A PFC ZVT-PWM Dc-Dc Converter for an Integrated Power Module


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Abstract:
This paper proposes a novel soft-switched dc-dc circuit to provide a zero-voltage transition at turn on for a conventional pulse width-modulated boost converter in a power factor correction (PFC) application. The proposed circuit enables a main switch of the dc-dc converter to turn on under a zero-voltage switching condition and simultaneously achieves both soft-switched turn on and turn off. Moreover, for the purpose of an intelligent power module, the proposed circuit is designed to satisfy several design constraints, including space saving, low cost, and easy fabrication. As a result, the circuit is easily realized by a low-rated MOSFET and a small inductor. The proposed method is implemented in MATLAB/Simulink and the waveforms are theoretically explained with the analysis of experimental results to measure the effectiveness of the circuit.

Keywords: Power factor correction, Soft switching power converters, Dc-Dc Converter, Zero-voltage transition (ZVT)

I. INTRODUCTION

Soft switching power converters are gaining more interest in power conversion technologies because of lower switching losses, reduce EMI, reduce voltage/current stress and allow a greater high switching frequency in high power applications. Despite the advantages of Soft Switching converters, its applications have been so far limited due to complexity in the design of Soft Switching circuits, and difficult in control realization. There has been a growing demand for a simple design that provides reliable control in a wide-range of operational condition. Power converters are developing very quickly for various applications such as power factor correction (PFC) and switched-mode power supply. One major force driving this development is the emergence of powerful and cost-effective integrated power multichip modules, based on the new concepts of building structure and advanced packing technology [1]–[3].

Several Soft Switching techniques have been developed such as the auxiliary resonant snubber inverter, the auxiliary resonant commutated pole inverter, the inductor coupled zero-voltage transition inverter (ZVT) , and the resonant dc link inverter. The RSI is suitable for single or three-phase inverters with multiple branches of auxiliary circuits but needs modification of space vector modulation to ensure zero voltage switching. The auxiliary resonant inverter requires large split capacitors to achieve a zero-voltage switching. The ZVT requires bulky coupled inductors to reset the has been used in other converters. To realize high resonant current. The resonant DC link inverter needs a device voltage rating higher than that which conversion efficiency, a soft switching circuit is
useful and effective technologies. And many soft-switching circuits have been applied to dc-dc converter. Soft switching generates electrical resonance between a capacitor and an inductor during a short turn-on/off period and consequently achieves zero-voltage and/or zero-current switching [4-10]. In recent years, the integrated multichip power module, which itself incorporates the aforementioned soft-switching transition technique, has been in demand because of the high performance requirements for energy efficiency, harmonics, EMI, and so on, due to enhanced regulations from government and energy societies.

This paper proposes a soft switching circuit with dc-dc converter that can be easily incorporated into a multichip power module. The proposed circuit enables a main switch of the dc-dc converter to turn on under a zero-voltage switching condition and simultaneously achieves both soft-switched turn on and turn off and also to reduce the cost and fabrication easy.

This paper is organized as follows: Section II describes the circuit. Section III discusses the simulation result and Section IV concludes the paper.

II. CIRCUIT DIAGRAM

![Circuit Diagram](image)

**Fig 1** The circuit scheme of the proposed ZVT-PWM boost converter.

This converter differs from the conventional PWM boost converter of a resonant branch, which consists of a resonant inductor Lr, a resonant capacitor Cr, and an auxiliary switch S2 (MOSFET). Generally, auxiliary switch S2 has a lower power rating than that of main switch S1 (insulated-gate bipolar transistor (IGBT)). Resonant capacitor Cr is the sum of the parasitic capacitor of S1 and others incorporating multichip module technology.

III. CIRCUIT DESCRIPTION

The proposed method is designed to provide zero voltage transition for a power factor correction application which in turn reduces the losses and improve the efficiency of the system.
The circuit is designed with a resonant inductor $L_2$, a resonant capacitor $C_1$, and an auxiliary switch $S_2$ (MOSFET) and is shown in figure 1. Generally, auxiliary switch $S_2$ has a lower power rating than that of main switch $S_1$ [insulated-gate bipolar transistor (IGBT)]. Resonant capacitor $C_1$ is the sum of the parasitic capacitor of $S_1$ and others incorporating multichip module technology. To describe the steady state analysis, the following assumptions are made:

1. Input voltage $v_1$ is constant
2. Output capacitor $C_3$ is sufficiently large
3. Main inductor $L_1$ is sufficiently large
4. Main inductor $L_1$ is much larger than auxiliary inductor $L_2$

**a) Analysis of operation stages**

For one switching cycle, the proposed circuit operations can be divided into eight stages.

