Abstract

The field of power electronics (PE) is experiencing a revolution by harnessing the superior technical characteristics of wide-band gap (WBG) materials, namely Silicone Carbide (SiC) and Gallium Nitride (GaN). Semiconductor devices devised using WBG materials enable high temperature operation at reduced footprint, offer higher blocking voltages, and operate at much higher switching frequencies compared to conventional Silicon (Si) based counterpart. These characteristics are highly desirable as they allow converter designs for challenging applications such as more-electric-aircraft (MEA), electric vehicle (EV) power train, and the like. This dissertation presents designs of a WBG based power converters for a 1 MW, 1 MHz ultra-fast offboard EV charger, and 250 kW integrated modular motor drive (IMMD) for a MEA application. The goal of these designs is to demonstrate the superior power density and efficiency that are achievable by leveraging the power of SiC and GaN semiconductors.

Ultra-fast EV charging is expected to alleviate the challenge of "range anxiety", which is currently hindering the mass adoption of EVs in automotive market. The power converter design presented in the dissertation utilizes SiC MOSFETs embedded in a topology that is a modification of the conventional three-level (3L) active neutral-point clamped (ANPC) converter. A novel phase-shifted modulation scheme presented alongside the design allows converter operation at switching frequency of 1 MHz, thereby miniaturizing the grid-side filter to enhance the power density.

IMMDs combine the power electronic drive and the electric machine into a single unit, and thus is an efficient solution to realize the electrification of aircraft. The IMMD design presented in the dissertation uses GaN devices embedded in a stacked modular full-bridge converter topology to individually drive each of the motor coils. Various issues and solutions, pertaining to paralleling of GaN devices to meet the high current requirements are also addressed in the thesis. Experimental prototypes of the SiC ultra-fast EV charger and GaN IMMD were built, and the results confirm the efficacy of the proposed designs.

Model predictive control (MPC) is a nonlinear control technique that has been widely investigated for various power electronic applications in the past decade. MPC exploits the discrete nature of power converters to make control decisions using a cost function. The controller offers various advantages over, e.g., linear PI controllers in terms of fast dynamic response, identical performance at a reduced switching frequency, and ease of applicability to MIMO applications. This dissertation also investigates MPC for key power electronic applications, such as, grid-tied VSC with an LCL filter and multilevel VSI with an LC filter. By implementing high performance MPC controllers on WBG based power converters, it is possible to formulate designs capable of fast dynamic tracking, high power operation at reduced THD, and increased power density.