A Family of New Zero-Voltage-Transition PWM Converter with Zero-Current Turnoff Auxiliary Switch

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Abstract: The shortcomings of zero-voltage-transition PWM converter is discussed ,and a new family of topologies of zero-voltage-transition PWM converter with soft-switched auxiliary switch is introduced .The experiments on a 290W boost converter and a 100W forward converter are carried out to prove the circuit.The efficiency increment of the new circuits are 2-5% comparing to hard switching circuits,and the switching noise is also greatly reduced.

1. Introduction

To reduce the size and weight of the converter,the easiest way is to increase the switching frequency.By increasing the frequncy, the size and weight of the transformer and filter can be greatly reduced, but the switching loss will increase simultaneously ,which results in poor efficiency and severe problem of heat sinking. Soft-swiching techniques,whereas,is a way to solve the problem,it greatly changes the concept of switching power conversion since 1980's.

The soft-switching converter can be classified in several families[1],such as:

1)Resonant and quasi resonant converters: zero-voltage-switching quasi-resonant converter (ZVS QRC), zero-current-switching quasi-resonant converter(ZCS QRC),zero-voltage -switching multi-resonant converter (ZVS MRC).

2)Zero-voltage-switching quasi-square wave converter (ZVS QSC).

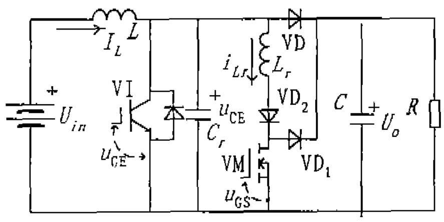
3)Zero-voltage-switching PWM converter (ZVS PWM)and zero-current-switching PWM converter(ZCS PWM).

4)Zero-voltage-transition PWM converter (ZVT PWM)and zero-current-transition PWM converter(ZCT PWM).

In those many topologies,ZVT PWM (shown in Fig.1) is one of the most valuable which uniquely suitable to high power application such as PFC(Power Factocr Correction) and high power SMPS(Switching Mode Power Supply), due to its high efficiency and wide line/load range [2] .

But there are still some shortcomings in the character of the ZVT PWM converter,although the main switch and diodes in the circuit are soft-switching,the auxiliary switch is not.This will reduce the total efficiency of the converter, especially when load is heavy.

In this paper, an extra inductor is introduced into the branch of auxiliary switch,which makes the auxiliary switch achieves zero current turnoff, thus may greatly reduce the switching loss of the auxiliary switch,without increasing the switching and conducting loss of the other components .The topologies and principle of the new family of converters are explained in detail ,and experiments have been done to prove them,the efficiencies of the new topologies are not only higher than that of the hard switching converters,but also higher than that of the traditional ZVT PWM converter.



a)ZVT PWM boost converter

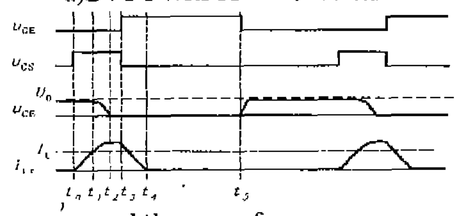

b)key waveforms

Fig.1 Topology and key waveforms of ZVT PWM boost converter

2. Topologies and principle of the new family of ZVT PWM converters

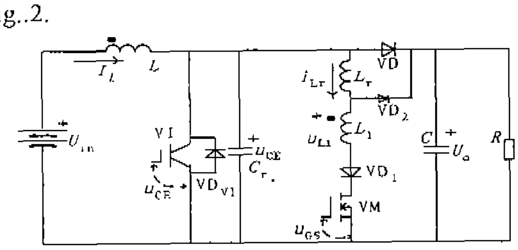
2.1 A new way to make the auxiliary switch to achieve zero current turnoff

In traditional ZVT PWM converter,the auxiliary switch is turned on before the main switch is turned on,and once the main switch is turned on,the resonant inductor is freewheeling through auxiliary switch and the main switch, without decrease.To release the energy store in the resonant inductor,the only way is to turn off the auxiliary switch directly,which may lead to turnoff loss.

