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Active Resonant Snubber for Ideal Switched PWM Converter

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Abstract: A new active resonant snubber (ARS) circuit providing the ideal switching conditions for PWM converter is presented. By using the proposed ARS circuit to PWM converters, the power switches can be operated to give zero-current and zero-voltage at both the instant of switch off and switch on, without increasing voltage/current stresses of the switches. Furthermore, the PWM converters employed ARS circuit has the advantage that it can operate at constant frequency, giving better definded EMI and filter ripple, and it is also suited for high-power application regardless of the semiconductor devices (such as MOSFETs or IGBTs) used as a power switches.

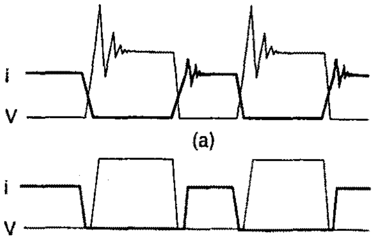

Fig. 1 Switching waveforms for PWM switching condition (a) and ideal switching condition (b)

1. Introduction

The PWM converters are widely used for the switched-mode power supplies in industries. It is well known that a PWM converter has desirable features such as simple topology, small number of circuit components, easy control and easy analysis. Without considering its turn-on and turn-off transition, the waveforms of the voltage across the switch and the current through the switch are square wave, implying low voltage and current stresses in the switch. However, PWM converters process power by interrupting the power flow by means of abrupt switching. This hard-switching operation results in serious problems related to turn-on and turn-off switching transition. Fig. 1(a) shows the switching waveform for a PWM converter. At turn-off, a high frequency oscillating vltage appears in the switch because of the parastic inductances in series with the switch. At turn-on, it is found that a surge current flows through the switch. This surge current is caused by the discharge of the parallel capacitance, which is charged at a high level voltage in OFF period. Both the voltage and current surges are major source of the EMI and RFI. Since they are damped by thr parasitic resistance in the circuit, the energy is lost. Furthermore, there is an overlap of the voltage and current during switching period, dissipating cirtain energy. All of them prevent the PWM converter from high frequency operation, which makes it impossible to miniaturize the power supply further.

To improve switching conditions for semiconductor devices in PWM converters, several resonant techniques were proposed. The resonant converter, which include the traditional series and parallel resonant converters, class-E converters, quasi-resonant converters, and multi-resonant converters, process power in a sinusoidal or quasi-sinusoidal form. The power switches are commutated with either zero-voltage switching(ZVS) or zero-current switching(ZCS), thus switching loss and stresses of the resonant converters are significantly reduced in comparison with the PWM converters. However, due to the resonant nature of the current and voltage waveforms, the operation of the resonant converters usually involves high circulating energy which results in a substantial increase in conduction losses. In addition, due to wide line/load range, most resonant converter operate with a wide switching frequency range, thus making the circuir design difficult to optimize.

As a compromise between the PWM and resonant techniques, zero-voltage transition(ZVT) and zero-current transition(ZCT) techniques were proposed recently aimed at ZVS condition for power MOSFETs and ZCS condition for IGBTs, respectively. These techniques are deemed desirable since it implement soft switching conditions for all semiconductor devices without increasing voltage/current stress. Unfortunately, each technique has certain disadvantages associated with it. For example, ZCT technique has a dissipation penalty due to the need to charge and discharge the drain/gate (Miller capacitance) and drain/source capacitances. This disadvantage also leads to the need for a faster gate drive, with the necessary circuit complexity. ZVT technique needs a less critical gate drive but has the disadvantage of a high frequency oscillating voltage across the power switch at turn-off time. In addition, ZVT technique can be effective only when applied to a MOSFET with nearly zero turn-on switching losses and employing ZCT technique to a IGBT effectively eliminates the turn-off switching losses by forcing the switch current to zero before the switch voltage

