Silicone Rubber Foam-Filled Post Insulators for Substations and Innovative Transmission Lines

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Agenda

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   + Applications
   + Portfolio
2. **Foam-Filled Station Posts**
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   + Production Technologies
   + Spin-Off Technologies
   + Applications
3. **HVDC Example Attica – Crete 500 kV**
4. **Electrical Breakdown Strength of Silicone**
5. **ECP Project**
6. **Trends, Challenges and Conclusions**

1. Station Post Insulators

Types

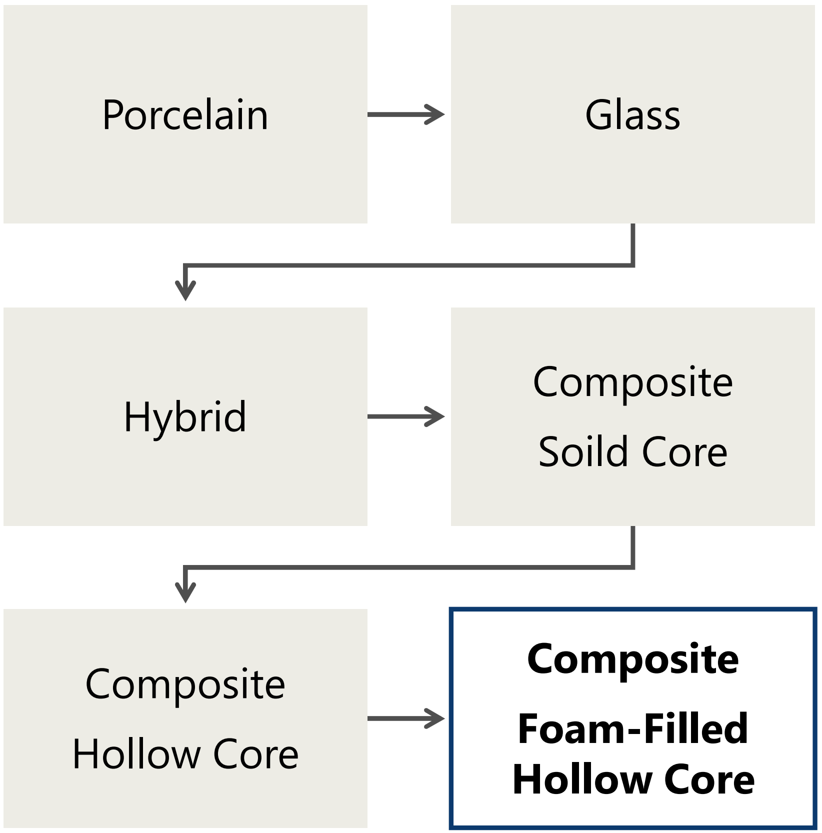
Porcelain	Glass	Hybrid	Composite Solid Core	Composite Hollow Core
IEC 60273	IEC 60273	IEC TR 62896	IEC 62231	IEC 62772
1 – 800 kV	1 – 800 kV	300 – 1.100 kV	1 – 245 kV	245 – 1.100 kV
Low deflections under cantilever load	Complex housing profiles (glass + cement)	Low deflections under cantilever load	Replacement of "brittle" porcelain types	High bending moments, low deflections
Optional RTV silicone coating	Optional RTV silicone coating	Combination of porcelain and composite technology	Limited applications due to high deflections	Single unit design, lightweight

Applications of station post insulators

- Bus bar supports (substations)
- Disconnector switches
- HVDC converters
- FACTS / platforms (UPFC, SVC, capacitive and reactive compensators)
- Coil supports
- Optical CT / VT supports
- Optical fiber bushings (station post type)

1. Station Post Insulators

Development | Foam-Filled Composite Hollow Core



Foam- / Gas-Filled Composite Hollow Core Station Posts

ReCoTec® Post Insulator

- All voltages up to 1.100 kV in single unit design available
- Meeting IEC 60273 or ANSI C29.19 requirements
- Gas- or foam-filled solutions
- Optional real-time gas monitoring equipment
- Lightweight high-strength design
- Wide variety of shed profiles for all voltage levels and conditions
- In-house engineering and simulation
- Eco-friendly (SF6 free)
- Vandalism and seismic resistance
- Superior pollution performance

1. Station Post Insulators

Application Spectrum

DC voltage [kV]	AC voltage [kV]	BIL / LIWV [kV]	SIWV [kV]	Type				
				Porcelain	Hybrid	CSP	CHSP Foam	CHSP Gas
	24	150		X		X		
	72,5	325		X		X		
	123	550		X		X		
	145	650		X		X		
	170	750		X		X		
	245	1.050		X		X	X	
	300	1.175	850	X	X		X	
352	362	1.300	950	X	X		X	
440	420	1.550	1.050	X	X		X	
550	550	1.800	1.175	X	X		X	X
618	800	2.100	1.550	X	X			X
820	1.100	2.700	1.950		X			X

