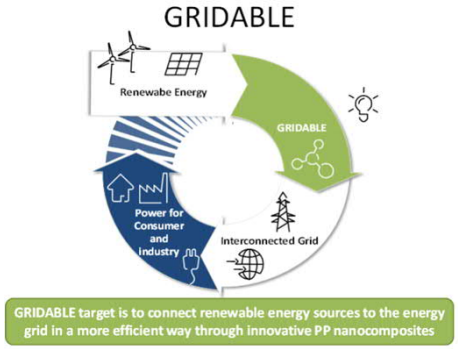
Final Webinar of the GRIDABLE Project

14th June 2021

GRIDABLE

PLASTIC NANOCOMPOSITE INSULATION MATERIAL ENABLING RELIABLE INTEGRATION OF RENEWABLES AND DC STORAGE TECHNOLOGIES IN THE AC ENERGY GRID



FUNDAMENTAL RESULTS OF CAPACITOR ELEMENT TESTS AND TESTS ON CAPACITOR DEMONSTRATOR UNITS

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ELECTRONICON Kondensatoren GmbH (EKG)

EC GRANT AGREEMENT NUMBER 720858

ELECTRONICON®

Kondensatoren GmbH Gera

- Manufacturer of high-class AC- and DC Capacitors
- Located in Gera, Thuringia - Germany
- Founded in 1938 as part of SIEMENS & HALSKE
- Since 1994 ELECTRONICON is a private owned company
- 100% of capacitor production is “Made in Germany”
- Own metal coating center for capacitor film in Gera
- Annual turnover between 50 M€ and 70 M€ (depending on projects)
- Around 450 employees in total
- Main products are custom tailored self-healing power capacitors like
  - Universal Capacitors for Power Electronics
  - Special capacitors for HVDC Classic and HVDC VSC projects
  - DC-Link capacitors
  - Traction capacitors
  - Low Voltage capacitors for Power Factor Correction & Power Quality
  - Medium Voltage PFC capacitors

GRID ABLE

HVDC CAPACITORS and ELECTRONICON within GRIDABLE

- Today HVDC-capacitors are the biggest and most expensive component within the HVDC power module.
- The aim of the capacitor project as part of Gridable is the reduction of size and cost for such component.

The sequence within the Gridable project was

- Development of nanofilm materials with possibly higher power density in operation
- Production tests on various scales
- Extensive electrical testing of materials and real size capacitors
- Improvements by a cyclical development process with industrial scale nanofilm-materials

  Prototype 1...3 (PT1...PT3) as a main result

- My presentation will mainly concentrate on EKG's work and the results of WP4

  Manufacturing and evaluation of industrial capacitor elements and demonstrator units of PT3 BOPP Nanofilms.

Capacitor films / elements / units

Phase 1 – tests on PT2 materials - Start of ELECTRONICON within Gridable project

- First extensive element / unit tests
  - 5 material systems (4,7µm and 9,5µm BOPP and Nano) tested in general (metallized samples A...E)
    - Single capacitor elements and full size HVDC-capacitors / Demonstrators of each film system manufactured and tested
    - Detailed tests done acc. to IEC 61071 plus EKG's own special voltage-step-test monitoring the Insulation Current (I) versus Voltage (U) -behavior of capacitor elements up to electrical breakdown
  - Main results of PT2 industrial material tests in short words:
    - Need to avoid agglomeration of Nanoparticles within the dielectric film
    - Concentrate on a 9,5µm film for PT3 production and further industrial investigation, as thin films offer no real advantage

Capacitor films / elements / units

- Phase 2 - PT3 materials (our main focus today)
  - 4 material systems of metallized film (F…I) tested in general
    - 9,5µm BOPP
    - 9,5µm BOPP with modified manufacturing process
    - 9,5µm BOPP-Nanofilm
    - 9,5µm Nano process (but without Nanoparticles) for more direct reference
    - Extensive production tests and electrical tests done acc. to IEC 61071 plus EKG's own special voltage-step-test monitoring the Insulation Current (I) versus Voltage (U) -behavior of capacitor elements up to electrical breakdown

