Voltage Ramp-rate Dependence of DC Breakdown in Polymeric Insulators: Physical Models versus Data

Allen Andersen, Krysta Moser, and JR Dennison

Utah State University
allen.andersen@aggiemail.usu.edu

Purpose/Aim

The standard handbook values for dielectric breakdown strength of necessity come from accelerated test methods. In some applications the breakdown voltage may vary significantly with voltage ramp rates; therefore, a theoretical model for the ramp-rate dependence of breakdown is needed to extrapolate from realistic tests to long-duration material service lifetimes.

Experimental/Modeling methods

Series of step-up to breakdown tests were performed for ramp rates from 0.5 to 500 V/s for biaxially-oriented polypropylene (BOPP), low density polyethylene (LDPE), and polyimide (PI) films. The data were fit with standard empirical methods, as well as two physics-based defect-driven models.

Results/discussion

Table 1 in the Appendix shows the models used to fit breakdown data. Empirical models can be fit to a given data set; however, they offer little—if any—physical insight. The simplest of physical models were observed only to apply to some materials, while others required more complete theoretical descriptions.

Conclusions

Voltage ramp rate can, in some materials, significantly affect the breakdown field. The voltage ramp rate dependence can be modeled using physical properties of the material.

Appendix

<table>
<thead>
<tr>
<th>Models of ramp-rate dependencies</th>
<th>Formula</th>
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</thead>
<tbody>
<tr>
<td>Standard Empirical Model</td>
<td>$F_{BD} \propto (\partial F / \partial t)^{a/(a+b)}$</td>
</tr>
<tr>
<td>First-Order Physical Model</td>
<td>$F_{BD}(r) \approx \sqrt{1.1346 F_{BD}(r_0)^2 \ln \left( r + \sqrt{1 + r^2} \right)}$</td>
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<tr>
<td>Defect-Driven Mean-Field Model (solved numerically)</td>
<td>$P_{BD} = 1 - \prod_{j=1}^{V/\Delta V} [1 - \alpha \Delta t \sinh[\beta(jV)^2]]$</td>
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Table 1. Models of ramp-rate dependencies