ZERO VOLTAGE SWITCHING DC-DC CONVERTER WITH HIGH VOLTAGE GAIN AND HIGH POWER APPLICATION

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Abstract

The technique of zero voltage switching in modern power conversion is explored. Several ZVS topologies and applications, limitations of the ZVS technique, and a generalized design procedure are featured. Two design examples are presented: a 50 Watt DC/DC converter, and an off-line 300 Watt multiple output power supply. This topic concludes with a performance comparison of ZVS converters to their square wave counterparts, and a summary of typical applications.

Introduction

Advances in resonant and quasi-resonant power conversion technology propose alternative solutions to a conflicting set of square wave conversion design goals; obtaining high efficiency operation at a high switching frequency from a high voltage source. Currently, the conventional approaches are by far, still in the production mainstream. However, an increasing challenge can be witnessed by the emerging resonant technologies, primarily due to their lossless switching merits. The intent of this presentation is to unravel the details of zero voltage switching via a comprehensive analysis of the timing intervals and relevant voltage and current waveforms. The concept of quasi-resonant, “lossless” switching is not new, most noticeably patented by one individual [1] and publicized by another at various power conferences [2,3]. Numerous efforts focusing on zero current switching ensued, likely candidate for first perceived as the tomorrow’s generation of high frequency power converters [4,5,6,7,8].

In theory, the on off transitions occur at a time in the resonant cycle where the switch current is zero, facilitat- 3-329 ing zero current, hence zero power switching. And while true, two obvious concerns can impede the quest for high efficiency operation with high voltage inputs. By nature of the resonant tank and zero current switching limitation, the peak switch current is significantly higher than its square wave counterpart. In fact, the peak of the full load switch current is a minimum of twice that of its square wave kin. In its off state, the switch returns to a blocking a high voltage every cycle. When activated by the next drive pulse, the MOSFET output capacitance (Goss) is discharged by the FET, contributing a significant power loss at high frequencies and high voltages. Instead, both of these losses are avoided by implementing a zero voltage switching technique [9,lO].

Zero Voltage Switching Overview

Zero voltage switching can best be defined as conventional square wave power conversion during the switch’s on-time with “resonant” switching transitions. For the most part, it can be considered as square wave power utilizing a constant off-time

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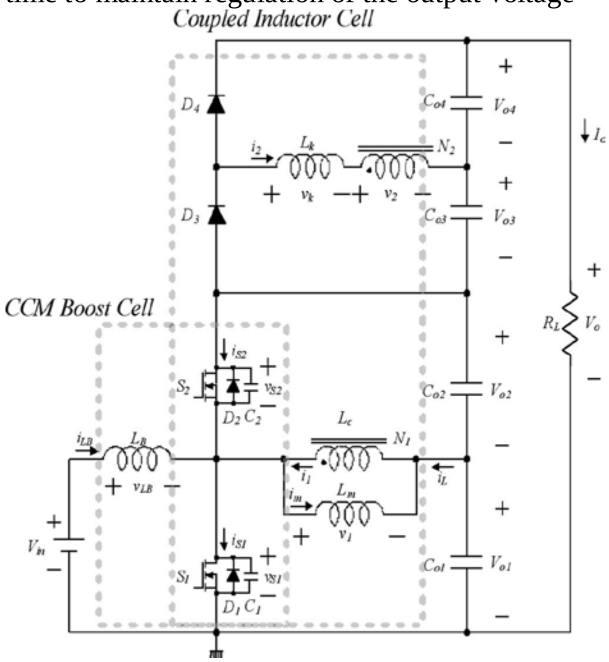
control which varies the conversion frequency, or on-time to maintain regulation of the output voltage



For a given unit of time, this method is similar to fixed frequency conversion which uses an adjustable duty cycle. Regulation of the output voltage is accomplished by adjusting the effective duty cycle, performed by varying the conversion frequency. This changes the effective on-time in a ZVS design. The foundation of this conversion is simply the volt-second product equating of the input and output. It is virtually identical to that of square wave power conversion, and vastly unlike the energy transfer system of its electrical dual, the zero current switched converter. During the ZVS switch off-time, the L-C tank circuit resonates. This traverses the voltage across the switch from zero to its peak, and back down again to zero. At this point the switch can be reactivated, and lossless zero voltage switching facilitated. Since the output capacitance of the MOSFET switch (Co& has been discharged by the resonant tank, it does not contribute to power loss or dissipation in the switch. Therefore, the MOSFET transition losses go to zero - regardless of operating frequency and input voltage. This could represent a significant savings in power, and result in a substantial improvement in efficiency. Obviously, this attribute makes zero voltage switching a suitable candidate for high frequency, high voltage converter designs. Additionally, the gate drive requirements are somewhat reduced in a ZVS design due to the lack of the gate to drain (Miller) charge, which is deleted when ***V&*** equals zero. The technique of zero voltage switching is applicable to all switching topologies; the buck regulator and its derivatives (forward, half and full bridge), the flyback, and boost converters, to name a few. This presentation will focus on the continuous output current, buck derived topologies, however a list of references describing the others has been included in the appendix.