2. Foam-Filled Station Posts

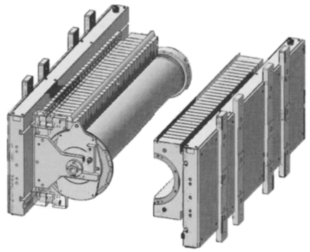
Requirements

- High mechanical strength
- Single unit design for HVDC and EHV (500 kV and above)
- Long-term moisture protection of the hollow internal volume without required monitoring
- No aging of internal filling media
- Robust and sustainable product and process technology
- Accommodation of high creepage factors
- Resistance against seismic and vandalism impacts
- No use of greenhouse gases like SF6

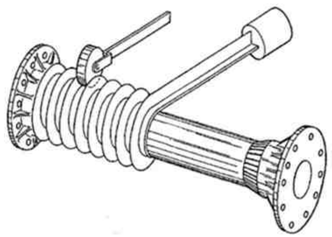
2. Foam-Filled Station Posts

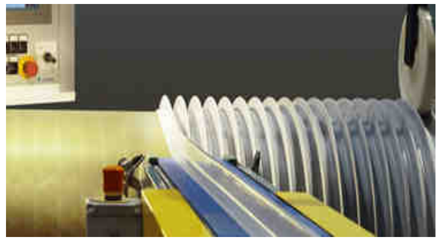
Production Technologies

- Manufacturing of GFRP tubes: **filament winding process**
- Application of silicone housing
  - **LSR / HTV injection molding**
    - Large volume production
    - Single shot lengths up to 3.000 mm
  - **HTV extrusion**
    - High design flexibility
    - Different shapes (cylindrical, conical) and shed profiles with less tooling / setup efforts feasible
- **Benefits of silicone housings**
  - Surface hydrophobicity
  - Hydrophobicity transfer mechanism (HTM)
  - Tracking and erosion resistance

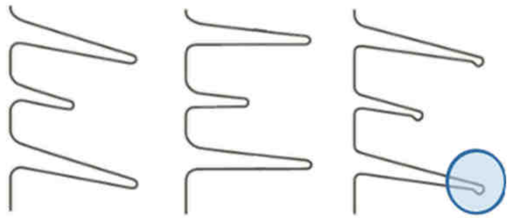


LSR / HTV injection molding





HTV extrusion

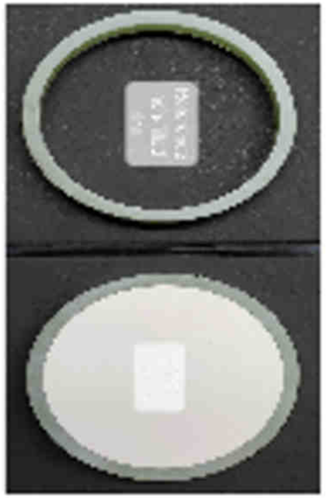


Shed profiles for specific applications:

- Anti-Fog (left)
- Aerodynamic (middle)
- Heavy Rain & HVDC (right)

2. Foam-Filled Station Posts
"Spin-Off" Technologies

+ **A. Foam Filling Technologies**
  - Conventional PUR based foam
  - Dry Syntactic Foam (polymeric expandable spheres)
  - Combinations of both
+ **B. Non-Metallic End Fittings**
  - no magnetic losses
  - no critical flange heating
  - no EMI
+ **C. Integration of Fiber Optic (FO) Solutions**
  - control / monitoring
  - smart metering
+ **D. Field Grading (MIVA, SG, RG)**
  - local AC/DC field mitigation
  - compact product design (diameter, corona rings)

A.


