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The Development of a DC Breakdown Voltage Test for Photovoltaic Insulating Materials

David C. Miller[1], Bernt Åke-Sultan[2], Axel Borne[3], Rene Eugen[4], Bradley L. Givot[5], Jürgen Jung[6], Steven W. MacMaster[7], Byron K. McDanold[1], Ulf H. Nilsson[2], Nancy H. Phillips[7], Ian A. Tappan[1], and Nick S. Bosco[1]

[1]National Renewable Energy Laboratory (NREL), [2] Borealis AB, [3]DuPont Photovoltaic and Advanced Materials, [4]Isovoltaic AG, [5]The 3M Company, [6]Agfa-Gevaert NV, [7]DuPont Photovoltaic Solutions,

Introduction

An interlaboratory study was conducted to support the development of a DC breakdown voltage (V_{BD}) test method for "relied-upon insulator" materials used in PV modules. Our study includes a round-robin (R-R) experiment, shared between seven institutions, and additional discovery experiments to improve understanding of the V_{BD} test method. The goals of this were to quantify the repeatability and reproducibility of the test method and the significance of relevant test parameters.

Materials

Backsheets

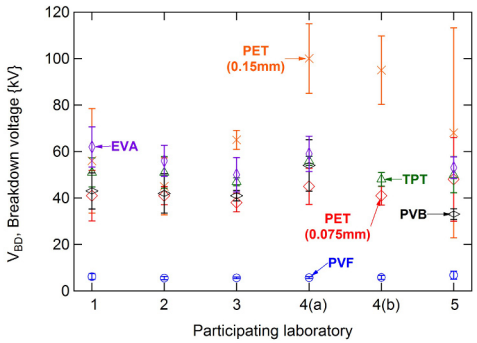
- polyethylene terephthalate (PET, two thicknesses)
- polyvinyl fluoride (PVF)
- PVF/PET/PVF ("TPT")

Encapsulants

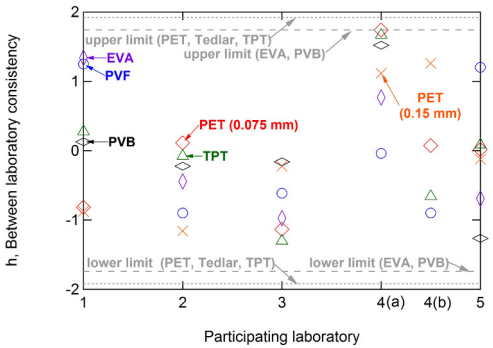
- poly(ethylene-co-vinyl acetate) (EVA)
- polyvinyl butyral (PVB)

Methods

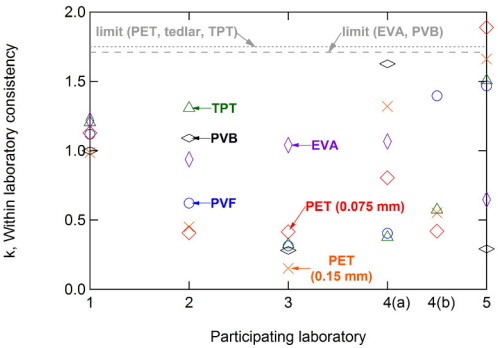
- 5 cm x 5 cm specimen size
- Five separate replicate specimens for variation < 15%, else 10 replicates
- Specimens conditioned at 23 ± 2° C/50 ± 5% RH for ≥ 24 h
- Test in dielectric medium, e.g., transformer oil or mineral oil
- Test duration ≥ 10 seconds, using ramp rates: 0.1, 0.2, 0.5, 1, 2, or 5 kV·s^{-1}.
- Weibull Analysis: 50 replicate specimens were tested for each backsheet material and 20 replicates were tested for each encapsulant.
- Pre-conditioning: 65° C with 10%, 20%, 40%, 60%, 80%, or 95% RH.
- Additional factors: ramp rate, polarity, electrode size and roughness, maximum current limit, and test temperature.



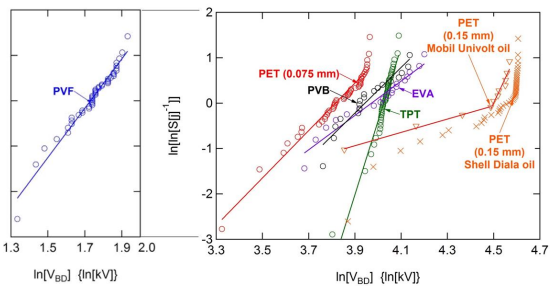
Results of the interlaboratory R-R for the six materials investigated



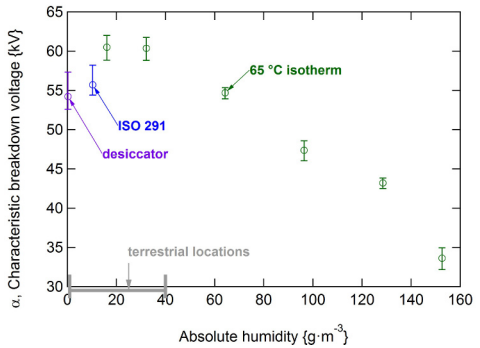
Mandel analysis for between-laboratory variability. The upper and lower 95% confidence interval limits are indicated.



Mandel analysis for within-laboratory variability. The 95% confidence interval limit is indicated.



Weibull analysis, for 50 replicate backsheet specimens or 20 replicate encapsulant specimens, at laboratory 4(a). Laboratory 4(b) measured 10 replicates for PET (0.15 mm).



Variation in α with specimen conditioning for TPT, shown relative to the range of humidity found in terrestrial locations.

Results

- All measurements fall within the 95% confidence interval limit for between-laboratory variability (*h*).
- The within-laboratory variability (*k*) falls within the range of typical variation at four out of five laboratories.
- The average *r* (variation within the laboratories) of ~10 kV is observed for all of the materials, whereas *R* (including the variation between the laboratories) was ~15 kV.
- The V_{BD} measured for PET (0.15 mm) at laboratory 4(a) and 4(b) was >95 kV, consistent with a material of twice the thickness of PET (0.075mm), 45±8 kV PET. Four laboratories, however, reported lower values for PET (0.15 mm), with relatively large variability. This suggests an intrinsic variability in the material and not an inconsistency in the test method.
- Weibull analysis suggests that a single population of defects causes the dielectric breakdown of PVF, PVB, TPT, and EVA.
- The upward inflection for PET (0.075 and 0.15 mm) suggests a second population of defects may contribute to its breakdown at the highest test voltages.
- In the Shell Diala oil, however, the inflection observed for PET (0.15 mm) is an artifact of the maximum test voltage of 100 kV.
- With specimen pre-conditioning, a variation on the order of 25 kV is observed for the isothermal test series.

Summary and conclusions

An interlaboratory study was conducted to quantify the precision of a recently-developed test method for the DC breakdown voltage of PV materials. Additional experiments were conducted to further develop the test method and quantify the factors of greatest influence. The proposed method will include 10 replicate specimens: only transformer oil or mineral oil is allowed as a dielectric medium, and the use of unequal diameter electrodes is not allowed. Since the study described here was completed, these refinements have been applied to the final VBD test method published in IEC TS 62788-2.

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See also (internet search) for: NREL/PO-5K00-68703 (poster)
NREL/CP-5J00-67736 (paper)