PT3 materials

- Element tests
  - 9,5µm-film – 4 material systems used for element sample manufacturing
  - 65µF single elements (same as for HVDC-capacitor / 108 per 7mF-Demonstrator)

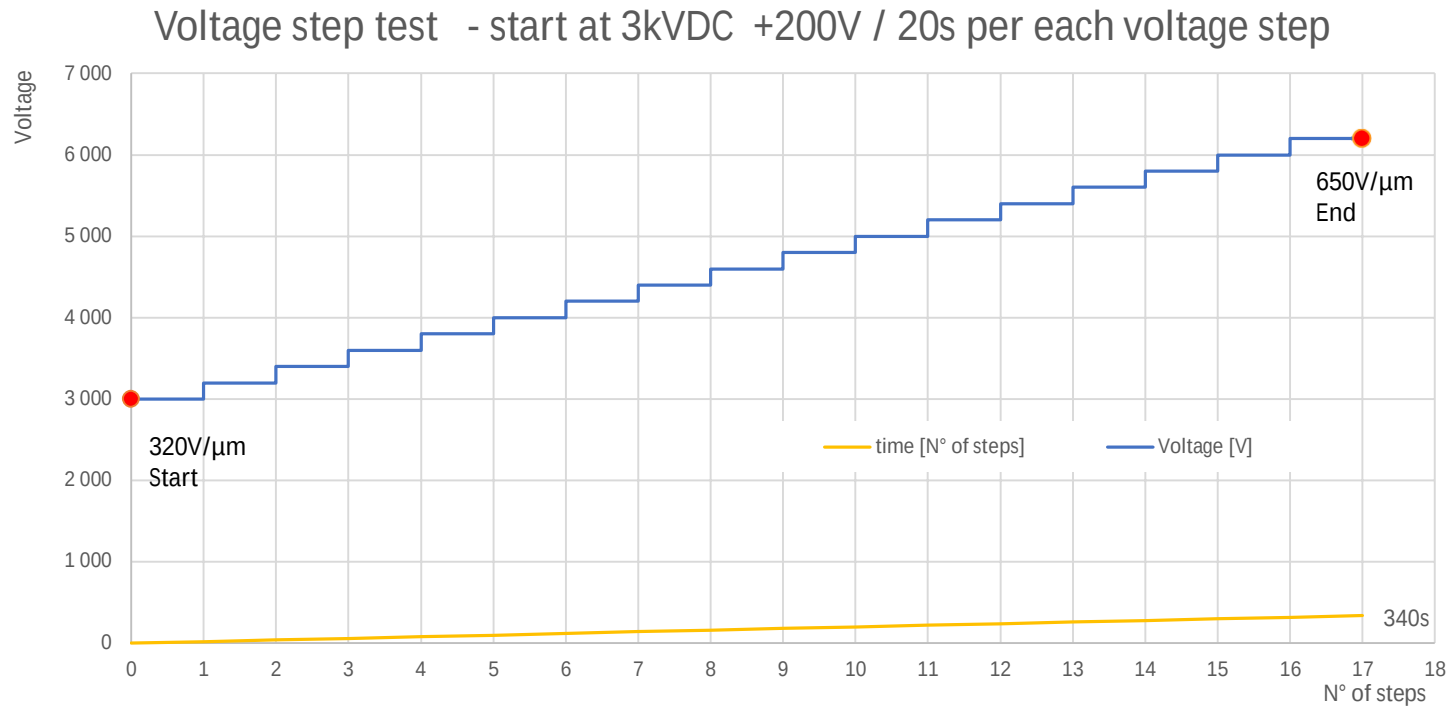
capacitor elements
used for step-test

single element capacitors
used for endurance test

PT3 materials

1. Element tests - Voltage step test

