Step Down Converter With Efficient ZVS Operation

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Abstract—Step down converters have many applications in modern electronic devices. For these purposes, circuits have voltage/current requirements outside the efficient range of most classical converters. Therefore there was an urge for development of new converter topologies. Converters employing soft switching methods were emerged as an efficient alternative while considering the switching losses of a conventional converter. Here modifications are made on conventional buck converter. An auxiliary switch, a diode, and a coupled winding to the buck inductor are added with the conventional buck converter. By transferring the buck inductor current to the coupled winding in a very short period, a negative built-up of leakage inductor current in buck winding is achieved, which guarantees the Zero-Voltage Switching (ZVS) operation of the buck switch in all load conditions. Furthermore, since the negatively built-up leakage inductor current is minimized after the zero voltage of the buck switch is achieved; the unnecessary current build-up and the conduction loss are minimized. Therefore, a converter with efficient ZVS operation with load variation is achieved. To verify the performance of this topology, simulations are done using MATLAB or SIMULINK.

Keywords—DC DC converters; buck converter; Zero Voltage Switching;

I. INTRODUCTION

Rapid technological changes have led to power electronic products playing a crucial role in daily life. Solar power regulators, LED, drivers and portable electronic equipment, such as laptop computers, cellular phones, and future microprocessors and memory chips, requires step down converters for their operation. Buck type dc - dc converters are widely employed for step down operation in the power electronics industry because no other topology is as simple. Their applications range from low-power regulators to very high power step - down converters, which are characterized by a low number of components, low control complexity, and no insulation.

For above mentioned applications, high power density, high efficiency, and low noise are the driving force in power converter research. High power density can be achieved by increasing switching frequency since magnetic and capacitive elements can be designed in small sizes in high frequencies but it increases switching loss and degradation of system efficiency. Soft-switching techniques can alleviate switching losses, and thus, they allow for higher frequency operation, higher efficiency, low harmonic level, and high power density. The choice of the soft-switching technique depends on the type of switching device, and the ZVS technique is more preferable in MOSFET switches since it eliminates the capacitive loss of a power switch during the turn-on transition.

Various types of ZVS techniques are presented in [1]-[7]. An efficiency improved version of Synchronous buck converter with passive auxiliary circuit is presented in [2]. This converter well utilized the parasitic components of the power switch with additional resonant components. However, higher voltage and current stresses are common in this converter. The active resonant tank can be used in converters with Synchronous Rectifiers (SR) to achieve the ZVS of the power switch [3]. In low output voltage dc-dc converters, SRs are widely utilized to reduce rectifier conduction loss and improve converter efficiency. By the introduction of the active resonant tank even though it eliminates reverse recovery of the body diode, this converter induces conduction loss in the added inductor and capacitor.

In [4] and [5] an auxiliary circuit is utilized to obtain zero voltage and zero current switching in zero voltage transition PWM converters. They provide zero-current switching during turn-on and zero-voltage switching during turn-off. The switches do not experience any over voltage/over current stress proportional to load as in resonant converters. The major disadvantage is that the active switches in the converter undergo zero-capacitive turn-on losses.

A simple ZVS buck converter with a coupled inductor is presented in [6] and [7] with small additional components. However, a large current is built up in the coupled winding in light-load conditions and therefore greatly increases conduction loss. In addition, less power is transferred to the output during the switch-off period, which increases the dc value of the buck-inductor current.

II. NEW ZVS TOPOLOGY

The new step-down ZVS converter composed of an auxiliary switch, a diode, and a coupled winding in the conventional buck inductor. The basic operation of the new converter topology can be explained as follows. During a very short turn-on period of the auxiliary switch, the buck inductor current is transferred to the coupled winding and the leakage inductor current is built up negatively. It makes the output capacitor of power switch to discharge hence obtaining zero voltage across the power switch. It guarantees the ZVS of the switch in all load conditions through the negative leakage inductor current. Furthermore, since the negatively built-up leakage inductor current is minimized after the zero voltage of the buck switch is achieved, the unnecessary current build-up and conduction loss are minimized as the load goes down, which indicates the efficient ZVS operation with load variation.

Figure 1. New ZVS Topology

The new step down converter topology is shown in Figure 1 the operating waveforms are shown in Figure 2.
Figure 2. Operational Waveforms

Mode 1 (t0 to t1): At t0 leakage inductor current iLr reaches the buck-inductor current iLb. Since buck switch Sb is in the on state, since n < 1 and Vin > Vo, VSx and VDx are positive and the output diode of switch Sx and diode Dx remains in the off state. This mode ends when switch Sb is turned off.

Mode 2 (t1 to t2): In Mode 2, diode Db is in the on state and the buck-inductor voltage VLb = -Vo. Since n < 1 and Vin > Vo, VSx and VDx are positive and the output diode of switch Sx and diode Dx remain in the off state. This mode ends when switch Sx is turned on.

Mode 3 (t2 to t3): When switch Sx is turned on, the coupled winding voltage Vx becomes Vin - Vo. Then, the voltage of leakage inductors VLr is given by

\[ V_{Lr} = - \left( \frac{V_{in} - V_0}{n} + V_0 \right) \]  (1)

Since turn ratio ‘n’ is a little smaller than unity, the leakage inductor voltage VLr has a large negative value. Then, the leakage inductor current iLr decreases rapidly down to zero since leakage inductor Lr has a very small value. The voltage of diode Dx and switch Sb is Vin during this mode. This mode ends when the leakage inductor current iLr reaches zero.

Mode 4 (t3 to t4): Mode 4 has a very short period compared with Mode 3. After the leakage inductor current iLr reaches zero, it flows in the negative direction and to the charge and discharge output capacitors of diode Db and the output capacitor of switch Sb, respectively, in a resonant manner, as shown in Figure 3. The voltage across switch Sb varies from Vin to zero in this mode. The ZVS of switch Sb is always achieved only if switch Sx is not turned off before voltage VSB reaches zero. Since the leakage inductor Lr and output capacitor Cs have very small values and the time interval within which switch voltage VSB decreases from Vin to zero is very short, switch Sx is never turned off before VSB reaches zero. Therefore, the ZVS of switch Sb is already guaranteed.

Mode 5 (t4 to t5): Mode 5 begins when VSB reaches zero voltage. When VSB reaches zero voltage, the output diode of switch Sb is turned on and maintained in its ON state during this mode since the voltage of the leakage inductor VLr remains negative such that the leakage inductor current still flows in the negative direction. Mode 5 ends when switch Sx is turned off.

Table I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>100 V</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>50 V</td>
</tr>
<tr>
<td>Output Power</td>
<td>300 W</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>125 KHz</td>
</tr>
<tr>
<td>Coupled Inductor</td>
<td>L1: 250.6µH, L2: 181.4µH, n: .85</td>
</tr>
<tr>
<td>Capacitor</td>
<td>Cs: 47µF</td>
</tr>
</tbody>
</table>

III. SIMULATION RESULTS

The circuit was simulated in MATLAB/SIMULINK. The open loop simulation of the converter is shown in Figure 3. The output voltage and current are shown in Figure 4.
IV. CONCLUSION

A new step down converter topology with efficient ZVS operation is discussed. Analysis and characterization of the different modes of operation of the converter is done. The new step down converter topology has high efficiency compared to classical buck converters and other ZVS based step down converters. It eliminates the drawbacks of existing ZVS topologies such as large number of components, circulating currents, high losses etc. Also it has a compact construction and has very good voltage regulation with simple control requirements.

REFERENCES


