Future large-scale all-electric transport systems will have high-power dense devices, such as high-temperature superconducting (HTS) motors, generators, and power distribution cable networks. A high power density is desirable to achieve the necessary efficiency and design with space and weight requirements. The electric transport systems would reduce greenhouse emissions and have other benefits, such as reduced noise, compared to the conventional platforms that use internal combustion for propulsion. Two such applications that are being developed are all-electric ships and electric aircraft. These platforms will have 30-100 MW power systems. Government agencies and industry are investing in the designs and component technologies to realize electric ships and aircraft.

The dissertation explored the superconducting power system and the ancillary cryogenic system designs suitable for incorporating and benefiting from HTS technologies. Part of the dissertation focused on HTS power cable designs. The thermal network modeling methodology was used to understand the implications of component failure and options to achieve resiliency.

A radial architecture for the ship power distribution network was investigated to fully utilize the HTS cable technology in achieving efficiency, stability, and resiliency. Two HTS cable topologies were explored to work with the radial system. HTS cable ampacity being sensitive to the operating temperature, the resiliency of the cryogenic system in supporting the electrical distribution network is critical. The results of the combined electrical and cryogenic thermal models show that cryogenic systems can support radial distribution. The models were used to map the cryogenic temperature profile of the distribution system in both normal and contingency operations involving a failure of one of the cables. The cryogenic system satisfactorily supported the increased current in the other cables to mitigate the loss of one of the cables with a manageable temperature increase of 2-3 K. The models also concluded that cryogenics does not hinder the radial distribution concept.

To assess the broader question of cryogenic fuels for large transport systems, a review was performed on the opportunities and challenges of cryogenic power devices for electric aircraft and the ongoing research and development efforts. Relative merits of Liquid Hydrogen (LH2) and Liquefied Natural Gas (LNG) are compared in supporting the HTS and normal metal devices. The mass flow rates and total fuel quantity requirements for both cryogenic fuels were simulated using thermal network models. A twin-aisle, 300-passenger aircraft with a 5.5 h flight duration was used for the models. The results show that the required masses of LH2 and LNG are 744 kg and 13.638 kg, respectively, for the cooling requirement. The corresponding volumes of LH2 and LNG required are 10,000 and 30,000 L, respectively. In both cases, the estimated mass of the fuel needed for the aircraft is more than what is necessary to maintain the cryogenic environment of the power devices. It was concluded that an electric aircraft with LNG-cooled normal metal devices is feasible. However, an aircraft with HTS devices cooled with LH2 is more attractive if the ongoing R&D efforts on HTS devices and green hydrogen infrastructure are successful. The emission reductions would be substantially higher with LH2, particularly with green hydrogen produced using renewable energy sources.

A coaxial superconducting gas insulated cable (SGIL) was designed, fabricated, and tested to understand the challenges in making compact cables cooled by gaseous helium. Two kinds of insulating spacers were explored to understand the effect of permittivity mismatch on the maximum electric field strength. The latest design of the dipole SGIL showed promising results of sufficiently high breakdown strength. Further investigations found that the cables suffer from corona discharge activity at the intended operating voltages, reducing the cables' lifespan. The major limiting factor of the design is the high electric field stress at the triple point, causing localized corona discharge activity in the gaseous cryogen trapped between the spacers. New dipole cable designs must address the high permittivity mismatch between GHe and the spacers to reduce the high field stresses. New geometries need to be explored to achieve desired dielectric properties while maintaining the heat transfer effectiveness and flexibility of HTS cables.

Potential failure modes of HTS devices and related cryogenic systems in electric ship applications are analyzed to understand and plan for the necessary mitigation systems. Risk-based FMEA methodology was adopted to aid in improving the resiliency of large superconducting power distribution systems. A concurrent FMEA study of cryogenic thermal and electrical systems in an HTS power distribution network is discussed. A one-line architecture for a power distribution system was developed to identify the critical parameters needed for performing FMEA for HTS power distribution systems. The failure modes are listed to show the interdependence of the electrical and cryogenic systems. The severity and detectability of various failures were used to formulate critical redundancy and mitigation tools to design resilient power distribution systems for electric ships.