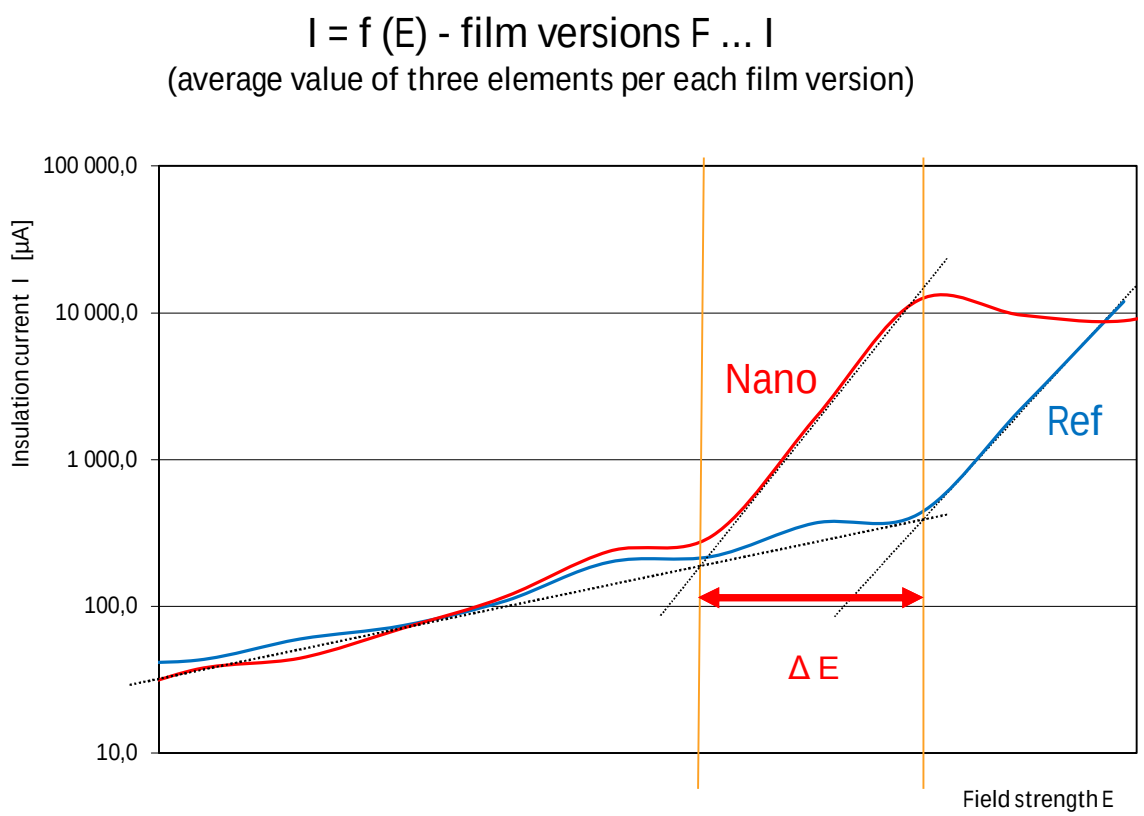
   short time voltage step-test on elements until electrical breakdown



Measurement of the insulation current at the end of each voltage step

PT3 materials

- Voltage step-test results (single element test)



2 conducting mechanism can be detected based on the 2 different linear slopes I vs E in log/lin-scale