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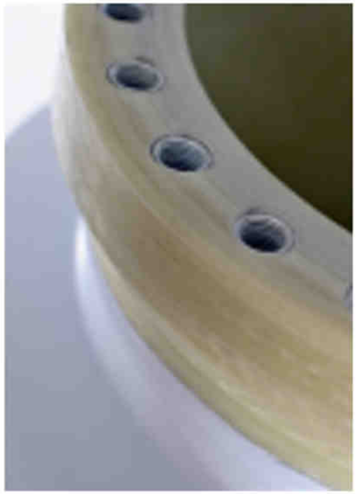
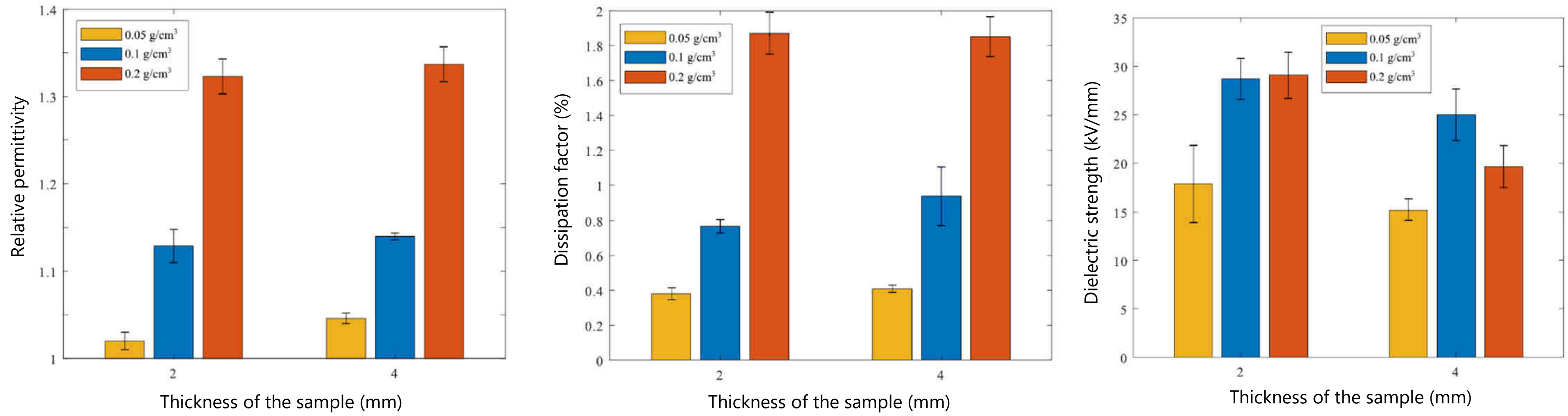


C.


D.


2. Foam-Filled Station Posts

Dry Syntactic Foam (DSF)

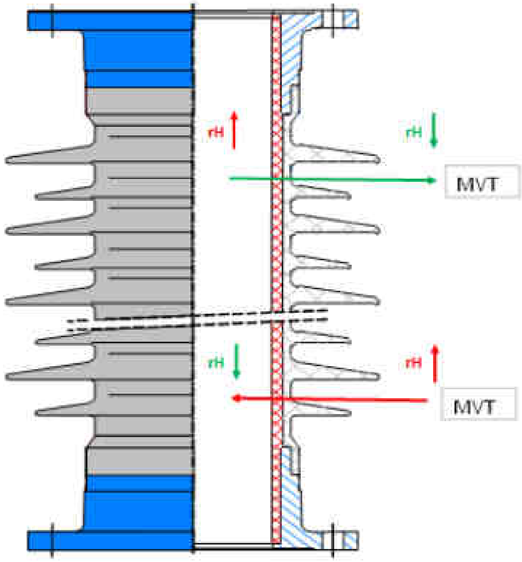


Dielectric characteristics of dry syntactic foam depending on the density

[D. Machetti, et al.: “Electrical characterization of low-density solid insulating fillers for hollow-core composite insulators”, Proceedings of the ISCD 2020]

2. Foam-Filled Station Posts

Motivation for Foam-Filling



Principle of moisture vapor transmission (MVT) theory

[source: TE Connectivity – Station Post Insulators White Paper]

- Moisture vapor transmission theory
  - GFRP tube with a MVT rate > 0
  - Non-equilibrium state => direction of vapor transmission follows the gradient of saturation of inside and outside of the insulator
- Station post insulators are passive applications without "internal heating"
- Performance under (harsh) environmental conditions (temperature fluctuations, UV radiation, pollution, wind, humidity, etc.)
- Risk with gas-filled insulators: Meeting of dew point => condensation due to temperature changes => outage of whole insulation system!

