Characterization of the breakdown voltage of vacuum interrupters by different procedures

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Outline

- Introduction and rationale
- Experimental setup
- Experimental result collected with AwBD procedure on VIs (repeatability check)
- Deconditioning effect at different gap lengths for VI
- Comparison between AwBD and Up-Down (UD) methods

Introduction and rationale

Vacuum interrupters have standard requirements to withstand voltage pulses

The Basic Insulation Level (BIL) is precisely codified (e.g peak voltage and shape of the voltage waveform)

The Lighting Impulse Voltage Waveform (LIVW) has a front time and a time to half-value of 1.2/50 μs

The electrical stress in this experiments is much higher than in the actual application

Different procedures for the LIVW application can be adopted to characterize the hold off voltage of a device under a statistical approach

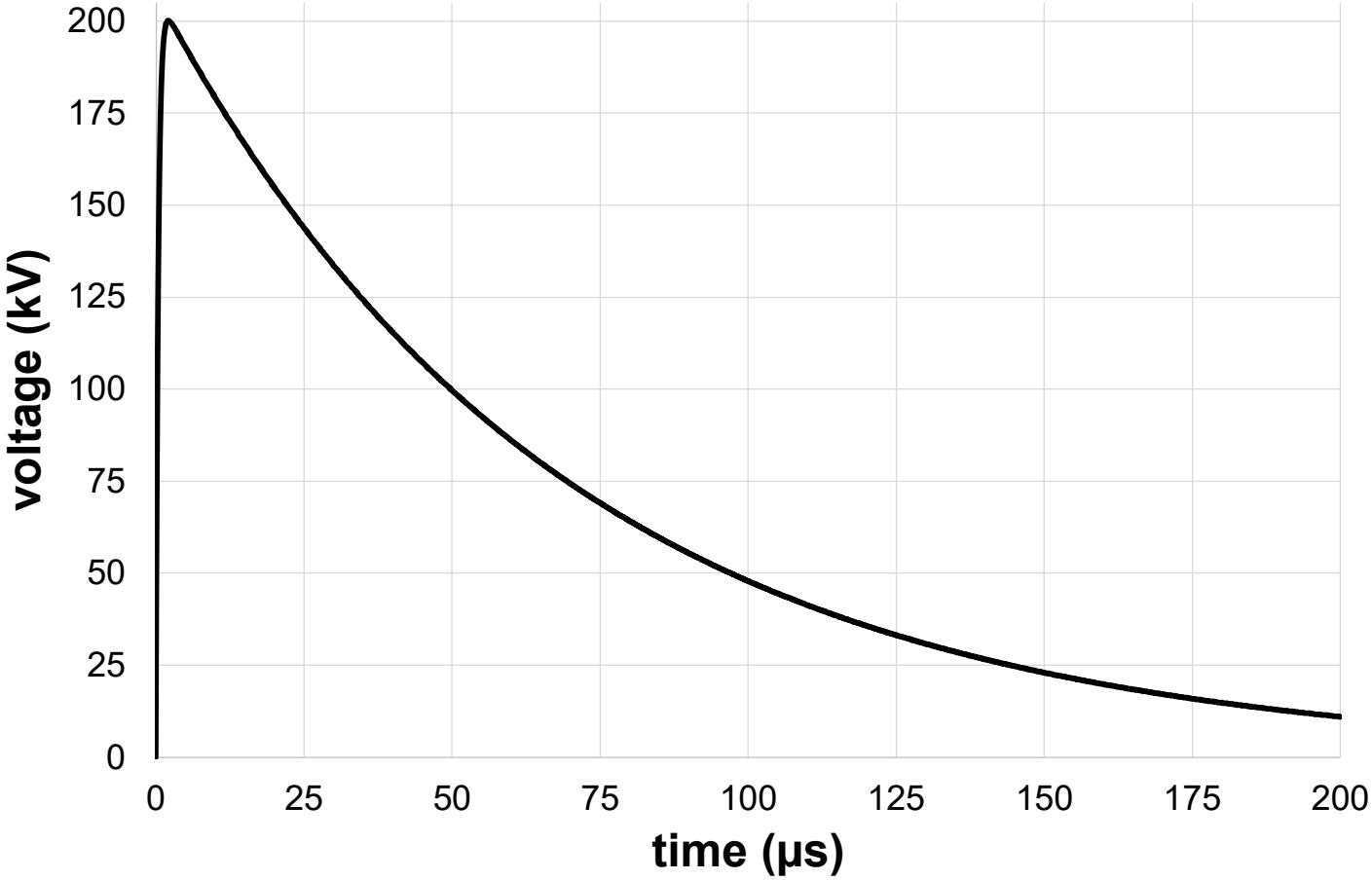
In this work 2 procedures have been investigated and the results have been compared

- Up and Down (UD)→ widely adopted
- Always Breakdown (AwBD)→ faster procedure to collect statistical results

The collected results have been adopted to tune and validate the Voltage Holding Predictive Model (VHPM) [2], a numerical tool developed at Consorzio RFX aimed at improving the design of high-vacuum complex electrostatic devices *(see N.Marconato presentation).*

[1] Hauschild W., Lemke E. (2019) Basics of High-Voltage Test Techniques. In: High-Voltage Test and Measuring Techniques. Springer, Cham. DOI 10.1007/978-3-319-97460-6
[2] N. Pilan, P. Veltri, A. De Lorenzi, Voltage holding prediction in multi electrode–multi voltage systems insulated in vacuum, IEEE Transactions on Dielectrics and Electrical Insulation 18 (2) (2011)

BIL lighting impulse voltage



Experimental setup

Marx Generator: 12 x 200kV=2.4 MV ($\eta=\frac{V_{peak}}{V_{charge}}=0.86$)