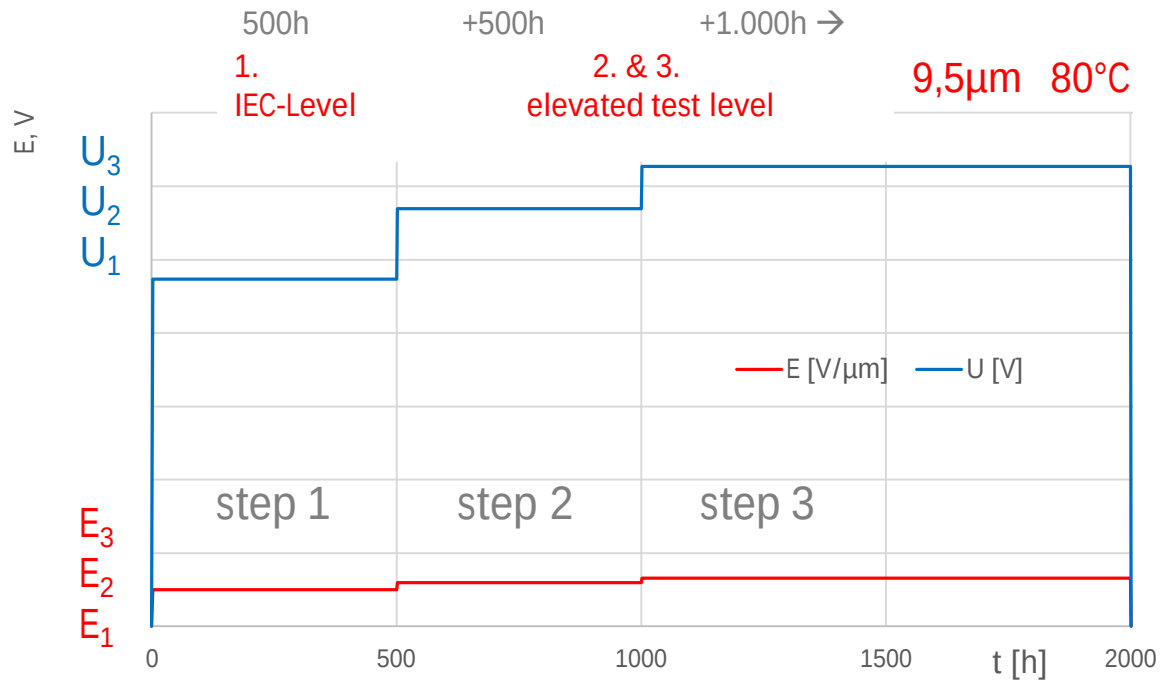
Second mechanism with higher gradient starts recognizable earlier for the Nano-material compared to the reference material

Probably the reason for additional aging effects on high electrical field strength and caused by agglomerates

PT3 materials

2. Element tests - Endurance test

carried out as a 2000h - 3 level DC voltage step-test on single element capacitors