By putting an extra inductor which is coupled with the filtering inductor in the branch of the auxiliary switch, a potential is introduced into the freewheeling loop of the resonant inductor,which makes the current decreases,thus can make the auxiliary switch achieve zero current turnoff.

2.2 Principle of the new ZVT PWM converters

The new ZVT PWM boost converter is shown in Fig..2.



a) new ZVT PWM converter

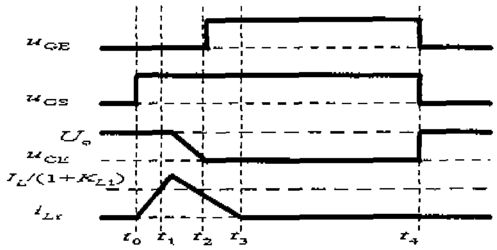

b) key waveforms

Fig.2 Topology and key waveforms of the new ZVT PWM boost converter

Comparing to Fig1a),there is only an extra inductor L_1 added to the branch of auxiliary switch in the topology shown in Fig2a),L_1 is coupled with the input filtering inductor L,and the turns ratio between L and L_1 is 1:K_{L1},where K_{L1} is about 0.1-0.3.Because of the existence of body diode of MOSFET VM,a diode has to be placed in series with VM to block the reverse current after the current i_{Lr} decreased to zero.And a small fast recovery diode VD_2 is also needed to clamp the overshooting voltage across the VM after the turnoff of VI.

There are five operation stages within one switching period:

1)t_0-t_1:the auxiliary switch is turned on at t_0,and i_{L1},the current of the resonant inductor L_r ,begins to go up,the current flowing through diode VD begins to decrease.The current increasing rate of $L_r$is:

$$\frac{\mathrm{d}\, i_{Lr}}{\mathrm{d}\, t} = \frac{U_o + u_{L_1}}{L_r} = \frac{U_o + K_{L_1}(U_o - U_{in})}{L_r} \quad (1)$$

When i_{Lr} reaches $I_L/(1+K_{L1})$,the current flowing through diode VD decreases to zero,and the diode turns off under the condition of zero current,without turnoff loss.

2)t_1-t_2:after the turnoff of the diode VD,the resonant capacitor C_r ,which is paralleling with the main switch VI,begins to resonant with the inductor L_r,the voltage across VI begins to decrease,until it reaches zero at t_2.

3)t_2-t_3:after the voltage across VI decreases to zero ,the body diode of VI turns on,and the voltage of VI is clamped to zero.the voltage across inductor L_1 is :

$$u_{L1}=K_{L1}U_{in} \quad (2)$$

which makes the current through L_r to decrease to zero at t_3,thus the auxiliary switch turns off under the condition of zero current.After its turnoff,the voltage across it keeps in zero.

4)t_3-t_4:after the current i_{Lr} decreases to zero,the current flowing through VI reaches I_L, and VI keeps conducting,until being turned off at t_4.

5)t_4-t_0:after the turnoff of VI,the voltage across VI and VM begin to increase,the voltage across VI goes up to U_o with an rising rate :

$$\frac{\mathrm{d}u_{CE}}{\mathrm{d}t} = \frac{I_L}{C_r} \tag{3}$$

The existence of C_r reduces the rising rate of u_{CE},so the turnoff loss can be greatly reduced.

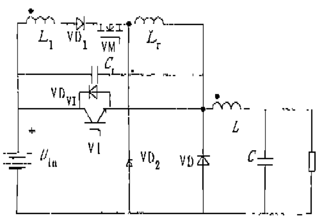
When the voltage of VI goes up ,the voltage across the VM goes up to :

$$U_{VM\max} = U_o + K_{L_1}(U_o - U_{in}) \tag{4}$$

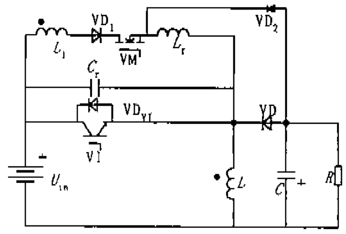
It is a little higher than U_o,with a proportion of 1.1-1.3,which is related to the value of input voltage.But there is always a rather high spike appearing at the rising edge of the voltage waveform of VM,which is caused by the ringing between L_1 and the parasitic capacitor of VM,so a very small fast recovery diode VD_2 has to be place in the circuit to reduce the spike.