2. Foam-Filled Station Posts

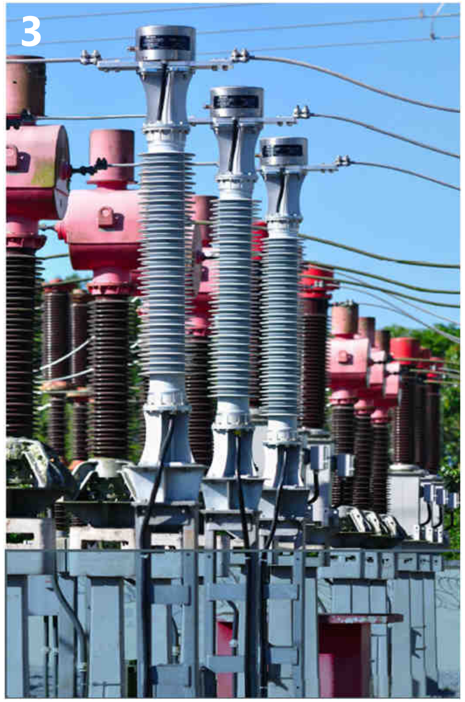
Filling Options

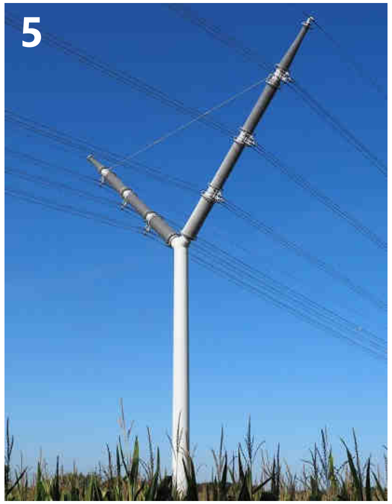
Issues	Filling				
	None	**Solid**	**Liquid**	**Gas**	**Foam**
Internal Electric Strength	**0**	++	++	++	+
Leak	-	++	-	--	++
MVTR Condensation	**0**	++	+	**0**	++
Monitoring	**0**	++	**0**	--	++
Weight	++	--	-	++	++

- **No filling** | Simple method, but strong influence by environmental conditions at manufacturing site (high humidity, rapid condensation during temperature changes)
- **Solid filling** | Positive rating, but heavy weight
- **Liquid filling** | Like solid, but leaking and potential monitoring is critical
- **Gas filling (pressurized)** | Like liquid, monitoring and leakage issues; condensation handling with desiccant application
- **Polyurethane (PU) Foam filling** | Good sealing of inner volume and bonding to GFRP tube, low density (0,4 g/cm^3), consistently positive assessment
- **Dry Syntactic Foam (DSF) filling** | Microspheres, innovation regarding low densities (0,1 g/cm^3), no chemical technology, very high dielectric strength, little service experience

2. Foam-Filled Station Posts

Applications



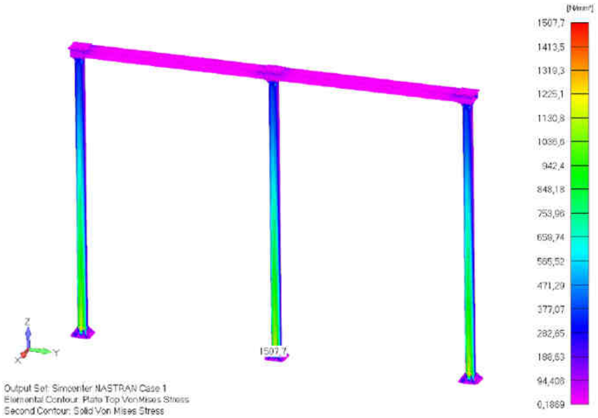


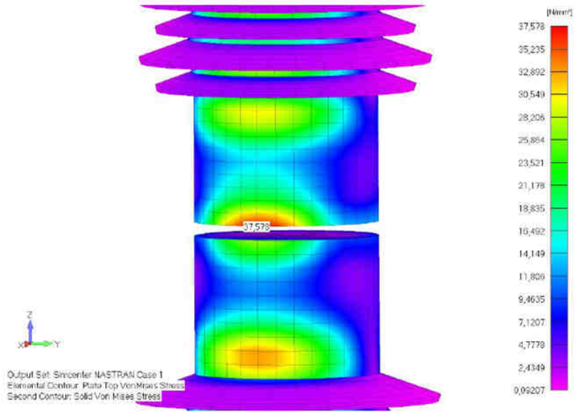
1 | CHSP (gas-filled) – coil support insulators **2** | 1.100 kV UHV disconnector **3** | Foam-filled CHSPs – 145 kV for optical CT

4 | Conical 362 kV for new generation of disconnector switches **5** | Future Application: 2 x 400 kV European Composite Pylon

3. HVDC ±500kV Attica – Crete (Greece)

Example for Solution with FFSP (commissioned 2022)





! Mechanical: Seismic requirements, not feasible with porcelain or hybrid SP

Technial Data:

Total Length h1:	7200 mm
Udc:	± 500 kV
Weight:	800 kg
Creepage Distance:	27220 mm (54 mm/kV)
SML:	20 kN
MML:	8 kN
MDCL:	10 kN
Diameter:	280 mm Hollow Core
BIL:	1800 kV
SIL:	1300 kV

