

**2010 Advanced Cables and Conductors Peer Review
Project Summary**

Project Title:	Strategic Dielectric R&D for HTS and Other OE Applications
Organization:	Oak Ridge National Laboratory
Presenters:	Isidor Sauers and Enis Tuncer
FY 2010 Funding:	\$600 K

Overall Project Purpose and Objectives:

The project objective is to develop and characterize cryogenic dielectric materials for use in HTS grid applications as well as other OE applications. A common feature in many of the HTS projects is the requirement for reliable high voltage electrical insulation. Failures in a few cases have underscored the need for improved dielectric materials and a better understanding of the high voltage design issues. Hence, a strategic program on cryogenic insulation continues which addresses the material, design and testing needs that are common to all the SPI/SPE projects and provides a data base of knowledge to facilitate the design and implementation of effective, innovative electric insulation systems.

2010 Approach and Results:

To meet the above objectives, the ORNL high voltage and dielectrics staff have produced in-house data on commercially available materials, worked on the development of novel materials for both cryogenic and conventional grid applications, and conducted a literature search on existing data that can be made available to others who need design information for HTS applications. The materials chosen are relevant to current HTS applications including HTS cables, HTS transformers and HTS fault current limiters. The work has focused on the following areas:

1. Physical properties of in-situ and ex-situ dielectric polymer nanocomposites (nanodielectrics) will be presented by focusing on the dispersion of particles and improvements in the dielectric breakdown strengths. The new materials have been characterized mechanically and electrically. The results will be discussed in terms of their potential application at cryogenic temperatures for HTS devices, as grading and support materials as well as electrical insulation. Initial theoretical work was started in nanocomposites to determine influence of constituents on local electrical fields. Two potential nanodielectrics were selected with CTD and puncture breakdown and surface flashover properties were characterized.
2. Breakdown and flashover in G10 (fiberglass reinforced plastic) and Ultem (polyetherimide), will be presented showing the scaling relationships with length that can aid in the design of these support materials in liquid nitrogen filled systems.
3. The breakdown strength of liquid nitrogen is affected by the presence of bubbles. A novel experimental configuration has been employed in which a heater is placed behind a circular plane electrode with a pin hole which allows bubbles to pass through into a plane-plane electrode gap. The electrodes are placed in a high voltage liquid nitrogen cryostat. The breakdown strength is measured as a function of heater power, liquid nitrogen temperature, and pressure. Data will be presented which shows that the breakdown strength abruptly decreases at a given heater power for a given liquid nitrogen pressure. The drop in breakdown strength is associated with the formation of a vapor bridge. The breakdown strength of "liquid nitrogen" at higher heater power follows Paschen's Law for gas breakdown. The heater power for which the decrease is observed increases as the pressure increases. The implications for fault current limiters are discussed.

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4. (a) One of the most perplexing issues in the design of liquid nitrogen insulated HTS equipment is what values to use for the high voltage breakdown strength of liquid nitrogen. The values range over several orders of magnitude depending on field geometry, electrode configuration (shape, size, gap length), voltage application (ac, dc, impulse), pressure, etc. It is generally accepted that the stressed area and volume must be taken into account but it has not been clear how to use these factors in predicting the breakdown strength. Previous attempts have focused on calculating the electric fields for non-uniform field geometries and using some arbitrarily determined fraction of the maximum field strength. We have taken a new approach which instead focuses on the geometrical electrode parameters of radius and gap to modify the abscissa (which indirectly takes into account the stressed area and volume). Impressive results have been obtained which produces a single plot that predicts to within about 20% the measured breakdown strength of liquid nitrogen produced by several laboratories covering about five orders of magnitude of interelectrode gap length. The data can be used for future designs of high voltage HTS equipment. (b) The liquid nitrogen database has been extended to solid materials in liquid nitrogen. In addition, the liquid nitrogen breakdown data from various authors has been plotted and compared under various breakdown conditions including different geometries and types of voltage application. These will be compared, providing interesting insight into the broad range of breakdown strengths obtained under a variety of conditions and the implication for engineering design rules.

2011 Plans and Expectations:

The 2011 plans are to continue the topics in 2010.

1. Continue to add to the liquid nitrogen database with papers on materials in liquid nitrogen. The plot of liquid nitrogen breakdown strength will be further fine tuned to provide improved predictability of the strength for various electrode shapes and gaps. The goal is to provide information useful for scale-up and design. To check this model further, additional data on LN2 will be taken emphasizing non-uniform fields at larger gaps which are useful for design purposes.
2. Novel materials based on nanocomposites with fillers which have high thermal conductivity.
3. G10 and Ultem flashover and scaling to longer lengths.
4. Model cable studies leading to higher voltages and voltage classes.
5. Effect of bubbles on liquid nitrogen breakdown with emphasis on sub-cooling.

Technology Transfer, Collaboration, Partnerships:

ORNL staff are involved in the organization of the Conference on Electrical Insulation and Dielectric Phenomena (sponsored by the Dielectrics and Electrical Insulation Society, DEIS, of the IEEE). Enis Tuncer is serving on the CEIDP Board and Isidor Sauers is the past Chairman of the conference and is currently on the CEIDP technical program committee. He is presently serving on the CIGRE Working Group (WGD1.15) Superconducting and Insulating Materials for HTS Power Applications and the IEEE Task Force on Fault Current Limiter Testing sponsored by the IEEE Switchgear ADSCOM. Enis Tuncer is serving as the Historian for the DEIS and is the Nominations Chair of the CEIDP. He is Publication Chair and Executive Board member of IPMHVC.

The ORNL staff has partnered with Southwire/Ultera on HTS cables and with Waukesha Electric Systems on HTS transformer R&D. Some of the materials proposed for HTS applications may also be used in conventional applications, as in the case of insulation for transformer coils in which dielectric tape insulation that is being studied works well with either oil or liquid nitrogen.

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In addition to the above collaborations and partnerships, ORNL was a partner to a small business in a SBIR funded in 2008 and a phase II proposal with CTD was awarded for 2009. Also a new project will be initiated on insulation breaks for the ITER fusion program in collaboration with CTD, who will be developing the insulation breaks while ORNL will be making the dielectric measurements at cryogenic temperatures.

Publications and presentations for the CEIDP, CEC-ICMS and ASC have been made. Drs. Tuncer and Sauers published a book chapter on nanodielectrics. Non HTS Advanced Cables and Conductor activities include superhydrophobic materials for outdoor high voltage insulation.