**Case 1:**

Main switch $S_1$ and auxiliary switch $S_2$ are off before $t_0$. When the auxiliary softly turns on at $t_0$, the auxiliary inductor $I_2$ current linearly increases from 0 to $I_i$ at $t_1$. During this period, diode $D_3$ is conducted. The time period $t_{01}$ of this stage is given by

$$t_{01} = \frac{I_i l_2}{v}$$

**Case 2:**

In this stage, the circuit starts to resonate between $L_2$ and $C_1$. Auxiliary inductor current $I_{2\text{ peak}}$ continues to increase up to $I_{2\text{ peak}}$. $C_1$ is discharged until the resonance brings its voltage to zero. This resonant time period $t_{12}$ is given by
\[ t_{12} = \frac{\pi}{2} \sqrt{\frac{C1}{I2}} \]

\[ I_{s2\text{.peak}} = I_i - I_{C1} = I_i + \frac{V}{Z} \sin(\omega(t_2 - t_1)) \]

**Case 3:**

When the antiparallel diode is conducting, the main switch current flows negatively for a very short time. Main switch voltage \( VCE_{S1} \) is zero at \( t_3 \). Main switch S1 is turned on under the zero-voltage switching condition.

**Case 4:**

Main switch current \( I_{s1} \) increases, whereas auxiliary switch current \( I_{s2} \) decreases. Therefore, the sum of both switch currents is equal to \( I_i \). In this stage, IGBT and MOSFET can be changed to the voltage source \( V_{sat_{S1}} \) and on-resistance \( R_{DS(on)_{S2}} \), respectively, for analysis. This is because the characteristic of the current flowing through the two switches is determined by the resistance elements of each switch. The equation for current \( I_{t2} \) is given by

\[ I_{t2}(t_4) = I_i e^{-\alpha t_4} + \frac{V_{sat_{S1}}}{R_{DS(on)_{S2}}} (1 - e^{-\alpha t_4}) \]

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**Fig 3** Theoretical waveforms of the proposed system
Case 5:

Auxiliary switch S2 is softly turned off. The flowing current in the auxiliary inductor is converted to voltage on the parasitic capacitor of S2. Auxiliary inductor current \( I_{l2} \) is zero at \( t_5 \).

\[
v_{CDS_{s2}}(t_5) = l_2 \frac{dI_{l2}(t_4-t_5)}{dt_4-t_5} \tag{5}
\]

\[
i_{l2}(t_5) = \frac{V_{sat_{s1}}}{R_{DS(on)s2}} (1 - e^{-\alpha t_4-t_5}) \tag{6}
\]

Case 6:

This stage is identical to the SPWM boost converter behavior. D is turned off at \( t_5 \). Main switch s1 conducts and \( I_i \) flows while the auxiliary circuit is inactive.

Case 7:

At this stage, the main switch is turned off, and resonant capacitor \( C_1 \) is linearly charged up to \( V_1 \) voltage. Diode D is turned on naturally at \( t_7 \).

Case 8:

This stage is a freewheeling condition as in the SPWM boost converter. Main switch S2 turns on again at \( t_0 \), and the operation mode repeats.

b) Selection of \( L_2 \) and \( C_3 \)

To minimize both the current ripple and the voltage ripple, we design \( L_2 \) and \( C_3 \) to be as large as possible. However, the system cost increases according to the stringency of the specification. The optimized \( C_3 \) and \( L_2 \) of the proposed ZVT-SPWM boost converter \([L_1]\) are designed by

\[
L_2 > \frac{(v_{1-min})^2}{2I_{ripple}f_{sw}\eta P_{out}} \left(1 - \frac{\sqrt{2}v_1(min)}{v}\right) \tag{7}
\]

\[
C_3 > \frac{P_{out}}{2\pi f_{line}v_{ripple}v} \tag{8}
\]

c) Selection of \( S_2 \)

\( S_2 \) is selected to satisfy the following condition \([L_2]\) :

\[
V_{sat,s1} < I_{5-s2}R_{DS(on)s2} \tag{9}
\]
d) Selection of L₂ and C₃

To achieve ZVT turn-on of the main switch, the turn-on signal of S₁ should be applied while its antiparallel diode is conducting. Moreover, Iₘₐₓ must be greater than the value of Iₑ. This value is determined by L₂ and C₃. From (3) L₂ and C₃ can be approximated.

IV. EXPERIMENTAL RESULTS

The proposed system is simulated in MATLAB/Simulink. The operation stages are analyzed to reduce the loss, to achieve ZVT turn-on of the main switch and to minimize the current and voltage Ripples. Figure 5 shows the simulation result.

V. CONCLUSION

This paper has presented a new ZVT-SPWM boost converter with an active snubber. This simple snubber circuit can be integrated into the multichip power module. The operation of the proposed circuit was theoretically described. As shown, the proposed method has a reduced circuit complexity, a minimized auxiliary inductor, and reduced CE. In addition, the main and auxiliary switches are confirmed to have ZVT turned on and softly turned on and...
off. The voltage stress of the auxiliary switch is found to quite low for the proposed converter system.

REFERENCES


