A Quadratic Buck Converter using a Non Dissipative snubber

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Abstract - This work presents a quadratic Buck converter associated to a non dissipative snubber. This approach allows the main switch to work in a ZVS way and the auxiliary switch to work in a ZCS way. Two capacitors, one inductor, one switch (auxiliary switch) and one diode in series with the main switch compose the non-dissipative snubber.

INTRODUCTION

The main motivation of this work was to develop converters to implement an UPS (Uninterrupted Power System) non isolated. This work introduces one of the developed converters. This converter will be used as battery charger. The main problem was to find a converter to provide a large range of conversion ratio.

The quadratic converter [7] provides a significantly wide conversion range for high frequency applications.

Nowadays, the utilities and power quality committees demand that the electronic equipments with one or more active switches present low electromagnetic interference (EMI) in the power system. A simple way of solving this problem is the use of switching techniques that employ null current and/or null voltage [1, 2, 3 and 10]. These techniques increase the converter efficiency and switch lifetime. Another alternative is the use of Quasi-Resonant PWM Converters [4, 5 and 6].

To contribute with the general research effort, this paper proposes to use a non-dissipative snubber [8 and 9] associated with a quadratic Buck converter shown in Fig.1.

THE NON-DISSIPATIVE SNUBBER

Fig. 1 shows the simplified schematic circuit of the non-dissipative snubber associated to a quadratic Buck Converter (QBUCK-PWM-ZVS-SR). This converter operates almost without commutation losses.

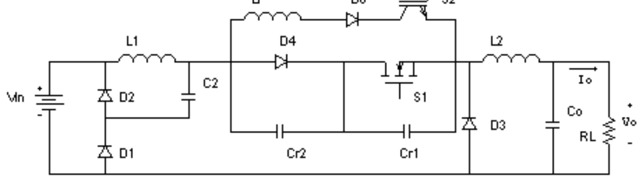


Fig. 1 - Buck converter associated with a non-dissipative snubber.

Switches S1 and S2 have soft-commutation. Switch S1 commutates in a ZVS way and switch S2 commutates in a ZCS way.

PRINCIPLE OF OPERATION

Following, a complete theoretical analysis for the approach showed in Fig. 1 will be presented.

The analysis begins with a description of the seven operational stages:

First Stage $[t_0, t_1]$ (Fig. 2) - This stage begins when switch S2 is turned on in a ZCS way. During this stage the resonant inductor current (ILr) rises linearly from zero to output current (Io) value.

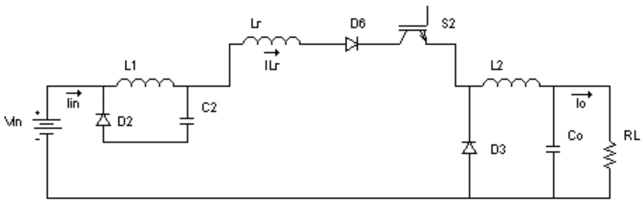


Fig. 2 - First Stage (t_0, t_1).

Second Stage $[t_1, t_2]$ (Fig. 3) - When resonant inductor current (ILr) is equal to output current (Io), this stage begins. During this stage the resonance among capacitors (Cr1 and Cr2) and inductor (Lr), begins. In this stage resonant capacitor 1 (Cr1) is discharged and resonant capacitor 2 (Cr2) is charged. This stage finishes when resonant capacitor 1 (Cr1) is completely discharged.

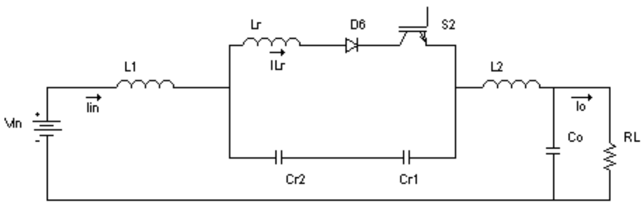


Fig. 3 - Second Stage (t_1, t_2).

Third Stage [t2, t3] (Fig. 4) - During this stage the main switch S1 is turned on in a ZVS way and diode D1 conducts simultaneously. This stage begins when voltage on resonant capacitor 1 (Cr1) is equal to zero. During this stage just capacitor 2 (Cr2) is in resonance with the inductor (Lr). When the resonant inductor current is equal to zero this stage finishes. After the resonant inductor current reaches zero, switch S2 can be turned off in a ZCS way.

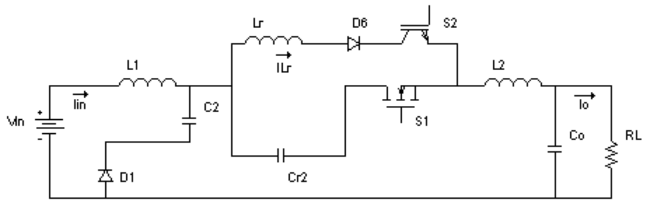


Fig. 4 - Third Stage (t_2, t_3).

