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PWM Soft Switched DC–DC Converter with Coupled Inductor

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Abstract- *In this paper, pulse width modulation soft switched DC-DC converter without high voltage & current stress is described. This converter does not require any extra switch to achieve soft switching, which considerably simplifies the control circuit. In this proposed converter, the switch is turned on under zero-current and is turned-off at almost zero-voltage condition. In this converter , it is desirable to control the output voltage by pulse width modulation because of its simplicity and constant frequency. The circuit is simulated using PSPICE and the output voltage is obtained as 100V for 50V input.*

Index Terms—*Pulse width modulation (PWM), soft single switched (SSS), zero current switching (ZCS), zero voltage switching (ZVS).*

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1. INTRODUCTION

When conventional PWM power converters are operated in a switched mode operation, the power switches have to cut off the load current within the turn-on and turn-off times under the hard switching conditions. hard switching refers to the stressful switching behavior of the power electronic devices During the turn-on and turn-off processes, the power device has to withstand high voltage and current simultaneously, resulting in high switching losses and stress. Dissipative passive snubber are usually added to the power circuits so that the ${dv}/{dt}$ & ${di}/{dt}$ of the power devices could be reduced, and the switching loss and stress be diverted to the passive snubber circuits.

However, the switching loss is proportional to the switching frequency, thus limiting the maximum switching frequency of the power converters. The stray inductive and capacitive components in the power circuits and power devices still cause considerable transient effects, which in turn give rise to electromagnetic interference problems. These soft-switched converters have switching waveforms similar to those of conventional PWM converters except that the rising and falling edges of the waveforms are 'smoothed' with no transient spikes as shown in Figure 1.

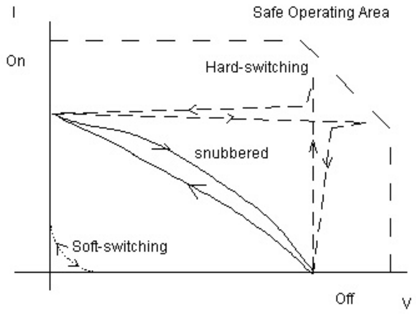

Fig. 1. Rising & falling edges of soft switched converters.

Unlike the resonant converters, soft-switched converters usually utilize the resonance in a controlled manner. Resonance is allowed to occur just before and during the turn-on and turn-off processes so as to create ZVS and ZCS conditions. Other than that, they behave just like conventional PWM converters.

Quasi resonant converters do not have any extra switch to provide soft switching conditions however they must be controlled by the variation of switching frequency [1]. zero voltage transition, zero current transition, and active clamped converters are PWM controlled but require at least two switches, which increases the complexity of power and control circuits[2]-[9]. PWM soft single switched converters usually have large no of passive elements, which makes the converter implementation difficult [10]-[14], [16].

The lossless passive snubber circuit introduced in [15] is simple and easy to implement. However, in this converter, a soft switching condition is not achieved for the switch turnoff instant. Furthermore in [16], an additional diode is added in main power path, which would further increase the conduction losses. In this paper, PWM SSS converters without any substantial increase in voltage and current stresses is presented Furthermore, in this converter, the number of additional components is not high. The switch in converter is turned on under zero current switching and is turned off at almost zero voltage switching condition. The converter main diode turns on under ZVS condition and turns off under zero voltage zero current switching condition.

Furthermore, an auxiliary diode turns on under ZVS condition. With simple modifications, many customized control integrated control circuits designed for conventional converters can be employed for soft-switched converters. Because the switching loss and stress have been reduced, soft-switched converter can be operated at the very high frequency (typically 500 kHz to a few Mega-Hertz). Soft-switching converters also provide an effective solution to suppress EMI and have been applied to dc-dc, ac-dc and dc-ac converters.