Output capacitor

Voltage divider

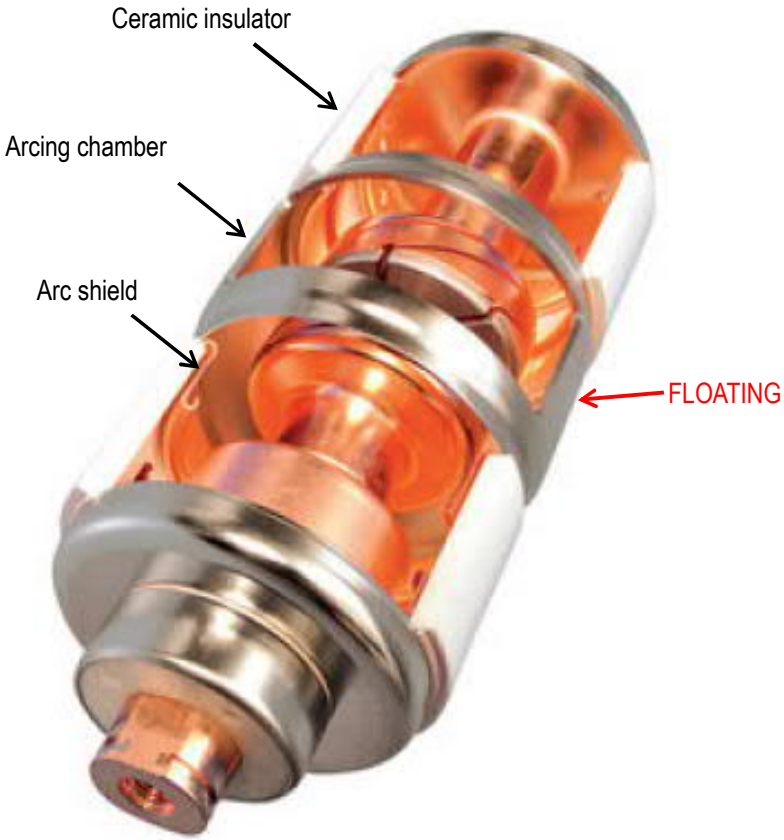
Cable to VI

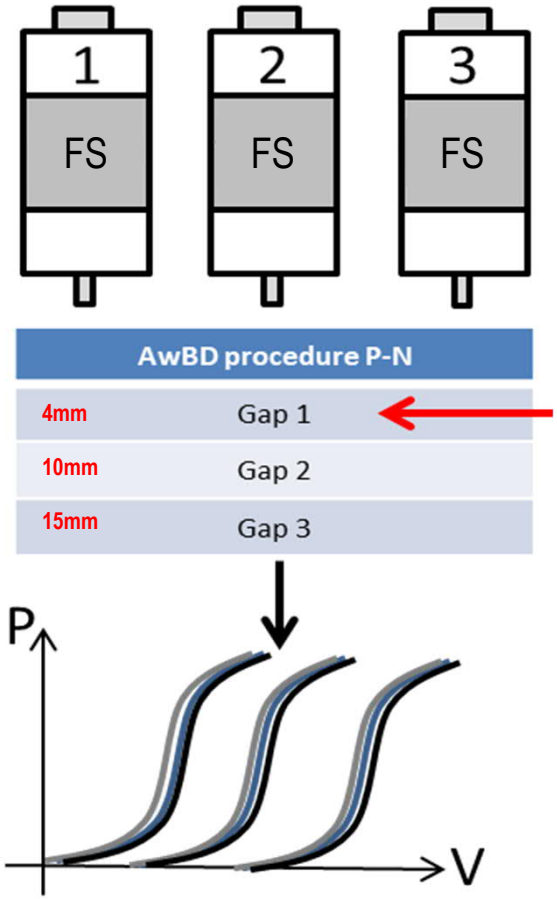
Ground plane

Vacuum interrupter

Cable to GND

Experimental results collected with AwBD procedure on FS VIs



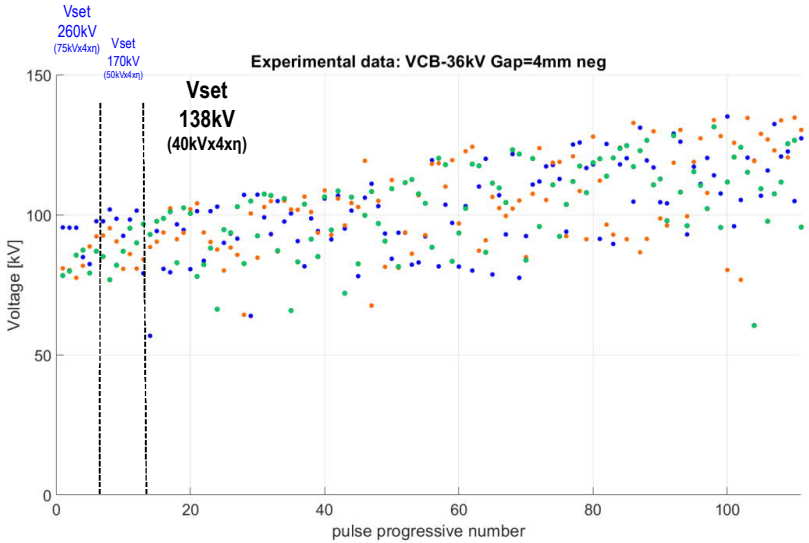


Experimental results collected with AwBD procedure on FS VIs: chronological sequence

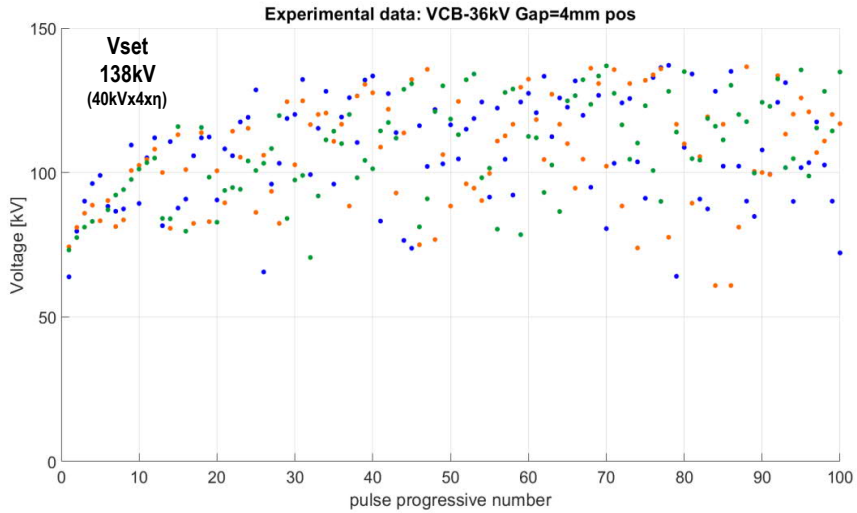
1. FS_01_4mm negative polarity
2. FS_01_4mm positive polarity
3. FS_01_10mm positive polarity
4. FS_01_10mm negative polarity
5. FS_02_4mm negative polarity
6. FS_02_4mm positive polarity
7. FS_02_10mm positive polarity
8. FS_02_10mm negative polarity
9. FS_03_4mm negative polarity
10. FS_03_4mm positive polarity
11. FS_03_10mm positive polarity
12. FS_03_10mm negative polarity
13. FS_03_15mm negative polarity
14. FS_02_15mm negative polarity
15. FS_02_15mm positive polarity
16. FS_03_15mm positive polarity
17. FS_01_15mm negative polarity
18. FS_01_15mm positive polarity

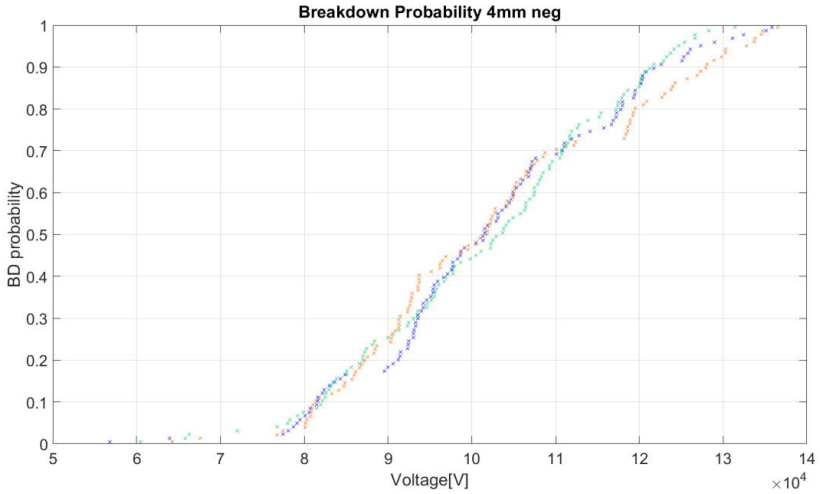
Experimental results collected with AwBD procedure on FS Vis: 4mm gap