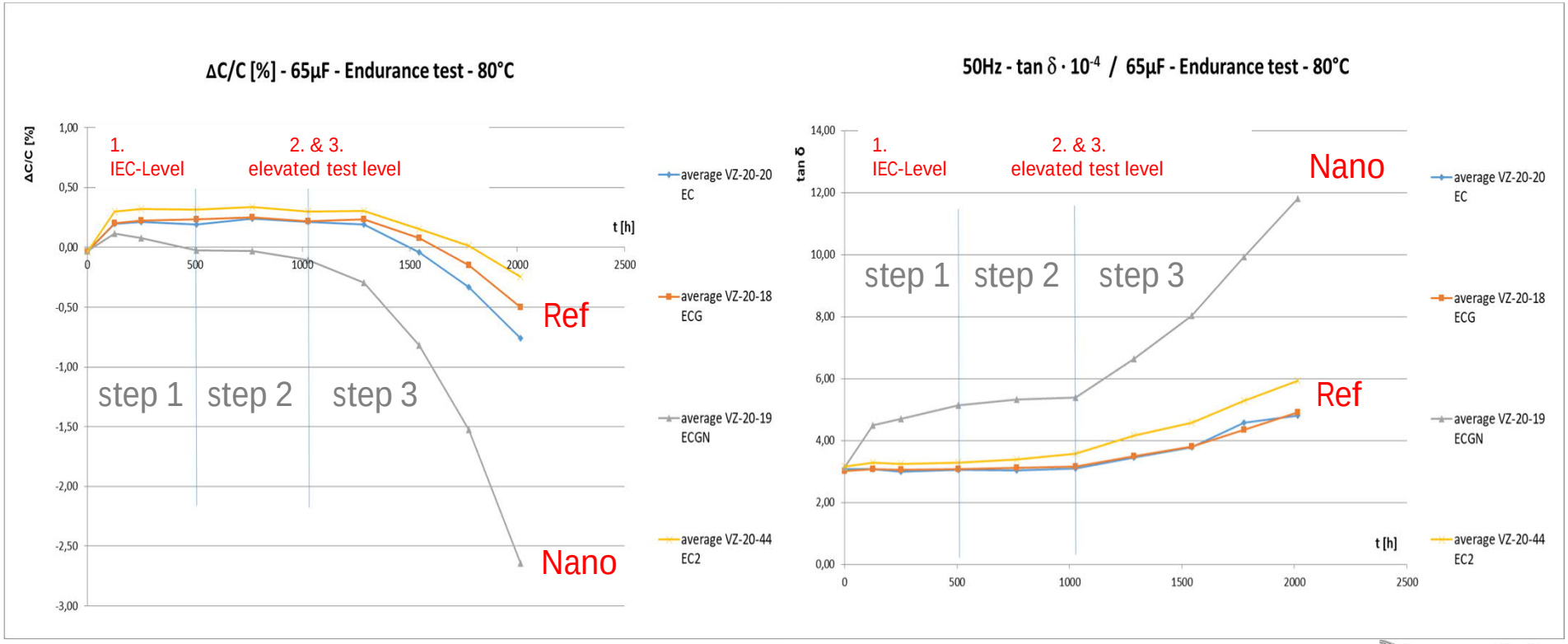


The field strength (E) is decisive for the total stress level.

The corresponding voltage (U) is derived from the film thickness.

PT3 materials

Endurance test results (single element capacitor test)



PT3 materials

Endurance test results (single element capacitor test)

- All PT3 materials meet the requirements at step 1 - IEC testing level
- Aging effects for C and tan δ in the Nano-material, caused by agglomerates, becomes only visible at step 3 level of elevated field strength which is a much better result than with the PT1 and PT2 Nanofilm materials

Conclusions

→ Use of the step 2 testing level for the following tests on the full size PT3 HVDC-capacitor demonstrators, containing 108 elements each.

→ Different from previous materials the step 2 testing level corresponds to a higher rated operating voltage of the full size HVDC-capacitors based on the PT3 Nanofilm.