2.3 The family of new ZVT PWM converters with zero current turnoff auxiliary switch.

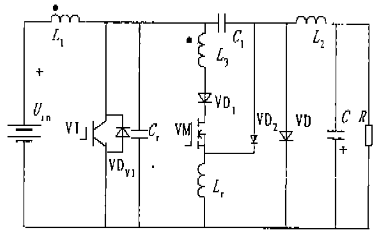
The non-isolated topologies are shown in Fig.3,and isolated topologies are shown in Fig.4. In isolated topologies,the extra inductor is coupled with the transformer,not with the filtering inductor.For the forward and half bridge topologies,however,the extra inductor can be coupled with the filtering inductance also.



a)Buck

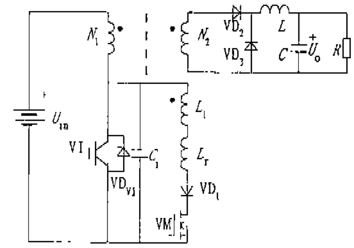


b)Step up and down

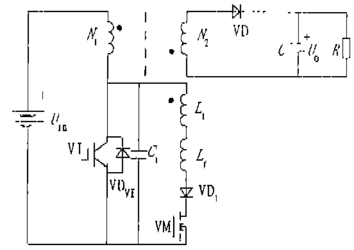


c)Cuk

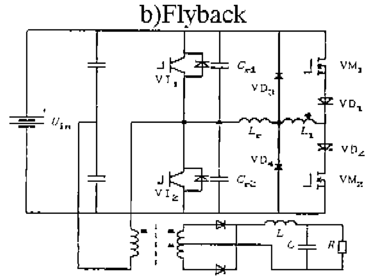
Fig.3 Non-isolated topologies of new ZVT PWM converters



a)Forward



b)Flyback



c)Half Bridge

Fig.4 Isolated topologies of new ZVT PWM converters

2.4 The characteristic of new ZVT PWM converter

The new family has many merits:

1)High efficiency .Both the main switch and the auxiliary switch can achieve soft-switching under wide line and load range.

2)Easy to control.There are many IC produces designed for traditional ZVT PWM converter can be used by applying an AND circuit to produce the driving signals of the auxiliary switch.

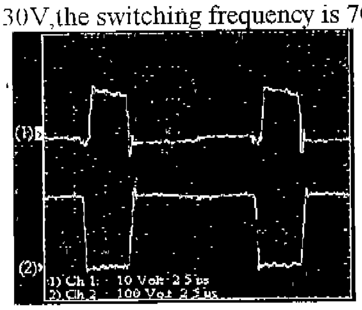
3)Low voltage and current stress on the switches. The highest voltage across main switch is U_o,and the highest voltage on the auxiliary switch is a little bit higher than U_o,with a proportion of 1.1-1.3.

3. Experiments

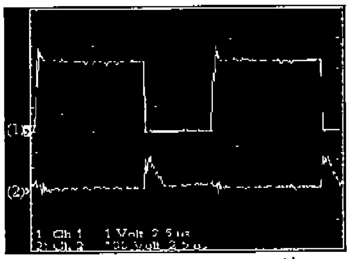
The experiments have been done on a 290W boost converter and a 100W forward converter to prove the applicability of the circuits.

In experiments on boost converter,the circuit of new ZVT PWM is compared with a hard switching one and a traditional ZVT PWM converter,using devices with same rating.The input voltage ranges from 120V to 150V,and the output voltage is regulated at 200V,The switching frequency is 70kHz.The faveforms of new ZVT PWM converter are shown in Fig.5a) and b),the total efficiencies of the three converters are shown in Fig5c),which shows that the new ZVT PWM converter is the highest.