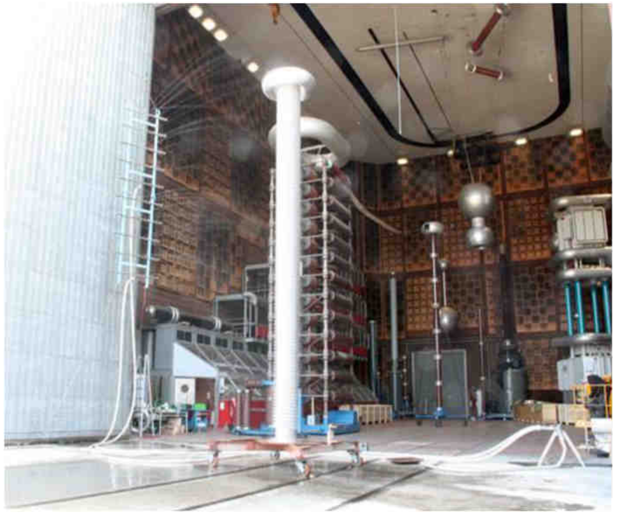
CF = 4,2 (<4,4 IEC 60815-4 LIMIT)

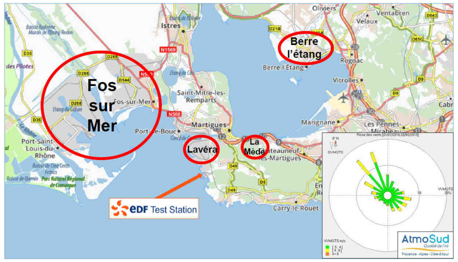
s/p = 1.0

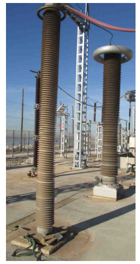
Round Drop Edge sheds / Alternating smooth

Corona ring at top end

Filling Medium: PUR Foam

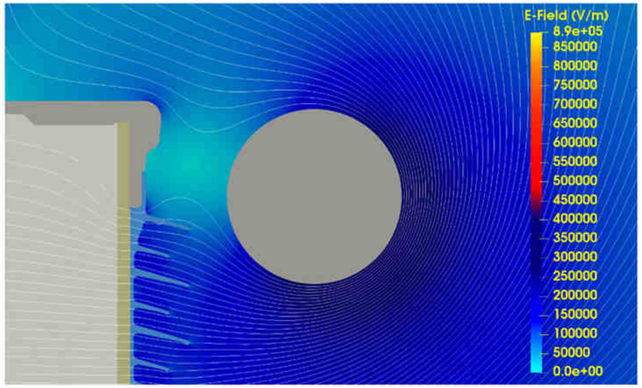




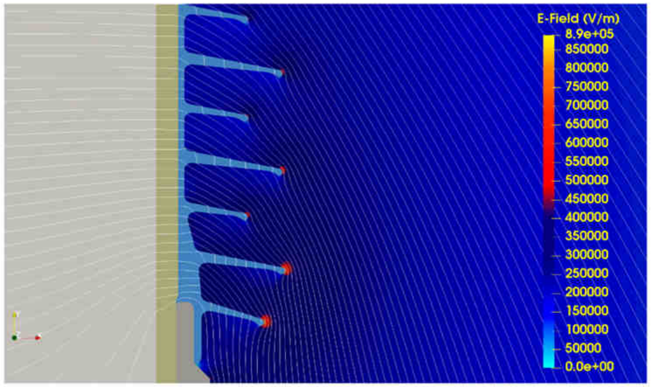


3. HVDC ±500kV Attica – Crete (Greece)

Electrical Design Challenges – Each Design needs to be validated!

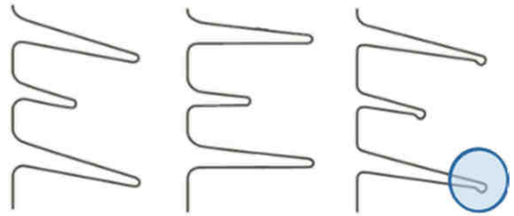


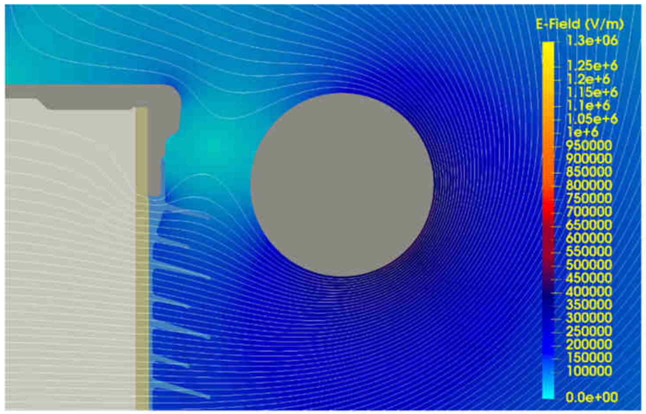
Top side



Bottom side

+ Electrical conductivity of the air at 1e-13 S/m:





