

Abstract of Ph.D. Thesis
“Capacitor-Centric Approaches for Size Reduction and Efficiency Improvement in Electric Vehicle Chargers”
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Power electronics play a crucial role in industrial applications, with electric vehicles (EVs) being one of the most prominent examples. EVs rely on battery chargers to replenish their battery packs, making features like efficiency, high power density, and reliability essential in such systems. Traditional grid-connected EV chargers typically use an AC-DC-DC architecture. However, this design often involves bulky electrolytic capacitors in single-phase converter systems, contributing to a larger overall footprint. A promising alternative to these capacitors is the use of active power buffers (APBs). APB converters enable the use of low-capacitance DC-port capacitors by either transferring the ripple from the DC port to another component within the circuit or by generating a counter-ripple waveform to cancel it out. These converters offer significant advantages, such as enhanced power density, improved reliability, and better input/output power quality. Due to these benefits, APBs were prominently utilised by participants in the Google Little Box Challenge, an industry-level competition aimed at advancing the power density of AC-DC converters.

Although APBs offer several advantages, their industrial application has been limited. This is mainly due to the considerable efficiency loss compared to passive solutions, the increased system complexity from adding switches and sensors, and their lack of robustness. While some challenges have been addressed through research, others remain under investigation, particularly regarding their practical implementation. This thesis focuses on the design and development of converters and techniques aimed at reducing capacitor requirements in single-phase and single-phase-derived converters. It presents novel and enhanced modulation and control strategies for APB converters, with a focus on improving performance and reducing complexity. To minimize ripple at the load end while using low-value capacitance, two types of APB topologies are examined: non-integrated and integrated APBs. The unique challenges of each category are addressed, and their suitability for EV chargers is analyzed in this thesis. Non-integrated APBs are commonly explored topologies for reducing capacitor ripple in AC-DC systems due to their independent control and plug-and-play operation. Based on their power processing capabilities, non-integrated APBs can be further classified into two categories: complete-power processing APBs and partial-power processing APBs. Complete-power processing APBs, which are most commonly used, tend to have higher efficiency drop. Many researchers have proposed control and modulation techniques to improve the efficiency of these APBs, bringing their losses closer to those of passive solutions, such as electrolytic capacitors (E-caps). Although operating these APB converter in a critical-conduction mode can reduce switching losses, this technique is not beneficial at high power levels. This thesis addresses enhanced modulation and control strategies for complete-power processing APBs, aimed at further improving efficiency across a wide range of operating conditions and optimizing performance during dynamic periods. Furthermore, partial-power processing APB converters, which exhibit efficiency comparable to passive solutions, have the drawback of an increased sensor count. This issue is tackled by introducing an adaptive non-linear control strategy to reduce reliance on sensors, thereby enhancing reliability and reducing system complexity. All modulation techniques and control algorithms are developed in the MATLAB/Simulink environment, followed by magnetic and thermal simulation validation in COMSOL Multiphysics. Finally, experimental verification is conducted on various two-layer PCB prototypes of different APB converters, as well as a conventional front-end AC-DC converter, using the Texas Instruments TMS320F28379D microcontroller.

To enable power decoupling with minimal or no additional semiconductor switches, the adoption of integrated APB converters has been proposed in the literature. These converters have gained attention in the research community in recent years due to their reduced cost and lower system complexity. This thesis also investigates the potential of integrating a secondary-stage DC-DC converter with the APB, thereby maintaining the front-end H-bridge-based AC-DC converter structure and paving the way for the use of integrated APBs in multilevel converters. Furthermore, the thesis explores the possibility of repurposing the decoupling circuitry of integrated APBs to add multifunctional capabilities in EVs. The integrated APB converters are first validated conceptually through simulations in MATLAB/Simulink and Ansys MAXWELL, followed by experimental verification using SiC MOSFET-based hardware prototypes.