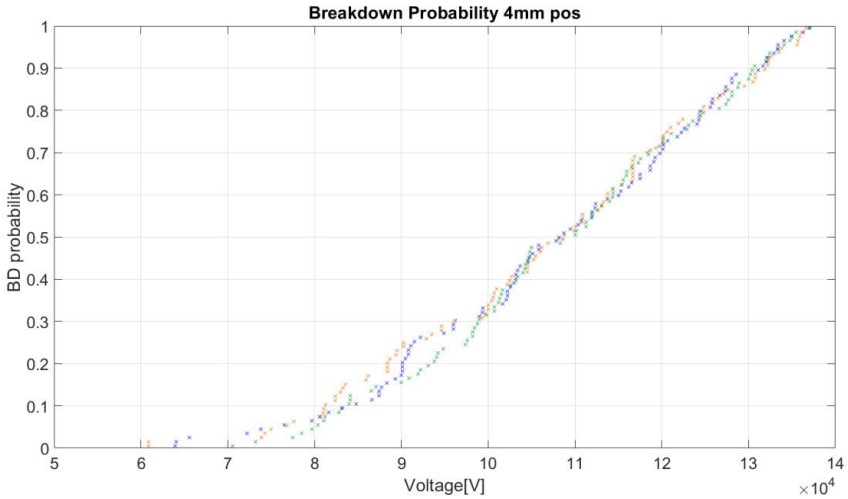
VI 01
VI 02
VI 03



time

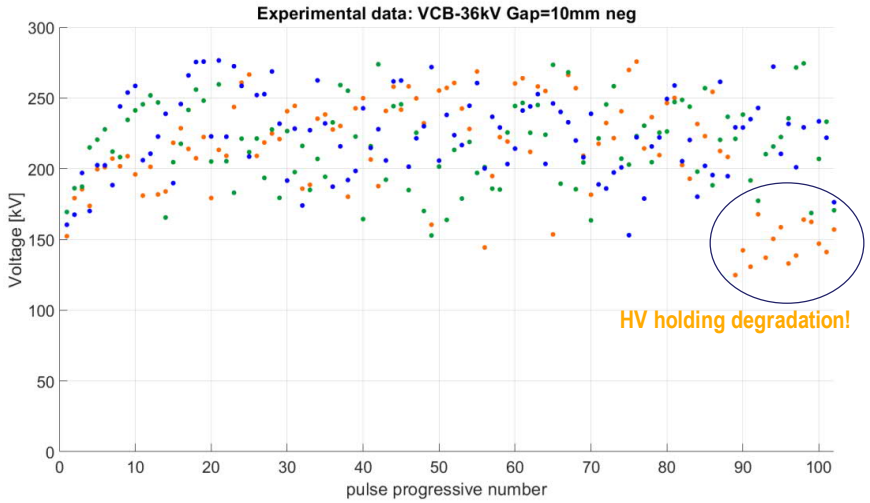






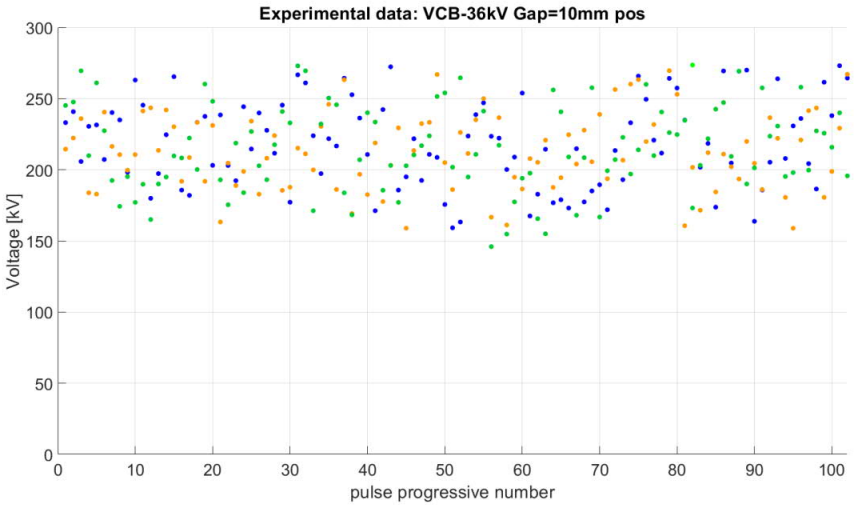
Experimental results collected with AwBD procedure on FS Vis: 10mm gap

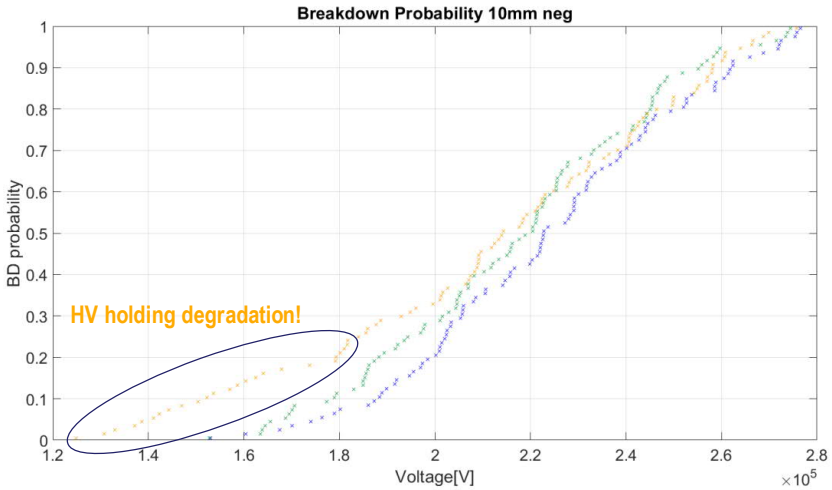
- VI 01
- VI 02
- VI 03

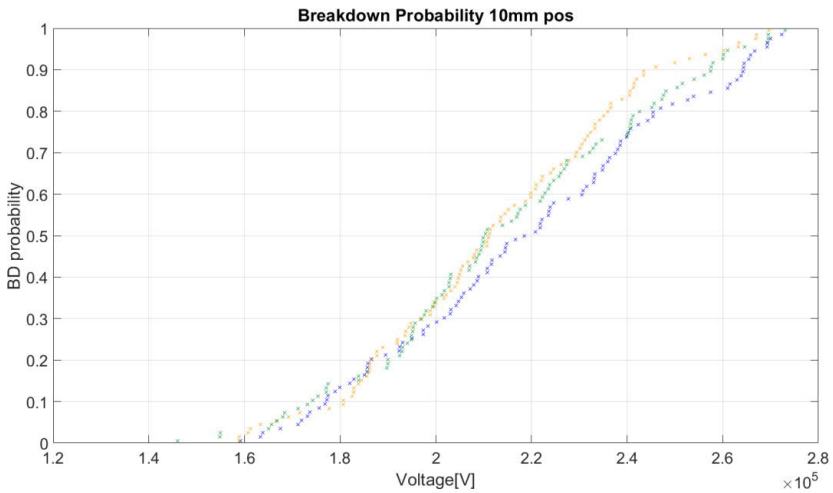


time

Vset
275kV
(80kVx4xη)