PT3 materials

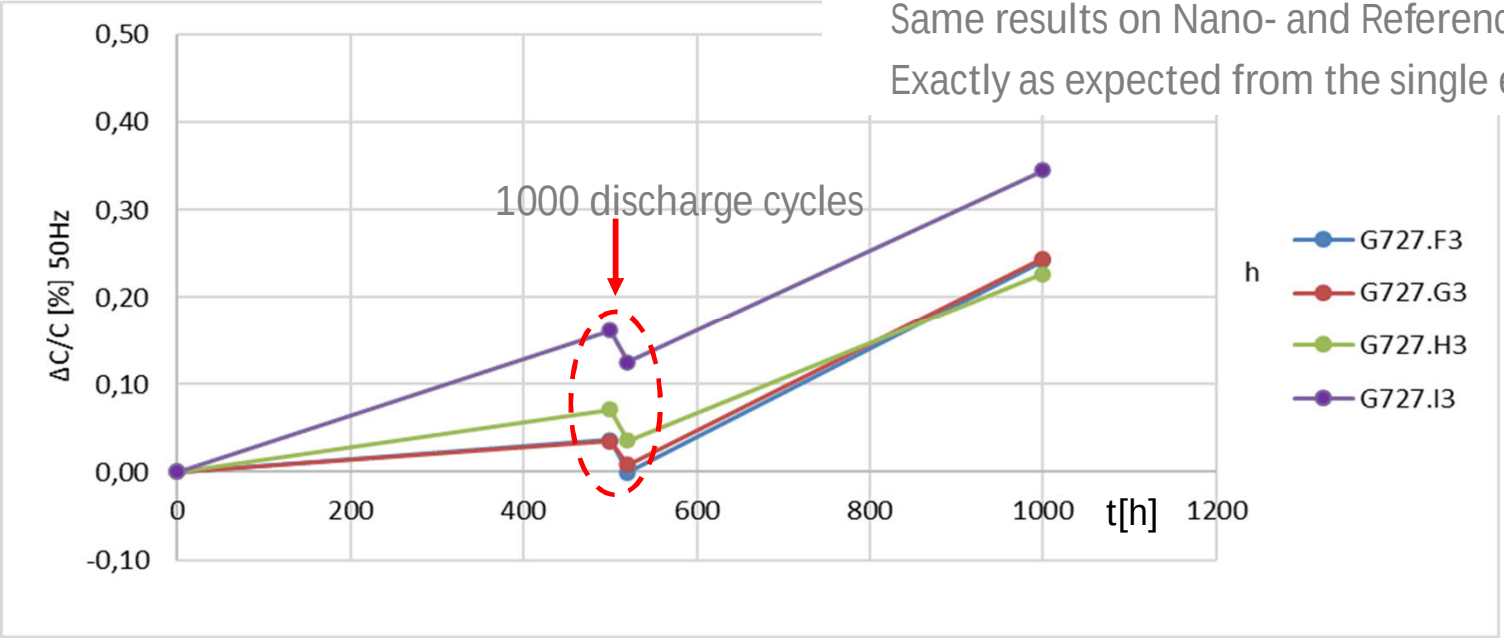
- HVDC-Demonstrator tests on full size capacitors
  - The same 9,5µm-film versions as for the single element tests have been used for building up the capacitor demonstrators, containing 108 elements each.
  - The total capacitance is 7mF per demonstrator.
  - The weight per full size capacitor demonstrator is about 80kg.
- Substantial electrical testing was done according to the standard for power electronic capacitors IEC 61071
  - Surge discharge test
  - Thermal stability test
  - Self-healing test

  Performed successfully and with no noticeable deviations between the 4 materials
  - Endurance test – The results of this most important test are shown in the following slides.

PT3 materials

- HVDC-Demonstrator - Endurance test results
  - test 2x500h @ step 2 voltage level / 75°C + 1000x discharge cycles
  - 7mF full size HVDC capacitor demonstrator