Since the output capacitances $C1$ and $C2$ of the switches are very small, the transition interval $Tt1$ is very short and it can be neglected. Therefore, the inductor currents iLB and iL can be considered to have constant values during mode 1. *Mode 2 [*$t1$, $t2$ *]:* At $t1$, the voltage $vS1$ across the lower switch S1 becomes zero and the lower diode D1 is turned on. Then, the gate signal is applied to the switch S1 . Since the current has already flown through the lower diode D1 and the voltage $vS1$ becomes zero before the switch S1 is turned on, zero-voltage turn-ON of S1 is achieved. Since the voltage across the boost inductor LB is Vin , the boost inductor current increases linearly from $ILB2$. Since $v1$ is $-V$in and vk is $Vo4 + nV$in , the magnetizing current im, the primary current $i1$, the secondary current $i2$, and the inductor current iL are given by

$$i_m(t) = I_{m1} - \frac{V_{\text{in}}}{L_m}(t - t_1)$$

$$i_2(t) = -I_{\text{D4}} + \frac{V_{o4} + nV_{\text{in}}}{L_K}(t - t_1)$$

$$i_1(t) = ni_2(t) = -nI_{\text{D4}} + n\frac{V_{o4} + nV_{\text{in}}}{L_K}(t - t_1)$$

$$i_L(t) = -i_m(t) + i_1(t) = -I_{m1} - nI_{\text{D4}} + \frac{V_{\text{in}}}{L_m}(t - t_1) + n\frac{V_{o4} + nV_{\text{in}}}{L_K}(t - t_1).$$

ZVS Benefits

- Zero power “Lossless” switching transitions
- Reduced EMI / RFI at transitions
- No power loss due to discharging Goss
- No higher peak currents, (ie. ZCS) same as square wave systems
- High efficiency with high voltage inputs at any frequency
- Can incorporate parasitic circuit and component ***L & C***

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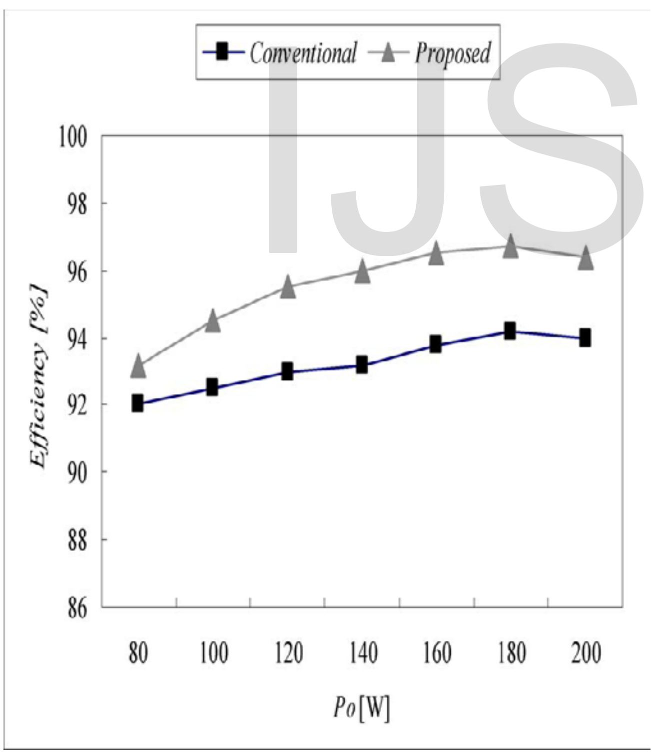
ZVS Differences

- Variable frequency operation (in general)
- Higher off-state voltages in single switch, unclamped topologies
- Relatively new technology - users must climb the learning curve
- Conversion frequency is inversely proportional to load current
- A more sophisticated control circuit may be required

Output



Conclusion

The zero voltage switched quasi-resonant technique is applicable to most power conversion designs, but is most advantageous to those operating from a high voltage input. In these applications, losses associated with discharging of the MOSFET output capacitance can be significant at high switching frequencies, impairing efficiency. Zero voltage switching avoids this penalty by negating the drain-to-source, "off-state" voltage via the resonant tank. A high peak voltage stress occurs across the switch during resonance in the buck regulator and single switch forward converters. Limiting this excursion demands limiting the useful load range of the converter as well, an unacceptable solution in certain applications. For these situations, the zero voltage switched multiresonant approach [14,15] could prove more beneficial than the quasi-resonant ZVS variety. Significant improvements in efficiency can be obtained in high voltage, half and full bridge ZVS applications when compared to their square wave design complements. Clamping of the peak resonant voltage to the input rails avoids the high voltage overshoot concerns of the single switch converters, while transformer reset is accomplished by the bidirectional switching. Additionally, the series transformer primary and circuit inductances can beneficial, additives in the formation of the total resonant inductor value. This not only reduces size, but incorporates the detrimental parasitic generally snubbed in square wave designs, further enhancing efficiency. A new series of control ICs has been developed specifically for the zero voltage switching techniques with a list of features to facilitate lossless switching transitions with complete fault protection. The multitude of functions and ease of programmability greatly simplify the interface to this new generation of power conversion techniques; those developed in response to the demands for increased power density and efficiency.

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