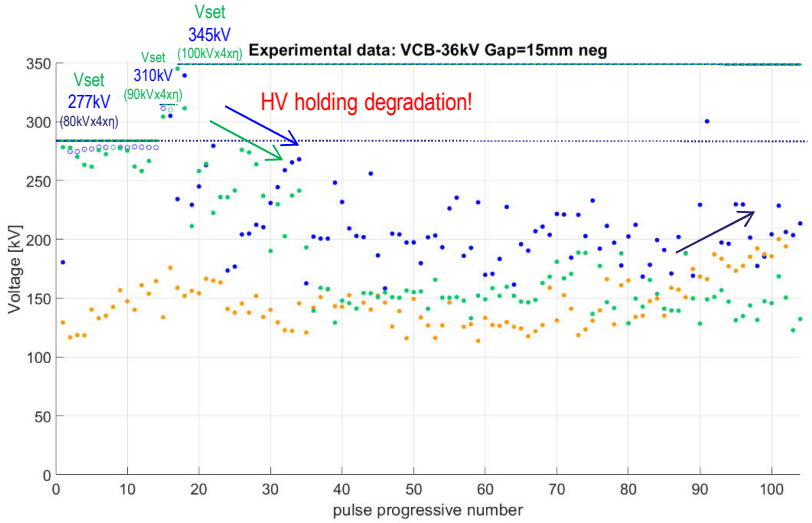




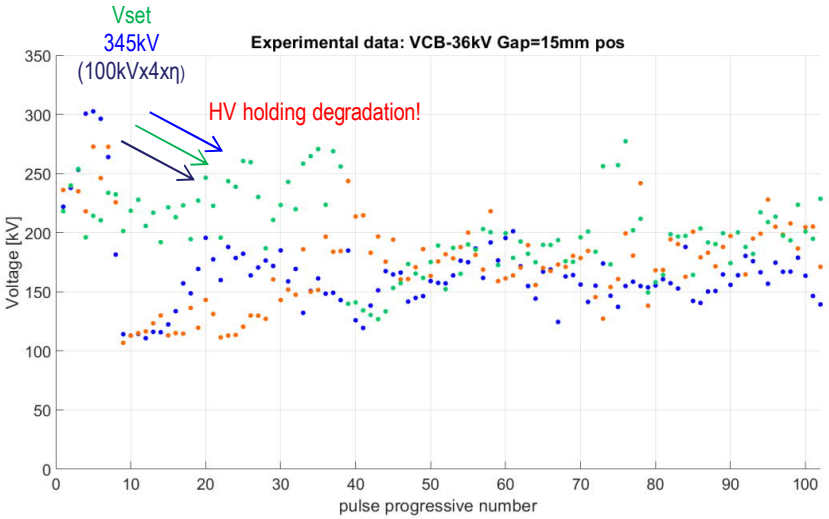


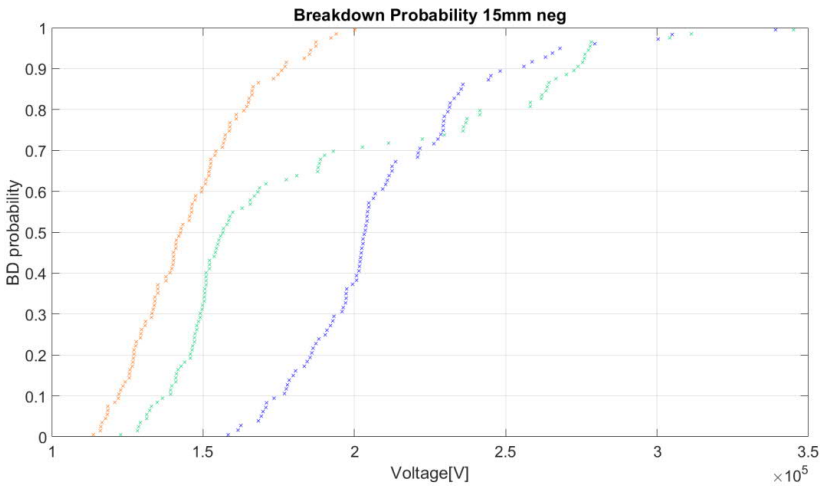
Experimental results collected with AwBD procedure on FS Vis: 15mm gap

