Extended Soft-switching Operation of the Dual Interleaved Boost Converter


School of Electrical and Electronic Engineering, The University of Manchester, Manchester, U.K. Contact: md.rishad.ahmed@postgrad.manchester.ac.uk

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Abstract

The use of soft-switching techniques, interleaved topologies and silicon carbide (SiC) MOSFETs can improve the efficiency and power-density of high-power, high-voltage DC-DC converters for electric vehicle and aircraft applications. In this paper, to extend the operating range of the Snubber Assisted Zero Voltage and Zero Current Transition (SAZZ) dual-interleaved boost converter beyond its inherent soft-switching limit of D=0.5, a resonant pulse transformer is proposed instead of the resonant inductor to enable soft-switching over the full duty ratio range. The 2:1 turns ratio of the transformer ensures full discharge of the snubber capacitor at all duty ratio values to facilitate zero voltage zero current switching (ZVZCS) at turn on of the main switching devices. The effectiveness of the topology has been confirmed by SPICE simulation and demonstrated by a multi-kW SiC MOSFET based SAZZ converter.

1 Introduction

To achieve high power-density in multi-kW DC-DC converters, wide band gap devices such as SiC MOSFETs are being considered. SiC devices enable high-frequency operation, which reduces the size of bulky passive components, however, switching losses and EMI issues can still limit the achievable operating frequency. Soft-switching techniques can remove most of the switching losses and also have the potential to reduce EMI [1]. A soft-switched SiC converter was proposed in [2] which combined the benefits of the dual interleaved boost converter with interphase transformer (IPT) with those of the Snubber Assisted, Zero Voltage and Zero Current Transition (SAZZ) converter. The prototype demonstrated a 50% reduction in switching losses compared with hard-switched operation, and achieved 98% efficiency when operating at 12.5 kW, 112 kHz and 400 V.

A limitation of the SAZZ converter is that soft-switching is only possible if the duty ratio (D) is greater than 0.5 as when D<0.5 the snubber capacitor cannot be fully discharged due to insufficient voltage difference between the output and input. One way to resolve the issue is to replace the main diodes with MOSFETs operating as synchronous rectifiers thereby allowing sufficient current to be established in the resonant inductor to facilitate soft-switching under D<0.5 conditions [3]. Apart from the additional transistors, this solution requires complex switching control and can result in increased conduction losses compared to hard-switching due to the extended conduction of the additional transistors. Another approach is to use the reverse recovery of the upper diode to develop adequate current in the resonant inductor [4]. This solution requires a slow diode which restricts the choice of snubber capacitor. The design was also optimised only for low-power (250W), D<0.5 operation. Some other techniques exist to extend the soft-switching region such as using a capacitive voltage divider in the auxiliary circuit [5], or using an additional capacitor to store and recycle the resonant energy [6]; in both cases balancing the capacitor voltages is a challenge, and the control becomes more complex.

In this paper a small pulse transformer with a 2:1 turns ratio is used to replace the resonant inductor of the conventional SAZZ topology so that the converter’s soft-switching region can be extended. The modified topology ensures soft-switching operation for the whole operating region of the converter. However, as no additional snubber capacitors were used during the experiments, only the turn on losses of the converter were completely eliminated. The turn-off losses were also significantly reduced as the energy stored in the device output and stray capacitances was recovered at turn on. Still, additional snubber capacitors can further reduce the turn off losses. The experimental result shows the superiority of the proposed topology over the previously published SAZZ topologies as zero-voltage-zero-current-switching turn on can be achieved for a wide range of duty ratios without additional control complexity.

2 Circuit description and operation

The converter topology is a modification of the SAZZ dual interleaved boost converter with interphase transformer (IPT) [2] as shown in Figure 1. The resonant inductor is replaced by a pulse transformer, Xa with 2:1 turns ratio. One additional diode (Daux3) and a RC snubber circuit are also added to the new configuration to ensure orderly operation as shown in Figure 1.

The soft-switching operation relies on the resonance between the leakage inductance of the pulse transformer and the snubber capacitors, C1 and C2, in parallel with the main switching devices Q1 and Q2. The auxiliary switching devices Q1aux and Q2aux are turned on just before the turn on of Q1.