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C3Or2C-04: Testbed for high current and high voltage characterization of gaseous helium cooled HTS power cables for electric transport systems

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High temperature superconducting (HTS) power cables offer promising solutions for electric aircraft and ships with power demands of up to 50 MW and 100 MW, respectively. However, their cryogenic cooling requirements present challenges. While liquid nitrogen is used for the grid applications of HTS cables, its limited temperature range (63-77 K) and asphyxiation risks make it suboptimal for transport applications. Gaseous helium emerges as a superior alternative, offering operational flexibility and broader temperature ranges without a phase change, despite its lower heat capacity and low dielectric strength of 4 kV/mm at 20 bar and 77 K. HTS cables'low mass and footprint make them particularly suitable for transport applications, leading to several ongoing developments in gaseous helium cooling systems, high-voltage designs, and cryogenic dielectrics.

The reliable operation of HTS cables at their intended voltage and current levels requires characterizing their electrical insulation systems and cryogenic thermal designs. Partial discharge inception voltage (PDIV) is a critical diagnostic tool for dielectric design validation. Partial discharge, when localized electrical stress exceeds the dielectric strength of small voids or defects within the insulation, generates tiny electrical pulses typically measured in picocoulombs (pC). These microscopic discharges, while small, can indicate insulation degradation and potential failure points, making PD monitoring essential for evaluating the long-term reliability of cryogenic cable systems. PD measurements present unique challenges in cryogenic circulation systems due to their inherent sensitivity to electromagnetic interference and noise. Traditionally, PD measurements in HTS systems have been conducted using Faraday cages for electromagnetic shielding, with the dielectric samples being investigated in a stagnant helium gas environment created through immersed gas cooling in liquid nitrogen. However, integrating a helium circulation system into the test loop introduces complexity due to the electromagnetic noise generated by operational components, such as compressors, circulation systems, and vacuum pumps, that can interfere with precise PD measurement. This dynamic environment necessitates implementing different measuring techniques and noise filtering strategies beyond conventional shielding methods. To address these challenges, we studied a 3-meter long HTS cable testbed integrated with a cryogenic circulation system, incorporating specialized measurement methodologies to tackle the measurement challenges in this dynamic setting. We performed comprehensive PD measurements to evaluate the dielectric properties and thermal management capabilities of GHe-cooled power cables. A custom-designed electrical break was incorporated into the testbed to ensure the safe isolation of the high voltage components from the cryogenic circulation system, enabling reliable PD measurements while maintaining thermal performance. The correlations between PD activity, operating conditions, and system parameters establish critical design guidelines for high-voltage and high current cryogenic power distribution systems in electric transportation platforms where partial discharge resilience is important for long-term reliability. The paper discusses the cable models, measurement techniques, experimental results, and practical insights derived from the testbed.

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