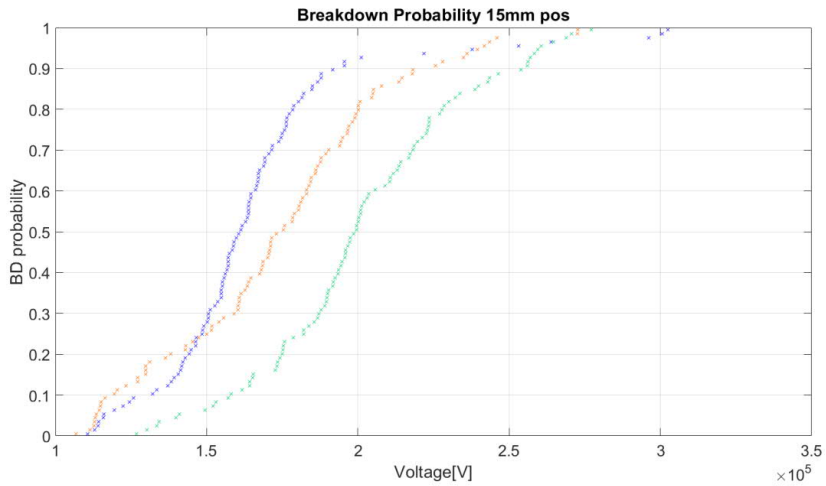
VI 01
VI 02
VI 03
NO BD



time



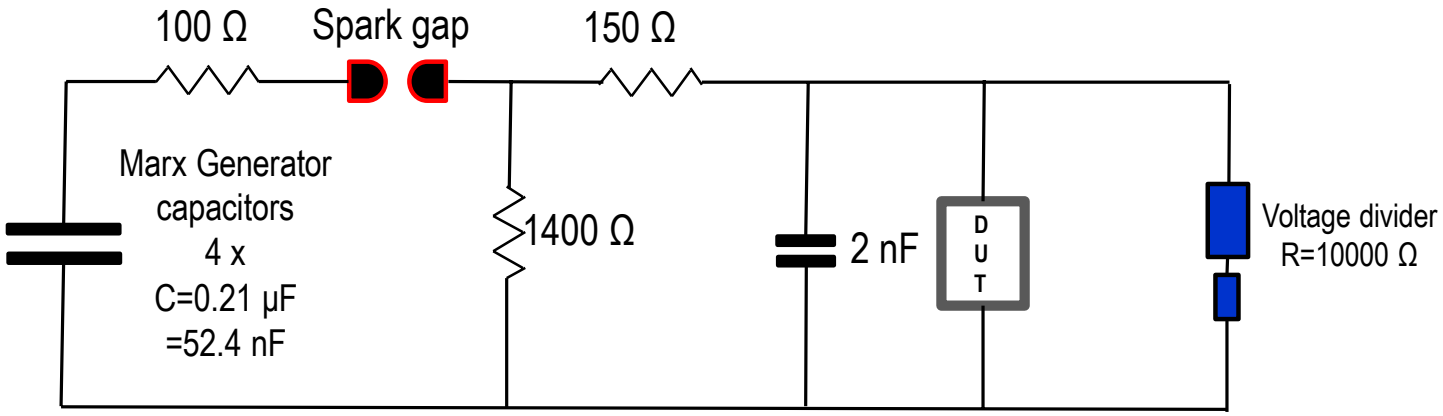


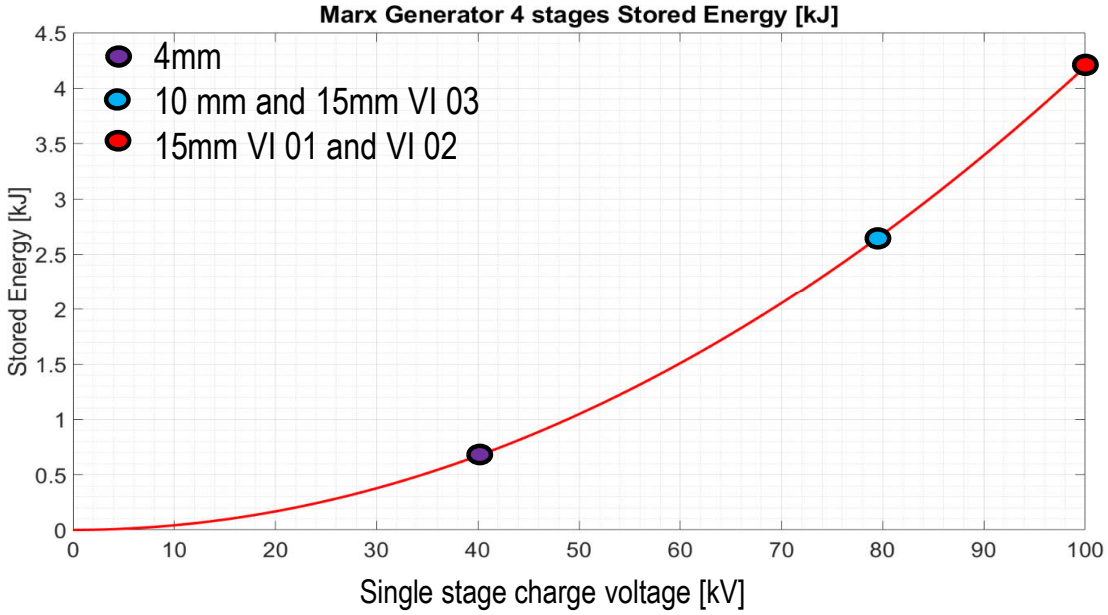


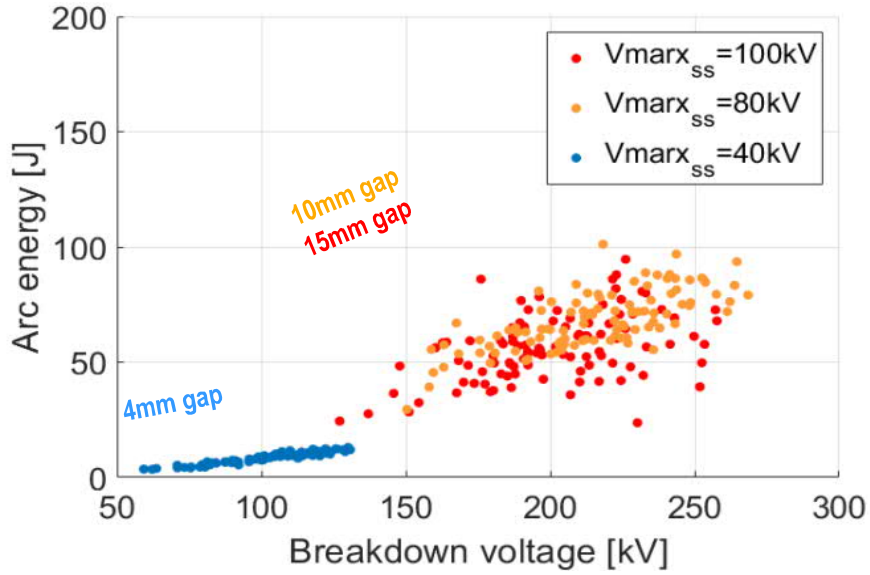
Experimental results collected with AwBD procedure on FS Vis: remarks

Marx generator:
Stages n°= 12
Vmax_stage=200kV
Vmax_generator=2400 kV

→ Only 4 stages were used for the tests







Experimental results collected with AwBD procedure on FS Vis: conclusions

- With 4mm gap all the VIs behave almost in the same way and there is a slightly conditioning during the pulses
- With 10mm gap VI_01 and VI_02 behave almost in the same way for the whole tests while VI_03 at a given time suddenly deconditions
- With 15mm gap the VIs behave in a different way and starting from good performances (VI_01 and VI_02) degraded pulse after pulse
- For 4mm gap V50% is about 110kV for all the VIs and polarities
- For 10mm gap V50% is about 220kV for all the VIs and polarities
- For 15mm gap V50% is scattered (from 140kV to 200kV) and different both among the VIs and polarities

Deconditioning effect at different gap lengths for FS VI

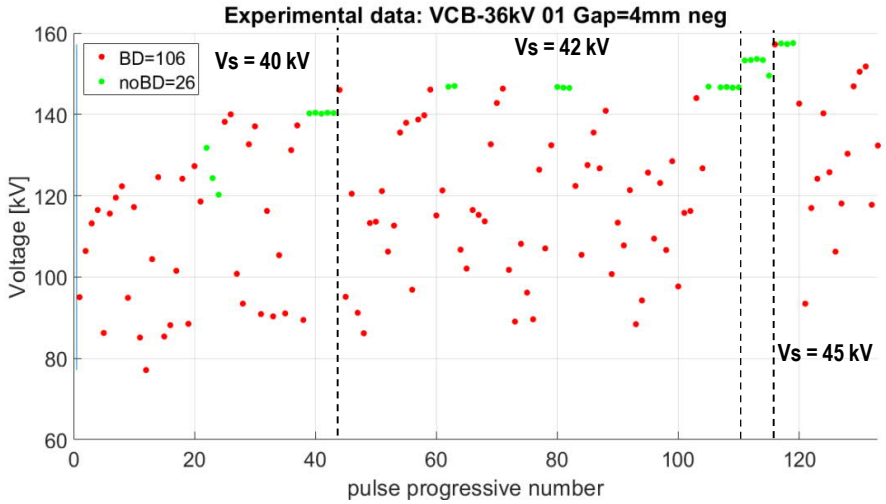
1. VI_01_4mm N AwBD
2. VI_01_4mm P AwBD
3. VI_01_10mm P AwBD
4. VI_01_10mm N AwBD

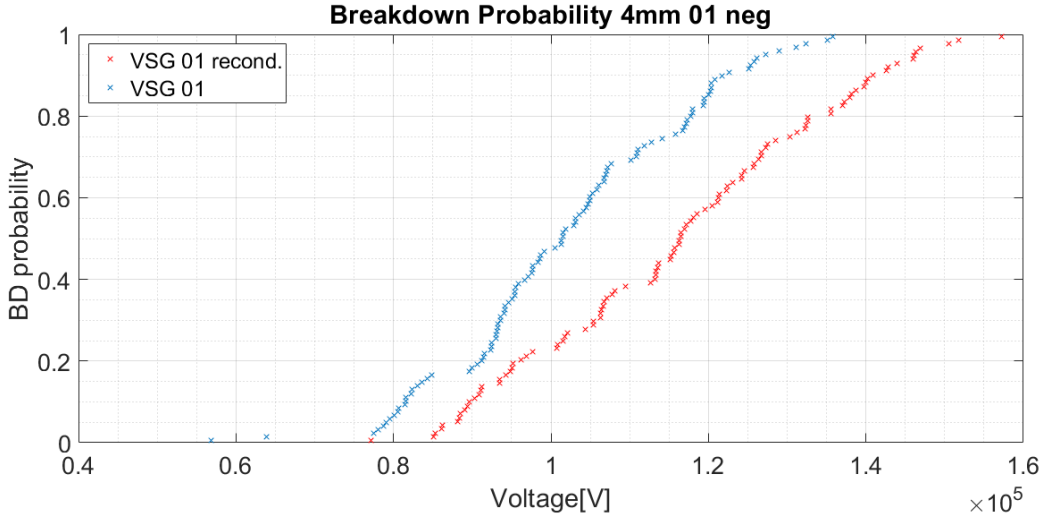
Reconditioning attempt!

