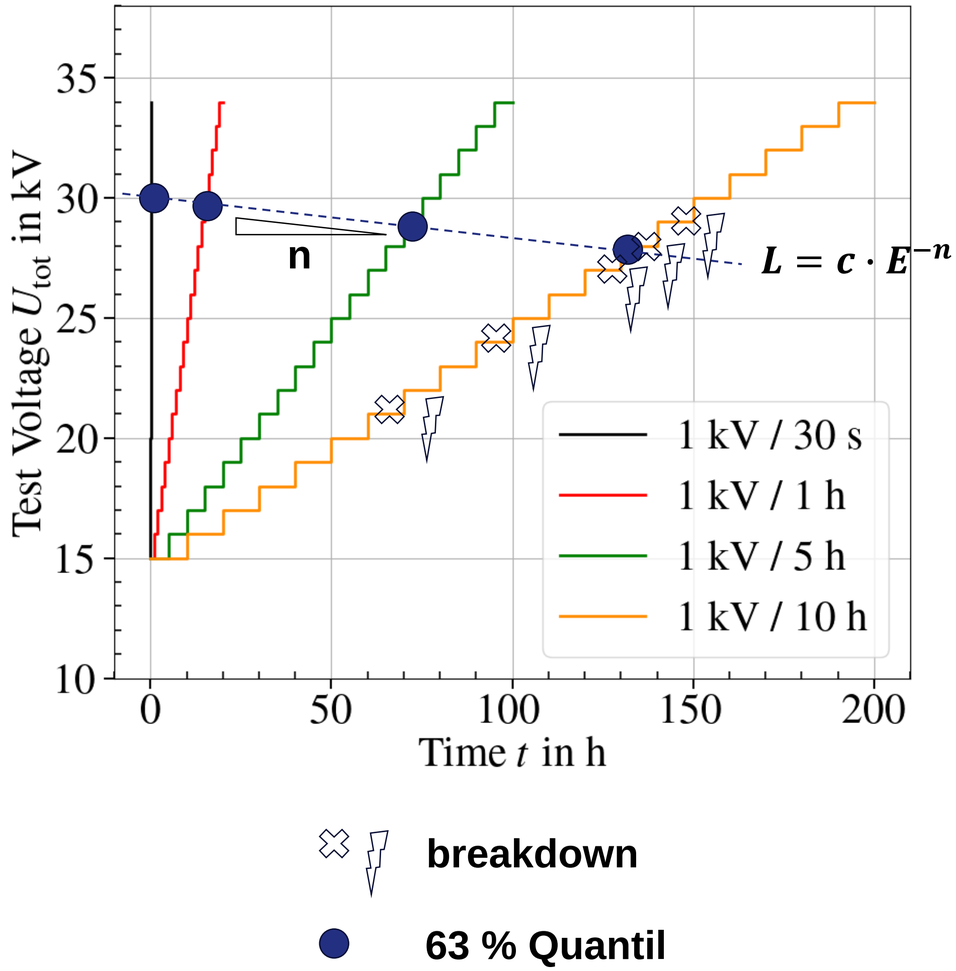



# Test Procedure – Step Test

**Test procedure on the example of stepwise increase**

- 4 different increase rates / dwell times
- Voltage increased till breakdown
- Calculation of distribution function Weibull distribution with 63 % value
- Calculation of life-time exponent (n) by regression line

