**Abstract**

This dissertation presents a comprehensive investigation of superconducting power distribution systems for electric aircraft, with specific application to the Integrated Zero-Emission Aviation (IZEA) aircraft concept. The research addresses critical challenges in developing high-power-density, lightweight electrical systems capable of supporting megawatt-scale propulsion requirements while operating in cryogenic environments. The study employs a systematic approach encompassing system-level design methodologies, detailed component modeling, and experimental validation. A Model-Based Systems Engineering (MBSE) framework is developed to capture complex interdependencies between electrical, thermal, and propulsion subsystems. The AeroCryoX library, implemented in MATLAB/Simulink, provides system level and certain device level modeling capabilities for cryogenic power system components including heat exchangers, compressors, gas turbines, and fuel cells. Four distinct power distribution architectures are analyzed, progressing from baseline designs through optimized configurations achieving power densities exceeding 40 kW/kg. The research demonstrates that multi-layer cable designs and bus bar integration strategies can significantly reduce system weight while maintaining operational redundancy. Thermal management analysis reveals the feasibility of graded heat exchanger systems for managing heat loads across multiple temperature zones (20-350 K) using liquid hydrogen as the primary coolant. Experimental validation includes testing of a 4 MW cryogenic bus bar system, demonstrating 68% reduction in aluminum conductor resistance at 77 K compared to room temperature. Contact resistance measurements at currents up to 3166 A confirm the viability of multilam connectors for high-current cryogenic applications. Partial discharge testing in 2.0 MPa helium gas validates dielectric spacer designs with inception voltages ranging from 18-25 kV DC at cryogenic temperatures. The research establishes that superconducting power distribution systems can achieve the demanding requirements for transport-category electric aircraft, providing power densities of 25-40 kW/kg while maintaining aviation safety and reliability standards. Main contributions of this dissertation include validated design methodologies for cryogenic power systems, system level thermal management strategies, and experimental validation of critical components under realistic operating conditions.