Fourth Stage [t_3, t_4] (Fig. 5) - This stage begins when ILr is equal to zero, and it finishes when voltage on resonant capacitor 2 (Cr2) is equal to zero. During this stage resonant capacitor 2 (Cr2) is discharged in a linear way by the input current (Iin).

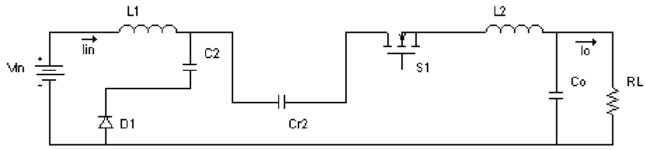


Fig. 5 - Forth Stage (t_3, t_4).

Fifth Stage [t4, t5] (Fig. 6) - This stage begins when voltage on resonant capacitor 2 (Cr2) is equal to zero then diode D4 conducts. When switch S1 is turned off in a ZVS way this stage finishes. During this stage, energy is transferred from the input voltage source (Vin) to the load. This stage is responsible for the converter PWM characteristics.

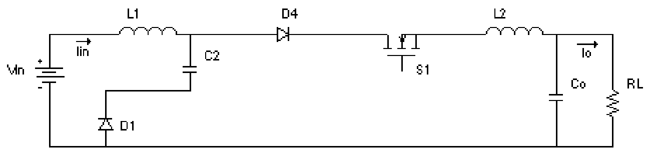


Fig. 6 - Fifth Stage (t_4, t_5).

Sixth Stage [t_5, t_6] (Fig. 7) - When main switch S1 is turned off, this stage begins. Input current flows through resonant capacitor 1 (Cr1), this capacitor is charged up to output voltage (Vo). This stage finishes when diode D3 is turned on.

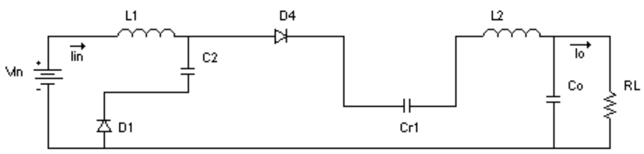


Fig. 7 - Sixth Stage (t_5, t_6).

Seventh Stage [t_6, t_7] (Fig. 8) - This is the freewheeling stage. During this stage the load current flows through freewheeling diode D3 and inductor L1 current flows through D2 transferring L1 stored energy to C2.

Fig. 8 – Seventh Stage (t_7, t_8).

From the operating stages, described above, one can obtain the waveforms shown in Fig. 9.

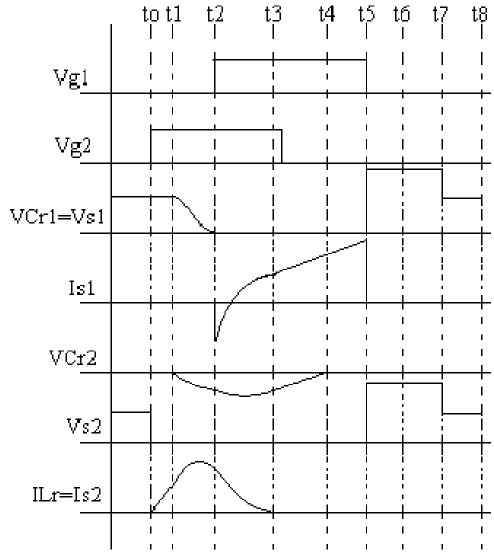


Fig. 9 - Theoretical waveforms for the QBUCK-PWM-ZVS-SR.

Analyzing the operation of converter from Fig. 1 the static gain can be obtained by (1).

$$G = \frac{Vo}{Vin} = \left\{ D + \frac{K1}{2\pi}\left[a\cos\left(-\frac{1}{X}\right) + \frac{X+1}{X\alpha} + \frac{\alpha}{2} \right]\right\}^2 \qquad (1)$$

Where:

$$X = \frac{Cr2}{Cr1} \qquad (2)$$

$$\alpha = \frac{Iin}{Vin}\sqrt{\frac{Lr}{Cr}} \qquad (3)$$

$$K1 = \frac{fs}{fo} \qquad (4)$$

Where:

Cr1 = Resonant capacitor 1;
Cr2 = Resonant capacitor 2;
Cr = Total resonant capacitance;
Lr = Resonant Inductor;
Iin = Input current;
Vin = Input voltage;
D = duty cycle;
fs = Switching frequency;
fo = Resonant frequency;
Vo = Output voltage.