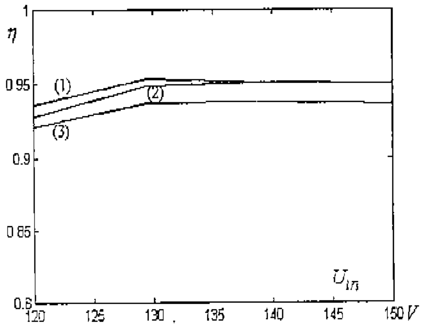
In the experiments on the forward converters, the new ZVT PWM circuit is compared with the hard switching one,the former one has not only the higher efficiency,but much lower noise as well. The waveforms and efficiency are shown in Fig.6.The input voltage ranges from 120V to 150V,and the output voltage is regulated at 30V,the switching frequency is 70kHz.



(1)u_{GE}:driving voltage:10V/div
(2)u_{CE}:collector-emitter voltage:100Vdiv
a)main switch

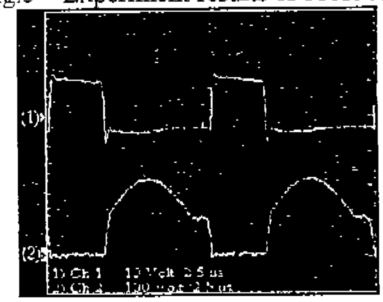


(1)u_{DS}:drain-source voltage:100V/格
(2)i_{Lr}:current:5A/格
b)auxiliary switch

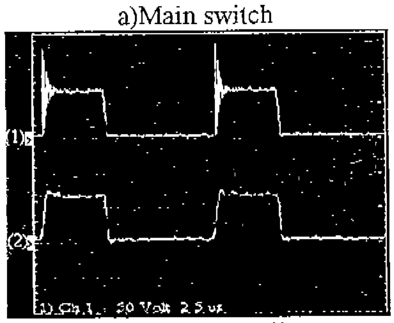


(1)new ZVT PWM
(2)ZVT PWM
(3)Hard switch
c)Total efficiency

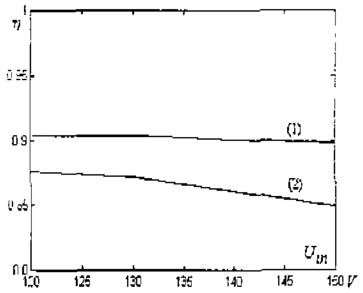
Fig.5 Experiment results of boost converters



(1)u_{GE}:driving voltage:10V/div
(2)u_{CE}:collector-emitter voltage:100V/div
a)Main switch



(1)Hard switch : 50V/格
(2)Soft switch : 50V/格
b)Voltage across rectifier



(1)Soft switch
(2)Hard switch
c)Total efficiency
Fig.6 Experiment results of forward converters

4. Conclusion

The hard switching of the auxiliary switch decreases the efficiency of the traditional ZVT PWM converter, especially when load is heavy, by applying an extra inductor which is coupled with the filtering inductor or the transformer,the auxiliary switch can achieve zero-current-switching,without increasing any switching or conducting losses to the other devices in the circuit,the voltage and current stress on the device are also low.The soft switching character can be maintained through wide line/load range.The new family of topologies has been proved by the experiment results on a 290W boost converter and a 100W. forward one.The efficiency increment are 2% and 5%, respectively .And switching noise of the circuits are also greatly reduced.

5.Reference

[1] Guichao Hua and Fred C. Lee "An Overview of Soft-Switching Techniques for PWM Converters " proceeding of the International Power Electronics and Motion Control Conference 1994 pp801-808.

[2] Guichao Hua,Ching-Shan leu.. "Novel Zero-Voltage-Transition PWM Converters" IEEE trans. on Power Electronics Vol.9 No.2 March 1994,pp213-219.