Abstract of the Thesis

The data center, telecom, and automotive electrical power delivery networks are undergoing major changes mainly by shifting towards a higher voltage, most commonly a 48-V, power delivery architecture to efficiently deliver the growing load demand. Moving towards a higher supply voltage lower the power distribution losses as well as reduce the number of power conversion stages. As a result, there is an increasing demand for a variety of extremely efficient and compact 48V-input DC-DC converters for supplying various digital loads and intermediate voltage rails having stringent requirements. Lately, the hybrid switched-capacitor (SC) converters, which are derived by combining a conventional SC voltage divider with a conventional magnetic-based converter, have gained wide popularity in various applications. They can utilize active and passive devices more efficiently to achieve higher efficiency and power density than conventional converters. This thesis introduces a number of hybrid SC converter-based 48V-input voltage regulator modules (VRMs) and a 48V/12V bus converter for the data center and telecom servers, and automotive computing and electrical power delivery systems.

Even though there exist a large number of solutions for each of these converter categories, they have a few major drawbacks. The existing isolated 48V-input VRMs solely depend on the transformer turns ratio for extending the conversion ratio and also require high voltage-rated primary side devices having high conduction and switching-related losses. In this thesis, a new switched-capacitor voltage divider-derived stacked half-bridge circuit is proposed for the primary side which uses a smaller turns-ratio transformer and reduced voltage-rated devices. The multiphase buck-derived hybrid switched-capacitor converters have been widely preferred for the non-isolated single-stage 48V-input VRMs due to their compact size, automatic phase current balancing, and low device voltage stresses. However, the interdependence of their switched-capacitor voltage divider ratio and the number of phases, as well as the inability of “phase shedding” and “discontinuous conduction mode” operation, result in poor light-load efficiency. This work modifies the structure of these multiphase buck-derived hybrid switched-capacitor converters to allow independent selection of the number of phases and switched-capacitor voltage divider ratio. As a result, the converters can operate over a wide range of conversion ratios and load current demands while maintaining good light-load efficiency. The soft-switching hybrid switched-capacitor converters have been popularly used in the first-stage of the two-stage 48 V-input VRMs and as the 48V/12V bus converter due to their compact size and low switching-related losses. However, these converters lack regulation capability and hence scalability, and poor robustness against the parameter variations. This thesis develops a variety of phase shift modulated soft-switched hybrid switched-capacitor converters for the first-stage of the two-stage 48V-input VRMs and for the 48V/12V bus converter which have efficient load regulation capability and excellent robustness against the parameter variations.

The steady-state operation and analysis of each of the proposed topologies are presented along with their large and small-signal modeling. The design of the power circuit as well as a closed-loop controller for each of these topologies are discussed in detail. Finally, experimental performance verification of each converter is presented.

Keywords: Open compute project, 48V server, mild hybrid vehicles, hybrid switched-capacitor converter, voltage regulator module, bus converter, exact-order discrete-time model.