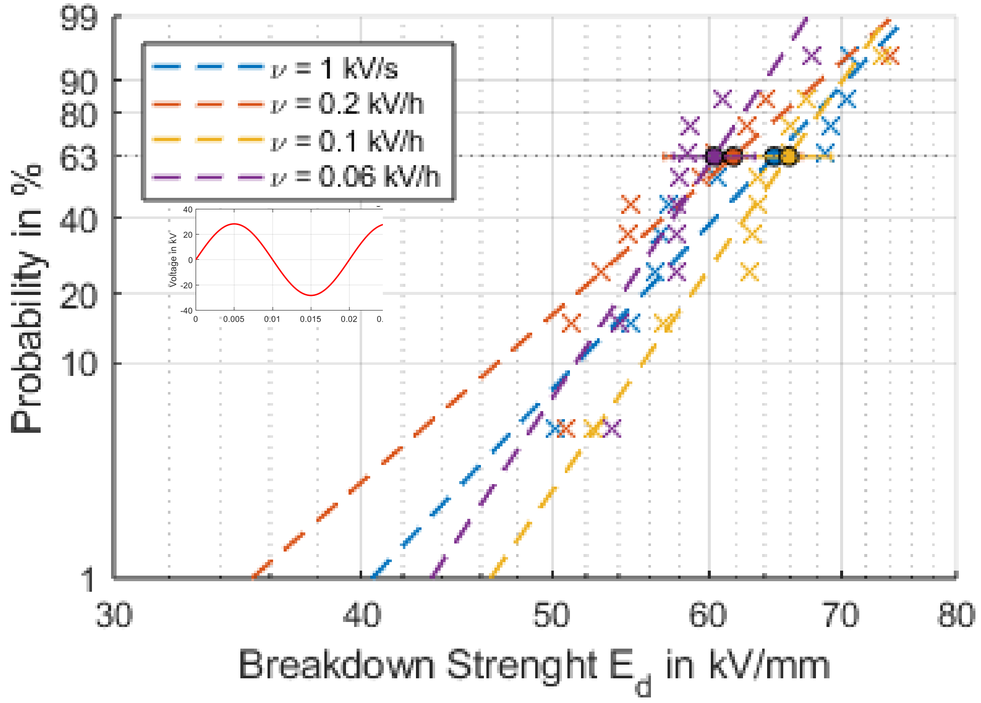
➢ Estimation of lifetime / “long-time” behaviour



# Comparison of Breakdown Strength wit AC and Distorted Voltage

# Results - 50 Hz

- Weibull distributions located close together for pure 50 Hz sine
- Minor effect of the voltage increase rate on the 63 %- quantile (60.4 kV/mm to 64.7 kV/mm)
- spread of the results is also within a similar range but slightly differs

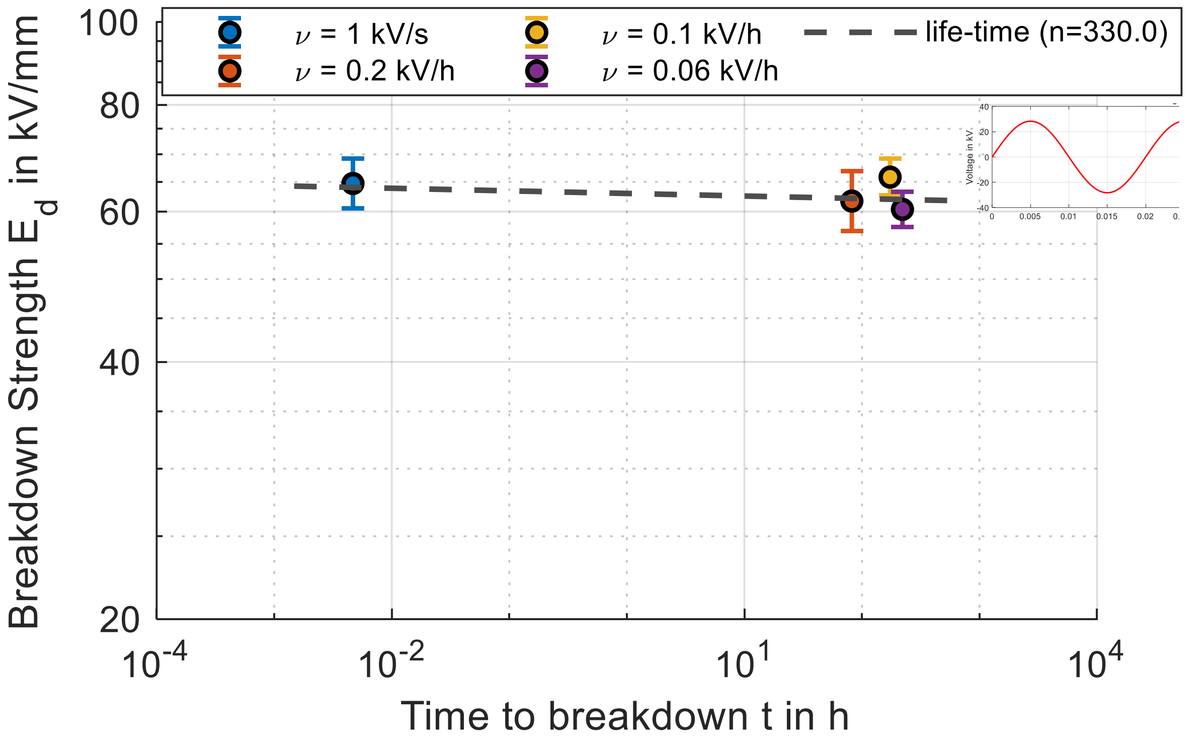


# Results - 50 Hz

- Based on 63 % quantiles of breakdown field strength and time to breakdown
- All evaluated values can be described with regression line
- Life-time exponent assumed to be 330 or lower with meets literature results