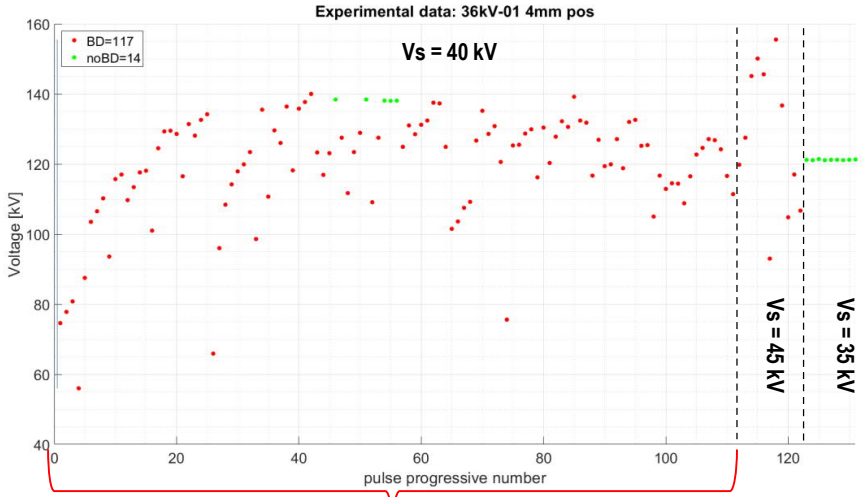
5. VI_04_4mm N UD
6. VI_04_4mm P UD
7. VI_04_4mm N UD (tested again)
8. VI_04_10mm P UD
9. VI_04_10mm N UD
10. VI_01_4mm P UD (tested again)