2. CIRCUIT DESCRIPTION AND OPERATION

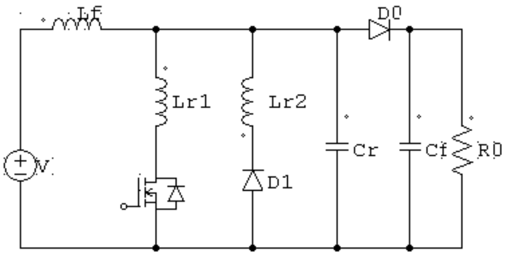

Fig. 2. PWM boost converter

The circuit configuration of PWM soft switched DC-DC converter with coupled inductors is shown in figure 2.1 the circuit components including L_{r1}, L_{r2}, D_1 & C_r are added to the conventional boost converter. It is assumed that L_f & C_f are large enough so that they can be replaced by a current source(I_{in}) and a voltage source(V_0).

Mode 1 [t_0–t_1]: At t_o switch is turned on under ZCS condition due to series inductor L_{r1}. The inductor current is represented as $I_{lr1}(t)$

$$I_{lr1}(t) = \frac{V_0}{L_{r2} * (t - t_0)} \tag{1}$$

At t_1, I_{lr1} reaches Iin therefore, the duration of this mode is change in time is represented as(Δt_1)

$$\Delta t_1 = t_1 - t_0 = \frac{L_{r1} I_{in}}{V_0} \tag{2}$$

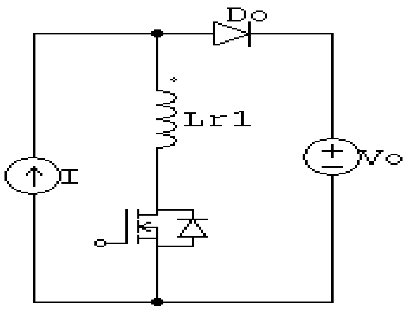

Fig. 3. Mode 1 Operation

Mode 2 [t_1–t_2]: At t_1, the L_{r1} current has reached I_{in}, and the diode D_o current has reached zero. Thus, the diode D_o turnoff is under ZCS. Lr1 starts to resonate with C_r. The resonant capacitor voltage

$$V_{cr}(t) = V_0 \cos(\omega r(t - t_1)) \tag{3}$$

The resonant inductor current is mentioned as

$$I_{lr1}(t) = \frac{I_{in} + V_0}{Z_{orn} * \sin(\omega r\,(t - t_1))} \tag{4}$$

This mode ends when the C_r voltage reaches zero. The duration of this mode, change in time (Δt_2)

$$\Delta t_2 = t_2 - t_1 = \frac{180}{2\omega_r} \tag{5}$$

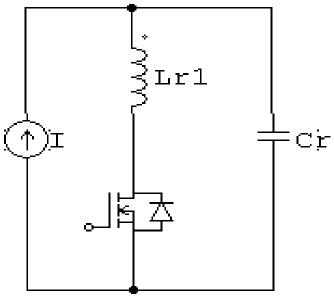

Fig. 4. Mode 2 Operation

Mode 3 [t_2–t_3]: When V_{cr} reaches zero, diode D_1 starts to conduct under ZVS condition. This mode ends when the switch is turned off. The duration of this mode, the change in time is represented as (Δt_3)

$$\Delta t_3 = DT_s - (\Delta t_1 + \Delta t_2) \tag{6}$$

Where D is switch duty cycle & Ts is switching period.

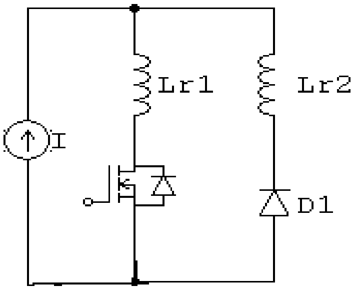

Fig. 5. Mode3 Operation

Mode 4 [t_3–t_4]: By turning switch off, the ampere turn of L_{r1} is transferred to L_{r2} now L_{r2} ampere turn is sum of its previous ampere turn plus the L_{r1}ampereturn.

