Abstract

This dissertation presents a comprehensive investigation into novel cryogenic electrical insulation designs and materials for high-temperature superconducting (HTS) power cables, with a primary focus on applications in electric aircraft and ships. The research addresses critical challenges in developing compact, efficient, and reliable HTS power distribution systems for transportation electrification, a field of growing importance in the face of global efforts to reduce carbon emissions and improve energy efficiency in the transport sector. The study explores several innovative approaches to enhance the performance and practicality of HTS cable systems in these demanding applications.

A key aspect of the research involves the characterization of dielectric fluids, particularly Novec 649, as potential cryogenic insulation media. These fluids were evaluated for their dielectric properties at both room and cryogenic temperatures, offering insights into their suitability for use in HTS cable systems. The study also delves into the development and testing of cryogenic epoxy-based coatings as electrical insulation for HTS cables, aiming to reduce partial discharge and improve overall dielectric strength. This novel approach could potentially overcome limitations associated with traditional insulation methods in cryogenic environments.

Utilizing advanced finite element analysis techniques, the research examines methods to understand and minimize electric field enhancement in cable designs, particularly at critical points such as terminations and interconnection nodes. This analysis provides valuable guidance for optimizing cable geometries and materials to enhance performance and reliability. Additionally, the study investigates high-current electrical arc faults and their effects on HTS cable systems, including fault propagation mechanisms and potential mitigation strategies, which are crucial for ensuring the safety and resilience of HTS power distribution systems in transportation applications.

A significant contribution of this work is the design and analysis of a novel warm dielectric termination concept for HTS cables, incorporating electrical breaks to enable more compact and efficient cable connections. This innovative approach addresses the challenges of integrating HTS cables with conventional power systems and could lead to more practical and space-efficient designs for electric aircraft and ships. To support these investigations, sophisticated experimental setups were developed to conduct measurements under cryogenic conditions. These include tests for partial discharge inception voltage, AC breakdown, and high-current faults, providing empirical data to validate theoretical models and inform design decisions. The research findings contribute substantially to the optimization of HTS cable designs for electric transportation applications, addressing critical aspects such as power density, reliability, and safety.

In conclusion, this dissertation provides valuable insights and innovative solutions for the development of next-generation HTS power distribution systems. The outcome of this research has significant implications for advancing the electrification efforts in the aerospace and marine industries, potentially paving the way for more efficient, environmentally friendly, and high-performance electric propulsion systems in the future.