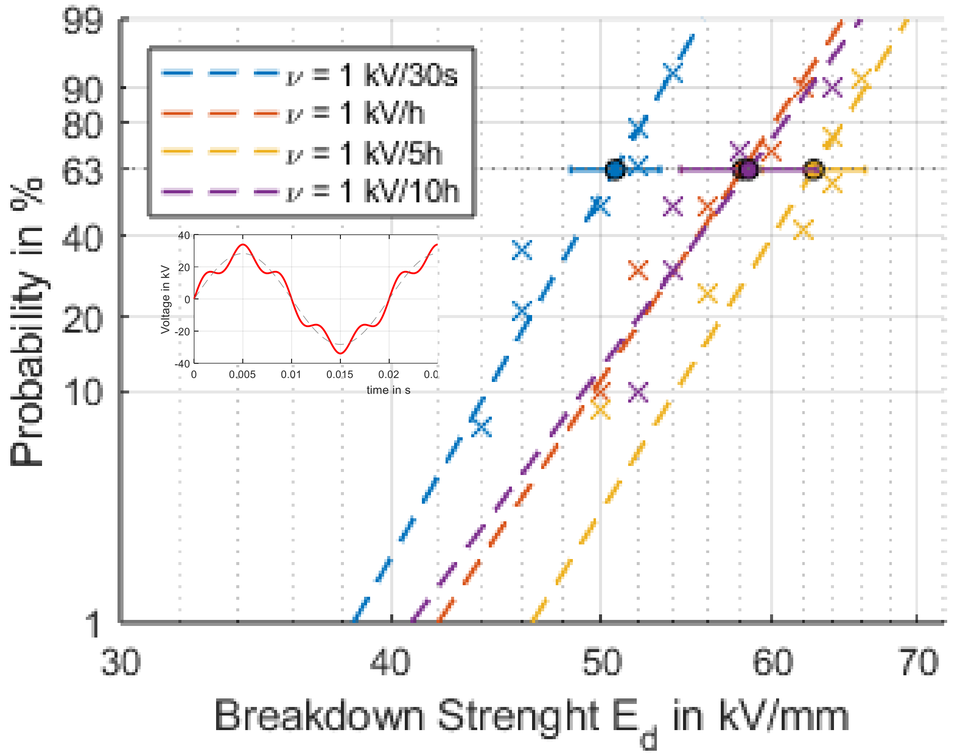
➢ No aging or degradation of silicone because of electric field strength

➢ Other effects (high temperatures, discharges etc.) must also be considered for real-world applications



# Results – distorted Voltage

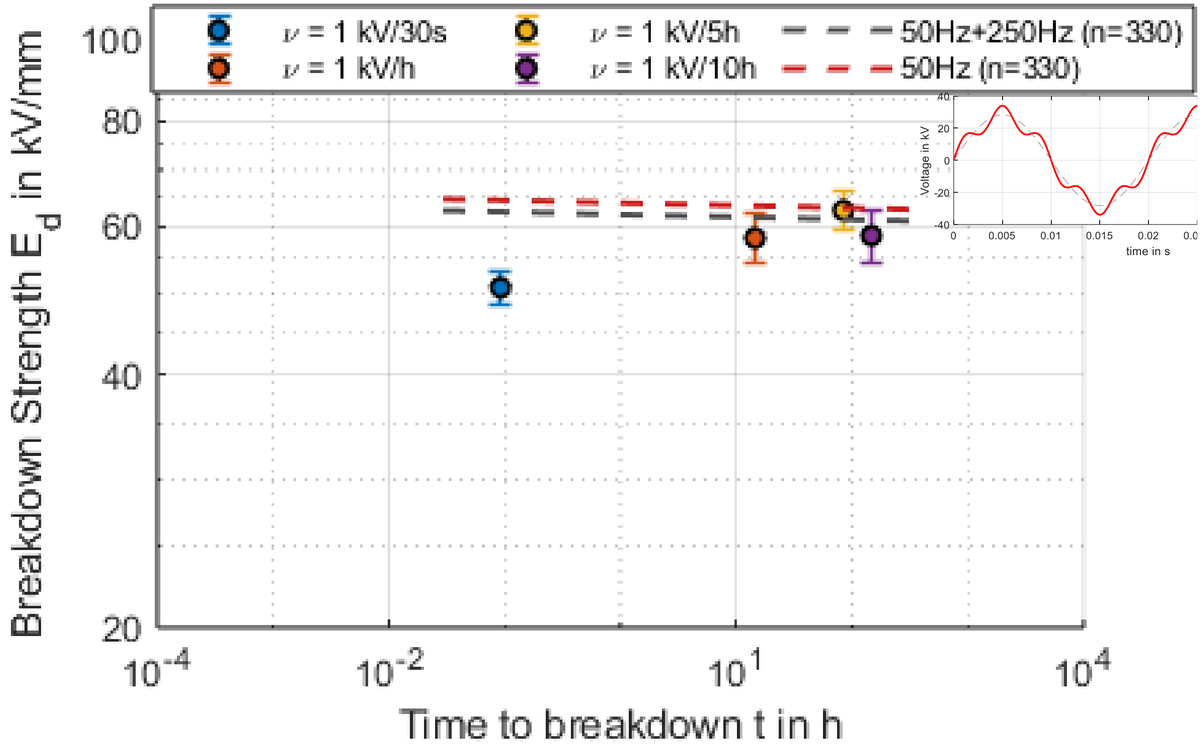
- Weibull distribution for distorted voltage with 50 Hz + 10 % of 5th harmonic distortion (250 Hz)
- Weibull distributions partly more clearly separated
- 63 %- quantile are also close together except 1kV/30s
- Minor effect of the voltage increase rate on the spread of the results very similar also to 50Hz