$$I_{lr13}\,N_1 + I_{lr2}N_2 = I_1N_2) \tag{7}$$

At t4, V_{cr} reaches Vo, the maximum voltage across the switch

$$V_{sw,max} = V_{sw}(t_4) = (1+\frac{1}{n})V_0 \tag{8}$$

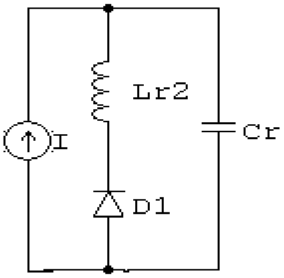

Fig. 6. Mode 4 Operation

Mode 5 [*t*4–*t*5]*:*This mode begins when the Cr voltage reaches Vo & the diode Do turns on under ZVS condition. At the beginning of this mode, L_{r2} current is represented as I_{lr2}(t)

$$I_{lr2}(t) = \frac{I_2 - V_0}{L_{r2}} * (t - t_4) \tag{9}$$

At t_5, theL_{r2} current reaches zero, and the Diode D_1 turns off under ZCS. The change in time

$$\Delta t_5 = t_5 - t_4 = \frac{L_{r2}I_2}{V_0} \tag{10}$$

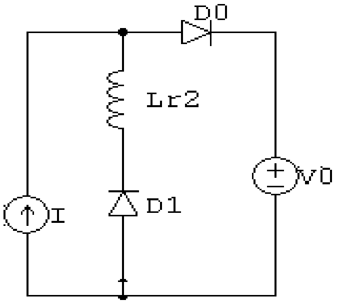

Fig. 7. Mode 5 Operation

Mode 6 [*t*5–*t*6]*:* In this mode I_{in} freewheels through the diode Do, & the current through inductors remains zero. Voltage across the capacitor stays at Vo. The duration of this mode, the change in time is represented as (Δt_6)

$$\Delta t_6 = (1-D)T_S - (\Delta t_5 + \Delta t_6) \tag{11}$$

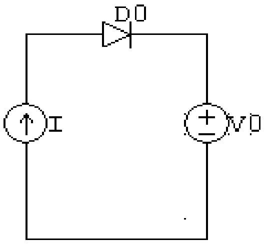

Fig. 8. Mode 6 Operation

3. Simulation Circuit and Results

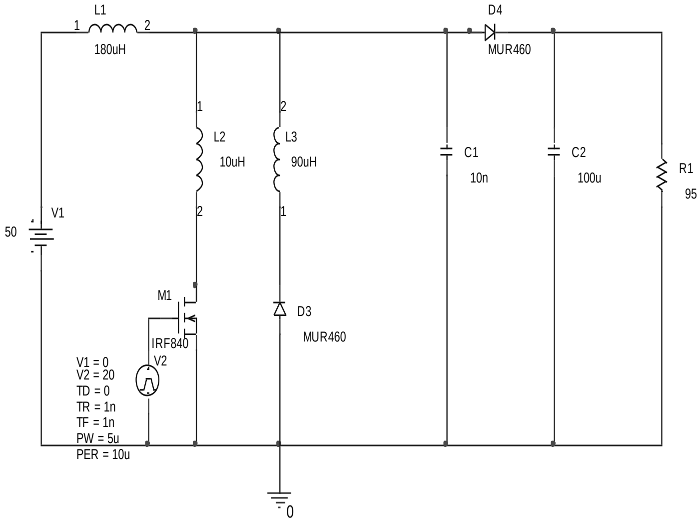

Fig. 9. Simulation Circuit

The design of the simulation circuit involves the selection of C_r, L_{r1}, and n. C_r provides the ZVS condition for the switch turnoff instant.

$$C_r = \frac{I_{Sw}t_f}{2V_{sw}} \tag{12}$$

Where t_f is the switch current fall time, I_{sw} is the switch current before turnoff, and V_{sw} is the switch voltage after turnoff. C_r is considered much larger than $C_{r,min}$ to guarantee soft switching. L_{r1} provides ZCS condition for the switch turnon instant.