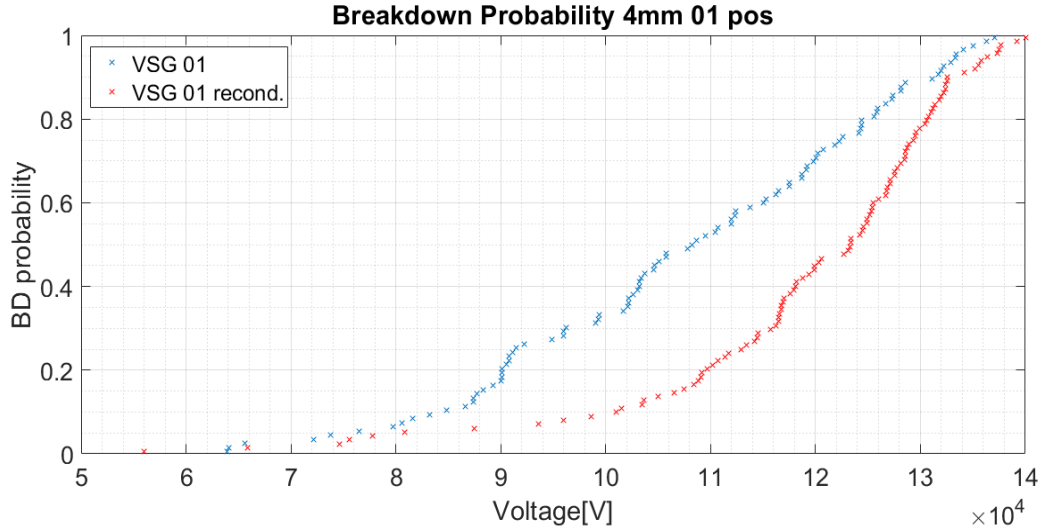
Test of a new VI with UD method

Reconditioning effect at different gap lengths for FS VI: 4mm



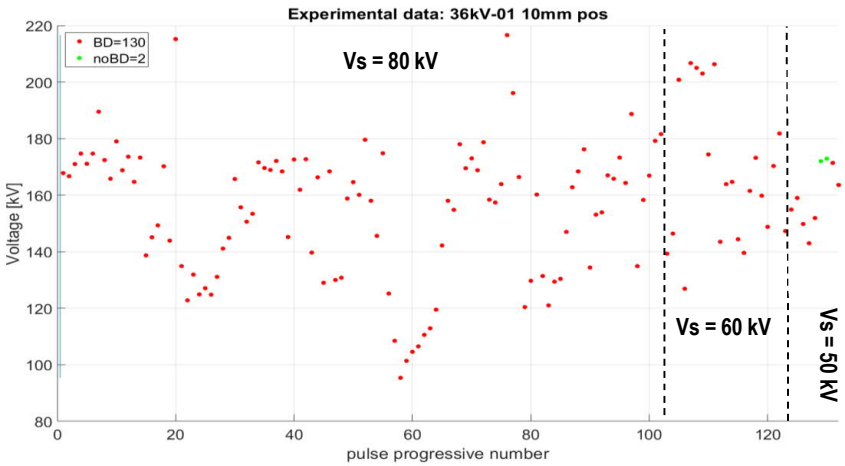


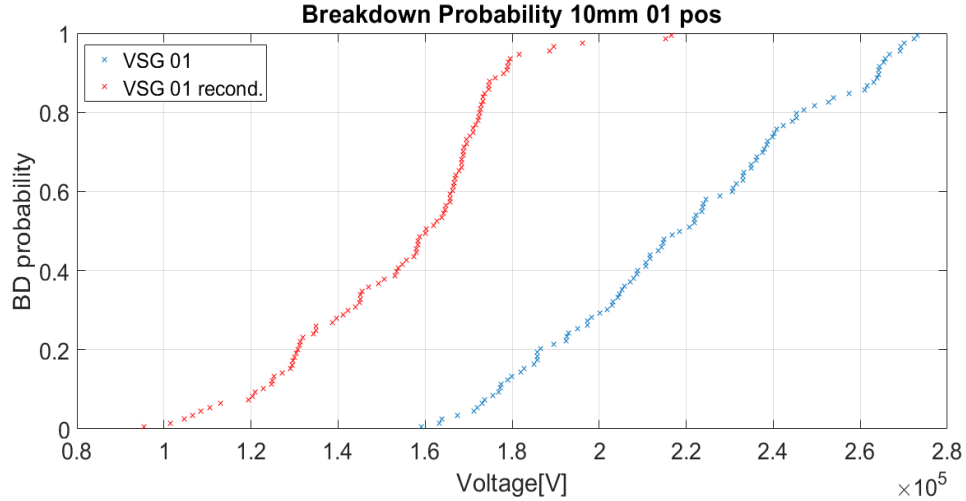


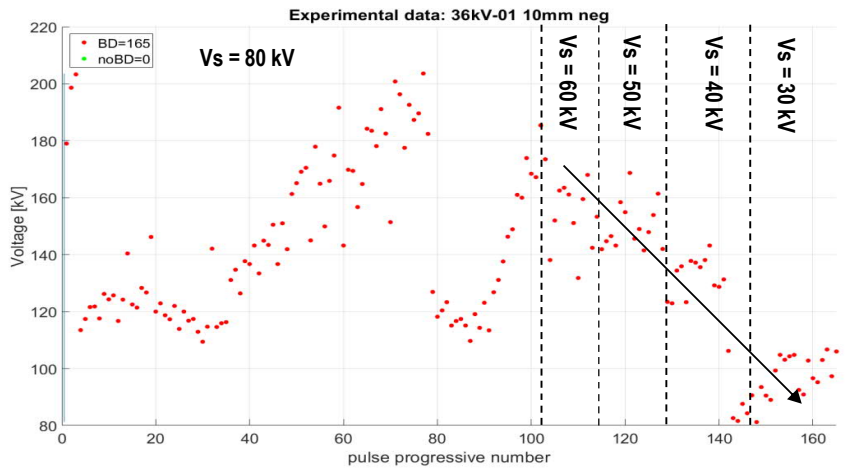


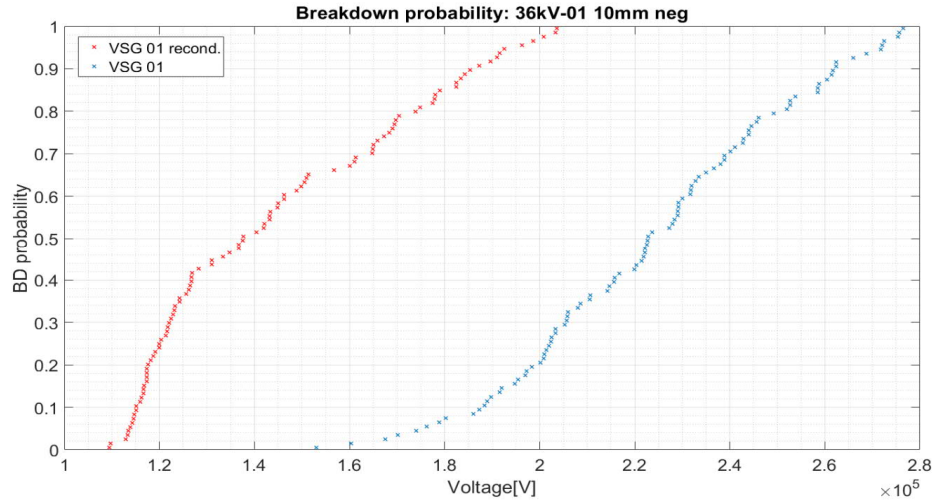
Data set for P

Deconditioning effect at different gap lengths for FS VI: 10mm





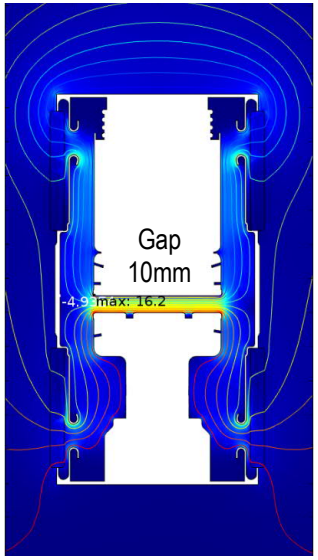


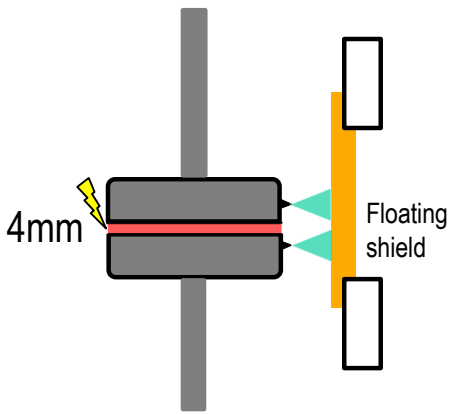


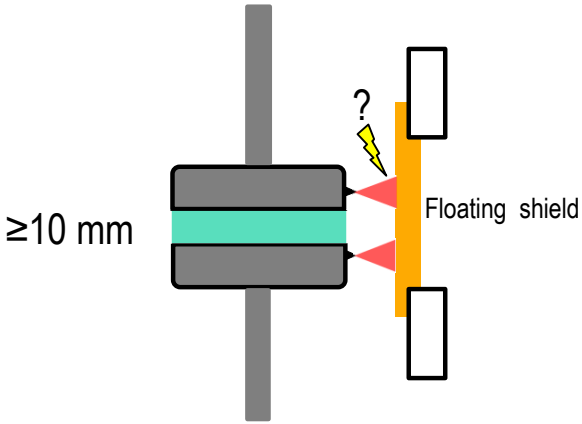
Remarks

1. VI 01_02_03 did not show any de-conditioning effect for 4mm gap length, even if during previous tests with 15mm gap de-conditioning was evident. The overall VH performances are better for both polarities w.r.t. new VIs.
2. VI 01_02_03 showed an evident de-conditioning effect for 10mm gap length for both polarities. Thousands pulses are not enough to produce any reconditioning effect.
3. VI_01_10mm N AwBD showed that breakdown voltage might be related to set voltage, lower set voltage -> lower average breakdown voltage. Voltage derivative (time) might be not negligible in breakdown voltage occurrence.

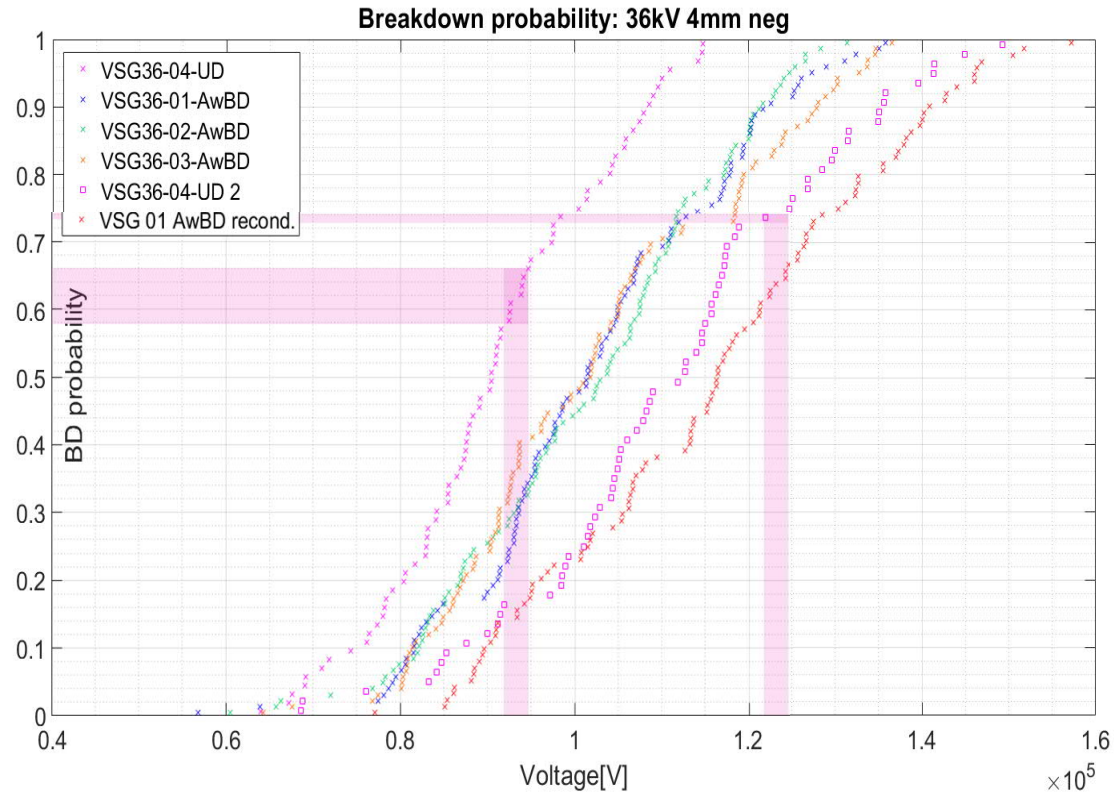
Possible explanation: micro-tips on the sides of electrodes might have been generated during 15mm gap tests due to high arc energy, with short gap their effect is masked since E between the plates is much greater than that involving electrodes side.