# Results – distorted Voltage

- 3 of 4 measured values are in similar range to 50 Hz sine,
- The values measured at 1 kV/30 s appear to contain measurement errors and is unexpected low; this needs to be investigated!
- Considering only the 3 points a similar lifetime curve can be calculated with similar exponent n

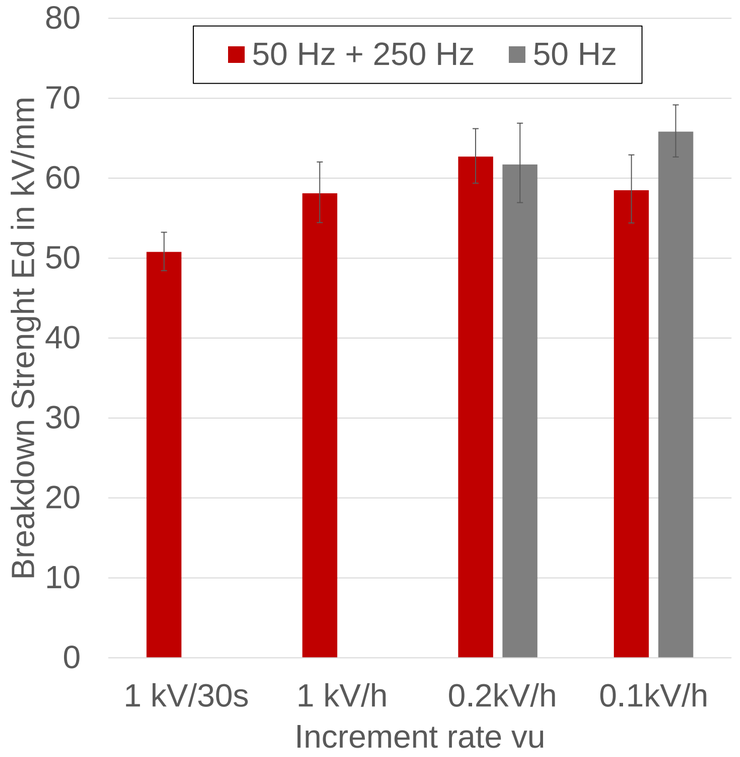
➢ no significant change in life-time characteristics is expected



# Results – distorted Voltage

- Direct comparison of breakdown field strength with comparable voltage increment rates
- no clear trend or significant difference is noticed as well

➢ For unfilled, low loss silicones, under distorted voltage conditions a negative influence on the breakdown voltage is not recognized



# Summary and Conclusion

# Summary and Conclusion

- The dielectric strength of silicone elastomers, without functional fillers, under the influence of harmonics has been investigated
- The tested silicone elastomer experience no electrical field aging under the used conditions
- Under distorted voltage conditions, the breakdown characteristics remained largely consistent with the 50 Hz results
  - similar Weibull slopes and location parameters
  - Similar life-time exponent

➢ Within the tested parameters, harmonic distortion does not significantly accelerate the aging process of low-loss silicone elastomers, other aging mechanism have to evaluated for real-world applications

➢ In contrast to this high loss materials or functional filled materials have shown a significant influence

➢ Constant Voltage Tests with long duration are currently in progress/planned

# Thank you for your attention!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