$$L_{r1} = \frac{V_{Sw}t_r}{I_{sw}} \tag{13}$$

Where t_r is the switch current rise time. L_{r1} is considered much larger than $L_{r,min}$ to guarantee soft switching. As n increases, the switch voltage stress in furth mode and freewheeling current in third mode decrease. However, this will result in a higher voltage stress of diode D_1 and limits the maximum duty cycle of the converter. Thus, soft switching condition at very light load current can be omitted, and a large value for n can be selected. The additional current and voltage stresses of a switch can be reduced to a small amount, by choosing large values of Z_r and n.

However, large values of Z_r and n limit the converter maximum duty cycle and soft switching. The designed values for L_{r1}, C_{r1}, and n are 18uH, 10nF and 3, respectively. Furthermore, the L_f and C_f values are 180uH and 100uF, respectively. IRF840 is selected for the converter switch, and MUR460 is chosen for diodes Do and D1. The PWM boost converter is simulated at 50v input voltage and 100v output voltage. The converter operates at 100 kHz and an output power of 120W.

3.1 Voltage waveform across load

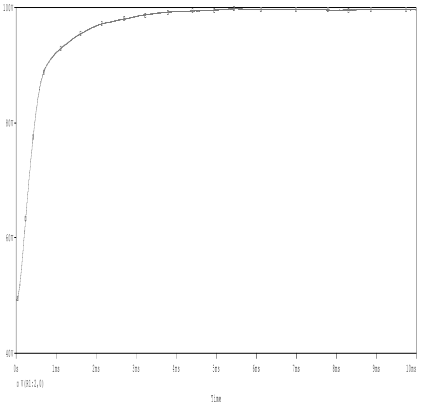

Fig. 10. Voltage waveform across load

Output voltage across load was obtained as 100V for a dc input of 50V.

3.2 Voltage & Current waveform across Main Switch

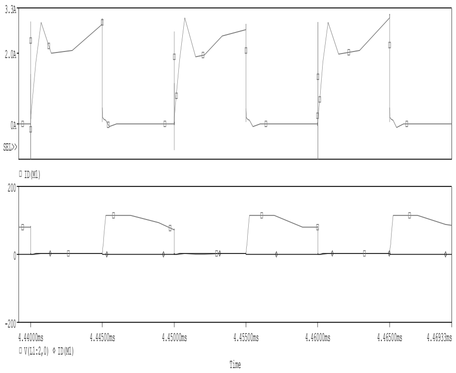

Fig. 11. Voltage & current waveform across mainswitch

Main switch is turned on under ZCS condition due to series inductor L_{r1} and turned off at almost ZVS. When voltage across main switch starts to fall from 100V to 0V at the same time switch current starts to rise from 0A to 3A.

3.3 Voltage & Current waveform across main diode

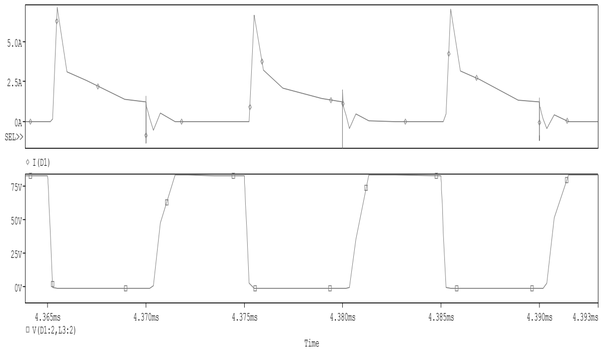

Fig. 12. Voltage & current waveform across main diode

Main diode D1 turns on under ZVS condition and turns off under ZVZCS condition. When voltage across main diode starts to fall from 100V to 0V at the same time diode current starts to rise from 0A to 8A.

4.CONCLUSION

In this paper, a new PWM SSS boost converter without high voltage and current stresses has been described. This converter does not require any extra switch to achieve soft switching, which considerably simplifies the control circuit.

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