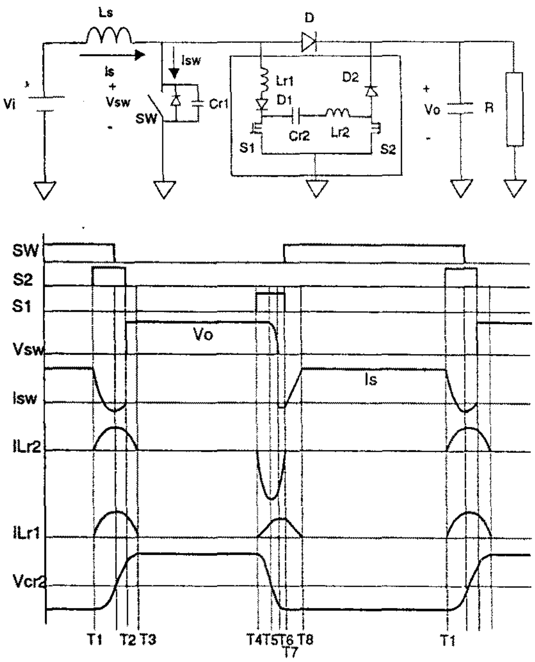

Fig. 2 Circuit diagram and key waveforms of the active resonant snubber based boost PWM converter

rise. Although these techniques are attractive for high-frequency operation, there are undesurable constraints in designing the power converter circuits. Consequently, a ideal switched PWM converter with zero voltage turn-on and zero current turn-off conditions can be expected to perfectly reduce the switching losses, switching noise and switching stresses, especially at high frequencies. The switching waveforms of this ideal switching condition is depitched in Fig. 1(b).

We presented an active resonant snubber (ARS) circuit providing the ideal switching conditions for PWM converter. By using the proposed ARS circuit to PWM converters, the power switches can be operated to give zero-current and zero-voltage at both the instant of switch off and switch on, without increasing voltage/current stresses of the switches. Furthermore, the PWM converters employed ARS circuit has the advantage that it can operate at constant frequency, giving better definded EMI and filter ripple, and it is also suited for high-power application regardless of the semiconductor devices (such as MOSFETs or IGBTs) used as a power switches.

2. Principle of Operation

The circuit diagram and key waveforms of the PWM boost converter employed ARS are shown in Fig. 2. ARS consist of two resonant inductor, L_{r1} and L_{r2}, a resonant capacitor, C_{r2}, two switches, S_1 and S_2, and three diode D_1 , D_2, and D_3. This ARS is active only during a short switching transition time to create the ideal switching switching condition for the main switch. To simplify the analysis, the boost inductor, L_f, is assumed to be large enough to be considcred as a current source, I_i. As shown in Fig. 2, eight operation stages exist within on switching cycle:

(a)T_1-T_2: Prior to T_1, the main switch, SW, is conducting, and C_{r2} is charged with certain voltage. At T_1, the auxiliary switch, S2, is turned on, starting a resonance between C_{r2}, L_{r1}, and L_{r2}. This resonance forces the main switch current to decrease in sinusoidal fashion. After a qeater of the resonant period, the C_{r2} voltage reduces to zero, and the L_{r2} and L_{r1} current reaches its maximum value.

(b)T_2-T_3: S2 is turned off shortly after SW is turned off. In steady state operation, the resonant inductor current at T_2 is always equal to I_s.

(c)T_3-T_4: At T_3, the cpacitor and inductors complete the half-cycle resonance, and D2 is reverse-biased. This operating stage is identical to the main switch off stage of the PWM boost converter.

(d)T_4-T_5: At T_4, the S1 is turn on. The L_{r1}, current linearly ramps up until it reaches I_s at T_5, where D is turned off with soft switching. Meanwhile, C_{r2} and L_{r2} form a half-cycle resonance through the S1, which reverse th epolarity of the C_{r2} voltage.

(e)T_5-T_6: L_{r1} current continues to increase due to the resonance between L_{r1} and C_{r1}. C_{r1} is discharged until the resonance brings its voltage to zero at T_6, where the anti-parallel diode of SW starts to conducts.

(f)T_6-T_7: The anti-parallel diode of SW is turned on. To achieve ZVS, the turn-on signal of SW should be applied while its body diode is conducting.

(g)T_7-T_8: At T_7, S1 is turned off. The energy stored in the L_{r1} is transferred to the C_{r2} during this time interval.

(h)T_8-T_0: The operation of the circuit at this stage is identical to that of the PWM boost converter. At T_0, S2 is turned off again, starting another switching cycle.