Simulation And Experimental Results

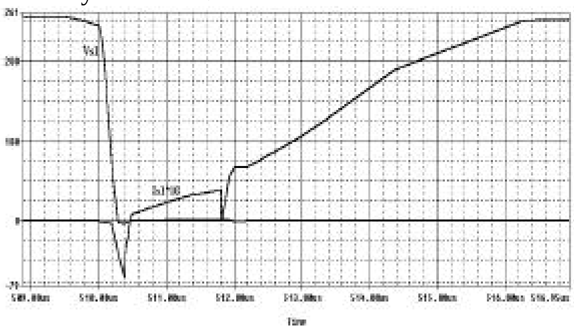
The proposed QBUCK-PWM-ZVS-SR converter (Fig. 1) was studied by simulation using the P-SPICE and using the following parameter set:

S1 = IRF740 (Mosfet);	S2 = Ideal ;
D6 = Ideal;	Other diodes = MUR1560;
L1 = 200μH;	L2 = 200μH;
fs = 100kHz;	Lr = 2.5μH;
Cr1 = 3.9nF;	Cr2 = 27nF;
C1 = C2 = 10μF;	P_0 = 60 W;
Vin = 180V;	Vo = 27V.

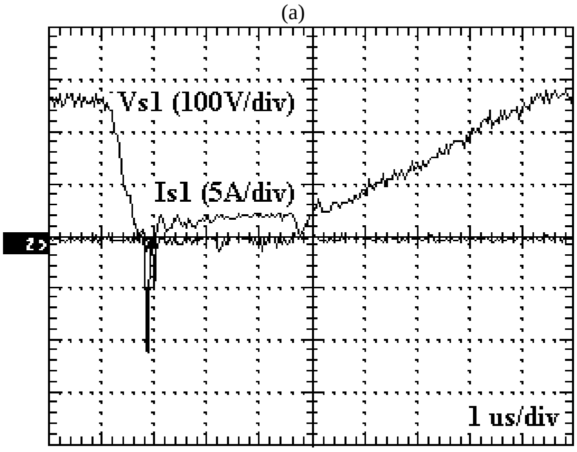
A prototype of the proposed QBUCK -PWM-ZVS-SR converter was built using the following parameter set:

S1 = IRF740 (Mosfet);	S2 = IRGBC20f (IGBT);
Diodes = MUR1560;	L1 = 200µH;
L2 = 200µH;	Lr = 2.5µH;
Cr1 = 3.9nF;	Cr2 = 27nF;
C1 = C2 = 100µF;	fs = 100kHz;
P_0 = 60 W;	Vin = 180V;
Vo = 27V.	

Fig. 10 and 11 shows the commutations in the active switch, one can see that main switch S1 (Fig 10) does not present stresses of current and/or voltage, however, auxiliary switch S2 (Fig 11) presents stresses of current, due to the resonant circuit. It can also be seen the ZVS commutation of main switch S1 and the ZCS commutation of auxiliary switch S2.

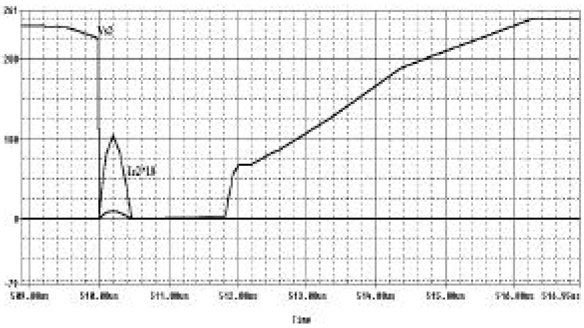


(a)

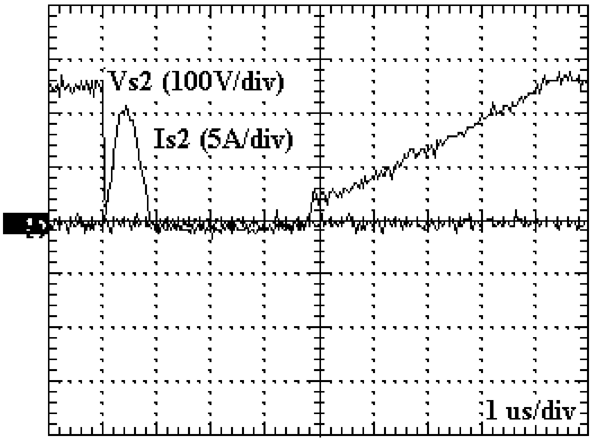


(b)

Fig. 10 – Simulation and experimental Results for nominal load:
a) Switch s1 waveforms for simulated results;
b) Switch s1 waveforms for experimental results;



(a)



(b)

Fig. 11 – Simulation and experimental Results for nominal load:
a) Switch s2 (auxiliary switch) waveforms for simulated results;
b) Switch s2 (auxiliary switch) waveforms for experimental results.

CONCLUSION

This paper presented a non-dissipative snubber associated with a quadratic Buck Converter (QBUCK-PWM-ZVS-SR). This converter works in a soft switching way, the main switch (S1) commutates in a ZVS way and the auxiliary switch (S2) commutates in a ZCS way. Simulation and experimental results confirm the non-dissipative switching of both switches.

This converter operates as a quasi-resonant one from the point of view of commutation and as a PWM one from the point of view of control. The main switch is not submitted to over voltages and/or over currents. The auxiliary switch is submitted to the resonant current. As result switching losses are reduced and conduction losses are almost the same as those observed in its PWM counterpart. This approach used only one auxiliary circuit to obtain soft switching.

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