Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10406

CHARACTERIZATION OF EXTRUDED MATERIAL SYSTEMS FOR HVDC APPLICATION

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Motivation

- Temperature- and stress-dependent conductivity have been widely utilized to characterize material performance in DC applications
- Yet time, temperature and stress history, and the presence of material interfaces, are known to impact conductivity, inclusive of charge injection and charge transfer
- An improved manner to characterize material system behavior is desired, inclusive of material interfaces, and under relevant conditions

Method/Approach

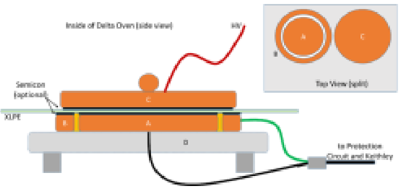
- Conductivity of insulation and insulation-semicon laminates are evaluated
- Long durations (24+ hours) of voltage application under steady conditions provide a means to monitor current transients
- Dynamic conditions of temperature probe temperature-dependence of conductivity of a given laminate
- Dynamic conditions of voltage (poling-depoling or polarity reversals) probe response of material system to changes in nominal applied field
- Asymmetric electrode-type and voltage polarity probe relative impact of charge injection/extraction.

Objects of investigation

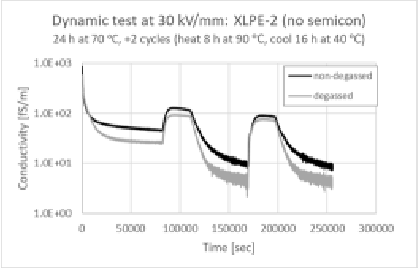
- **XLPE-1:** Commercially available XLPE with reduced crosslink density, claimed suitable up to 525kV DC.
- **SC-1:** Semiconductive shielding compound recommended for use with XLPE-1.
- **XLPE-2:** New XLPE with crosslink density expected of XLPE, recommended for up to 525kV DC and 90 °C
- **SC-2:** Semiconductive shielding compound designed for use with XLPE-2.
- **SC-3:** Semiconductive shielding compound with minor modifications relative to SC-2.
- 1mm crosslinked insulation specimens; degassed (when specified) for 4 days in 60 °C vacuum oven
- 0.5mm crosslinked semicon specimens; degassed for 3 days in 60 °C vacuum oven
- Laminate contact achieved through 1-hr thermal conditioning in 3-electrode cell (nominal pressure)

Experimental setup & test results

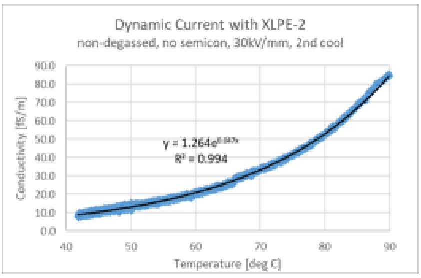
- Schematic of 3-electrode cell within a Delta oven



- Thermally Dynamic Evaluations



- A fit of the temperature-dependence of conductivity during natural cooling of oven (thermal time constant of 18000s)



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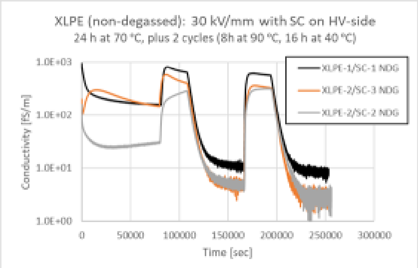
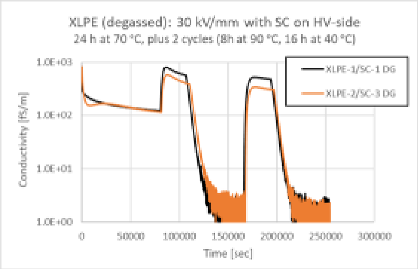
Experimental setup & test results (2)

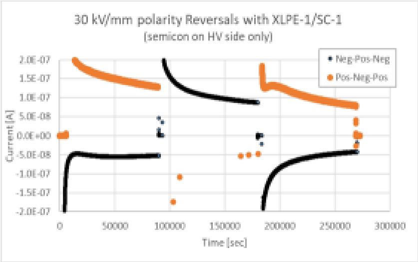
- Thermally Dynamic Evaluations with Semicons