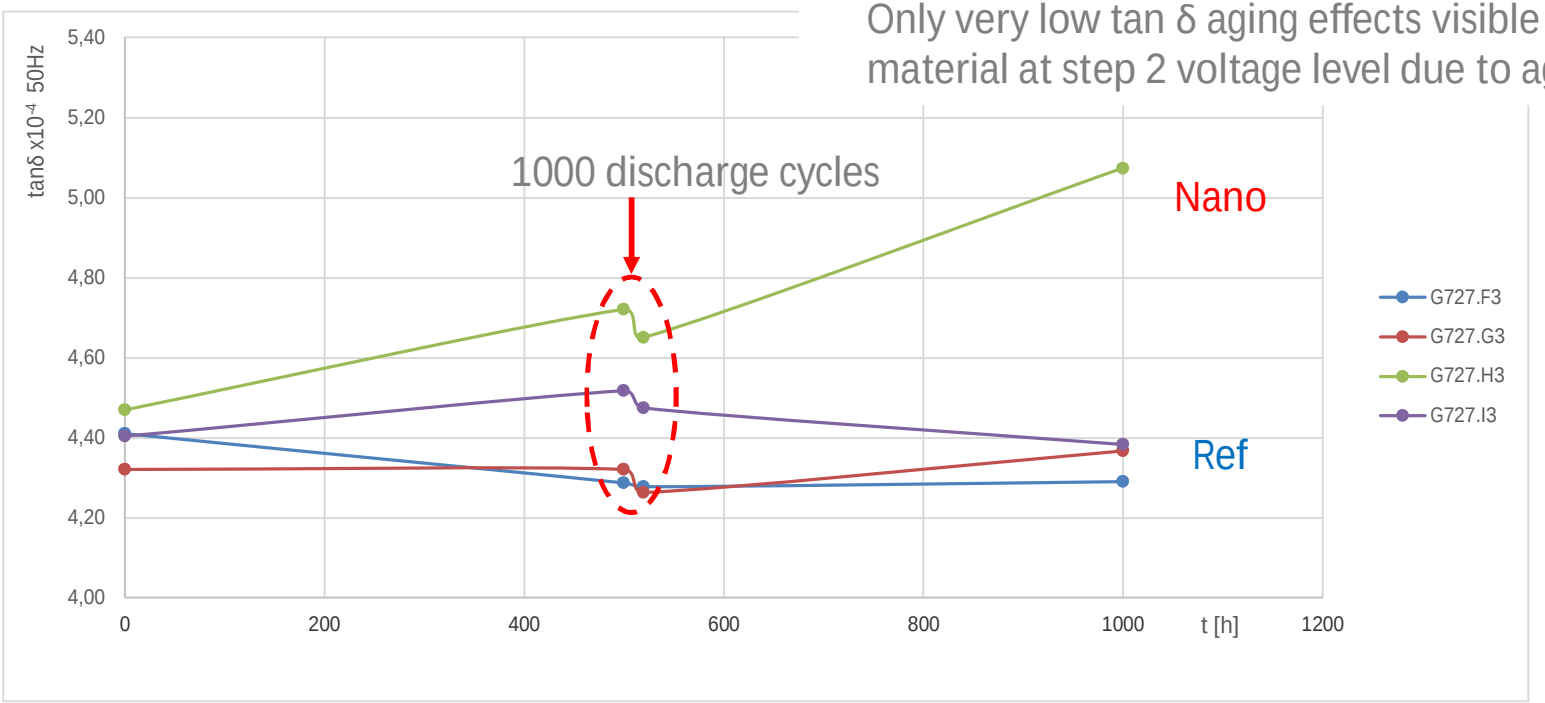
No aging effects visible in Capacitance;
Same results on Nano- and Reference-materials;
Exactly as expected from the single element tests



PT3 materials

- HVDC-Demonstrator - Endurance test results
  - test 2x500h @ step 2 voltage level / 75°C + 1000x discharge cycles
  - 7mF full size HVDC capacitor demonstrator

Only very low tan δ aging effects visible for Nano-material at step 2 voltage level due to agglomerates



PT3 Summary of results - conclusion

- Electrical test results on PT3 elements
  - At voltage levels greater than step 3 a higher insulation current is detected at Nanofilm capacitor elements
  - At step 3 voltage level slightly higher aging effects for C and tan δ at Nanofilm
  - Below and up to step 2 test level almost identical behaviour of all PT3 film versions in electrical tests

- Electrical test results on PT3 demonstrators
  - Successful electrical tests at real full size Nanofilm HVDC capacitor demonstrators
  - No recognizable differences in the Self-healing properties
  - No visible differences in the thermal stability of the capacitors
  - No noticeable deviations in the surge current behaviour between the different capacitor materials

PT3 Summary of the results - conclusion

- Remaining tasks
  - Agglomeration of nanoparticles , several micrometers in size, act as an impurity within the dielectric film
  - Agglomerates are the starting point for additional aging and insulation current effects as shown in the tests

  But: It is a material-task, not a capacitor manufacturing task

- Overall Conclusion
  - We are able to manufacture, test and operate full size Nanofilm HVDC power capacitors
  - Capacitor production is possible on the basis of state of the art machines and processes (including Metallizing, Slitting, Winding, Shooping, Annealing, Assembling, Testing, Monitoring etc.)
  - "Agglomerate-free"- Nanofilm would be ready for use in large power capacitors

Thank you for your attention!

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