Abstract

Electric vehicle (EV) powertrains must maintain high efficiency across wide voltage and power ranges to achieve high power density and extended vehicle range. This thesis explores two-stage EV powertrain configurations and proposes three-phase unfolding as an innovative alternative to conventional pulse width modulation (PWM) based motor drives. Additionally, novel non-isolated topologies for the dc-dc stage are introduced using input-parallel output-series (IPOS) connections of basic modules.

A three-phase unfolding-based powertrain is presented to replace the conventional system comprising a bidirectional boost dc-dc converter and a two-level voltage source inverter (VSI). While traditional systems rely on high-frequency PWM switching in both stages, the unfolding approach employs a high-frequency dc-dc stage to generate piecewise sinusoidal dc-link voltages. These voltages are then unfolded into sinusoidal three-phase ac voltages by a three-level inverter operating at the fundamental frequency, significantly reducing inverter switching losses.

This thesis introduces a non-isolated dc-dc stage for the unfolder system integrating a non-inverting buck-boost (NIBB) converter and a voltage balancer circuit. Analysis reveals that the balancer circuit processes only a fraction of the total power, reducing component size and minimizing losses compared to systems with two isolated full-power processing converters. The analysis and operation of the proposed unfolding based powertrain are validated on a 5 kW SiC-based prototype employing speed sensorless field oriented control on an induction machine.

A detailed efficiency comparison with conventional two-stage motor drives highlights significant loss reduction in the unfolding-based system due to low-frequency inverter switching and partial power handling by the balancer circuit. The unfolding approach also eliminates high-frequency components in the motor common-mode voltage, effectively mitigating damaging common-mode currents. Furthermore, the highly sinusoidal line-line voltages generated by the unfolding system eliminate motor terminal overvoltage issues, even with long

cables. These advantages were validated through both simulations and experiments.

In addition to the unfolding system, this thesis investigates novel IPOS buck-boost converter topologies tailored for the dc-dc stage. The IPOS connection is especially suited for the wide voltage range encountered in powertrain applications. A symmetric IPOS configuration with two NIBB modules is proposed, demonstrating reduced semiconductor and passive component stress while while offering high-gain. Strategic module deactivation at low output voltages is used to further enhance efficiency. Comparative analysis shows superior switch utilization, lower filter energy ratings, and higher efficiency than conventional buck-boost designs. The operation, control, and efficiency of the proposed system is validated on a 5 kW prototype with peak efficiencies exceeding 98%.

Lastly, an improved asymmetric IPOS buck-boost converter topology is introduced, combining an NIBB module with a boost module. A seamless mode transition control strategy is developed to optimize performance based on voltage gain requirements. Compared to a standalone NIBB converter, the asymmetric design achieves higher efficiency using lower-rated devices while maintaining comparable filter size. A 24 kW three-phase interleaved prototype is developed with measured efficiencies exceeding 99% across an output voltage range of 250–800 V, affirming its suitability for high-performance EV powertrains.