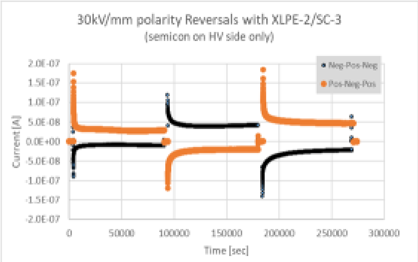


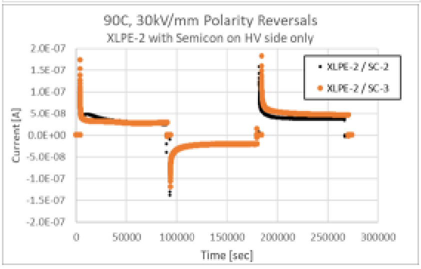
Experimental setup & test results (3)

- 30kV/mm Polarity Reversals at 90 °C for XLPE-1 (Semicon on HV-side only)



- 30kV/mm Polarity Reversals at 90 °C for XLPE-2 (Semicon on HV-side only)





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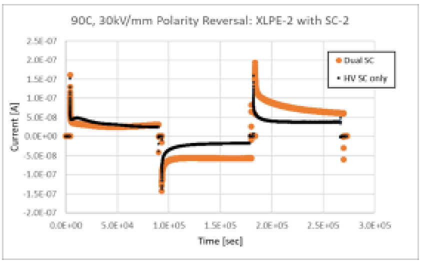
(continued)

Experimental setup & test results (4)

- 30kV/mm Polarity Reversals at 90 °C for XLPE-2 (Semicon on both sides)



- Tabular Results of Poling-Depoling and Polarity Reversal Evaluations

24-h Conduction Current [nA] at 30kV/mm and 90C				
	XLPE-1/SC-1	XLPE-2/SC-2	XLPE-2/SC-3	SC-2/XLPE-2/SC-2
Individual 24-h Poling Tests				
SC (+)	118		35 ; 27	
SC (-)	-47		-10 ; -8	
Polarity Reversals, 24h each, Pos-Neg-Pos				
SC(+)	127	25	29; 22; 32	32
SC(-)	-48	-18	-21; -27; -18	-57
SC(+)	75	34	46; 32; 47	61
Polarity Reversals, 24h each, Neg-Pos-Neg				
SC(-)	-51		-10	
SC(+)	87		42	
SC(-)	-43		-22	

Discussion

- The presence of the semicon increases apparent conductivity. Thermally dynamic evaluations without semicon result in an estimate for exponential temperature-dependence coefficient of 0.05 K^{-1}, while having semicon on HV side increased that estimate to about 0.10 K^{-1}.
- The 24-hour apparent conductivity of degassed XLPE-2 at 30kV/mm and 90 °C without semicon was found to be 14 and 19 fS/m in replicate tests. With SC-2 on HV side under positive polarity values of 113 and 147 were found, while under negative polarity values of only 39 and 42 fS/m were measured.
- Results suggest semicon enhancement of charge injection by the semicon under either polarity, with a more promounced impact when the semicon is at negative polarity.
- Polarity reversals under asymmetric conditions also show enhancement of current with the semicon at positive polarity versus negative. Repeating the polarity reversal evaluations begining with an initial negative poling cycle shows similar behavior.
- Fabrication of a semicon 3-electrode specimen resulted in symmetric current response with polarity reversal evaluations when comparing pos-neg-pos and neg-pos-neg sequences.

Conclusion

- Due to pronounced interfacial effects in DC applications, characterization of material system performance should include the relevant material interfaces.
- Dynamic temperature- and stress- evaluations of system laminates provides insight into charge transport mechanisms with enhanced interfacial charge transport at the semicon-insulation interface.
- Polarity reversals of asymmetric laminates suggests a greater impact of the semicon to enhance hole injection/electron extraction.
- For material systems in poling-depoling and polarity reversals evaluations at 90 °C and 30kV/mm, the XLPE-2 system yielded lower and more stable conductivity than that of the XLPE-1 system.