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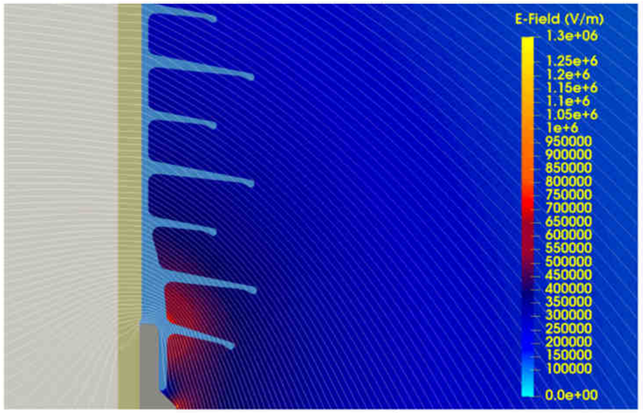


Bottom side

+ Electrical conductivity of the air at 1e-12 S/m:
  - Grading Rings
  - MIVA application

! **Electrical:** Field Grading and Field Control (MIVA) at critical points (shed tips), round shed edges, HTV Extrusion Technology!

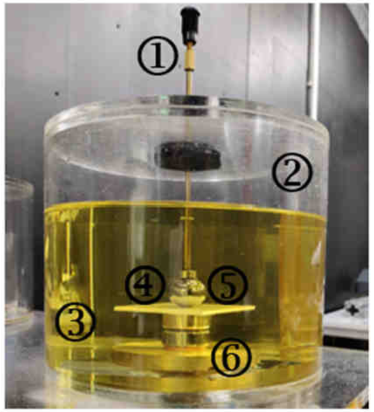
4. AC/DC Electrical Breakdown Strength of Silicones

Standard Requirments:

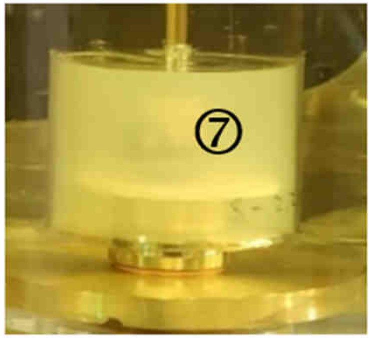
- DL/T 376: 20 kV/mm with AC and 30 kV/mm with DC (on 2 mm thick specimens, formerly 1 mm)
- DL/T 810: 30 kV/mm with DC (on 2 mm thick specimens)
- IEC/TR 62039: (10 kV/mm for sheath materi-als on 1 mm thickness).

① High Voltage connection
② Acrylic glass container
③ insulating oil Shell Diala
④ spheric electrode ø 20 mm
⑤ specimen
⑥ grounded plate electrode ø 25 mm
⑦ specimen embedded in Silicone Rubber

1. Tests under Oil at AC and DC stress:



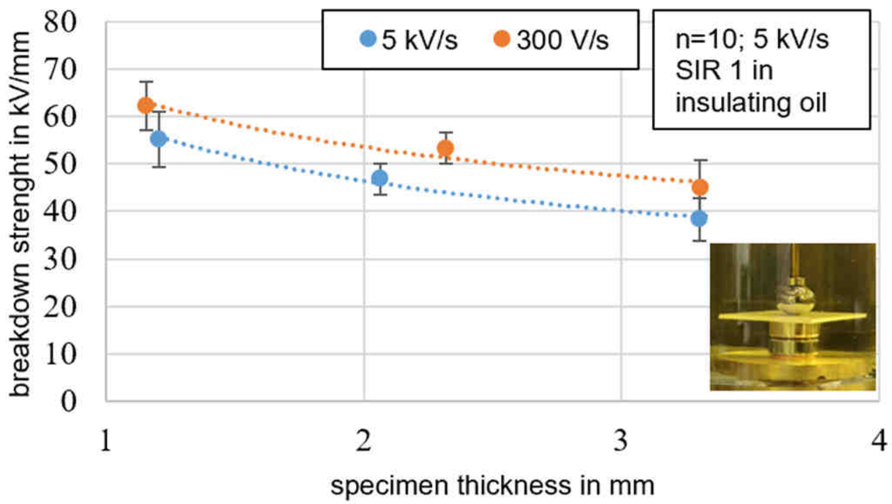
2. Tests with Silicone embedded test samples:



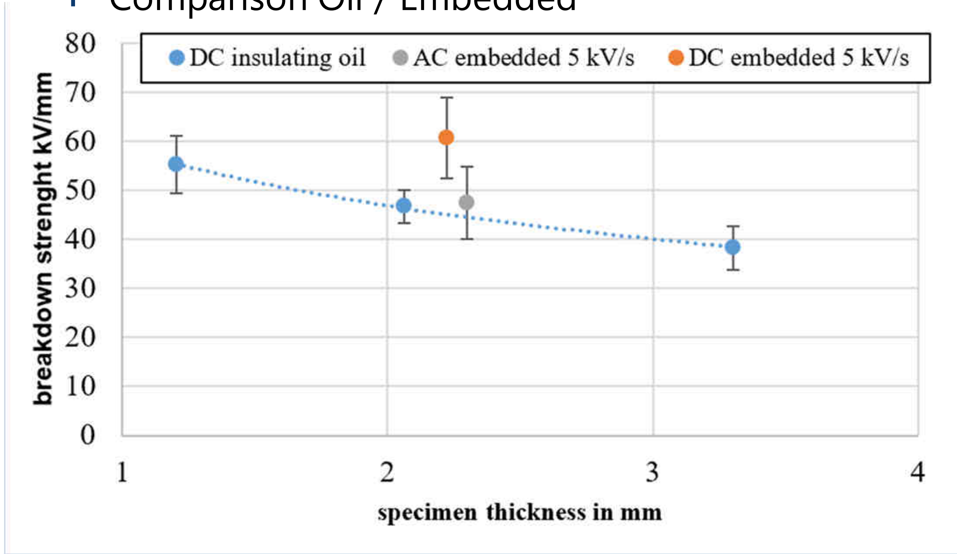
! Even under Oil all minimum requirements of the standards are met to 100%.
Further Investigations with embedded breakdown samples were investigated

4. Test Results

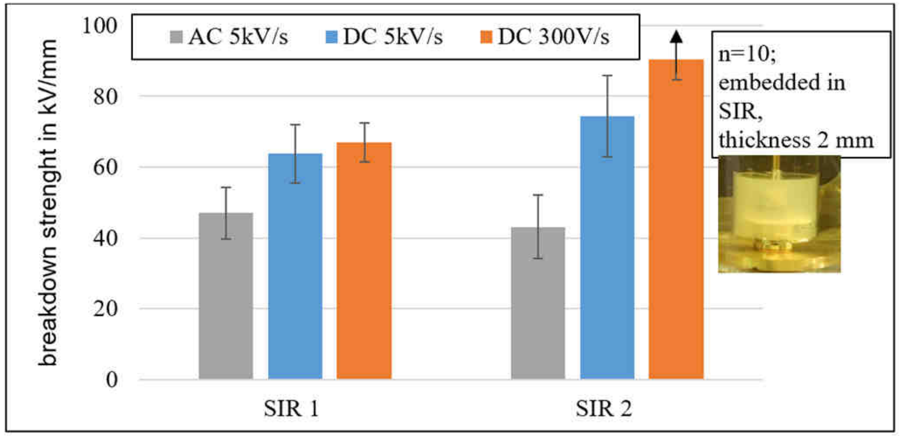
+ Breakdown Tests under Oil



+ Comparison Oil / Embedded



+ Comparison Oil / Embedded Electrodes



+ The electrical breakdown strength under DC voltage stress was investigated in detail. The DC breakdown strength is higher than the AC one and far above the minimum requirements as per DLT or IEC standards. For verification tests, embedded electrodes are recommended.

5. European Composite Pylon (ECP)
Overhead Line Concept

- EU funded project (2019 – 2022), partners: Maschinenfabrik Reinhausen, Bystrup, Dervaux, Nexans, Valmont
- Goal: development of a compact power pylon with low impact on the environment and landscape
- Conductor-carrying crossarms are made of (foam-filled) composite hollow core insulators.
- ECP key facts (compared to conventional 2 x 400 kV lattice tower)
  - Height: 30 m (56 m)
  - Footprint: 3 m^2 (64 m^2)
  - Assembly: ≥ 2 per day (1 per week)
- Three full-scale 2 x 400 kV demonstration power pylons were produced and assembled in Denmark.

Demonstrator of 400 kV European Composite Pylon

6. Trends

- Porcelain and composite technology are both mature - potentials regarding **economic and ecological filling media** for filling of the internal volume of CHSP are given and related R&D work is in progress ("syntactic foams").

- Special **insulating flanges** are entering the market especially for **anti-magnetic** couplings parts. Hollow station post insulators enable design of new optical fiber bushings and **optical CT / VT applications**.

- In general, a very positive market trend towards composite insulators. Concerns regarding life-time expectations have been solved by **long-term service experiences of more than 35 years**.