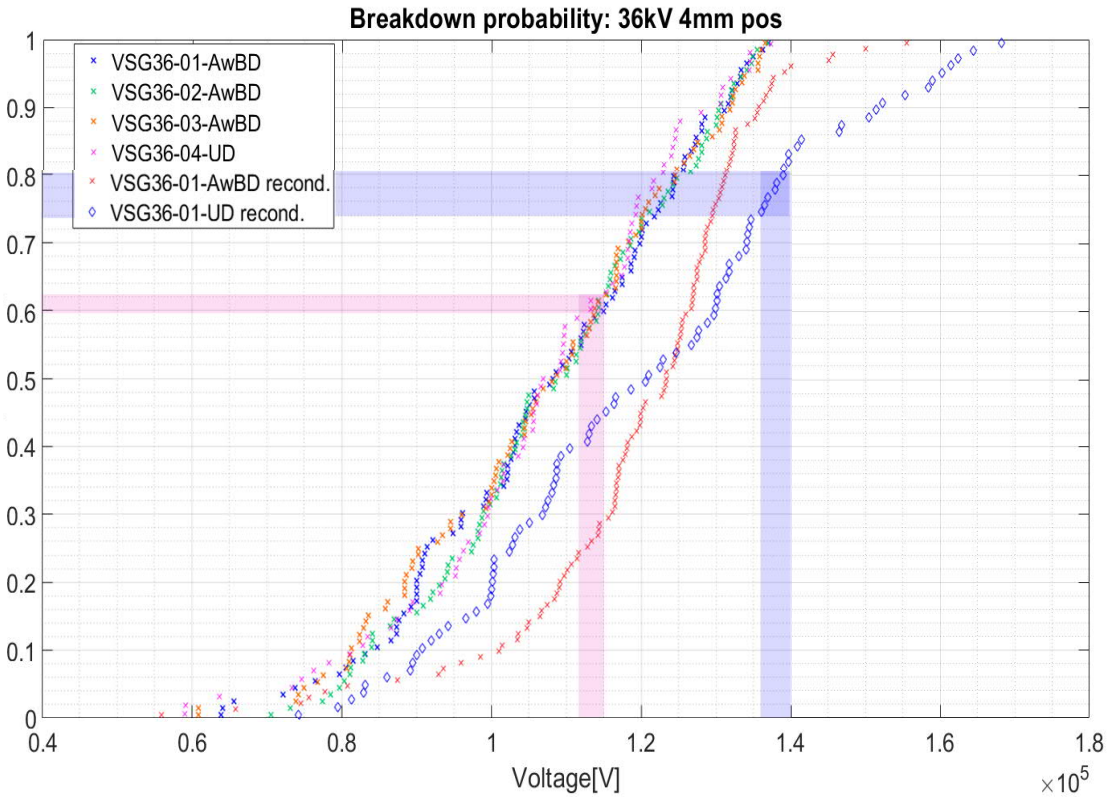




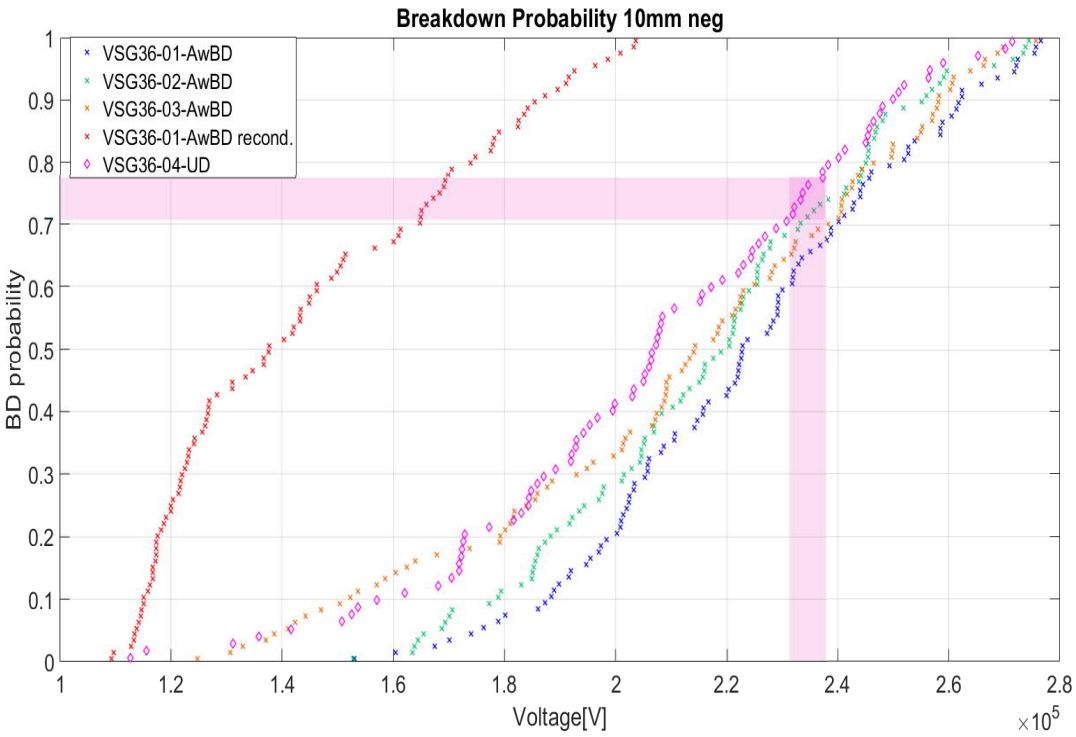


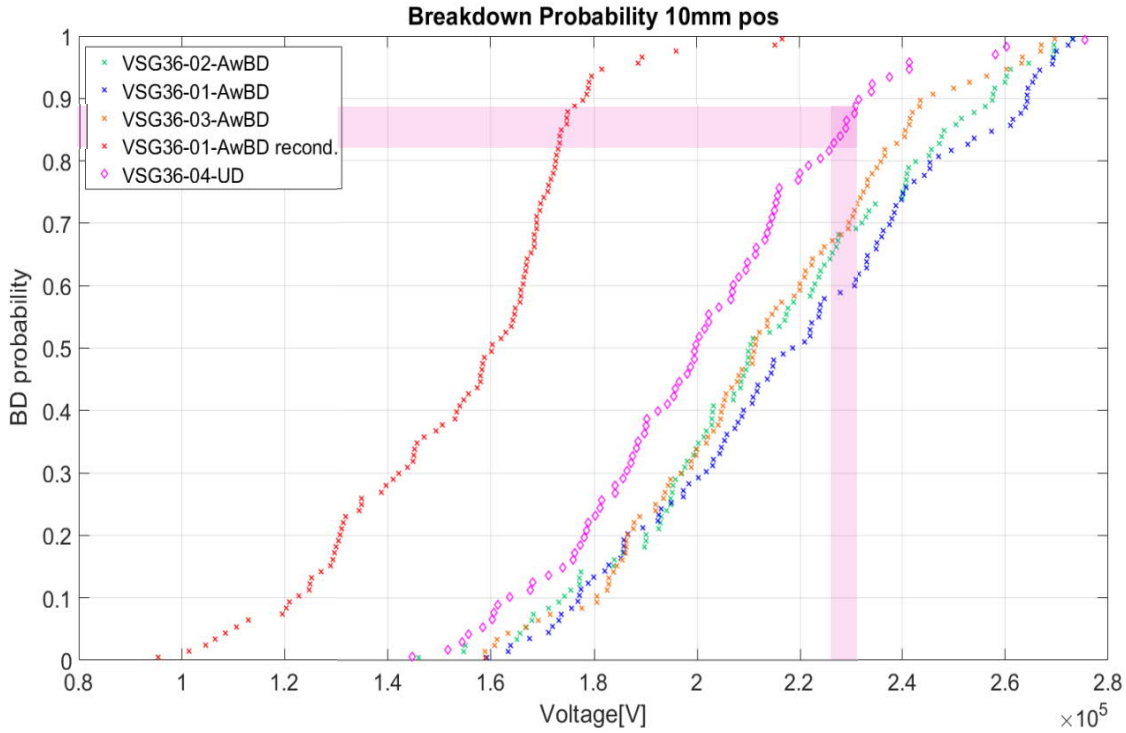
Comparison among procedures: 4mm summary





Comparison among procedures: 10mm summary





Conclusions and remarks

1. Tests on the breakdown behavior of commercial vacuum interrupters.

2. AwBD (always breakdown) procedure gave repeatable results over different polarities and particularly for the 4mm contact gap. The AwBD also give similar results for 10mm gap, but with wider scatter (possible due to conditioning / higher breakdown energy).

3. De-conditioning events could be recovered from for the 4mm gap (with the lower arc energy), but very limited re-condition at larger gaps. Possible effect from the applied voltage / voltage rise time / delay between breakdown and voltage collapse needs to be studied.

4. Good general agreement between the AwBD and the up-and-down methods. The AwBD allows for much quicker data acquisition, so it gives significant practical advantages.

5. Data is the basis for further future comparisons to breakdown models.