3. Novel Features and Simulation Results

3-1. Zero switching loss : It can be seen that the power switch regardless MOSFET or IGBT is commutated under idel switching condition. The ZVS turn-on and ZCS turn-off switching technique makes the remarkly reduced switching loss and EMI, and is attractive for high-voltage conversion applications. In addition, the rectifier diode is also commutated under soft-switching. Thus, this technique is very useful for power factor correction application, where the rectifier diode suffer from severe reverse recovery problems. Therefore, implementing idel switching for the power switch and soft switching for the rectifier diode in such a circuit is particulary rewarding.

3-2. Mimimun switch voltage and current stress : From Fig. 2, it can be seen that the voltage and current waveforms of the switches in the proposed converter are essentially square-wave without voltage and current overlap. Both the power switch and the rectifier diode are subjected to mimimum voltage and current stresses. In addition, the ZVS turn-on and ZCS turn-off time can be short with respect to the switching cycle, so the operation of the proposed converter resembles that of the boost PWM converter during most portion of cycle. Circulating energy employed to realize ZVS is therefore mimimum. The auxilary switches can be very small compared to the main switch, as it only handles small amounts of resonant-transition energy. Since ideal-switching is achieved without increasing switch voltage and current stresses, the penalty of increase in conduction loss is minimal.

3-3. Wide ideal switching ranges : One drawback of ZVS-QRC and ZVS-PWM techniques is that the soft-switching condition is strongly dependent on load current and input voltage. This situation is opposite in a proposed converter. In the proposed converter, I_s decreases when the load current is

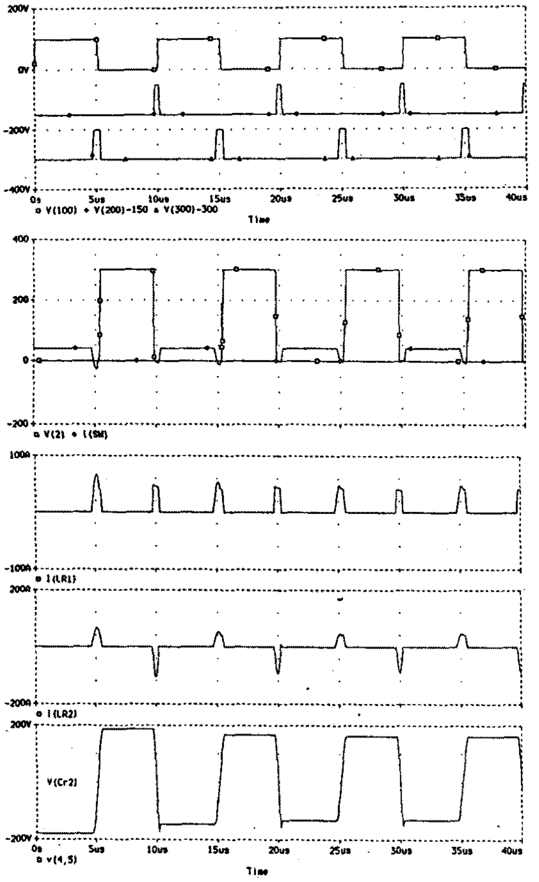

Fig. 3 Simulation results of the proposed converter

reduced, or line voltage increases. Therefore, as long as we make the resonant transition time enough, ideal switching operation will be ensured for whole line and load range.

3-4. Constant frequency operation : Due to constant frequency, the design optimization of the new circuit is easily attainable. In addition, since the operation of the proposed converter resembles that of its PWM counterpart except during short resonant transition time, current-mode control can be directly applide to the proposrd circuit.

Fig. 3 shows the simulation results of the proposed converter with Pspice. it can be seen that the above description is confirmed by this results.

4. Conclusion

We presented an active resonant snubber (ARS) circuit providing the ideal switching conditions for PWM converter. By using the proposed ARS circuit to PWM converters, the power switches can be operated to give zero-current and zero-voltage at both the instant of switch off and switch on, without increasing voltage/current stresses of the switches. Furthermore, the PWM converters employed ARS circuit has the advantage that it can operate at constant frequency, giving better definded EMI and filter ripple, and it is also suited for high-power application regardless of the semiconductor devices (such as MOSFETs or IGBTs) used as a power switches.

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