6. Challenges

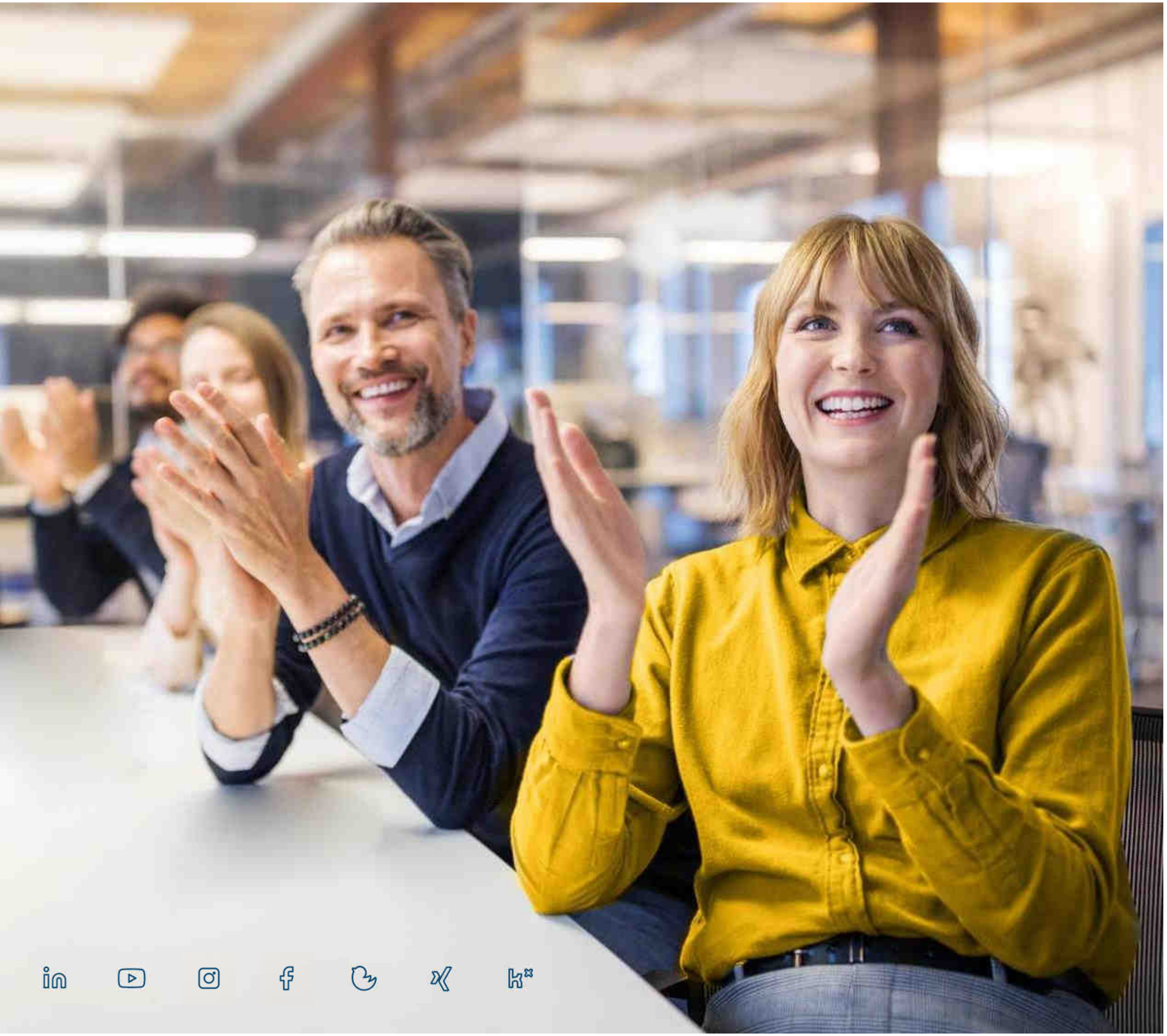
→ **Standardization** works for composite station post portfolio (e.g. ANSI C29.19, IEC 62231) - range above 245 kV is not yet standardized.

→ A challenge is to **define tests that secure service proven stable designs** and to distinguish those from just cost optimized "cheap" solutions that may compromise life-time and quality expectations and would give a negative reputation to the technology.

→ IEC and other committees are in charge to develop and establish proper test methods to prevent this. Established **IEC TC 36 MT 24 ("Composite Insulators for Substation Products")** is an existing maintenance team that shall realize this task and to revise the related important standards and of course also the base standard IEC 61462.

6. Conclusion

- The advantages of composite station post insulators are given with the **light-weight, high-strength and high pollution resistance (hydrophobic surface) properties** and highest design and manufacturing flexibility, especially for voltage classes exceeding 420 kV and for 800 kV HVDC and 1200 kV UHV.
- In the next 20 years composite station post insulators will outperform and replace conventional insulators in all industrial solutions due to economic, ecological and technical advantages also considering the evaluation according the **TCO (“Total Cost of Ownership”)** model which includes initial product costs, supply chain, environmental requirements, maintenance, life-time and risk assumptions.
- **In short words:** The industry is ready with supply, standardization and application of these composite products.



Thank you for your interest.

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