Abstract

A DC-DC converter plays the key role in efficient DC power processing in portable devices to meet the demand for fast transient response, high efficiency, and stringent output voltage regulation over a wide range of load current and input voltage. Current-mode control (CMC) achieves better dynamic performance and line regulation over voltage mode control; however, it suffers from poor load regulation and current-loop instability for duty ratio $D > 0.5$. Variable frequency CMC techniques, such as constant ON-time and constant OFF-time offer inherent current-loop stability, which make them useful for wide duty ratio operations. However, constant ON/OFF-time control techniques suffer from varying switching frequency at steady-state and often require an additional PLL circuit for frequency regulation. Digital implementation makes it easier to adapt the constant-time parameter for frequency regulation and offers flexibility for real-time controller tuning. However, the choice of sampling frequency which would ensure robust closed-loop stability still remains a challenge.

This thesis proposes novel constant ON/OFF-time digital CMC architectures for buck, boost, and non-inverting buck-boost (NIBB) converters using event-based sampling methods. This achieves robust closed-loop stability over a wide duty ratio range. A hybrid constant ON/OFF-time modulation technique is proposed to achieve fast transient performance using single digital modulator and voltage controller. The proposed method achieves superior stability margin and reduced right-half-plane (RHP) zero effect in non-minimum phase converters over fixed-frequency CMC. Thereafter, a digital CMC tuning method is proposed in boost and NIBB converters to achieve near time-optimal recovery for a step change in load current and reference voltage. Finally, a multi-mode digital controller is proposed to achieve fast transient response and high light-load efficiency with smooth controller transitions and programmable switching frequency. The buck, boost, and NIBB converter prototypes are made and the proposed architectures are implemented using an FPGA device. A dimmable LED array driving case study is considered, and the proposed methods are experimentally verified.

Keywords: DC-DC converters, constant ON-time modulation, constant OFF-time modulation, event-based sampling, digital current-mode control, RHP-zero, time-optimal recovery