Ph.D Thesis: Design and Development of Soft-Transition Networks for Charge-pump Based Interleaved Boost Converters
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ABSTRACT

Charge-pump based boost converters are effective in realizing high voltage boosting at moderate duty ratios while the interleaved operation of individual boost cells ensure the source current ripple frequency is double that of the individual cells switching frequency. Hence, charge-pump based interleaved boost converters not only yield a high voltage gain but also exhibit improved source current ripple profile. With this motivation, this thesis investigates the performance improvement aspects of charge-pump based interleaved boost converters. Here, the attention is primarily on reduction of switching losses by reshaping the switch electrical quantities (voltage across the switch and current flowing through the switch) so that losses within the switching devices are either minimized or eliminated during transitions (i.e., switch-OFF to ON transition, switch-ON to OFF transition). Though, reshaping of voltage and current flowing through switch is possible in many ways, but this thesis was focused to design and develop auxiliary transition networks which are feasible only for fixed frequency of operation.

The existing soft-switched interleaved boost converters invariably uses stand-alone zero-voltage and zero-current transition networks. Here, each switch has its associated auxiliary transition network. Although these schemes are shown to be effective in terms of soft-switching performance, but the corresponding system power density is low on account of more number of components involved in the soft-switching networks. Moreover, the requirement of multiple active switches and the associated gate driver circuitry also adds to the control complexity of the interleaved boost converters. With the aim to reduce the number of auxiliary transition networks, firstly investigation pertaining to development of common soft-switching network for multi-phase interleaved boost converters is carried out. This is possible in interleaved converter topologies because the turn-ON/turn-OFF instants of the switches are phase-shifted by 360/N, where 'N' is the number of interleaved boost cells and there is presence of sufficient time delay between any two turn-ON/turn-OFF instants. Use of common soft-switching network effectively reduces the number of resonating inductors, active switches and the associated gate driving circuit requirement. Based on this concept, three different soft-switching networks were proposed for charge-pump based dual boost converters. The first two transition networks incorporate a unified soft-switching network, but it ensures ensures zero-voltage turn-ON and zero-current turn-OFF of the main switching devices with appropriate gating scheme. The two soft-transition networks mentioned above are effective in terms of soft-switching of the main switches both during turn-ON and turn-OFF transitions along with the ZCS turn-OFF of the main diodes. However, the auxiliary switch turns-OFF in hard-switched manner. To overcome this issue, a coupled inductor assisted zero-voltage transition network is proposed for dual-phase interleaved converters. The proposed soft-transition network ensures complete soft transitions to the main as well as the auxiliary devices. The measurements of the soft-switched prototype circuit demonstrated a 2 ~ 4 % efficiency improvement over the hard-switched counterpart. The transition loss reduction obtained through the proposed ZVZCT network are also demonstrated through sample temperature measurements of heat-sinks associated with the switching devices. Furthermore, all the proposed transition networks resulted in soft-transitions over a wide range of loads at a fixed frequency of operation.